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THE LU-EAGLE MODEL WITH DISAGGREGATED PUBLIC EXPENDITURE

PABLO GARCIA SANCHEZ ALBAN MOURA

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Abstract. We augment the original LU-EAGLE model with disaggregated public expenditure, allowing for (i) a distinction between public consumption and investment expenditures, (ii) complementarity between public and private consumption, (iii) a productive role for public capital, and (iv) separate private and public employment. This extended model embeds a wide range of transmission channels from public expenditures and allows for a detailed analysis of the general-equilibrium effects of public demand in Luxembourg. Model simulations suggest that a rise in public employment induces the strongest GDP response in the short run, while a rise in public investment has the largest effects in the long run. The results also indicate that crowding-out effects through changes in net exports are essential in determining fiscal multipliers for small open economies such as Luxembourg.

JEL Codes: C54, E17, E32, E37, E62, F47.

Keywords: DSGE models, open economy models, fiscal policy, Luxembourg.

Banque centrale du Luxembourg (BCL), Département Economie et Recherche, 2 boulevard Royal, L-2983 Luxembourg, Luxembourg. E-mail: pablo.garciasanchez@bcl.lu, alban.moura@bcl.lu. For useful comments and suggestions, we thank Olivier Delobbe, Paolo Fegatelli, Patrick Fève, Paolo Guarda, Abdelaziz Rouabah, and Olivier Pierrard, as well as BCL colleagues.

Résumé Non Technique

Pendant la récession de la fin des années 2000, de nombreux gouvernements à travers le monde ont adopté des plans de relance budgétaire (l'on peut citer le plan de 2008 pour l'Union Européenne et ceux de 2009 pour les Etats Unis et pour la Chine), ce qui a ravivé le débat quant à la capacité de l'instrument budgétaire à stabiliser l'économie. Plus récemment, la baisse continue des taux d'intérêt a réduit le coût de la dette publique dans les économies avancées, relançant les voix en faveur d'une politique budgétaire plus expansive. D'autre part, la faiblesse de l'inflation a conduit la politique monétaire à baisser les taux d'intérêt nominaux à des niveaux proches de zéro (et parfois négatifs), ce qui amène à penser qu'une éventuelle détérioration des conditions économiques pourra exiger une réponse plus active de la politique budgétaire dans le futur.

Au vu de ces débats, ce travail propose une extension du modèle LU-EAGLE, un modèle d'équilibre général de l'économie luxembourgeoise développé à la Banque centrale du Luxembourg. La version originale du modèle étant déjà assez riche quant à la description des instruments d'imposition, l'extension vise à enrichir le volet relatif aux dépenses publiques.

Plus précisément, nous introduisons trois changements dans le modèle :

- Premièrement, nous remplaçons l'hypothèse restrictive selon laquelle le secteur public achète un bien homogène et improductif par l'hypothèse plus réaliste selon laquelle il existe trois types de dépense publique : la consommation publique hors rémunération des employés du secteur public, l'investissement public et la rémunération des employés du secteur public.
- Deuxièmement, nous introduisons un nouveau mécanisme de propagation relatif aux chocs de consommation publique, sous la forme de complémentarités entre la consommation privée et publique. Intuitivement, dans le modèle ces complémentarités poussent les ménages à augmenter leur consommation suite à une hausse de la consommation publique, de manière à obtenir un effet d'entraînement de la demande privée.
- Troisièmement, nous relâchons l'hypothèse selon laquelle les dépenses publiques sont totalement improductives, en supposant que le stock de capital public augmente la productivité du secteur privé. Ce mécanisme permet de transformer ce qui est initialement un choc de demande (une hausse de l'investissement public) en un choc d'offre (une hausse de la productivité du secteur privé), offrant un canal supplémentaire pour l'analyse de la politique budgétaire.

Nous calibrons la nouvelle version du modèle sur des données luxembourgeoises, en portant une attention particulière aux paramètres spécifiques à l'extension. Les plus importants concernent le degré de complémentarité entre la consommation privée et publique et l'effet du stock de capital public sur la productivité du secteur privé. Nous calibrons le degré de complémentarité de manière à reproduire dans le modèle les résultats d'une analyse de type VAR structurel pour le Luxembourg, selon laquelle la consommation

privée augmente suite à un choc positif de consommation publique. En ce qui concerne l'effet du stock de capital sur la productivité du secteur privé, nous considérons plusieurs valeurs tirées de la littérature académique.

Nous simulons ensuite le modèle pour étudier son comportement à la suite de chocs augmentant soit la consommation publique, soit l'investissement public, soit l'emploi public. Nous obtenons trois résultats principaux :

- En présence de complémentarités, une hausse de la consommation publique au Luxembourg entraîne une réponse positive de la consommation privée et de l'investissement privé. Cependant, l'impact sur le PIB reste limité de par l'important effet d'éviction lié aux importations.
- Une hausse de l'investissement public peut avoir des effets positifs importants dans le moyen/long terme. L'amélioration de la productivité du secteur privé stimule les capacités de production et augmente la compétitivité de l'économie, ce qui permet de satisfaire une hausse de la demande intérieure et extérieure.
- Une hausse de l'emploi public génère l'effet d'entraînement le plus important sur le PIB à court terme, en grande partie à cause d'un moindre effet d'éviction par les importations.

Selon ces simulations, les trois catégories de dépenses publiques considérées induisent des réponses différentes de l'économie luxembourgeoise. Ainsi, aucun des instruments budgétaires ne "domine" les autres. Au contraire, les effets hétérogènes que nous identifions permettent au décideur de politique économique de combiner les différentes dépenses afin de mieux cibler l'état du cycle économique et son horizon de planification.

Pour la même raison, le modèle indique qu'une réorientation des différents types de dépenses publiques peut avoir des effets importants sur l'économie, même à dépense totale inchangée. Nous illustrons cette propriété en simulant l'impact d'une baisse de la consommation publique associée à une hausse de l'investissement public du même montant. Le modèle suggère qu'une telle réorientation a un effet positif sur l'économie dans le moyen terme, tout en limitant les coûts de transition grâce à son caractère budgétaire neutre.

Enfin, soulignons que selon le modèle les multiplicateurs fiscaux au Luxembourg sont de taille limitée: le multiplicateur associé à l'emploi public dépasse légèrement l'unité à court terme, mais à long terme tous les multiplicateurs convergent vers des valeurs inférieures à 0,60. Comme déjà établi pour d'autres pays, ces multiplicateurs limités reflètent les effets d'éviction importants présents dans des petites économies ouvertes telles que le Luxembourg.

1. Introduction

Interest in the general equilibrium effects of fiscal policy has been growing since the deep recession of the late 2000s. Governments in major economies around the world reacted to the crisis by implementing large-scale fiscal plans aimed at supporting aggregate demand and limiting the trough in aggregate activity, which raised debate among both academics and policymakers about the effectiveness of fiscal policy as a stabilization tool.[1] More recently, the fall in interest rates lowered the cost of public debt for several countries, fueling support for more expansionary fiscal policy in advanced economies (Blanchard, 2019). In addition, the constraint on euro-area monetary policy from the effective lower bound on nominal interest rates suggests that a more active fiscal policy response will be needed should growth deteriorate in the future (International Monetary Fund, 2019).

Against this backdrop, this paper provides background documentation for a fiscal extension of LU-EAGLE, a DSGE model developed at the Central Bank of Luxembourg to support short- and medium-run analysis of the Luxembourg economy (Moura and Lambrias, 2018). Because the original model already features a rich description of taxation, the extension considered here focuses instead on adding detail to public expenditures. More precisely, we introduce three changes to the model. First, we replace the restrictive assumption that the government purchases a single homogeneous good with a decomposition of public expenditures into three components: public consumption, public investment, and compensation of public employees. Second, we introduce a new propagation channel in the model for public consumption shocks, namely a complementarity between private and public consumption. In simple words, this complementarity makes it optimal for households to increase their consumption expenditure after a rise in public consumption, which triggers a crowding-*in* effect on private demand. Third, we relax the extreme assumption that all public spending is unproductive by introducing positive spillovers from public capital (and thus public investment) on the productivity of the private sector. This mechanism effectively transforms a short-term demand shock (the rise in public investment) into a medium-run supply shock (the rise in productivity), providing yet another channel by which public expenditures affect the economy.

Our modeling choices build upon a large literature started by Baxter and King (1993), that studies the aggregate effects of fiscal policy in general equilibrium. Complementarity between private and public consumption as a transmission mechanism for fiscal policy has been emphasized by, among others, Bouakez and Rebei (2007) and Fève, Matheron, and Sahuc (2013), while the impact of public investment on private-sector productivity is

[1] Examples of these large-scale fiscal packages include the 2008 European Economic Recovery Plan in the European Union, the 2009 American Recovery and Reinvestment Act in the United States, and the 2010 fiscal stimulus plan in China. As regards the debate about the appropriate use of fiscal policy, the most striking example is perhaps the 2009 statement by the Cato Institute, endorsed by 300 economists including Nobel laureates Buchanan, Prescott, and Smith, that "it is a triumph of hope over experience to believe that more government spending will help the U.S." fight the recession (`https://object.cato.org/sites/cato.org/files/pubs/pdf/cato_stimulus.pdf`).

discussed in, e.g., Glomm and Ravikumar (1997) and Leeper, Walker, and Yang (2010). For public employment, the standard reference is Finn (1998). The empirical relevance of these features, either together or in isolation, has been documented using large-scale DSGE models estimated for the United States (Leeper, Traum, and Walker, 2017) or the euro area (Forni, Monteforte, and Sessa, 2009; Coenen, Straub, and Trabandt, 2012, 2013). Finally, we note that Jacquinot, Clancy, and Lozej (2014) proposed a fiscal extension of the EAGLE model for Ireland and Slovenia, featuring complementarity and public investment. Compared to their work, we focus on the Luxembourg economy and also consider public employment.

To calibrate our extension of LU-EAGLE, all parameters already present in the original model remain unchanged and we focus instead on a handful of new parameters. The most important ones determine to the degree of complementarity between private and public consumption in Luxembourg and the productivity spillovers from public capital.

We calibrate the degree of complementarity based on empirical evidence. Specifically, we estimate the response of private consumption in Luxembourg to a shock to domestic public consumption using a simple structural vector autoregression (SVAR) in the spirit of Blanchard and Perotti (2002). To save space, we relegate estimation details to Appendix A and focus here on the results. Figure 1 reports the estimated impulse-response functions of public and private consumption, together with approximate 95% confidence bands. The finding is clear: in Luxembourg, private consumption rises following a positive shock to public consumption. The effect is short lived, as the response of private consumption is only significantly positive for one year after the shock. We interpret this result as signaling short-run complementarity between private and public consumption and we use the magnitude of the estimated responses to calibrate the strength of this relationship in the DSGE model.

As discussed in Leeper, Walker, and Yang (2010) and Sims and Wolff (2018), it is more difficult to find reliable empirical evidence regarding the magnitude of spillovers from public capital. As a result, we follow these authors and calibrate the elasticity of private-sector productivity to public capital to a moderate value. We also conduct extensive robustness exercises varying the values of both the degree of consumption complementarity and the productivity spillovers from public capital.

We then report simulations describing the model behavior in response to shocks to public consumption, public investment, and public employment. We obtain three main findings:

- In the presence of consumption complementarity, a rise in public consumption in Luxembourg has positive spillovers on private domestic demand: both private consumption and investment increase after the shock. However, aggregate GDP is unaffected because strong international leakages cause a large fall in net exports that more than outweighs the rise in domestic demand.
- A rise in public investment has important positive effects on the Luxembourg economy in the medium term. Spillovers from higher public capital improve

private-sector productivity, which increases the economy's production possibilities to accommodate a sustained rise in domestic and foreign demand.

- A rise in public employment induces the strongest GDP response in the short run, largely because net exports only respond slowly.

Because the three public expenditure shocks generate different responses from domestic variables, no tool systematically outperforms the others when it comes to temporarily stabilizing or stimulating the economy. Rather, their heterogeneous effects imply that policymakers can decide the appropriate spending mix depending on current economic developments and on their planning horizon. The heterogeneity also implies that budget-neutral reorientations of public expenditures can have real effects. We illustrate this idea building on a simulation proposed by Jacquinot, Clancy, and Lozej (2014), in which public expenditures are reallocated away from consumption and toward public investment. We find that the reorientation has strong beneficial effects on the economy in the medium term, while short-run costs are mitigated due to the budget-neutral nature of the reform.

Finally, the model implies relatively small fiscal multipliers in Luxembourg: only public employment is associated with a multiplier above one in the short run, and all multipliers converge to values below 0.60 in the long run. These small multipliers reflect the strong crowding-out effects arising from the openness of the Luxembourg economy. This is in line with the empirical regularities discussed in Ilzetzki, Mendoza, and Végh (2013), who find that fiscal multipliers tend to be smaller in more open economies.

The rest of the paper is organized as follows. Section 2 provides an overview of the original LU-EAGLE model and discusses the extension of the fiscal block. It also presents the calibration of the model. Section 3 reports the results of the simulation exercises, characterizing the economy's responses to the three spending shocks. To highlight the new mechanisms, we contrast these responses to those induced by the standard public expenditure shock in the original LU-EAGLE. Section 4 discusses the fiscal multipliers associated with each instrument and analyzes the reorientation package. Finally, Section 5 concludes.

2. LU-EAGLE with an Extended Fiscal Sector

In this section, we briefly review the structure of the original LU-EAGLE model and present the fiscal extension.[2] We then discuss the calibration of the extended model.

2.1. **LU-EAGLE.**

LU-EAGLE is a DSGE model developed at the BCL to study macroeconomic interdependence between the Luxembourg economy and three foreign blocks corresponding to the rest of the euro area, the United States, and the rest of the world. It constitutes the Luxembourg version of the EAGLE model developed by the European System of Central Banks and described in Gomes, Jacquinot, and Pisani (2012). As

[2]The interested reader is invited to refer to Gomes, Jacquinot, and Pisani (2012) and Moura and Lambrias (2018) for exhaustive presentations of the original EAGLE and LU-EAGLE models.

such, it incorporates specific mechanisms designed to reproduce some important characteristics of Luxembourg's economy. As discussed in Moura and Lambrias (2018), these specificities include the high import content of public consumption and exports, as well as the contribution of foreign (cross-border) workers to the labor force. The model is also consistent with a common monetary policy in Luxembourg and the rest of the euro area, with monetary policy differing in the United States and the rest of the world.

Aside from these elements, all four blocks are modeled in a symmetric fashion using a standard DSGE framework. On the demand side, each block features two types of households that differ depending on their access to financial markets. More precisely, unconstrained agents are able to smooth their consumption profile using money, bonds, and physical capital, whereas constrained agents can only save using money. Both types of households supply labor services in a monopolistically-competitive labor market and face Calvo frictions in wage setting. On the supply side, the model distinguishes between final and intermediate goods in each block. Intermediate goods are produced by monopolistically competitive firms using capital and labor services, and they are sold both at home and abroad.[3] Due to Calvo frictions, intermediate prices adjust only sluggishly. Finally, competitive retailers produce the final goods used for consumption and investment by aggregating domestic and imported intermediate varieties.

Finally, turning to the policy side, Luxembourg and the rest of the euro area share a central bank in charge of the common monetary policy for the euro area, while the two other blocks each have their own monetary authority. All central banks in the model follow a Taylor rule setting the policy rate to target inflation and the output gap. Regarding fiscal policy, each block features a domestic public authority raising revenues from taxes levied on the private sector using a rich set of instruments (VAT-like tax on consumption, labor tax, capital tax, social security contributions). The model is less detailed concerning public expenditures, which only consist of purchases of a final and unproductive government good and lump-sum transfers paid to households. In the next section, we enrich this public spending component to match the sophisticated tax structure.

2.2. **Fiscal extension.** We introduce three changes to improve the model's ability to generate rich analyses regarding the aggregate effects of public expenditures in the Luxembourg block. First, we relax the assumption that the government purchases a single homogeneous good and instead split public purchases into three distinct components corresponding to public consumption, public investment, and compensation of public employees. Second, we introduce complementarity between private and public consumption in the household utility function, a strong propagation mechanism for public spending shocks. Third, we model the effects of public capital on the productivity of the private sector. Throughout, we rely heavily on Jacquinot, Clancy, and Lozej (2014), who provided a similar fiscal extension of the original EAGLE model.

[3]To be exact, only a fraction of intermediate varieties can be traded internationally in the model.

2.2.1. *Government budget constraint.* The original LU-EAGLE model assumes that the public authority purchases a nominal amount $P_t^G G_t$ of the final government good in each period. In the fiscal extension, we instead assume that public purchases can be decomposed into public purchases of the consumption good in the amount $P_t^C G_t^C$, public purchases of the investment good in the amount $P_t^I G_t^I$, and public purchases of labor services in the amount $(1+\tau_t^{W_f})W_t N_t^G$:

$$P_t^G G_t = P_t^C G_t^C + P_t^I G_t^I + \left(1+\tau_t^{W_f}\right) W_t N_t^G. \tag{1}$$

Here, P_t^C and P_t^I are the market prices of the consumption and investment goods, W_t is the market wage, and $\tau_t^{W_f}$ denotes the social security contribution rate faced by employers. This equation implicitly assumes that the same good is used for public and private consumption, since their market prices are equal. A similar argument shows that the same good is used for private and public investment, and that the same labor input is used in private and public production.

Taking into account the fact that, in the model, public expenditures also include transfer payments to households TR_t and the reimbursement of debt B_{t-1}, the fiscal authority's budget constraint at date t is

$$\begin{aligned} P_t^G G_t + TR_t + B_{t-1} = (M_t - M_{t-1}) + \tau_t^C P_t^C C_t + \left(\tau_t^N + \tau_t^{W_h} + \tau_t^{W_f}\right) W_t N_t^D \\ + \tau_t^K \left[R_t^K u_t - (\Gamma_{u,t}+\delta) P_t^I\right] K_{t-1} + \tau_t^D D_t + T_t + R_t^{-1} B_t. \end{aligned}$$

The right-hand side of the constraint presents government income, which includes seigniorage $M_t - M_{t-1}$, taxes on consumption expenditures $\tau_t^C P_t^C C_t$, taxes and social contributions on labor $(\tau_t^N + \tau_t^{W_h} + \tau_t^{W_f}) W_t N_t^D$, taxes on capital and profits $\tau_t^K [R_t^K u_t - (\Gamma_{u,t} + \delta) P_t^I] K_{t-1} + \tau_t^D D_t$, lump-sum taxes T_t, and new bond issuance $R_t^{-1} B_t$. In these expressions, M_t is the supply of money, τ_t^C is the tax rate on consumption expenditures, τ_t^N is the tax rate on labor income, $\tau_t^{W_h}$ and $\tau_t^{W_f}$ are the social contribution rates facing households and firms, N_t^D is equilibrium employment, τ_t^K is the tax rate on capital income, R_t^K is the rental rate of capital services, u_t is capital utilization, $\Gamma_{u,t}$ is the cost of increasing utilization, δ is the depreciation rate, K_t is the capital stock, τ_t^D is the tax rate on corporate profits (or dividend payments) D_t, and R_t is the nominal interest rate.

2.2.2. *Complementarity and the propagation of public consumption shocks.* Following, among others, Bouakez and Rebei (2007) and Fève, Matheron, and Sahuc (2013), we allow public consumption to enter household utility in a non-separable fashion. Formally, the fiscal extension postulates that households have a flow utility function of the form

$$V_t = z_{CON,t} \frac{\widehat{C}_t^{1-\sigma} - 1}{1-\sigma} - \frac{1}{1+\zeta} N_t^{1+\zeta}, \tag{2}$$

where

$$\widehat{C}_t = \left(C_t + \psi_G G_t^C\right) - \kappa \left(C_{t-1} + \psi_G G_{t-1}^C\right). \tag{3}$$

Here, $z_{CON,t}$ is a shock to consumers' preferences, $\sigma > 0$ is the inverse elasticity of intertemporal substitution, $\zeta > 0$ is the inverse Frisch labor supply elasticity, N_t denotes hours worked (or employment), and $\kappa \in [0, 1)$ measures (external) consumption habits.

This specification of preferences implies that households' utility depends on private consumption C_t and public consumption G_t^C in a non-separable fashion.[4] As a result, in this setup changes in public consumption affect private consumption decisions directly by shifting the marginal utility of consumption. The strength and, most importantly, the sign of this effect depend on the parameter ψ_G, which governs the degree of complementarity or substitutability between public and private consumption:

- When $\psi_G < 0$, the two variables are utility complements since a rise in G_t^C raises the marginal utility of C_t. In this case, private consumption tends to react positively to an increase in public consumption, since the latter makes higher C_t more desirable.
- When $\psi_G > 0$, the two variables are utility substitutes since a rise in G_t^C lowers the marginal utility of C_t. In this case, private consumption tends to react negatively to an increase in public consumption, since the latter makes higher C_t less desirable.
- When $\psi_G = 0$, public consumption does not appear in the utility function and households have exactly the same preferences as in the original LU-EAGLE model. In this case, there is no direct effect from public consumption on household choices and only the indirect wealth effect related to changes in the net present value of tax outlays remains.

The macroeconomic literature suggests that allowing public and private consumption to be complements constitutes a powerful amplification mechanism ensuring the propagation of public consumption shocks to macroeconomic aggregates. For instance, in a Bayesian prior analysis of a medium-scale monetary DSGE model of the U.S. economy, Leeper, Traum, and Walker (2017) find that "the preference parameter that determines the [...] substitution between government and private consumption [...] is by far the most important parameter for determining the magnitude of multipliers," with higher output and consumption multipliers associated with complementarity rather than substitutability. In addition, the data strongly support this mechanism as public and private consumption are estimated to be complements both in the United States (Fève, Matheron, and Sahuc, 2013; Leeper, Traum, and Walker, 2017) and in the euro area (Coenen, Straub, and Trabandt, 2012, 2013; Fève and Sahuc, 2017). As for Luxembourg, our VAR estimates discussed in the Introduction also suggest the existence of complementarity.

[4]This is true even if we write $\widehat{C}_t$ as a linear function of private and public consumption, as opposed to the Constant Elasticity of Substitution (CES) specification adopted in Coenen, Straub, and Trabandt (2012, 2013) and Jacquinot, Clancy, and Lozej (2014). Indeed, what matters is that flow utility V_t is not separable in C_t and G_t^C. From a practical perspective, the CES specification is equivalent to our simpler framework once the models are linearized.

2.2.3. *Public capital and the propagation of public investment shocks.* As discussed in Section 2.2.1, the government purchases an amount G_t^I of investment goods in each period. These public investment outlays contribute to the stock of public capital K_t^G according to the standard law of motion

$$K_t^G = (1 - \delta_G) K_{t-1}^G + G_t^I,$$

where $\delta_G \in [0, 1]$ is the depreciation rate of public capital. This formulation does not allow for time to build in public capital formation, but it would be straightforward to extend the model to include such implementation delays.

Following Leeper, Walker, and Yang (2010) and Coenen, Straub, and Trabandt (2012, 2013), we capture the productive role of public capital in the model by making it an input in the production function of intermediate firms. Specifically, the production functions in the tradable (T) and non-tradable (N) sectors become

$$Y_{T,t}^S = z_{T,t} \left(K_{t-1}^G\right)^{\alpha_G} \left(K_{T,t}^D\right)^{\alpha_T} \left(N_{T,t}^D\right)^{1-\alpha_T} - \psi_T, \tag{4}$$

$$Y_{N,t}^S = z_{N,t} \left(K_{t-1}^G\right)^{\alpha_G} \left(K_{N,t}^D\right)^{\alpha_N} \left(N_{N,t}^D\right)^{1-\alpha_N} - \psi_N. \tag{5}$$

Here, Y denotes the net output of a given intermediate firm, z is a productivity shifter, K^D and N^D are firm demands for (private) capital and labor services supplied by households, and $\psi \geq 0$ is a fixed cost of production (we omit the sectoral subscripts for clarity). The parameter $\alpha_G \geq 0$ defines the elasticity of gross output with respect to public capital, taken to be identical across sectors. Given that intermediate firms take K_{t-1}^G as given in their profit maximization program, public capital affects production in much the same way as the technology shifter z. Also note that public capital is a non-rival input: all intermediate firms benefit from the same public capital stock K_{t-1}^G.

To understand how public investment affects firms' decisions in the model, it is useful to compute the marginal cost in each sector, given by

$$MC_{T,t} = \frac{1}{z_{T,t} \left(K_{t-1}^G\right)^{\alpha_G}} \left(\frac{R_t^K}{\alpha_T}\right)^{\alpha_T} \left[\frac{\left(1 + \tau_t^{W_f}\right) W_t}{1 - \alpha_T}\right]^{1-\alpha_T}, \tag{6}$$

$$MC_{N,t} = \frac{1}{z_{N,t} \left(K_{t-1}^G\right)^{\alpha_G}} \left(\frac{R_t^K}{\alpha_N}\right)^{\alpha_N} \left[\frac{\left(1 + \tau_t^{W_f}\right) W_t}{1 - \alpha_N}\right]^{1-\alpha_N}. \tag{7}$$

These equations show that higher levels of public capital raise productivity in the private sector and lowers its marginal costs when $\alpha_G > 0$. By the same token, the marginal products of private capital and labor services increase for all levels of K^D and N^D, inducing firms to demand more capital and labor from households. As a result, it is possible for public and private investment to increase together in the model, thereby avoiding typical crowding-out effects.

2.2.4. *Public employment and the propagation of public employment shocks.* Finally, building on work by Finn (1998), Forni, Monteforte, and Sessa (2009), and Kilponen, Orjasniemi, Ripatti, and Verona (2016), we assume that the government hires household labor to produce a generic public service.

As in these papers, we do not explicitly model the production function associated with public employment. Instead, we follow the convention in national accounting that treats public services as a specific component of public consumption.[5] This component is valued at its production cost, which explains why the compensation of public employees appears as an independent term in equation (1) defining total government expenditures. In the model, expenditures on public services are different from what we call public consumption, since the latter consist in purchases of consumption goods produced by private firms while the former is publicly produced.

We impose additional assumptions to limit changes to the labor-market block of the model. In particular, we assume that public labor demand is allocated uniformly across resident and cross-border workers, as well as across household types (constrained and unconstrained). As a result, foreign workers account for the same share of the workforce in the private and public sectors of the model. This assumption overestimates the share of cross-border workers in the public sector, which tends to hire Luxembourg residents more often than the private sector.[6] However, it simplifies the model by allowing for a single, homogeneous labor input. In particular, we can write total labor demand N_t^D as

$$N_t^D = N_{T,t}^D + N_{N,t}^D + N_{G,t}^D,$$

where $N_{T,t}^D$, $N_{N,t}^D$, and $N_{G,t}^D$ respectively denote labor demand by intermediate firms producing tradable goods, labor demand by intermediate firms producing non-tradable goods, and labor demand by the public sector.

In economic terms, a rise in public employment triggers an immediate increase in the production and consumption of public services, which mechanically raises GDP. Total labor demand also increases, as well as equilibrium employment. This is associated with higher household labor income, which may have a positive impact on aggregate demand if the negative wealth effect of higher future taxes is not too strong. In this case,

[5]Lequiller and Blades (2014) is a useful reference for understanding national accounting. They explain on pp. 138-139 why public services are recorded as public consumption: "Expenditures by general government are considered by convention as forming part of the final uses [...] of general government itself. For example, current expenditure on police and education is regarded as consumption by general government. What lies behind this strange convention, given that these services benefit households and enterprises? Essentially, it is because no one knows how to attribute this expenditure precisely to the beneficiaries, since they do not buy them, even though they pay the taxes that finance them. It has therefore been agreed not to attempt to allocate these expenditures to their beneficiaries but to attribute all these expenditures to general government itself, by convention."

[6]According to the Luxembourg Agence pour le Développement de l'Emploi (ADEM), in early 2019 cross-border workers accounted for 20% of jobs in the public sector and 51% in the private sector. The economy-wide average in Luxembourg was 45%.

firms need to sustain higher levels of production and start hiring workers, amplifying the original shock. At the same time, public employment tends to crowd out private employment through rising wages, so the net response of private employment depends on the relative strength of opposing effects. The share of cross-border workers in public employment is also an important parameter, since wages paid to these employees are not spent domestically and create a form of leakage. Because our modeling of the labor market overestimates the weight of cross-border workers in the public sector, we expect the model to magnify this leakage effect and therefore underestimate the actual response of domestic variables.

2.2.5. *Closing the model.* We close the model by postulating standard autoregressive processes for public consumption, public investment, and public employment:

$$\begin{aligned} P_t^C G_t^C &= (1-\rho_{gc})\bar{G}^C + \rho_{gc} P_{t-1}^C G_{t-1}^C + \epsilon_{gc,t}, \\ P_t^I G_t^I &= (1-\rho_{gi})\bar{P}^I \bar{G}^I + \rho_{gi} P_{t-1}^I G_{t-1}^I + \epsilon_{gi,t}, \\ N_t^G &= (1-\rho_{gn})\bar{N}^G + \rho_{gn} N_{t-1}^G + \epsilon_{gn,t}, \end{aligned}$$

where barred variables denote steady-state values, the ρ coefficients lie between 0 and 1, and the ϵ are independent shocks. Note that public expenditures on goods are determined in nominal terms, whereas public employment is determined in terms of the actual labor force employed by the public sector. Importantly, our setup assumes that the components of public expenditures evolve exogeneously and do not respond to endogenous developments in the economy.[7]

Finally, we modify a number of market-clearing conditions as follows:

$$\begin{aligned} Q_t^C &= C_t + \Gamma_{v,t} + G_t^C, \\ Q_t^I &= I_t + \Gamma_{u,t} K_{t-1} + G_t^I, \\ NT_t &= NT_t^C + NT_t^I, \\ HT_t &= HT_t^C + HT_t^I + HT_t^X, \\ IM_t^{H,CO} &= IM_t^{C,CO} + IM_t^{I,CO} + IM_t^{X,CO}. \end{aligned}$$

The first two equations incorporate public consumption and investment in the market-clearing conditions for consumption and investment goods, while the last three equations remove the composite government good present in the original LU-EAGLE model from the market-clearing conditions for intermediate and imported goods. The modified market-clearing condition for labor is provided in Section 2.2.4. Nominal GDP is defined as

$$GDP_t = P_t^C C_t + P_t^I I_t + P_t^G G_t + P_t^X X_t - P_t^{IM} IM_t,$$

where X_t and IM_t denote exports and imports, while P_t^X and P_t^{IM} are the associated deflators.

[7]In particular, we do not consider endogenous fiscal rules similar to those considered in, e.g., McGrattan (1994), Jones (2002), or Leeper, Plante, and Traum (2010).

2.3. **Calibration.** The fiscal extension introduces a number of new parameters compared to the original LU-EAGLE model. In this section, we elaborate on the calibration of these new parameters, listed in Table 1. All parameters present in the original LU-EAGLE model are unchanged; see Moura and Lambrias (2018) for their values. In particular, regarding the import content of final demand, we keep the following values computed from input-output tables published by the STATEC: 49% for private consumption, 64% for investment, and 68% for exports.

We choose the steady-state levels of public consumption $\bar{G}^C$, public investment $\bar{G}^I$, and public employment $\bar{N}^G$ to reproduce three sample averages computed from Luxembourg national accounts over the period 2010-2017. More precisely, we set $\bar{G}^I$ and $\bar{N}^G$ by matching the observed average GDP shares of expenditures on public investment and on public employment, respectively 4% and 8.5%. We then fix $\bar{G}^C$ to ensure that the sum of public consumption and expenditures on public employment represents 17% of GDP on average, just as in LU-EAGLE.[8]

Turning to the autoregressive parameters determining the persistence of the various fiscal shocks in the model, we use the same value of 0.95 as in LU-EAGLE.

We set the parameters defining the endogenous propagation of fiscal shocks with reference to both earlier literature and our own empirical evidence. Starting with the degree of substitutability/complementarity between private and public consumption, we set $\psi_G = -0.15$. This value implies that public consumption is slightly complementary with private consumption and ensures that the model generates a positive, but short-lived comovement between these variables as implied by the SVAR results discussed in the Introduction. It is also quite a conservative value, as it implies a lower degree of complementarity compared the estimates by Fève, Matheron, and Sahuc (2013) and Leeper, Traum, and Walker (2017) for the United States or Coenen, Straub, and Trabandt (2012, 2013) for the euro area.

Finally, we assume that public capital depreciates at the same rate as private capital, so that $\delta_G = 0.025$, and we set the productivity of public capital to $\alpha_G = 0.05$. This is the baseline value in the literature incorporating public investment in DSGE models (see, e.g., the discussion in Leeper, Walker, and Yang, 2010). It is also reasonably close to the estimates reported by Coenen, Straub, and Trabandt (2012, 2013) for the euro area. In Section 3.5, we study the sensitivity of model results to different values of ψ_G and α_G.

3. Model Dynamics

This section presents a set of simulations describing the effects of fiscal policy shocks in the augmented version of LU-EAGLE. We also contrast these effects with those of an increase in public expenditures in the original LU-EAGLE model and explain how the

[8]In national accounts, public consumption does not include public investment, which is part of gross capital formation, as is private investment. This justifies our strategy to identify the sum of public consumption and expenditures on public employment in the model with the measure of public consumption available in the data.

richer fiscal block explains the differences. In all simulations, we consider shocks that increase public expenditures by one percent of *ex ante* GDP. Throughout, we focus on the responses of domestic variables, i.e. variables from the Luxembourg block of the model.

3.1. **Public expenditure shock in the original LU-EAGLE.** We start by reviewing the effects of an exogenous increase in public expenditures in the original LU-EAGLE model. Our discussion, which builds on Section 4.3 in Moura and Lambrias (2018), highlights the propagation channels of fiscal policy shocks in a standard New-Keynesian DSGE model in which public expenditure affects neither household utility nor firm productivity.

Figure 2 shows the responses of selected Luxembourg variables to the shock. Real GDP increases by about 0.75% on impact, before slowly returning to its steady-state level as the effects of the shock vanish. At all horizons, the response of output is smaller than the actual increase in public expenditures, which signals that public demand crowds out private demand in the model. Indeed, the rise in public expenditures triggers a persistent fall in both private consumption and investment, after a short-lived increase in the latter. Importantly, the negative response of private consumption is not consistent with the positive one estimated from the SVAR. Finally, exports fall and imports rise, which weighs further on GDP.

Three economic mechanisms shape these responses to the public expenditure shock in the model. The leading force is the negative wealth effect experienced by resident households, which captures the change in household spending caused by variations in perceived wealth. In the model, rational and forward-looking agents anticipate that the government will increase future taxes following a rise in spending to respect its intertemporal budget constraint. As a result, households recognize that their lifetime wealth drops after the public expenditure shock and they react by cutting consumption and investment expenditures, as shown in Figure 2.

The second important mechanism is international trade. Since exports fall while imports rise after the shock, the effect of a rise in public expenditures on Luxembourg net trade is clearly negative according to the model. The underlying logic is straightforward. On the one hand, domestic production incorporates substantial import content in Luxembourg, so that the rise in GDP must be associated with higher imports. On the other hand, the increase in demand pushes domestic firms to raise prices, as can be seen from the behavior of CPI inflation; export prices rise too and foreign demand partly shifts away from Luxembourg products.

The third mechanism is a positive intertemporal substitution effect linked to the response of the real interest rate. Because Luxembourg represents a small share of euro-area GDP and inflation, the area-wide nominal policy rate barely responds to the public expenditure shock in Luxembourg. As a result, the rise in domestic inflation translates directly into a fall in the real interest rate in Luxembourg, which supports aggregate demand by front-loading consumption and making investment less costly. However, we can conclude

from the negative responses of consumption and investment that the substitution effect is weaker than the wealth effect in the model.

This simulation clarifies how the extended fiscal block modifies the behavior of the model. First, the introduction of a complementarity between private and public consumption makes households willing to increase consumption after a rise in public consumption, counteracting the negative wealth effect. Second, introducing public capital in production makes the private sector more productive after a rise in public investment, counteracting the inflationary pressures weighing on external demand. This is what we show below.

3.2. **Public consumption shock.** We now turn to the model with the extended fiscal sector. Figure 3 shows the responses of domestic variables to an exogenous increase in public consumption in Luxembourg.

The behavior of real GDP is similar to that in the original LU-EAGLE model: it jumps by about 0.70% at the date of the shock and slowly reverts to its steady state afterward. However, this similarity masks important differences in the responses of the various subcomponents of aggregate demand. In particular, in the extended model private consumption rises by 0.40% on impact and remains above its steady state during the first year after the shock, which is consistent with the SVAR estimates reported in Figure 1. In addition, the rise in public consumption triggers a sustained increase in investment in the extended model. There is also a jump in inflation explained by the initial increase in real wages; that movement is only short lived given the declining profile of wages and production costs in subsequent periods. Overall, these responses suggest that an increase in public consumption has positive spillovers on private domestic demand and does not trigger crowding-out effects.

These positive spillovers arise from the complementarity between private and public consumption. As can be seen from equations (2) and (3), the marginal utility of private consumption in the extended model is given by

$$\frac{\partial V_t}{\partial C_t} = z_{CON,t} \left[\left(C_t + \psi_G G_t^C \right) - \kappa \left(C_{t-1} + \psi_G G_{t-1}^C \right) \right]^{-\sigma}.$$

When private and public consumption are complementary in the household utility function ($\psi_G < 0$), a rise in public consumption G_t^C increases marginal utility. Households are thus more willing to consume, which explains the positive short-run response of private consumption shown in Figure 3. Therefore, complementarity introduces a new mechanism in the model and offsets the negative wealth effect associated with the fiscal shock. However, the positive response of private consumption is rather short lived, so that the negative wealth effect grows over time as public consumption returns to its steady-state level.

Contrasting Figures 2 and 3 also raises an apparent contradiction: in spite of the positive responses of both household consumption and investment in the extended model, the increase in real GDP is actually smaller than in the original model, in which domestic

private demand falls after the shock (0.70% versus 0.75%). This apparent inconsistency arises from international trade. In particular, given the large import content of both private consumption and investment in Luxembourg (respectively 49% and 64%), the increase in domestic demand is associated with a strong upward movement in imports, which causes a fall in net exports twice as large in the extended model as in the original LU-EAGLE. In addition, the rise in inflation weighs on domestic competitiveness and lowers foreign demand for Luxembourg products, strengthening the fall in net exports and limiting the response of GDP. Thus, our experiment demonstrates that standard amplification channels for public demand shocks, which have been shown to boost GDP movements in relatively close economies such as the US or the EA (Coenen, Straub, and Trabandt, 2012, 2013; Fève, Matheron, and Sahuc, 2013; Leeper, Traum, and Walker, 2017), are less powerful in very small very open economies such as Luxembourg. This is well in line with the stylized fact found by Ilzetzki, Mendoza, and Végh (2013) that smaller economies tend to have smaller fiscal multipliers.

We conclude from this model simulation that, in line with the literature, postulating complementarity between private and public consumption provides a strong amplification channel for public spending shocks in LU-EAGLE. Indeed, the extended model implies that both private consumption and investment respond positively to an increase in public consumption. However, the extended model is not able to generate a stronger response of aggregate GDP compared to the original LU-EAGLE model, as the strong open-economy channel in Luxembourg outweighs the rise in domestic demand *via* the fall in net exports.

3.3. **Public investment shock.** Figure 4 shows the responses of domestic variables to an exogenous increase in public investment in Luxembourg according to the model with the extended fiscal block.

The public investment shock we consider has the same persistence as the public consumption shock discussed in Section 3.2. As a result, the response of public expenditures in the lower panel of Figure 4 largely mirrors that in Figure 3. More precisely, in both simulations the maximum increase in public spending occurs when the shock hits the economy, followed by a progressive return toward the steady state. This gradual normalization process explains why the public consumption shock has its maximum effect on GDP on impact rather than at longer horizons.

As shown in Figure 4, a rise in public investment has very different economic implications, with a maximum effect on aggregate variables such as GDP, investment, or exports, occurring only in the medium run, about 5 years (20 quarters) after the shock. This delayed amplification reflects the behavior of the stock of public capital. Because capital depreciation is a very slow process, public capital keeps rising for several years after the shock, even though public investment quickly reverts to its steady state.

The extended model implies that higher government investment raises real GDP at all horizons, with an increase ranging from 0.20% on impact to 0.30% after 20 quarters (5 years). Private investment also exhibits a sustained upward movement, while household

consumption falls slightly but persistently due to the usual negative wealth effect of higher public expenditures. As for international trade, exports follow the same upward path as investment and are 0.20% higher after 20 quarters, while imports rise by 0.50% on impact before progressively reverting to the steady state. Given the larger movement in imports, the net effect on the trade balance is negative during the 5 years following the shock.

These dynamics reflect the progressive contribution of the stock of public capital to private sector productivity. Indeed, as implied by equations (4) and (5), a rise in public capital has the same effects on domestic firms as an increase in total factor productivity. In the short run, the response of public capital is limited and productivity is roughly unchanged, but resident agents rationally anticipate future increases in efficiency and production. Therefore, they find it optimal to borrow from abroad against these good prospects, which explains the initial rise in imports. As time goes by, the stock of public capital increases, making domestic firms more efficient, so that the initial public investment shock turns into a positive supply shock. Investment rises significantly as the return to capital increases, inflation declines with production costs, and there is a boost to external competitiveness reflected by the real exchange rate and the terms of trade.

Overall, the simulation suggests that the model economy responds very differently to an increase in public consumption or in public investment. In particular, the public consumption shock has larger effects in the short run and decreases foreign competitiveness, much as a standard domestic demand shock, while the public investment shock supports aggregate supply in the medium run and generates a non-inflationary expansion. These differences provide the fiscal authority with alternative policies to stabilize aggregate developments in the economy, a point we discuss in more detail in Section 4.2.

3.4. **Public employment shock.** Figure 5 shows the responses of domestic variables to an exogenous increase in public sector employment according to the extended model. As in the previous simulations, the shock is calibrated to increase public expenditures by one percent of *ex ante* GDP, which requires an important rise of about 12% in public employment. Given the strong positive response of real wages, the *ex post* increase in public expenditure is slightly higher than in the previous simulations.

Real GDP increases by 1.10% on impact, reflecting only the rise in public expenditure. All other components of aggregate demand fall after the shock: consumption, investment, and net exports all feature hump-shaped negative responses that reach their trough about two and a half years (10 quarters) after the initial rise in public employment. Compared to the previous simulations, the fall in net exports is limited, which explains why raising public employment has the strongest effect on GDP according to the model. Interestingly, Rapa (2017) also finds large effects of public employment shocks using a quantitative DSGE model of Malta, another euro-area small open economy.

Total employment increases and the rise in real wages reflects tighter conditions in the labor market. Given the drops in all components of private production (private consumption, private investment, exports), private employment necessarily decreases in

response to the shock. It follows that the public employment shock exerts a crowding-out effect on the private sector by tightening the labor market. Firms also raise their prices in light of higher production costs, which boosts inflation and dampens the external competitiveness of the Luxembourg economy. Specifically, both the real exchange rate and the terms of trade signal that domestic production becomes more expensive relative to foreign goods.

A striking implication of the model is that households choose to cut on both consumption and investment expenditures even as labor income increases. This means that the negative wealth effect experienced by resident households largely outweighs the benefits linked to higher current income. A potential explanation is linked to the fact that the model overestimates the share of cross-border workers in the Luxembourg public sector. In practice, resident workers probably benefit more from the rise in public employment, so their labor income will be higher than implied by the model. This may counteract the negative wealth effect associated with the shock and support private domestic demand.

It is also interesting to note that all three expenditure shocks (to public consumption, investment, and employment) have roughly identical effects on public finances. As can be seen from the bottom right panels from Figures 3, 4, and 5, the primary deficit increases by slightly less than one percent of steady-state GDP on impact and progressively returns to its steady-state value. It follows that all shocks have similar implications for the government budget constraint, the only difference being that deficit reverts much faster in the case of a public investment shock, as economic activity develops in the medium run.

3.5. **Robustness to model calibration.** Finally, we briefly discuss the robustness of the above results to alternative assumptions regarding the values taken by two key model parameters: the degree of substitutability/complementarity between private and public consumption ψ_G and the elasticity of private production to the stock of public capital α_G. Obviously, the calibration of these two coefficients is key to the behavior of the model after shocks to public consumption or investment, which justifies a sensitivity analysis.[9] We solve and simulate the model for all different parameter configurations we consider.

Figures 6 and 7 show the responses of domestic variables to a public consumption shock under two alternative values for ψ_G. Figure 6 postulates a lower degree of complementarity between household consumption and public consumption by setting $\psi_G = -0.075$, while Figure 7 assumes substitutability by calibrating $\psi_G = 0.075$. Comparing the results to those from the benchmark calibration highlights that the degree of complementarity mostly affects the responses of household consumption and GDP to the public consumption shock. More precisely, the stronger the complementarity, the more private consumption and GDP increase after the shock. In the extreme case of substitutability,

[9]We do not perform robustness checks for the shock to public employment, as the only sensible exercise — imposing a different share of cross-border workers in the private and public sectors — would require more than a simple recalibration, as different types of labor would need to be introduced in the model. We leave this issue for future work.

private consumption drops in response to the public consumption shock, weighing on GDP. Comparing these responses to the SVAR estimates reported in Figure 1 confirms our benchmark calibration of $\psi_G = -0.15$, which yields a private consumption response that is more in line with the empirical evidence.

Figures 8 and 9 show the responses of domestic variables to a public investment shock under two alternative calibrations: a low value of $\alpha_G = 0.02$ in Figure 8 and a high value of $\alpha_G = 0.10$ in Figure 9. These values are based on the lower and upper bounds for the productivity effect of public capital found in the literature (see Sims and Wolff, 2018, for a useful review). Comparing the results from the alternative calibrations of α_G demonstrates that model implications can be very sensitive to the value taken by this coefficient. Most importantly, moving from a low to a high calibration of α_G generates marked differences in the behavior of GDP and consumption in the medium run. When public capital has little effect on aggregate productivity, GDP exhibits a weak response (+0.15%) in the medium run and consumption responds negatively to the shock. On the other hand, when public capital has strong spillovers, the medium-term response of GDP is much higher (+0.60%) and consumption has a positive response in all periods. In the absence of a reliable estimate of α_G, quantitative statements about the effects of public investment shocks should be taken with a grain of salt.

4. Fiscal Multipliers and Expenditure Reorientation

This final section provides alternative measures of the aggregate impact of fiscal policy on the economy, in the form of fiscal multipliers associated with each policy instrument. To illustrate the ability of the model to evaluate policy changes in several dimensions, it also considers the effects of reorienting public expenditures away from consumption and toward investment.

4.1. **Fiscal multipliers.**

The impulse-response functions discussed in the previous section show that the shocks to public consumption, investment, and employment trigger different dynamics in terms of both magnitude and persistence. This heterogeneity raises an issue of comparability: for instance, how can we compare the output response to a shock with short-lived but important effects, such as the public employment shock, with that to a shock with more muted but persistent effects, such as the public investment shock?

Present-value fiscal multipliers provide a simple way to address this issue by computing the cumulative GDP gain obtained at a given horizon for one additional euro spent on a specific policy instrument.[10] The expression for the multiplier at horizon k is given by

$$M(j) = \frac{\sum_{j=0}^{k} R^{-j} dY_j}{\sum_{j=0}^{k} R^{-j} dG_j},$$

[10]Ramey (2016) argue forcefully in favor of using present-value multipliers to assess the aggregate effects of fiscal policy, instead of the peak-to-impact approach from Blanchard and Perotti (2002).

where dY_j and dG_j respectively denote the response of nominal GDP and the variation in nominal public expenditures j periods after the shock, while R is the steady-state gross nominal interest rate. The numerator of this ratio is the present value of cumulative GDP gains up to date j, while the denominator is the present value of the cumulative fiscal cost associated with the shock. Since both the gain and the cost are converted to date-0 units, present-value multipliers are well designed to compare the GDP effects of different fiscal shocks at various horizons.

Table 2 reports the fiscal multipliers associated with the public expenditure shock in the original LU-EAGLE model, as well as with the public consumption, investment, and employment shocks in the model with the extended fiscal sector. As discussed in Moura and Lambrias (2018), the multiplier associated with aggregate public expenditures in LU-EAGLE is below one at all horizons: it takes its maximum value of 0.80 on impact and decreases over time, converging to 0.50 in the long run. These moderate values are consistent with the empirical literature on fiscal multipliers, which concludes that more open economies are associated with smaller multipliers (Ilzetzki, Mendoza, and Végh, 2013).

The extended model considers a richer set of fiscal instruments and provides a finer picture of spending multipliers in Luxembourg. Three results stand out. First, the multiplier associated with public consumption has a profile similar to that in the standard LU-EAGLE model, except that it is shifted downward: it starts below 0.70 and slowly converges to a long-run value close to 0.40. To a large extent, this smaller multiplier reflects the leakages associated with the larger impact on imports in the extended model. Second, the multiplier associated with public investment is smaller but increases over time: starting at the moderate value of 0.23, it rises after two years and reaches a value close to 0.40 at the 5-year horizon, and to 0.60 at the 10-year horizon. This demonstrates that the aggregate effects of the fiscal shocks are front-loaded with public consumption and back-loaded with public investment. Third, the multiplier associated with public employment is the largest, even though our model likely underestimates the response of the economy to the public employment shock. The multiplier is above one on impact and remains higher than the other multipliers up to 5 years after the shock.[11]

According to these results, increasing public employment appears to be the most effective channel to stimulate the economy in the short run, while increasing public investment has the strongest effects in the medium to long run. Therefore, no public expenditure tool clearly outperforms the others when it comes to temporarily stabilizing or stimulating the economy; rather, policymakers can choose the appropriate spending mix depending on both the current economic situation and their planning horizon.

[11]An obvious caveat is that we focus on models with minimal amounts of economic slack. When the economy is in a severe downturn with important slack in the labor and goods markets, fiscal multipliers may be larger than the 'normal-times' values we report. However, in a review of the literature about fiscal multipliers in the United States, Ramey (2016) concludes that there is "little evidence of state dependence, based on recessions, elevated unemployment rates, or the zero lower bound."

Table 3 reports the multipliers corresponding to the robustness exercises conducted in Section 3.5. The results are not surprising for the shock to public consumption: the stronger the degree of complementarity between household and public consumption, the higher the fiscal multiplier. The patterns are more interesting for the public investment shock. When public capital has only a limited contribution to total factor productivity, the multiplier is essentially flat just above 0.20 and the back-loading in terms of GDP gains arises only in the long run, after the 5-year horizon. On the other hand, when spillovers are important, back-loading is significantly enhanced: the 5-year multiplier equal 0.58, just as the employment multiplier, while the 10-year multiplier slightly exceeds one. Again, this highlights the sensitivity of model results to assumptions about the productivity of public capital.

4.2. **Expenditure reorientation.** Finally, we illustrate the ability of the model to evaluate policy changes involving simultaneous changes in different forms of public expenditures. The example we consider, based on Jacquinot, Clancy, and Lozej (2014), consists in an *ex ante* neutral reorientation of public expenditure in which investment increases by 1% of *ex ante* GDP while consumption is cut by the same amount.

Figure 10 reports the results of this simulation. Because shocks to public consumption and investment have different effects, the model implies rich aggregate dynamics following the reorientation. In the short term, output falls by 0.5%, partly because household consumption reacts negatively to the cut in public consumption due to complementarity, partly due to the higher import content of investment relative to consumption. After two years, private firms become more productive as public capital accumulates and, as a result, all components of aggregate demand increase: households consume more as they earn higher wages, the return to capital pushes investment up, and the trade balance expands as competitiveness improves. These positive effects on the economy are long lasting due to the slow depreciation of public capital. Throughout the experiment, total public expenditures barely move (except for a small shift due to relative price movements), so that the net effect on the primary deficit is rapidly positive as the economic expansion results in higher tax revenues.

Although we do not run the same sensitivity checks for this exercise, it is straightforward to infer how alternative values of ψ_G and α_G would affect the results. Increasing the complementarity between private and public consumption would strengthen the short-run costs associated with the cut in public consumption, while increasing the productivity effects of public capital would amplify the long-run gains from public investment and may also support household consumption in the short run.

This experiment illustrates that different economic situations will require a different fiscal policy mix, including simultaneous changes in the components of public expenditure in proportions that depend on both the policymaker objectives (short term vs. long term) and on the characteristics of the economy (the values of α_G and ψ_G in particular).

5. Conclusion

This paper describes an extension of the DSGE model LU-EAGLE to enhance the analysis of fiscal policy in Luxembourg. Compared to the original version, the extended model embeds a wider range of transmission channels for fiscal policy, including a distinction between public consumption and public investment, complementarity between private and public consumption, a productive role for public capital, and the consideration of public employment.

Simulations from the extended model yield three results:

- When private and public consumption are complementary in the representative household utility function, a public consumption shock has positive spillovers on private domestic demand. In particular, a rise in public consumption is associated with positive responses of both private consumption and investment. However, international leakages caused by the fall in net exports outweigh the rise in private domestic demand, limiting the GDP response.
- An increase in public investment has a strong positive effect on domestic aggregate supply in the medium and long run, boosting the economy's productivity and generating a non-inflationary expansion. The key mechanism is the slow build-up of public capital and its positive spillovers on private sector productivity, which make it possible to accommodate the rise in both domestic and foreign demand.
- Finally, we find that a rise in public employment induces the strongest GDP response in the short run, largely because it is associated with only a limited fall in net exports. This finding is likely to be stronger in a recession, when the labor market features some slack.

These heterogeneous effects of public expenditure shocks suggest that no tool systematically outperforms the others when it comes to temporarily stabilizing or stimulating the economy. Rather, the different effects imply that policymakers can implement alternative spending mixes depending on economic developments and on their planning horizon.

The model also implies relatively small fiscal multipliers in Luxembourg. Public employment is the only instrument associated with a multiplier that exceeds unity on impact, and over time all multipliers converge to limited values ranging from 0.35 to 0.60. To a large extent, these small multipliers reflect the strong crowding-out effects arising from the openness of the Luxembourg economy.

We conclude by mentioning a couple of open issues that could be addressed in future research. First, our sensitivity analysis highlights the importance of a few parameters in shaping the model's quantitative properties. These parameters include the degree of complementarity between private and public consumption and the impact of public capital on private sector productivity, but we also think of the relative weight of resident and cross-border workers in public employment. Refining the calibration of these parameters by relying more on the data, perhaps through estimation, would improve the reliability of the quantitative results. Estimation would also make it possible to consider replacing the

exogenous processes for the public spending components with endogenous fiscal rules. Second, our analysis only covers transitory (but persistent) fiscal shocks. In practice, fiscal shocks tend to be permanent, which changes the relative strength of the associated wealth and substitution effects. Hence, it might be interesting to introduce permanent fiscal shocks in the model.

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Appendix A. The Fiscal SVAR

This appendix provides more details about the structural Vector Autoregressive (SVAR) model used to identify the short-run response of private consumption in Luxembourg to a shock to domestic public consumption. As explained in the Introduction, our objective is to provide an empirical motivation for the introduction of complementarity between private and public consumption in the extended DSGE model.

The estimated reduced-form VAR is given by

$$z_t = a + B(L)z_{t-1} + u_t, \tag{8}$$

where z_t is a vector of observable variables, a is a vector intercept, $B(L)$ is a finite-order matrix polynomial in non-negative powers of the lag operator L, and u_t is a vector of serially uncorrelated shocks. Our vector of observables includes an index of effective foreign demand addressed to Luxembourg, real public consumption, real private consumption, real GDP, and inflation.[12] The first four variables appear in logarithm, while the last one is a growth rate. The foreign demand series is an internal ESCB trade-weighted average of real imports in Luxembourg's partner countries; it is included in the VAR to control for foreign developments. Public consumption is measured by final consumption expenditures of the general government, while private consumption is measured by final consumption expenditures of households and non-profit institutions serving households. Inflation is measured by the growth rate of the GDP deflator. Finally, all series are quarterly and seasonally adjusted and the estimation sample covers the period 1995Q1-2018Q3.

Prior to estimation, we perform the Johansen test and find evidence that the variables are co-integrated. As a result, we estimate the VAR in levels. Based on the Bayesian Information Criterion, we pick a model with one lag. We also checked that our findings are robust to allowing for additional lags. Furthermore, a multivariate LM test statistic confirms that the residuals are uncorrelated at different time horizons.

We identify public consumption shocks using a Cholesky decomposition, as used by Blanchard and Perotti (2002) and many others.[13] Since public consumption is ordered first among the domestic variables, public consumption shocks can simultaneously affect private consumption, GDP, and inflation in the identified VAR. This property is also verified in the LU-EAGLE model, in which all domestic variables react to fiscal shocks on impact.

[12] In practice, we treat foreign demand as exogenous with respect to Luxembourg variables, reflecting the absence of significant feedback from Luxembourg to the rest of the world. From a formal perspective, this amounts to imposing zero restrictions on the matrix polynomial $B(L)$ and on the covariance matrix of the residuals.

[13] Ramey (2011, 2016) notes that the Blanchard-Perotti identification fails to control for anticipation effects, which might bias the estimated impulse-response functions. Since it is not possible to implement Ramey's (2011) narrative identification strategy on Luxembourg data, the extent of fiscal foresight in Luxembourg remains an open question.

Appendix B. Tables and Figures

Table 1. Parameter calibration.

Parameter	Symbol	Value
Public consumption		
Steady state level	$\bar{G}^C$	0.55
Autoregressive coefficient	ρ_{gc}	0.95
Complementarity with private consumption	ψ_G	-0.15
Public investment		
Steady state level	$\bar{G}^I$	0.26
Autoregressive coefficient	ρ_{gi}	0.95
Depreciation rate of public capital	δ_G	0.025
Productivity of public capital	α_G	0.05
Public employment		
Steady state level	$\bar{N}^G$	0.31
Autoregressive coefficient	ρ_{gn}	0.95

Table 2. Fiscal multipliers.

Model	Shock	Q1	Y1	Y2	Y3	Y4	Y5	Y10
Original	Public expenditures	0.80	0.73	0.64	0.59	0.55	0.53	0.50
Extension	Public consumption	0.67	0.60	0.52	0.47	0.45	0.43	0.43
	Public investment	0.23	0.22	0.24	0.28	0.32	0.37	0.59
	Public employment	1.07	0.98	0.83	0.72	0.63	0.58	0.46

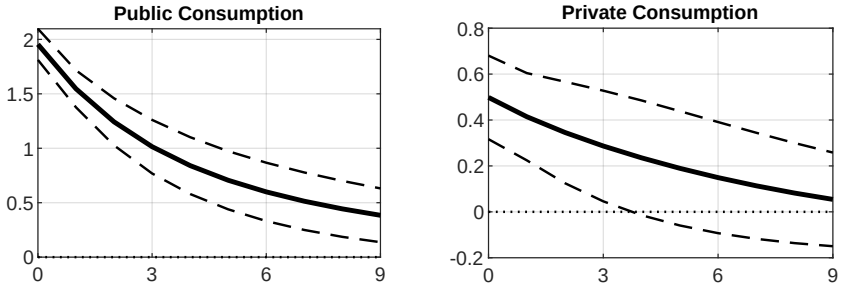
Notes. Fiscal multipliers are defined as the ratio of the present value of the change in GDP up to date j to the present value of the change in public expenditures up to date j. Q1 is the first quarter after the shock, while Y1 to Y10 represent years one to ten after the shock. 'Original' refers to the original LU-EAGLE model (Moura and Lambrias, 2018) and 'Extension' to the extended model of this paper.

Table 3. Robustness check: Fiscal multipliers.

Shock	Calibration	Q1	Y1	Y2	Y3	Y4	Y5	Y10
Public consumption	$\psi_G = -0.075$	0.63	0.57	0.49	0.45	0.42	0.41	0.40
	$\psi_G = 0.075$	0.57	0.51	0.44	0.39	0.37	0.35	0.35
Public investment	$\alpha_G = 0.02$	0.22	0.20	0.20	0.20	0.22	0.24	0.34
	$\alpha_G = 0.10$	0.24	0.26	0.32	0.40	0.49	0.58	1.01

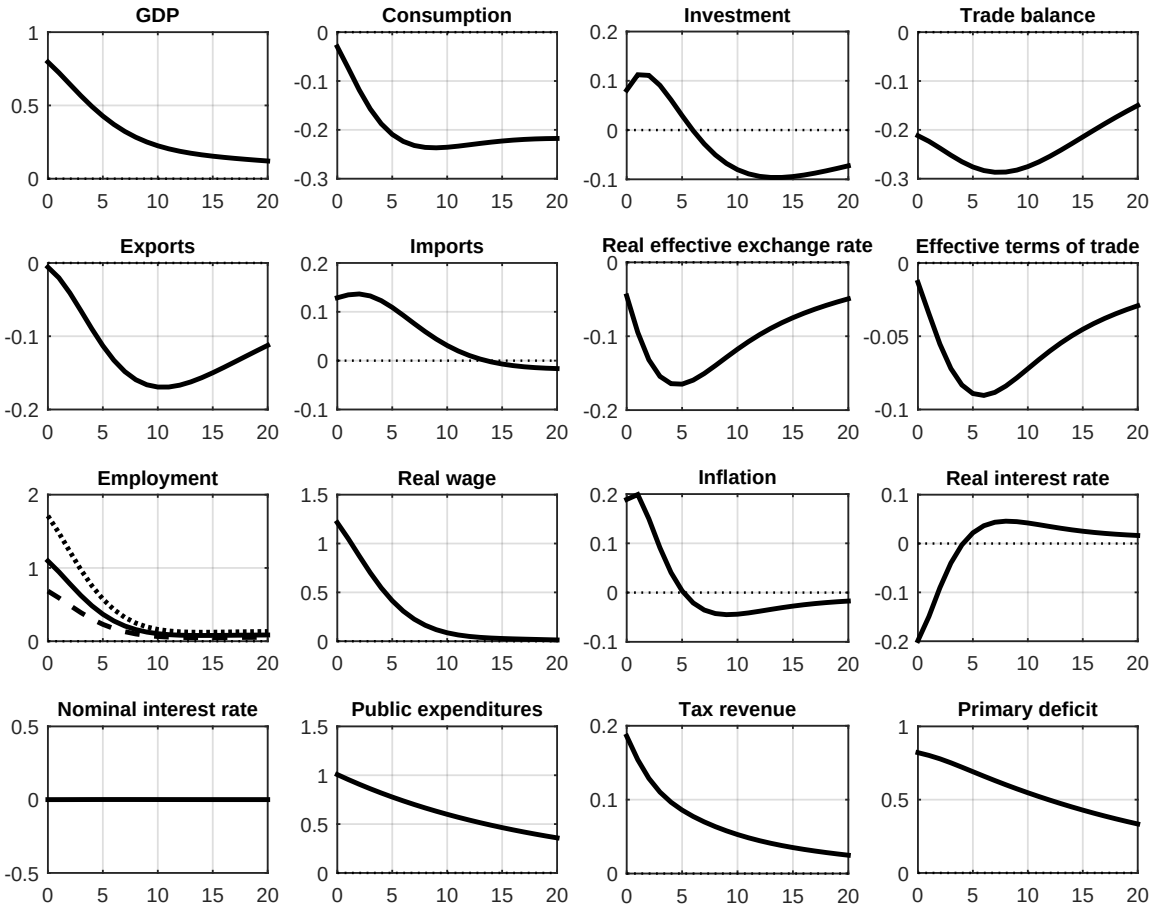
Notes. Fiscal multipliers defined as the ratio of the present value of the change in GDP up to date j to the present value of the change in public expenditures up to date j. Q1 is the first quarter after the shock, while Y1 to Y10 represent years one to ten after the shock.

FIGURE 1. SVAR-based impulse-response functions to a public consumption shock in Luxembourg.



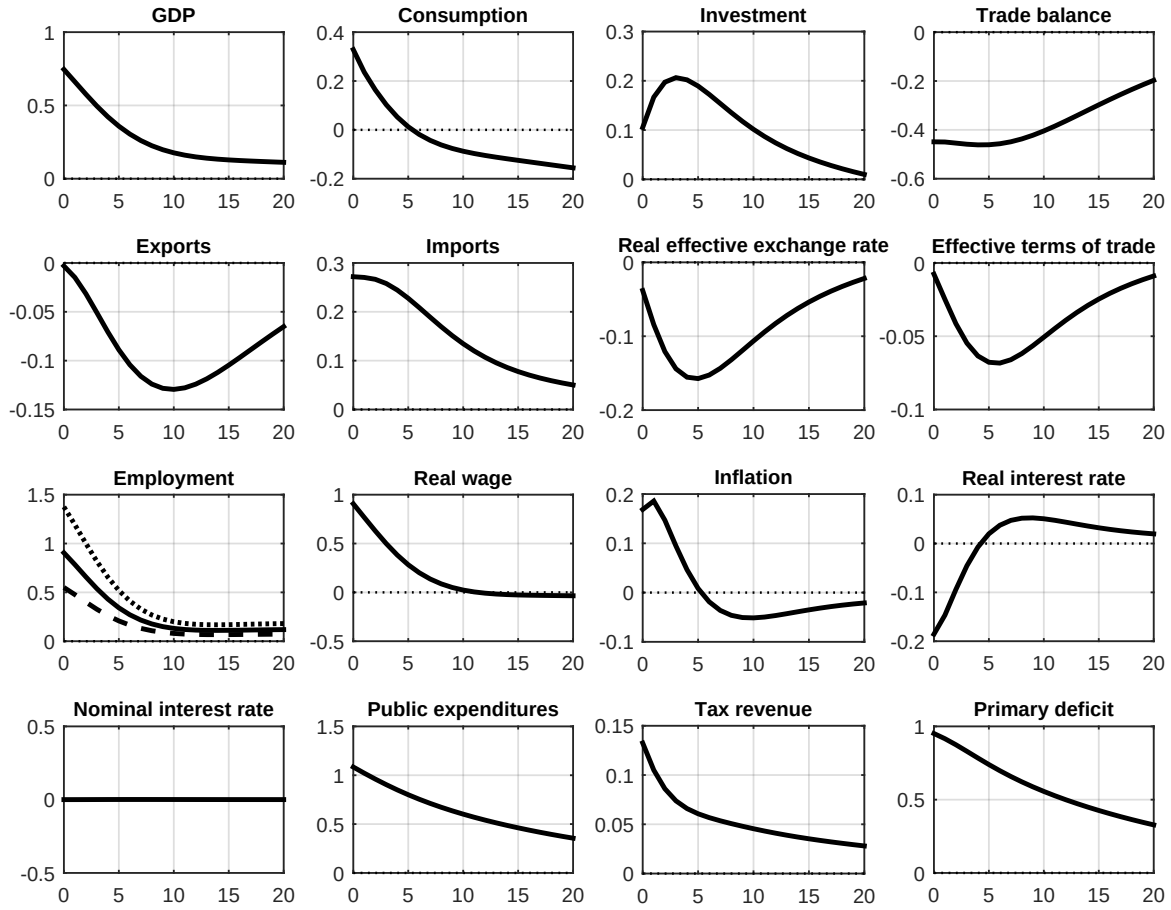
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state. The solid lines represent the impulse-response functions to a one-standard-deviation shock to public consumption, while the dotted lines indicate two-standard-error confidence bands. The model has a single lag and the estimation sample is 1995Q1-2018Q3; see Appendix A for details.

FIGURE 2. Increase in public expenditures in Luxembourg — Original LU-EAGLE model.



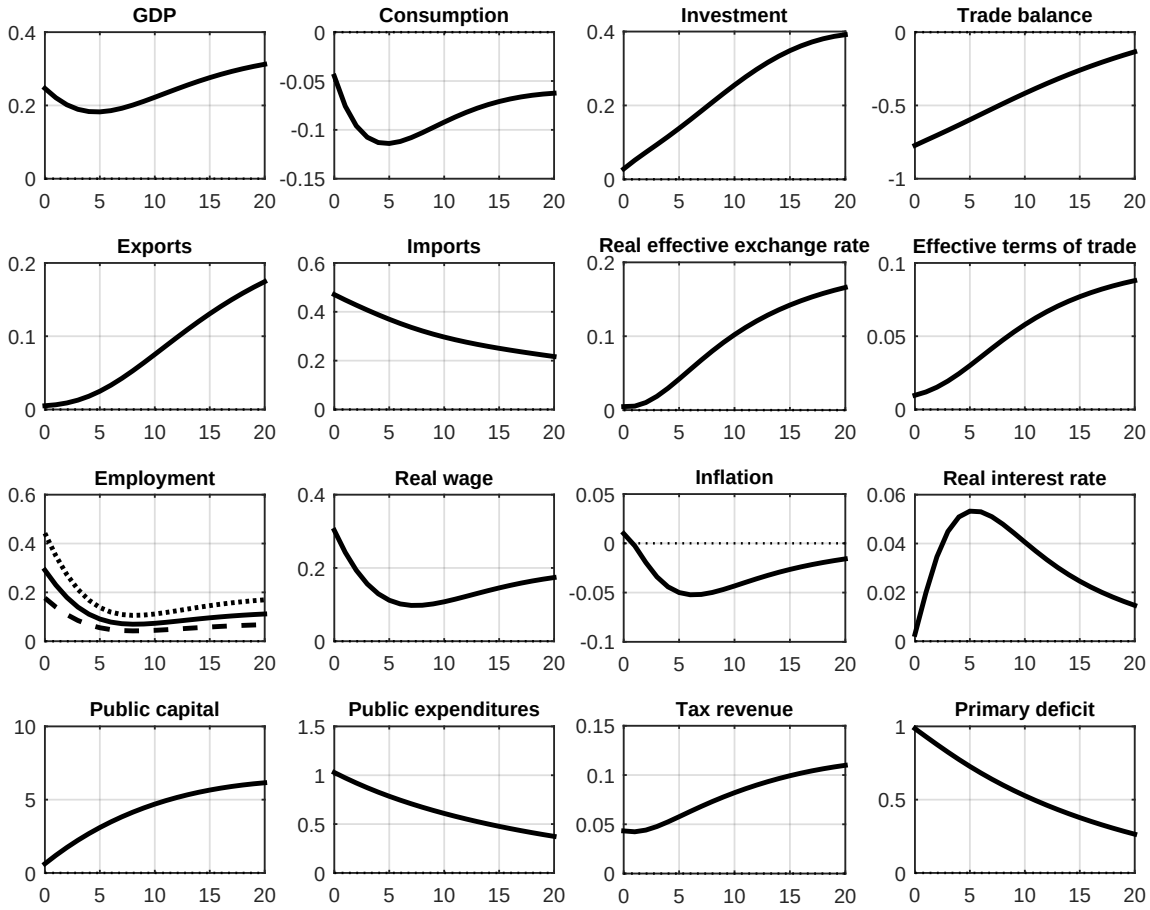
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public expenditures by 1% of *ex ante* GDP.

FIGURE 3. Increase in public consumption in Luxembourg — Extended LU-EAGLE model, baseline calibration.



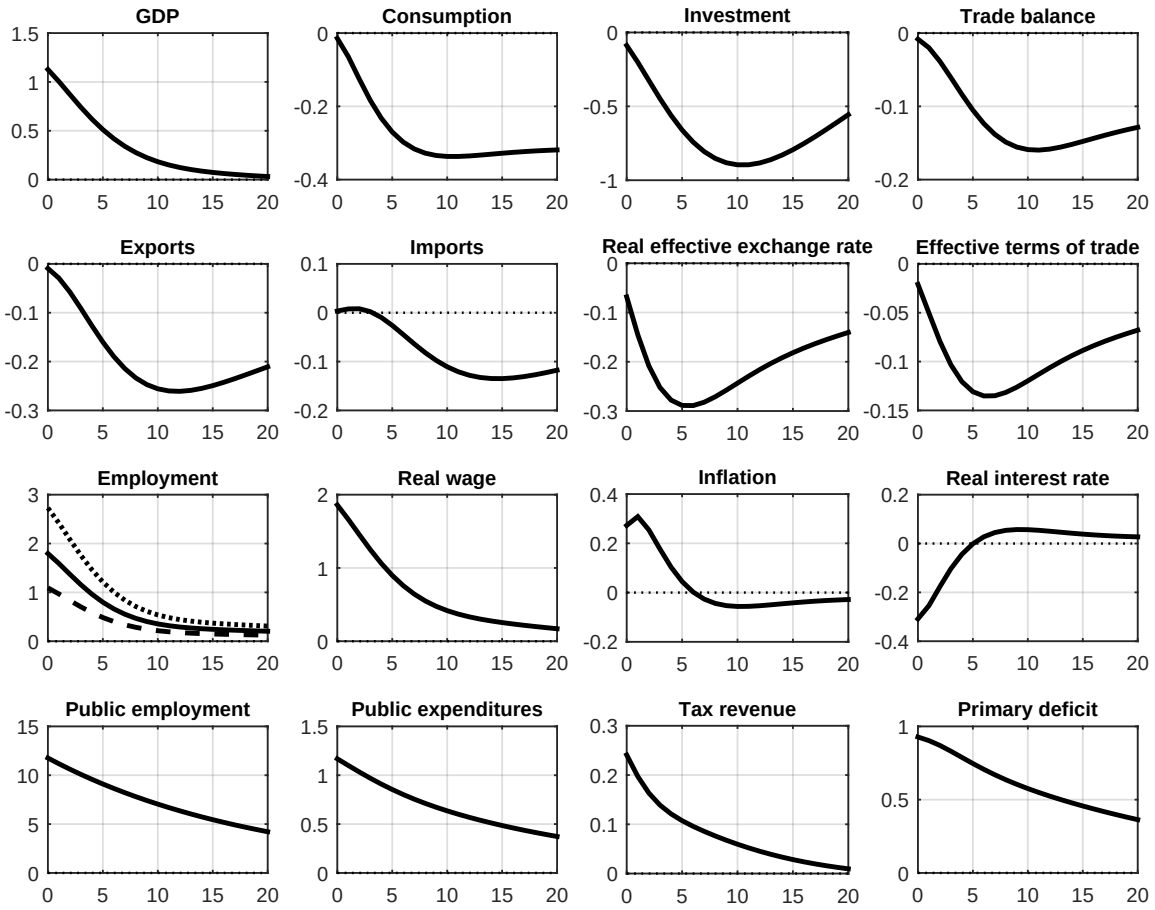
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public consumption by 1% of *ex ante* GDP.

FIGURE 4. Increase in public investment in Luxembourg — Extended LU-EAGLE model, baseline calibration.



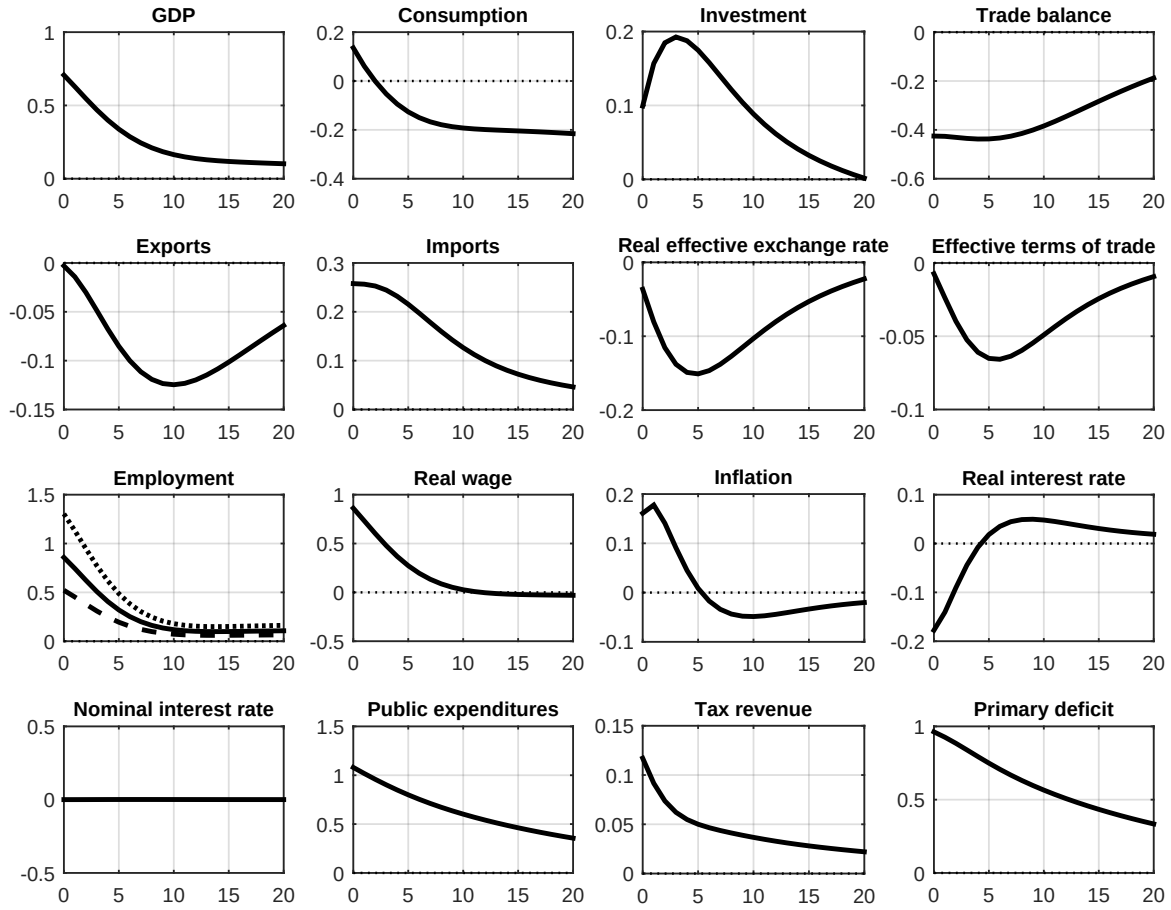
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public investment by 1% of *ex ante* GDP.

FIGURE 5. Increase in public employment in Luxembourg — Extended LU-EAGLE model, baseline calibration.



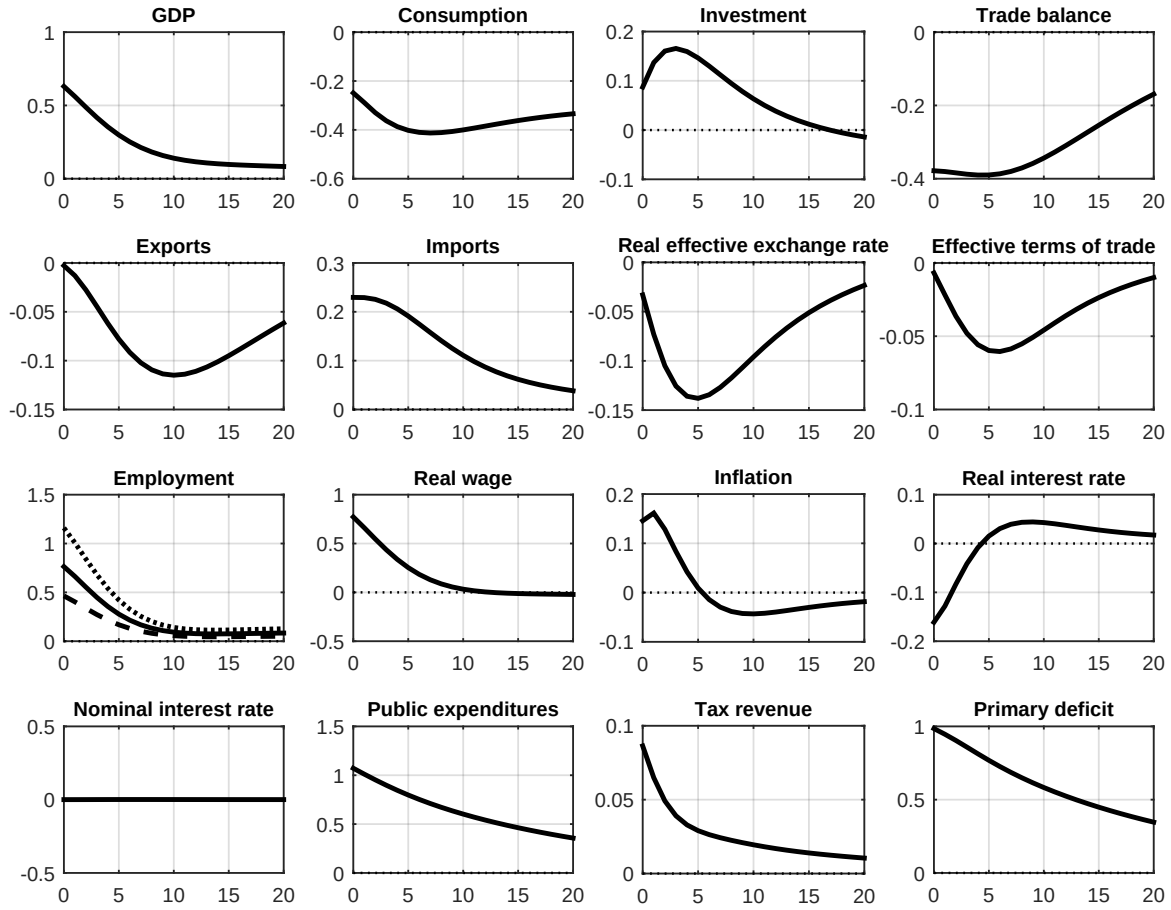
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase expenditures on public labor by 1% of *ex ante* GDP.

FIGURE 6. Robustness check: Effects of the public consumption shock when $\psi_G = -0.075$.



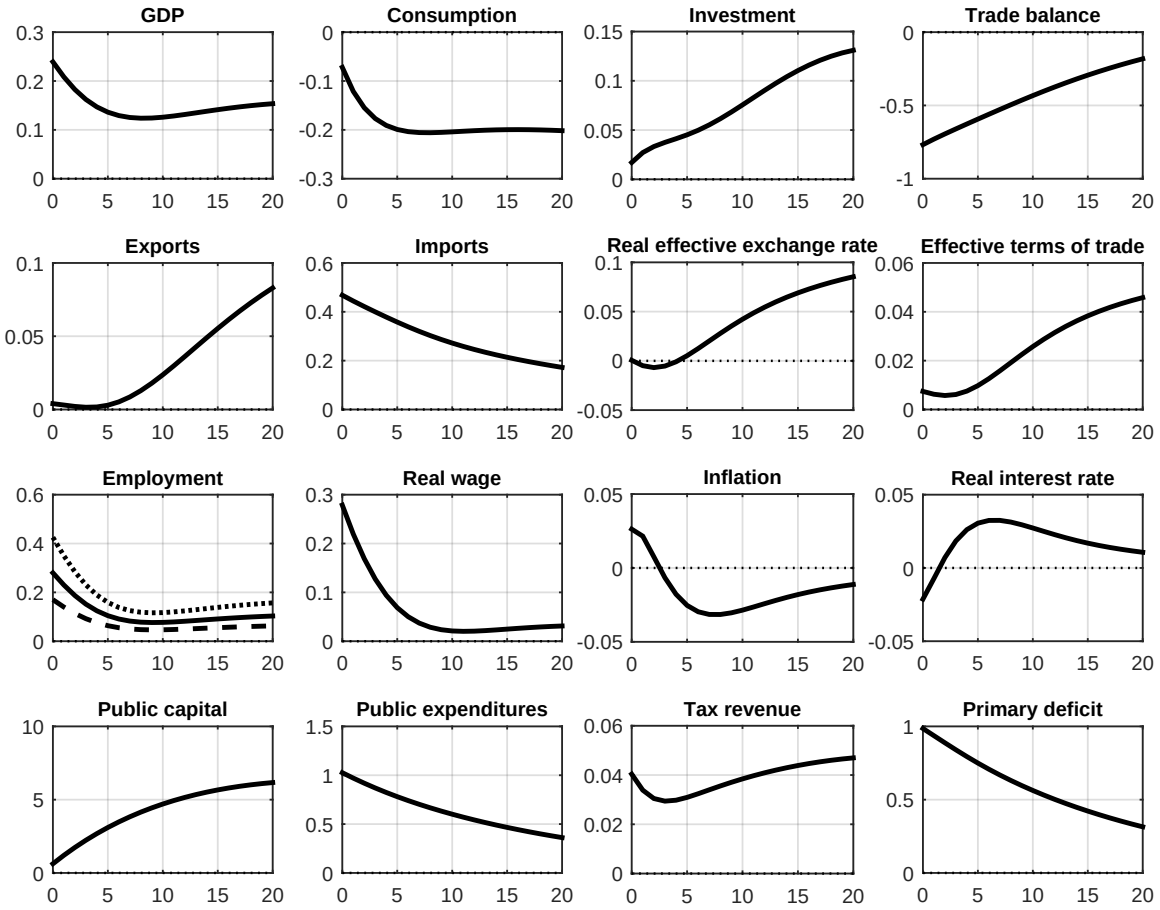
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public consumption by 1% of *ex ante* GDP.

FIGURE 7. Robustness check: Effects of the public consumption shock when $\psi_G = 0.075$.



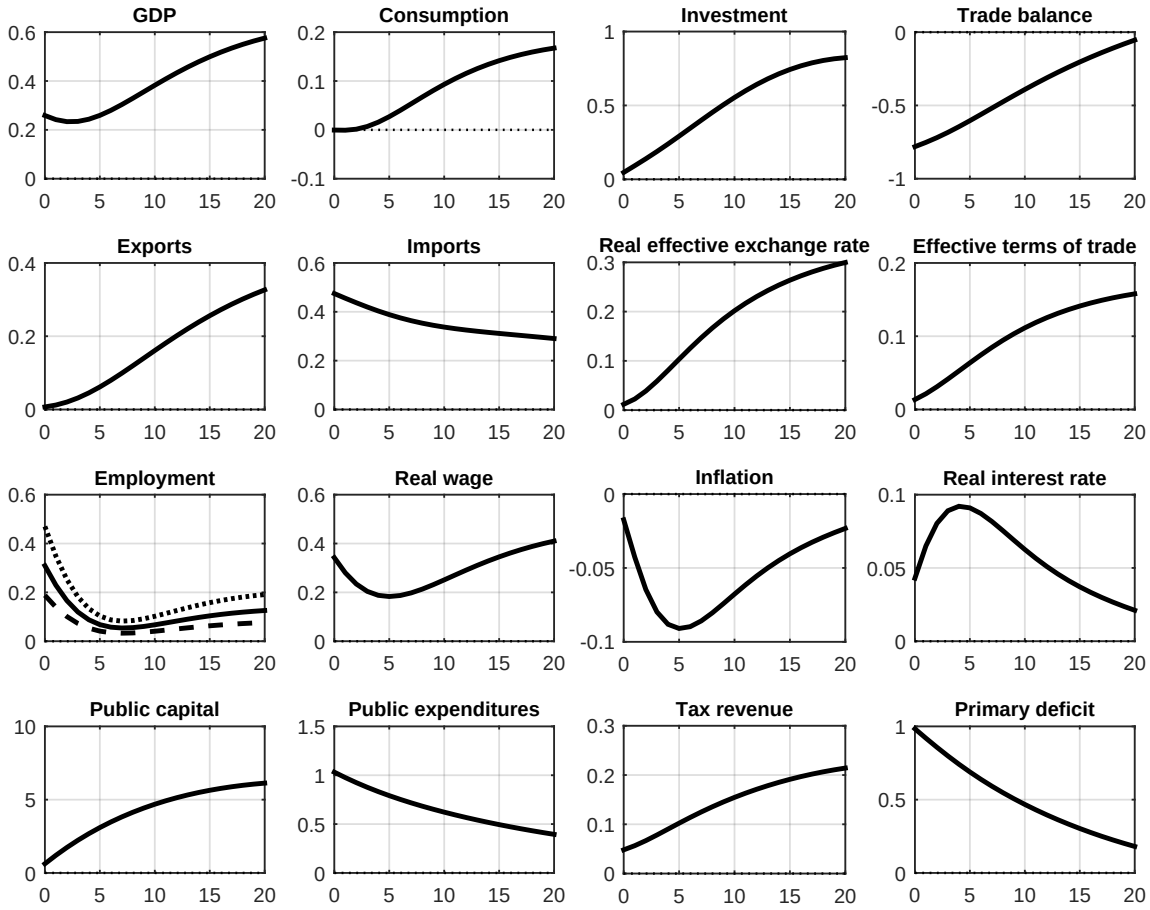
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public consumption by 1% of *ex ante* GDP.

FIGURE 8. Robustness check: Effects of the public investment shock when $\alpha_G = 0.02$.



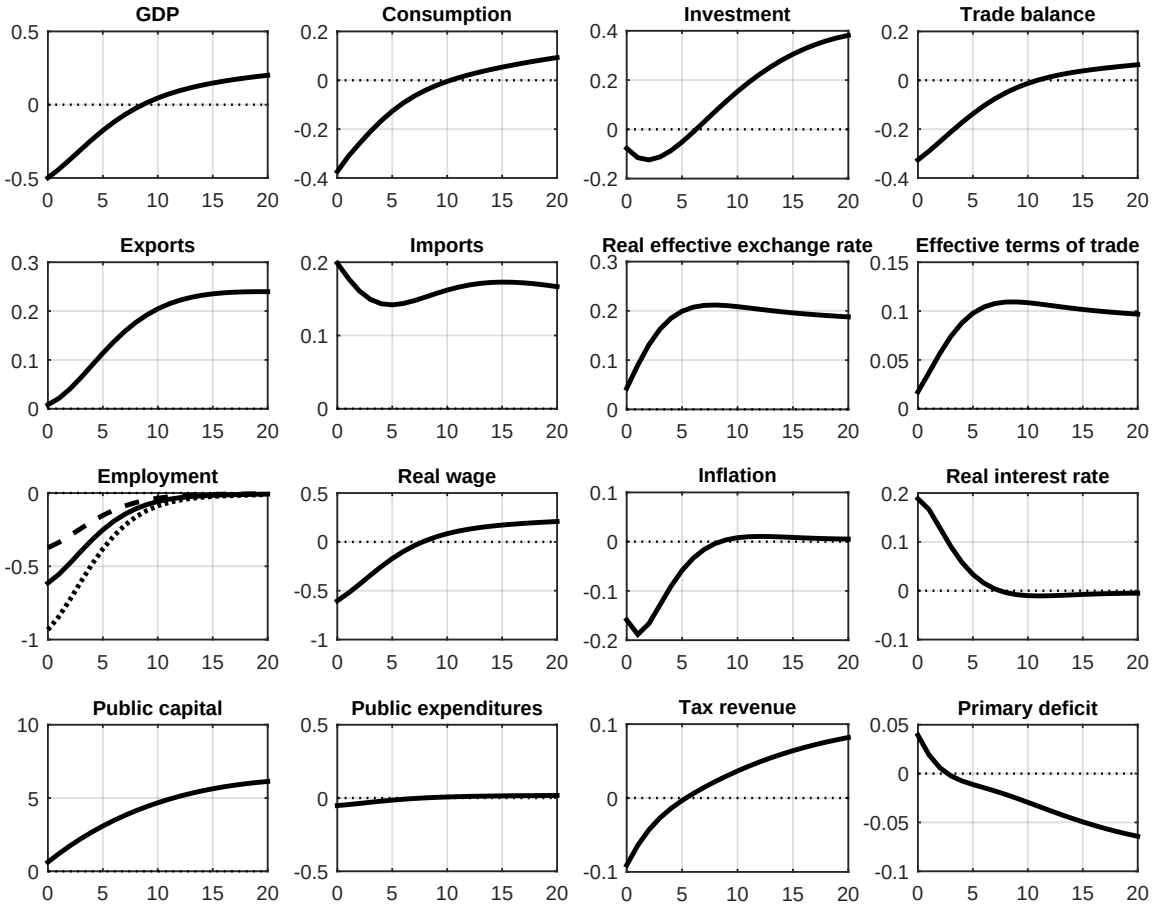
Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public investment by 1% of *ex ante* GDP.

FIGURE 9. Robustness check: Effects of the public investment shock when $\alpha_G = 0.10$.



Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to increase public investment by 1% of *ex ante* GDP.

FIGURE 10. Reorientation of public expenditure.



Notes. Horizontal axis: quarters. Vertical axis: % deviations from the steady state, except for the trade balance, public spending, tax revenue, and the primary deficit (%-points of steady-state GDP), as well as inflation and interest rates (annualized %-point deviations). A rise in the exchange rate (terms of trade) signals a depreciation (deterioration). For employment, the dashed line represents resident labor, the dotted line cross-border labor, and the solid line average labor. The shock is normalized to decrease public consumption by 1% of *ex ante* GDP and increase public investment by the same amount.

BANQUE CENTRALE DU LUXEMBOURG

EUROSYSTÈME

2, boulevard Royal
L-2983 Luxembourg

Tél.: +352 4774-1
Fax: +352 4774 4910

www.bcl.lu • info@bcl.lu