Production Networks and International Fiscal Spillovers

Michael B. Devereux
Karine Gente
Changhua Yu

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Michael B. Devereux[†]

University of British Columbia

Karine Gente[‡]

Aix-Marseille University

Changhua Yu[§]

Peking University

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Abstract

This paper analyzes the impact of fiscal spending shocks in a dynamic, multi-country model with international production networks. We first derive a decomposition of the effects of a fiscal spending shock on the GDP of any country. This decomposition defines the response as the sum of a Direct, Income, and Price effect. The Direct Effect depends only on structural parameters and is independent of assumptions about monetary policy, wage setting, or capital mobility, while the Price Effect is zero in the aggregate across countries. We apply this decomposition to an analysis of fiscal spillovers in the Eurozone, using the production network structure from the World Input Output Database (WIOD). We find that fiscal spillovers from Germany and some other large Eurozone countries may be large, and within the range of empirical estimates. Without international production network linkages, spillovers would be only a third as large as predicted by the baseline model. Finally, we explore the diffusion of identified government spending shocks at the sectoral level, both within and across countries, using an empirical measure of the response, based on the theoretical decomposition. The empirical estimates are strongly consistent with the theoretical model.

Keywords: Production Network, Fiscal Policy, Spillovers, Eurozone, Nominal Rigidities

JEL Codes: E23   E62   F20   F42   H50

[†]Vancouver school of economics, University of British Columbia, NBER and CEPR. Address: 6000 Iona Drive, Vancouver, BC Canada V6T 1L4. E-mail: devm@mail.ubc.ca

[‡]Faculty of Economics and Management, Aix-Marseille Universite, CNRS, AMSE, Marseille, France. Address: MEGA, Site Pauliane-MEGA, 424, chemin du Viaduc, 13080 Aix-en-Provence, France. karine.gente@univ-amu.fr.

[§]China Center for Economic Research, National School of Development, Peking University, 5 Yiheyuan Rd, Haidian, Beijing, China, 100871. E-mail: changhuayu@nsd.pku.edu.cn.

1 Introduction

In response to the global financial crisis and the Covid-19 pandemic, many countries initiated large fiscal stimulus programs to boost their domestic economies. Given close international linkages through trade and capital flows, it should be expected that these policies would have substantial spillover effects on other countries. Empirical evidence shows that fiscal spillovers across borders can be large, depending on how fiscal shocks are identified (e.g., Auerbach and Gorodnichenko, 2012a; Amendola, Di Serio, Fragetta and Melina, 2020). Nevertheless, many model based analyses suggest that fiscal spillovers across countries are negligible, given the size of trade openness at the aggregate level. [1]

Recent research argues that production linkages between countries can have important implications for aggregate co-movements, for instance see Burstein, Kurz and Tesar (2008), Giovanni and Levchenko (2010), and Giovanni and Levchenko (2012). Motivated by this, our paper investigates the importance of production networks in accounting for fiscal spillovers across countries. It has been well documented that international trade is dominated by trade in intermediate products. Firms in many countries intensively use intermediate inputs produced by their own industry and also by other home and foreign industries. These input-output linkages not only link production lines globally, but also serve as important channels for shock propagation within a country and across borders. How do these input-output linkages affect domestic and foreign fiscal multipliers?

The key contribution of our paper is to construct a theoretical decomposition of the impact of fiscal spending shocks on real value-added GDP that operates within and across countries, and to show how the domestic and international production network operates through each channel of this decomposition. The decomposition is then applied to the countries of the Eurozone using empirical input-output measures. We focus particularly on the Eurozone both because international production linkages among Eurozone countries are likely to be significantly larger than among other countries, and due to the presence of a common currency, so the nominal exchange rate regime plays no role in the diffusion of fiscal shocks across borders. The main question addressed is how the production network affects the response to fiscal policy shocks, both at the aggregate country-level as well as at the level of individual sectoral responses. A particular focus of inquiry is to explore how policy spillovers from a center country fiscal stimulus

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[1]See for instance, Cwik and Wieland (2011), Goujard (2016) , and Ivanova and Weber (2011). We discuss further empirical research on fiscal spillovers below. Other theoretical papers however show larger spillovers in theoretical models, which are discussed in greater detail below.

(Germany in our baseline case) depends on the degree of wage rigidity, the stance of monetary policy, and the degree of international capital mobility, and importantly, how each of these characteristics plays a role in each channel of our theoretical decomposition.

Our baseline model is a multi-country version of Bigio and La'O (2020), which is a general equilibrium multi-sector model, but we extend the model to a dynamic environment with international capital mobility and costly wage adjustment. Although the dimension of the model is relatively large, we show that the response of value-added GDP to a fiscal spending shock can be decomposed into three simple and intuitive effects. We denote these as the "Direct Effect", the "Income Effect", and the "Price Effect". Each of these channels captures the way in which a fiscal spending shock operates through the domestic and international sectoral production network to impact on final output of the domestic or foreign country. [2]

The Direct Effect pertains to the way in which a government spending shock in a source country directly affects demand for the output of the domestic or foreign sector in which the government spends, how this in turn impacts on demand for the intermediate goods of connected sectors, and how this goes on to affect output of all sectors within and across countries. Two key features of this Direct Effect are a) it is always positive, and b) that it does not depend on the stance of monetary policy, even in the presence of sticky nominal wages. The Income Effect captures the way in which the spending shock affects value added GDP through private sector demand both within the source country and across other countries. By impacting on aggregate consumption in the source country and recipient countries, through both a-temporal and inter-temporal channels, the spending shock affects demand across sectors based on the preferences of all country's consumers for the output of domestic and foreign sectors. In turn, this affects demand for intermediate goods provided by connected sectors through the production network. The Income Effect may be positive or negative, and may be positive for some countries and negative for other countries. Moreover, the Income Effect depends critically on the stance of monetary policy. In general, it is greater in aggregate, the more accommodative is monetary policy to the fiscal spending shock itself. The Price Effect captures a type of network adjusted real exchange rate, and measures the impact of the fiscal spending shock on an index of the prices of government and private sector absorption prices relative to wage costs. Again this operates not just directly through measured

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[2]It is important to note that these effects are not orthogonal to one another, since they are all measured as responses to the same fiscal shock.

price indices, but through the effect of prices on demand through the production network. A positive price effect increases demand for a country's value-added GDP, while a negative Price Effect reduces it. A key feature of the decomposition is that the aggregate Price Effect across all countries sums to zero. Hence, the Price Effect serves to redistribute the demand response to the fiscal spending shock from one country to another.

We go on to apply this decomposition to the impact of a fiscal spending shock in a center country. Our quantitative model is built around 12 countries; 11 countries of the Eurozone and the 'rest of the world'. The model is calibrated using the measures of input-output connections from the World Input Output Tables for this set of countries.

We present three sets of results, which differ based on the degree of capital mobility, the degree of wage rigidity, and the stance of monetary policy. In the first specification, we look at the impact of a spending shock arising in Germany in a model without any capital mobility, where wages are fully sticky, and where monetary policy is designed to stabilize aggregate nominal consumption, separately for the Eurozone and the rest of the world. In this specification, we find large spillovers of a German spending shock to other European countries, quite in the range of empirical estimates. The Direct Effect of the shock is a relatively small component of the total average spillover. The largest part of the spillover comes from the Price Effect, which is positive for all European countries, even Germany, but negative for the rest of the world. The Income Effect is also positive for all EZ countries except Germany. This arises because monetary policy implicitly accommodates the fiscal expansion across borders by stabilizing aggregate EZ consumption. But when we re-do this exercise by recalibrating the model to remove the international production network, the average of the Direct Effect falls substantially, and this in turn leads to a large reduction in the Price Effect. In the aggregate, fiscal spillovers are cut by more than half when we remove international production linkages. But nominal rigidities also play a key role. In the same model even with the empirical international production linkages, spillovers are approximately zero if wages are fully flexible.

We then extend the analysis to a fully dynamic setting with capital mobility, partially sticky wages and monetary policy in the EZ set by a Taylor rule which targets country weighted overall EZ CPI inflation. The Direct effect of the spillover is the same as before, since this depends only on the structural parameters of fiscal spending shares and the production network. But the Price effect is substantially reduced, since wages can adjust, and the monetary policy rule acts to dampen consumer and government

goods prices. Moreover, the Income effect now becomes negative for all EZ countries, since the Taylor rule monetary policy tends to raise real interest rates for each EZ country, leading to a fall in present consumption across all countries. Overall, the fiscal spillover is less than half that of the static model with a monetary policy that stabilizes nominal consumption. But again, we find that the network matters. If we shut down the production network fiscal spillovers fall substantially even from this lower average level.

The experience of the last decade calls into question the assumption that monetary policy acts to offset the impact of fiscal stimulus. We therefore explore a third specification where a fiscal spending shock in Germany occurs in a period where the nominal interest rate is constrained by the zero bound for a finite number of periods. We apply this assumption within the dynamic model, with capital mobility and partial wage adjustment. As before, the Direct Effect is exactly the same as the previous specification. But with no response of the EZ interest rate, we find very large cross country fiscal spillovers, much larger even in the first static economy specification. Moreover, now we find large positive Price Effects and Income Effects for all countries in the EZ, even for the source country Germany. The spillover to the rest of the world is negative, due to a negative Price Effect, although the overall impact on the rest of the world is quantitatively very small. The key factor in this specification is that EZ fiscal spending leads to substantial currency *depreciation* [3]. Again, however, we find that eliminating the production network has a very large dampening effect on cross country fiscal spillovers. [4]

How useful is our fiscal spending decomposition from an empirical point of view? In a final section of the paper we show how the three channels described above can be measured in the data, using the observed input-output coefficients. We specify a regression model based on sectoral rather than aggregate data. This model can be used to test the importance of each channel and the overall relevance of the decomposition. Specifically, we regress the change in sectoral value added across time and countries on separate measures of the Direct, Income and Price effect constructed from the data, following the theoretical definition of these measures, using a structural VAR identification of fiscal spending shocks in Germany, according to Blanchard and Perotti (2002) and Ramey and Zubairy (2018). The estimates from the regressions are closely aligned with their theoretical counterparts.

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[3]This is consistent with previous literature on the ZLB in open economies e.g. Cook and Devereux (2011a).

[4]The text follows the literature in assuming fiscal spending shocks are financed by lump-sum taxes. Appendix F allows for income-tax financed spending. There we show that own multipliers are smaller, but fiscal spillovers are *larger* than in the baseline case.

While the main set of results are presented for the impact of a German fiscal spending shock, the Appendix presents analogous results for spending shocks arising in other countries, notably France and Italy. The main features of the results carry over to these alternative cases, also the quantitative effects are somewhat smaller.

The structure of paper is as follows. The next section presents a review of background literature. Section 3 lays out the baseline model. Three channels of fiscal spillover and analytical results are presented in Section 4. The calibration of the model to the WIOD is discussed in section 5 and the quantitative results of the model for the aggregate response to fiscal policy shocks follow next. Section 6 looks more closely at the sectoral responses to fiscal shocks, and the last section concludes.

2   Related Literature

This paper links to numerous branches of the literature. First, our paper contributes to the literature on production networks and macroeconomic impact of shocks. Following the pioneering work of Gabaix (2011) and Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2012), Acemoglu, Ozdaglar and Tahbaz-Salehi (2017) investigate the propagation of microeconomic shocks through input-output linkages and find that when input-output linkages are unbalanced, micro shocks can lead to sizable macroeconomic tail risks. Baqaee and Farhi (2019) provide conditions that production networks can substantially amplify sectoral productivity shocks in dynamic stochastic general equilibrium models. They suggest to use higher-order approximation techniques to solve dynamics models in order to capture the effect of production networks.[5] In a companion research, Baqaee and Farhi (2020) provide a general non-parametric formula for aggregating microeconomic shocks in general equilibrium economies with distortions. In an empirical setting, di Giovanni and Hale (2020) quantify the role of global production linkages in explaining spillovers of U.S. monetary policy shocks to stock returns of 54 sectors in 26 countries, and find that global production linkages contribute to most of the total impact of U.S. monetary policy shocks on average country-sector stock returns. Flynn, Patterson and Sturm (2020) investigate a sticky-wage economy with many sectors and regions, linked to one another through an arbitrary input-output structure, and find empirically that production network plays a role in shaping optimal policy. In most cases

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[5]Pasten, Schoenle and Weber (2016) study a multi-sector Calvo model with intermediate inputs and explore the real effects of monetary policy shocks. Based on first-order approximations, they find heterogeneity in input-output linkages contributes only marginally to the real effects of monetary policy shocks. Following a similar approach, Bouakez, Rachedi and Emiliano (2018) explore fiscal multiplier in a multi-sectoral closed-economy monetary model.

the production network literature has focused on productivity shocks (see Bigio and La'O, 2020; Baqaee and Farhi, 2019), with substantial attention to the idea that the networks may allow sectoral productivity shocks to propagate to the aggregate economy.[6] Nevertheless, our focus is on demand shocks, and specifically fiscal spending shocks.

The most related papers are Acemoglu, Akcigit and Kerr (2015) and Bigio and La'O (2020). Bigio and La'O (2020) explore how production networks and distortions affect the propagation of sectoral productivity shocks in a closed economy multi-sector real business cycle framework and apply the framework to analyze shock propagation through the USA input-output linkages. Our paper makes use of a similar framework as Bigio and La'O (2020), but there are several important differences between our paper and theirs. First, we focus on a multi-country world economy. Second, we explore how the demand side shocks–fiscal spending shocks–are propagated across borders through international input-output linkages. Third, our model features nominal wage rigidities as in the literature (see Schmitt-Grohé and Uribe (2016)). We find that international production networks substantially increase fiscal policy spillovers across borders in a model with nominal wage rigidities, while the spillovers are quite small in a model with flexible prices and wages. Acemoglu, Akcigit and Kerr (2015) explore the propagation of macroeconomic shocks through input-output and geographic networks and they find that demand-side shocks propagate upstream and supply-side shocks propagate downstream in a closed economy. Our paper features labor markets segmentation across countries and provides three theoretical channels of shock propagation, and we find that government expenditures have both upstream and downstream effects through these channels.

Second, our paper is related to studies on intermediate inputs and business cycles. Basu (1995) and Dupor (1999) incorporates multi-sector production structures into closed economy business cycle models. Bouakez, Cardia and Ruge-Murcia (2009) explore the idiosyncratic sectoral dynamics in an economy with heterogeneous production sectors in response to monetary policy shocks. Along international dimension, Giovanni and Levchenko (2012) investigate how country size and international trade affect macroeconomic volatility. Based on a cross-country, industry-level panel dataset of manufacturing production and trade, Giovanni and Levchenko (2010) find that sector pairs that experience more bilateral trade exhibit stronger comovement, particularly for cross-border industry pairs that use each other

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[6]More recent works include Jones (2011); Atalay (2017); Luo (2020); Acemoglu and Azar (2020); Lim (2018); Dong and Wen (2019) and Miranda-Pinto and Young (2018).

as intermediate inputs. In a multi-country multi-sector world economy, Huo, Levchenko and Pandalai-Nayar (2019, 2020) explore how productivity shocks contribute to international comovement and don't find much comovement through propagation of productivity shocks. The input-output linkages in our model are similar to those of the above papers, but we follow the recent literature that deviates from Hulten's theorem (Hulten, 1978; Baqaee and Farhi, 2019) via introducing nominal rigidities and alternative monetary regimes into a multi-country world economy.

Third, this study also provides a micro-foundation of fiscal spillovers. Theoretically, our results indicate that the fiscal spillovers could be large or small, depending on which sectors a government chooses to spend, how sectors are linked via various production networks, how factor prices adjust, and how monetary policy responds. As mentioned above, a sizeable empirical literature finds large positive spillovers of fiscal policy shocks, particularly from the US (e.g. Auerbach and Gorodnichenko, 2012b), but also from large European countries. Beetsma, Giuliodori and Klaassen (2006), focusing on the trade channel of fiscal spillovers, find that a fiscal stimulus of 1% GDP in Germany leads to an average increase of 0.15% of GDP in other European countries. Dabla-Norris, Dallari and Poghosyan (2017) estimate a GVAR model using quarterly data on 10 euro countries. They find fiscal spillovers are the highest when Germany or France are the country originating the fiscal shock with impact multipliers that are on average .1 percent of GDP for a 1 percent of GDP shocks to Germany. A more recent paper by Ayobami, Paez-Farrell and Thoenissen (2022) explore the spillover effects of fiscal policy shocks from the US and Germany using a Bayesian VAR approach, and find sizeable impact spillovers from both countries. In particular, they find a 1 percent of GDP shock from Germany to have on average a .2 percent of GDP positive spillover on France, Spain, and the Netherlands.[7] Another important recent theoretical paper is Cacciatore and Traum (2020), who study the role of international trade following unanticipated government spending and income tax changes, and find that fiscal multipliers depend on relative import shares, the way that government finances its budget and currency invoicing of exports. In our model, the import share of government is determined by the data, government spending is lump-sum tax financed in order to cleanly separate the fiscal multiplier and spillover, and prices are fully flexible, although wage rates may be sticky.

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[7]Ayobami, Paez-Farrell and Thoenissen (2022) also show that their results can be rationalized within a DSGE open economy model. Their model emphasizes heterogeneous households and borrowing constrained firms. Other relevant empirically focused papers that involve fiscal spillovers are Beetsma, Giuliodori and Klaassen (2008), Corsetti and Muller (2013) and Cacciatore and Traum (2020). Auerbach, Gorodnichenko and Murphy (2020) estimate local fiscal multipliers and spillovers for the USA and find strong positive spillovers across locations and industries.

In terms of the decomposition methodology, our paper is similar to Auclert (2019), and vom Lehn and Winberry (2021), but our focus is within an international dimension and investigating the impacts of government spending shocks and alternative monetary regimes. Also, Caliendo, Parro and Tsyvinski (forthcoming) explore internal and external distortions that affects transactions across sectors or across borders to study the world's input-output structure, and find that internal distortions have a much larger effect on world's output than external distortions. Huo, Levchenko and Pandalai-Nayar (2019) study the role of production networks in international GDP comovement and provide an additive decomposition of bilateral GDP comovement into various comoments that capture shock transmission and shock correlation, but focus instead on TFP and labor supply shocks. Finally, Gourinchas, Kalemli-Özcan, Penciakova and Sander (2021) develop a multi-country model similar to the present study, but focus on the role of the Covid-19 fiscal policy responses of countries, and their spillover effects. Their study differs in many respects from ours, mostly importantly in the particular theoretical decomposition of the impacts of fiscal policy that is the focus of our paper.

3   A Multi-Country Model with Production Networks

We first develop a multi-country model and then show how it can be used to construct the decomposition of the GDP response to government spending shocks. Consider a world economy with K countries and N sectors. Let index m or n denote a country, i or j denote a sector. The world economy has firms, consumers, governments and monetary authorities, and the horizon is infinite. We divide the world into two groups of countries. The first group consists of the first $K - 1$ countries who form a monetary union, say the Eurozone, while the second group of countries consists of the rest of the world and is captured by country K, say the dollar zone. Countries differ in size and the degree of interconnectedness of input linkages. Labor is mobile across sectors within each country but immobile across countries.[8] Asset markets are incomplete and households can trade international bonds across borders to smooth consumption over time.

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[8]Although goods and labor markets are highly integrated in the Eurozone (Caliendo, Opromolla, Parro and Sforza, 2017), spatial wage gaps still persist even within a country (Heise and Porzio, 2018).

3.1 Firms

Since prices are flexible and we abstract from capital accumulation, firms face a purely static problem. Following the international trade literature (i.e., Anderson and Van Wincoop, 2003; Caliendo, Parro and Tsyvinski, forthcoming; Allen, Arkolakis and Takahashi, 2020), we assume constant returns to scale in production. Assume that a firm in sector j, country n has the production technology using labor $L_{nj,t}$ and intermediate inputs $M_{nj,t}$ to produce sectoral output $X_{nj,t}$, given by:

$$X_{nj,t} = L_{nj,t}^{1-\alpha_{nj}} M_{nj,t}^{\alpha_{nj}}$$

where α_{nj} denotes the share of intermediate inputs in the production. Intermediate input $M_{nj,t}$ consists of varieties produced by domestic and foreign sectors

$$M_{nj,t} = \Pi_{m=1}^{K} \Pi_{i=1}^{N} M_{mi,nj,t}^{\omega_{mi,nj}}$$

where $M_{mi,nj,t}$ denotes the variety produced by sector i in country m used by sector j in country n. $\omega_{mi,nj}$ captures the corresponding variety input share with $\sum_{m=1}^{K} \sum_{i=1}^{N} \omega_{mi,nj} = 1$. [9]

Goods are freely traded across borders. The law of one price implies that prices of goods are equalized when expressed in the same currency, $P_{nj,t} = \mathcal{E}_t P_{nj,t}^*$, where $P_{nj,t}$ and $P_{nj,t}^*$ denote the euro and dollar price of a good produced by sector j in country n respectively (variables in the rest of the world are denoted by a superscript $*$), and $\mathcal{E}_t$ is the nominal exchange rate, euro price of dollar. A rise in $\mathcal{E}_t$ means a euro depreciation against the dollar.

Producers' cost minimization implies

$$P_{nj,t} = \left(\frac{W_{n,t}}{1-\alpha_{nj}}\right)^{1-\alpha_{nj}} \left(\frac{P_{nj,t}^m}{\alpha_{nj}}\right)^{\alpha_{nj}}$$

where $W_{n,t}$ stands for the nominal wage in country n, and $P_{nj,t}^m$ is the price of firm nj's input bundle,

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[9]Note that since we are exclusively focusing on government spending shocks, we assume a constant total factor productivity, normalized to unity. Also, in the baseline model we assume an elasticity of substitution of one across intermediate inputs, as in Acemoglu, Akcigit and Kerr (2015), Bigio and La'O (2020), Gourinchas, Kalemli-Özcan, Penciakova and Sander (2021). In the Appendix, we estimate the elasticity directly from the data and find that it is around one.

which is an aggregation of all of its input varieties,

$$P_{nj,t}^m = \Pi_{m=1}^{K}\Pi_{i=1}^{N}\left(\frac{P_{mi,t}}{\omega_{mi,nj}}\right)^{\omega_{mi,nj}}.$$

Given a nominal wage $W_{n,t}$ and input bundle price $P_{nj,t}^m$, the optimal factor demand can be written as

$$W_{n,t}L_{nj,t} = (1 - \alpha_{nj})P_{nj,t}X_{nj,t}$$

$$P_{nj,t}^m M_{nj,t} = \alpha_{nj}P_{nj,t}X_{nj,t}$$

$$M_{mi,nj,t}P_{mi,t} = \omega_{mi,nj}P_{nj,t}^m M_{nj,t} = \alpha_{nj}\omega_{mi,nj}P_{nj,t}X_{nj,t}$$

Since labor is the only primary input and firms earn zero profits, sectoral value-added in country n is then equal to the cost of labor,

$$P_{nj,t}^y Y_{nj,t} \equiv W_{n,t}L_{nj,t}$$

where $Y_{nj,t}$ defines sectoral real value-added and $P_{nj,t}^y$ is the corresponding real value-added price.

3.2   Households

There is a representative household in each country. Households in the Eurozone have preferences given by

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \xi^t u(C_{n,t}, L_{n,t})$$

where ξ is a subjective discount factor, $u(C_{n,t}, L_{n,t}) \equiv U(C_{n,t}) - V(L_{n,t}^c)$, $U(C_{n,t}) \equiv \frac{C_{n,t}^{1-\sigma}-1}{1-\sigma}$, $V(L_{n,t}^c) \equiv \frac{(L_{n,t}^c)^{1+\eta}}{1+\eta}$. $L_{n,t}^c$ is wholesale labor supplied by the household, with $n = 1, \cdots, K-1$. The households have consumption aggregators $C_{n,t}$ defined over all country-sector goods as

$$C_{n,t} = \Pi_{m=1}^{K}\Pi_{i=1}^{N}C_{mi,n,t}^{\beta_{mi,n}}$$

where $\beta_{mi,n}$ represents a consumption expenditure share on goods produced by sector i in country m with $\sum_{m=1}^{K}\sum_{i=1}^{N}\beta_{mi,n} = 1$. Cost minimization implies

$$P_{mi,t}C_{mi,n,t} = \beta_{mi,n}P_{n,t}^c C_{n,t}$$

$$P^c_{n,t} = \Pi^K_{m=1} \Pi^N_{i=1} \left(\frac{P_{mi,t}}{\beta_{mi,n}} \right)^{\beta_{mi,n}}$$

Households in the Eurozone have access to a euro denominated nominal bond. In country n, the aggregate households' budget constraint is given by

$$P^c_{n,t} C_{n,t} + \frac{B_{n,t+1}}{R_{t+1}} + \frac{1}{2} \psi^b_n \left(\frac{B_{n,t+1}}{P^c_{n,t}} - b_n \right)^2 P^c_{n,t} = (1 - \tau^c_n) W^c_{n,t} L^c_{n,t} + B_{n,t} + D^w_{n,t} + T^g_{n,t} + T^w_{n,t} \quad (1)$$

The left hand of the equation above presents households total expenditures, including consumption expenditures $P^c_n C_{n,t}$, and savings $\frac{B_{n,t+1}}{R_{t+1}}$ adjusted by a portfolio adjustment cost $\frac{1}{2} \psi^b_n \left(\frac{B_{n,t+1}}{P^c_{n,t}} - b_n \right)^2 P^c_{n,t}$ where ψ^b_n is an adjustment cost parameter and b_n is the steady state real bond holdings. The right hand side states various incomes, including after tax (τ^c_n) labor income $(1 - \tau^c_n) W^c_{n,t} L^c_{n,t}$, with $W^c_{n,t}$ and $L^c_{n,t}$ being the wage rate and labor supply in the competitive wholesale labor market, and profits and lump sum transfers from various sources $D^w_{n,t} + T^g_{n,t} + T^w_{n,t}$, which will be defined later.

Optimal labor supply and bond holdings are determined by the conditions below

$$(1 - \tau^c_n) \frac{W^c_{n,t}}{P^c_{n,t}} = \frac{V'(L^c_{n,t})}{U'(C_{n,t})} \quad (2)$$

$$U'(C_{n,t}) = \mathbb{E}_t \xi U'(C_{n,t+1}) \frac{R_{n,t+1}}{\pi^c_{n,t+1}} \quad (3)$$

where $R_{n,t+1}$ denotes the effective nominal return rate of bond holding faced by households in country n, which is defined as $\frac{1}{R_{n,t+1}} \equiv \frac{1}{R_{t+1}} + \psi^b_n \left(\frac{B_{n,t+1}}{P^c_{n,t}} - b_n \right)$, and $\pi^c_{n,t+1}$ is the consumer price index inflation $\pi^c_{n,t+1} \equiv \frac{P^c_{n,t+1}}{P^c_{n,t}}$, denominated in euro.

Households in the rest of the world K have the same preference over consumption and labor supply. Their budget constraints differ in two respects. First, the nominal wage is sticky in domestic currency. Second, households in country K hold both a euro denominated nominal bond $B_{K,t+1}$ and also a dollar denominated nominal bond B^*_{t+1},

$$P^{c*}_{K,t} C_{K,t} + \frac{B_{K,t+1}}{\mathcal{E}_t R_{t+1}} + \frac{1}{2} \psi^b_K \left(\frac{B_{K,t+1}}{\mathcal{E}_t P^{c*}_{K,t}} - b_K \right)^2 P^{c*}_{K,t} + \frac{B^*_{t+1}}{R^*_{t+1}} =$$

$$(1 - \tau^c_n) W^{c*}_{K,t} L^c_{K,t} + \frac{B_{K,t}}{\mathcal{E}_t} + B^*_t + D^w_{K,t} + T^g_{K,t} + T^w_{K,t} \quad (4)$$

The optimal labor supply is similar to equation (2) but with nominal price and wage denominated in dollars. The consumption Euler equation for domestic and international bonds are,

$$U'(C_{K,t}) = \mathbb{E}_t \xi U'(C_{K,t+1}) \frac{R_{t+1}^*}{\pi_{K,t+1}^{C*}}, \ U'(C_{K,t}) = \mathbb{E}_t \xi U'(C_{K,t+1}) \frac{R_{K,t+1}}{\pi_{K,t+1}^{C*}} \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} \tag{5}$$

where $R_{K,t+1}$ represents the effective nominal return on the euro denominated bond, which is defined similarly as in the Eurozone.

3.3 Nominal Wage Rigidity

Although firms have flexible prices, we allow for nominal wage rigidity. Assume that there exists monopolistically competitive retail labor service providers with measure one. The retail labor providers transform homogenous wholesale labor services from households into different varieties $L_{n,t}(h)$ with a one-for-one technology. These differentiated labor services are aggregated to a labor bundle via a constant return to scale technology. Domestic firms will hire these labor bundles to produce output. The bundled labor services $L_{n,t}$ in country n have the following form,

$$L_{n,t} = \left(\int_0^1 L_{n,t}(h)^{\frac{\theta_n-1}{\theta_n}} dh \right)^{\frac{\theta_n}{\theta_n-1}}$$

where θ_n is the elasticity of substitution among different labor services. Cost minimization of labor bundlers implies that the demand for variety h satisfies

$$L_{n,t}(h) = \left(\frac{W_{n,t}(h)}{W_{n,t}} \right)^{-\theta_n} L_{n,t} \tag{6}$$

The composite wage rate faced by firms reads

$$W_{n,t} = \left(\int_0^1 W_{n,t}(h)^{1-\theta_n} dh \right)^{\frac{1}{1-\theta_n}}$$

Retail labor providers set nominal wages for varieties of labor service in domestic currency. They can reset their wages each period but suffer a wage adjustment cost (Rotemberg, 1982). Profits per period

gained by wage setter h equals total revenues net of wholesale labor costs and of wage adjustment costs,

$$D_{n,t}^w(h) = (1 + \tau_n^w)W_{n,t}(h)L_{n,t}(h) - W_{n,t}^c L_{n,t}(h) - \frac{\psi_n^w}{2}\left(\frac{W_{n,t}(h)}{W_{n,t-1}(h)} - \pi_n^w\right)^2 W_{n,t}$$

where τ_n^w stands for labor subsidy, ψ_n^w controls the cost of wage adjustment, and π_n^w is the steady state wage inflation. The retail labor provider h solves

$$\max_{\{W_{n,t}(h),L_{n,t}(h)\}} \mathbb{E}_{nh,s} \sum_{t=s}^{\infty} \Lambda_{n,s,t} \frac{P_{n,s}^c}{P_{n,t}^c} D_{n,t}^w(h)$$

subject to demand for variety h in equation (6). $\mathbb{E}_{n,s}$ denotes a mathematical expectation conditional on information observed by labor provider h in country n period s. The stochastic discount factor is given by $\Lambda_{n,s,t} \equiv \xi^{t-s} U'(C_{n,t})/U'(C_{n,s})$. In a symmetric equilibrium, all labor providers in country n choose the same wage, $W_{n,t}(h) = W_{n,t}$, when resetting their wages. Consequently, the supply of each variety of labor service is identical, $L_{n,t}(h) = L_{n,t}$. The optimality condition for wage-setting can be simplified as

$$L_{n,t}\theta_n\left(w_{n,t}^r - \chi_n\right) - \psi_n^w \pi_{n,t}^w(\pi_{n,t}^w - \pi_n^w) + \mathbb{E}_{n,t}\left[\Lambda_{n,t,t+1}\psi_n^w \frac{\pi_{n,t+1}^w}{\pi_{n,t+1}^c}\pi_{n,t+1}^w(\pi_{n,t+1}^w - \pi_n^w)\right] = 0 \qquad (7)$$

where $w_{n,t}^r \equiv W_{n,t}^c/W_{n,t}$ captures the relative labor cost, and wage inflation $\pi_{n,t+1}^w \equiv W_{n,t+1}/W_{n,t}$, and $\chi_n \equiv (1 + \tau_n^w)\frac{\theta_n - 1}{\theta_n}$ denotes the wedge in the retail labor service market.

The total profits from retail labor providers become

$$D_{n,t}^w \equiv \int_0^1 (1 + \tau_n^w)W_{n,t}(h)L_{n,t}(h)dh - \int_0^1 W_{n,t}^c L_{n,t}(h)dh - \int_0^1 \frac{\psi_n^w}{2}\left(\frac{W_{n,t}(h)}{W_{n,t-1}(h)} - \pi_n^w\right)^2 W_{n,t}$$

Similarly, wage setters in the rest of the world have the following optimal condition for wage setting,

$$L_{K,t}\theta_K\left(w_{K,t}^{r*} - \chi_K\right) - \psi_K^w \pi_{K,t}^{w*}(\pi_{K,t}^{w*} - \pi_K^{w*}) + \mathbb{E}_{K,t}\left[\Lambda_{K,t,t+1}\psi_K^w \frac{\pi_{K,t+1}^{w*}}{\pi_{K,t+1}^{c*}}\pi_{K,t+1}^{w*}(\pi_{K,t+1}^{w*} - \pi_K^{w*})\right] = 0 \quad (8)$$

with the relative labor cost $w_{K,t}^{r*} \equiv W_{K,t}^{c*}/W_{K,t}^*$, and wage inflation $\pi_{n,t+1}^{w*} \equiv W_{n,t+1}^*/W_{n,t}^*$.[10]

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[10]In the following analysis, we express all nominal variables in euro. Competitive goods markets and the law of one price imply $P_t^c = \mathcal{E}_t P_t^{c*}$, $P_t^g = \mathcal{E}_t P_t^{g*}$ and similarly for other prices. Nominal wage rates are sticky in domestic currency, either euro or dollar. We define $W_{K,t}^c \equiv \mathcal{E}_t W_{K,t}^{c*}$.

3.4 Monetary and Government Policy

In the full version of the model, the monetary authority in the monetary union targets the CPI inflation in the union, and the rest of the world also targets the CPI inflation. The monetary policy rules are specified as [11]

$$\frac{R_{t+1}}{R} = \left(\Pi_{n=1}^{K-1} \left(\frac{\pi_{n,t}^c}{\pi_n^c} \right)^{\rho_n} \right)^{(1-\rho_r)\rho_\pi} \left(\frac{R_t}{R} \right)^{\rho_r}, \tag{9a}$$

$$\frac{R_{t+1}^*}{R^*} = \left(\frac{\pi_{K,t}^{c*}}{\pi_K^{c*}} \right)^{(1-\rho_r)\rho_\pi} \left(\frac{R_t^*}{R^*} \right)^{\rho_r}. \tag{9b}$$

A variable without time subscript denotes its steady state value. ρ_r captures the persistence of the nominal interest rate and ρ_n is a weight of country n in CPI inflation in the monetary union, with $\sum_{n=1}^{K-1} \rho_n = 1$. ρ_π captures the willingness of monetary authority leaning against union-wide CPI inflation. When $\rho_\pi \to +\infty$, the monetary authority strictly targets CPI inflation. An analogous relationship holds for the rest of world monetary policy.

We assume total government spending is exogenous, but the breakdown between different sectors' and country's goods is determined as a cost minimization given an aggregator for total spending as function of individual final goods, in the same manner as that of the household aggregator, although with different weightings on goods. Thus we have

$$G_{n,t} = \Pi_{m=1}^K \Pi_{i=1}^N G_{mi,n,t}^{\gamma_{mi,n}}$$

with $\sum_{m=1}^K \sum_{i=1}^N \gamma_{mi,n} = 1$. Cost minimization implies

$$P_{mi,t} G_{mi,n,t} = \gamma_{mi,n} P_{n,t}^g G_{n,t}$$

$$P_{n,t}^g = \Pi_{m=1}^K \Pi_{i=1}^N \left(\frac{P_{mi,t}}{\gamma_{mi,n}} \right)^{\gamma_{mi,n}}$$

A government finances its expenditure via a labor income tax and a lump-sum transfer from households

$$-T_{n,t}^g + \tau_n^c W_{n,t}^c L_{n,t}^c = G_{n,t} P_{n,t}^g$$

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[11]We also consider a monetary rule that targets nominal consumption expenditure in the Eurozone or the rest of the world respectively in section 4 below.

Subsidies to retail labor service providers are also financed by lump sum taxes on households

$$T_{n,t}^w \equiv - \int_0^1 \tau_n^w W_{n,t}(h) L_{n,t}(h) dh.$$

3.5 Market Clearing Conditions

Labor market clearing condition for the wholesale labor market is

$$\int_0^1 L_{n,t}(h) dh = L_{n,t}^c$$

Combining labor demand (6), the labour market clearing condition in the retail labor markets reads

$$L_{n,t}^c = \int_0^1 L_{n,t}(h) dh = L_{n,t} = \sum_{j=1}^N L_{n,j,t}$$

The market clearing condition for goods produced by sector nj reads,

$$X_{nj,t} = \sum_{m=1}^K \tilde{C}_{nj,m,t} + \sum_{m=1}^K G_{nj,m,t} + \sum_{m=1}^K \sum_{i=1}^N M_{nj,mi,t} \tag{10}$$

where $\tilde{C}_{nj,m,t}$ is consumption demand by country m for goods produced by country-sector nj but taking into account of portfolio and wage adjustment costs, with $\tilde{C}_{m,t} \equiv C_{m,t} + \frac{1}{2} \psi_m^b \left(\frac{B_{m,t+1}}{P_{m,t}^c} - b_m \right)^2 + \frac{\psi_m^w}{2} \left(\pi_{m,t}^w - \pi_m^w \right)^2 \frac{W_{m,t}}{P_{m,t}^c}.$

The bond market clearing conditions read

$$\sum_{n=1}^K B_{n,t+1} = 0$$

$$B_{K,t+1}^* = 0$$

In the baseline model, we consider government spending shocks

$$\log \left(\frac{G_{n,t}}{\bar{G}_n} \right) = \rho_g \log \left(\frac{G_{n,t-1}}{\bar{G}_n} \right) + \epsilon_{n,t}, \text{ with } \epsilon_{n,t} \sim N(0, \sigma_g^2) \tag{11}$$

where $\bar{G}_n$ denotes the steady state government spending, ρ_g represents the persistence of government

spending and σ_g^2 stands for the variance of government spending shocks.

3.6 The Competitive Equilibrium

The competitive equilibrium in the world economy is defined as follows. Given government expenditure shock processes (11) and monetary policies (9), (i) firms in sector j country n in period t choose optimal labor input $L_{nj,t}$ and intermediate inputs $\{M_{mi,nj,t}\}_{mi}$ to maximize their profits, given prices for goods $\{P_{nj,t}\}_{nj}$ and wage $W_{n,t}$; (ii) households in country n choose optimal labor supply $L_{n,t}^c$ and consumption composite $C_{n,t}$ and its varieties $\{C_{mi,n,t}\}_{mi}$, given prices for goods $\{P_{mi,t}\}_{mi}$ and wholesale wage rate $W_{n,t}^c$ and $W_{K,t}^{c*}$; (iii) retail labor service providers $h \in [0,1]$ set the optimal nominal wage rate $W_{n,t}(h)$ and $W_{K,t}^*(h)$, given their labor demand and the aggregate wage rate $W_{n,t}$ and $W_{K,t}^*$; (iv) wholesale and retail labor markets clear, prices $\{P_{nj,t}\}_{nj}$ clear corresponding goods markets in each sector and each country, R_{t+1} clears the euro denominated bond market and R_{t+1}^* clears the dollar denominated bond market.

In the deterministic steady state, all exogenous shocks and endogenous variables are constant. We assume that a labor subsidy offsets monopoly power in labor markets, that is $\chi_n = 1$ at the steady state. Then $\xi R = 1$. Given price indices above, consumption C and the nominal wage W are determined by labor market clearing condition and country resource constraints.

4 A GDP Decomposition for Fiscal Shocks

The nominal GDP of country n is the sum of sectoral value-added in this country,

$$P_{n,t}^y Y_{n,t} = \sum_{j=1}^{N} P_{nj,t}^y Y_{nj,t}$$

According to the Divisia index, real value-added is calculated given fixed nominal prices (see vom Lehn and Winberry, 2021). Then the log change of real GDP can be written as,

$$d \log Y_{n,t} = \sum_{j=1}^{N} \frac{P_{nj}^y Y_{nj}}{P_n^y Y_n} d \log Y_{nj,t} = \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d \log Y_{nj,t}$$

where variables without time subscripts denote the steady state value of those variables. The second equality comes from the fact that value-added is only created by labor, and wages are equalized across sectors, $\frac{P_{nj}^y Y_{nj}}{P_n^y Y_n} = \frac{W_n L_{nj}}{W_n L_n} = \frac{L_{nj}}{L_n}$.

The change of sectoral real value-valued given fixed nominal prices and wages can be written as

$$P_{nj,t}^y dY_{nj,t} = P_{nj,t} dX_{nj,t} - P_{nj,t}^m dM_{nj,t}$$

which can be further written as

$$P_{nj,t}^y Y_{nj,t} d\log Y_{nj,t} = P_{nj,t} X_{nj,t} d\log X_{nj,t} - P_{nj,t}^m M_{nj,t} d\log M_{nj,t}$$

Substituting producers' optimality conditions into the equation above, yields

$$d\log Y_{nj,t} = d\log L_{nj,t}$$

That is, up to a first order approximation, the change of sectoral real value-added is fully determined by the change of labor. Substituting this equation into the country level value-added, yields,

$$d\log Y_{n,t} = \sum_{j=1}^N \frac{P_{nj}^y Y_{nj}}{P_n^y Y_n} d\log L_{nj,t} = \sum_{j=1}^N \frac{L_{nj}}{L_n} d\log L_{nj,t} = d\log L_{n,t}$$

Note that the log linearized version of the labor market clearing condition reads $d\log L_{n,t} = \sum_{j=1}^N \frac{L_{nj}}{L_n} d\log L_{nj,t}$, which delivers the third equality. Therefore, we summarize the relationship above in result 1.

Result 1. *Up to a first order approximation, a country's change in real GDP is completely determined by its labor movement, and moreover, real GDP grows one for one with labor growth, $d\log Y_{n,t} = d\log L_{n,t}$.*

4.1   Three Channels of Fiscal Spillovers

From producers' labor demand, we have

$$L_{nj,t} = \frac{(1-\alpha_{nj})P_{nj,t}X_{nj,t}}{W_{n,t}} = \frac{(1-\alpha_{nj})P_{nj,t}X_{nj,t}}{\mathcal{M}_t} \frac{\mathcal{M}_t}{W_{n,t}}$$

where $\mathcal{M}_t = \sum_{k=1}^{K} P_{k,t}\tilde{C}_{k,t}$ represents the nominal value of total consumption across all countries, expressed in euro.

Taking log on both sides of the expression above and then substituting it into the expression of real value-added, yields,

$$d\log Y_{n,t} = \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d\log L_{nj,t} = \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d\log\left(\frac{P_{nj,t}X_{nj,t}}{\mathcal{M}_t}\right) - \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d\log\left(\frac{W_{n,t}}{\mathcal{M}_t}\right) \qquad (12)$$

This expression links aggregate value added to sectoral gross output and labor cost. Following Auclert (2019) and vom Lehn and Winberry (2021), who focus on the investment network or monetary policy in a closed economy, we instead explore various channels of fiscal spillover across borders. Substituting factor demand into the goods market clearing conditions (10), taking a log linearization around the deterministic steady state, and then substituting the related expressions into the aggregate real value-added in each country (12) above, yields the following result (the proof is shown in the appendix),

Result 2. *Up to a first order approximation, the impact of fiscal spending shocks on a country's real GDP can be decomposed into three channels: a "Direct Effect", an "Income Effect", and and a "Price Effect",*

$$d\log Y_{n,t} = \underbrace{\sum_{j=1}^{N} \frac{L_{nj}}{L_n}\left(\sum_{k=1}^{K}\tilde{\omega}_{nj,k}d\log G_{k,t}\right)}_{Direct\ Effect} + \underbrace{\sum_{j=1}^{N} \frac{L_{nj}}{L_n}\left(\sum_{k=1}^{K}\tilde{\mu}_{nj,k}d\log\tilde{C}_{k,t}\right)}_{Income\ Effect}$$

$$+ \underbrace{\sum_{j=1}^{N} \frac{L_{nj}}{L_n}\left(\sum_{k=1}^{K}\tilde{\omega}_{nj,k}d\log P_{k,t}^g\right) + \sum_{j=1}^{N} \frac{L_{nj}}{L_n}\left(\sum_{k=1}^{K}\tilde{\mu}_{nj,k}d\log P_{k,t}^c\right) - d\log W_{n,t}}_{Price\ Effect} \qquad (13)$$

where $\tilde{\omega}_{nj,k}$ ($\tilde{\mu}_{nj,k}$) is a weight of a government spending shock (consumption change) from country k to country-sector nj at the steady state respectively,

$$\tilde{\omega}_{nj,k} \equiv \frac{P_k^g G_k}{P_{nj}X_{nj}} \sum_{m=1}^{K}\sum_{i=1}^{N} \ell_{nj,mi}\gamma_{mi,k} \geq 0$$

$$\tilde{\mu}_{nj,k} = \frac{P_k^c C_k}{P_{nj}X_{nj}} \sum_{m=1}^{K}\sum_{i=1}^{N} \ell_{nj,mi}\beta_{mi,k} \geq 0$$

and $\ell_{nj,mi}$ is the (nj, mi)-th element of a Leontief inverse matrix.[12]

The 'Direct Effect' captures how an increase in government spending directly increases domestic and foreign sectoral value-added both through direct government purchases, and through the production network, given unchanged prices and income. The weight $\tilde{\omega}_{nj,k}$ captures the direct and indirect effect of government spending on sectoral output through the production network. For instance, an increase in government spending in country k leads to higher demand for variety produced by sector i of country m when $\gamma_{mi,k} > 0$, which in turn drives up demand for intermediate input produced by its own sector and other sectors. The compound effect through the production network is captured by the Leontief inverse, with element $\ell_{nj,mi}$, and then summed across all sectors i and countries m. Note that this Direct effect is always nonnegative, responding to a rise in a country's fiscal spending. Another point worth of emphasizing is that the Direct effect doesn't depend on monetary policy rules and nominal rigidities, which is summarized in the following result,

Result 3. *The Direct effect doesn't depend on nominal rigidities, monetary policy rules and capital mobility across borders.*

We also note that in the absence of any imported intermediate inputs, the Leontief inverse is a block diagonal matrix, $\ell_{nj,mi} = 0$ if $n \neq m$. In addition, if government spending completely falls on domestically produced goods, $\gamma_{mi,k} = 0$ if $m \neq k$. Combining these two special scenarios, the weight in the Direct effect $\tilde{\omega}_{nj,k} = 0$ if $n \neq k$. That is, government spending doesn't spill over to other economies through the Direct effect. But as long as firms make use of imported intermediate inputs to produce and/or government spending falls partly on imported goods, a rise in a country's government spending will have a positive spillover through the Direct effect to other countries. We can further show in Appendix A that the Direct effect depends on a number of factors summarized in result 4 below.

Result 4. *For a given government spending shock by country k, $d \log G_{k,t}$, the Direct effect is larger when (a) the shock origin country is larger (higher GDP share in the world economy), (b) fiscal spending*

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[12]The Leontief inverse matrix $\mathcal{L} \equiv (\mathbb{I} - \Omega)^{-1}$, with

$$\Omega = \Omega_0 \circ (e_{KN} \alpha'), \alpha = \begin{bmatrix} \alpha_{11} \\ \alpha_{12} \\ \vdots \\ \alpha_{KN} \end{bmatrix}, \qquad \Omega_0 = \begin{bmatrix} \omega_{11,11} & \omega_{11,12} & \cdots & \omega_{11,KN} \\ \omega_{12,11} & \omega_{12,12} & \cdots & \omega_{12,KN} \\ \vdots & \vdots & \vdots & \vdots \\ \omega_{KN,11} & \omega_{KN,12} & \cdots & \omega_{KN,KN} \end{bmatrix}$$

where $\circ$ denotes element wise product (Hadamard product). e_{KN} is a column vector of length $K \times N$ and each element is one.

relative to consumption is larger, (c) higher trade intensity in intermediate inputs (larger off-diagonal elements of Leontief inverse), and (d) higher government spending share (higher $\gamma_{mi,k}$).

The 'Income Effect' shows how domestic real income and consequently domestic consumption responds to shocks, given unchanged prices. For instance, a rise in fiscal spending in country k may increase demand for varieties produced by domestic and foreign sectors both directly and indirectly through the production network. The response of consumption can be driven by both intra-temporal and inter-temporal effects. When nominal prices remain unchanged, a higher gross output also leads to a higher labor income, and consequently higher consumption, which in turn may lead to a further higher sectoral value added. But changes in government spending also affect interest rates and exchange rates, which can affect the inter-temporal path of consumption, particularly in the presence of endogenous capital flows. Note that for the shock origin country, fiscal spending is financed through income taxes, implying that households after-tax income declines when government increases its fiscal spending, suggesting a negative income effect. Similar to the structure of government spending on different varieties, $\tilde{\mu}_{nj,k}$ captures how a change in consumption can be propagated across borders through the international production network. Of course, when firms don't use intermediate imported goods to produce and consumption is completely home biased, $\tilde{\mu}_{nj,k} = 0$ if $n \neq k$, the change in consumption of country k won't affect foreign firms' value added. We note also that the Income effect may be positive or negative, and in general will differ in sign across countries, as we show quantitatively below.

The 'Price Effect' captures how changes in the prices of final absorption relative to the labor cost affects value-added. Final absorption consists of households consumption and government expenditure. Prices change may affect a country's value-added through the direct and indirect consumption and government demand for goods produced by this country via production network. The Price effect can be understood as a *network adjusted real exchange rate* and may work as an expenditure switching effect.[13] When this term is positive, price movements increase value added in country n.

Note that firms are competitive producers and earn zero profits in equilibrium. Therefore, the price of each country-sector good can be expressed as a function of nominal wages in national currency and the nominal exchange rate between the monetary union and the rest of the world. When nominal wages are sticky and unchanged, and the rest of the world maintains a peg to the monetary union, the Price effect

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[13]Nevertheless, due to the fact that both households and government consume goods produced by the world economy and further through international production network, the distinguishing between home goods and foreign goods is quite ambiguous.

will disappear. When the rest of the world stabilizes domestic prices, rather than the nominal exchange rate, price changes are ultimately tied to changes in the nominal wage rates and the nominal exchange rate across all K countries, which in turn changes value-added through the Price effect in equilibrium.

4.2 Fiscal Spillovers and World GDP

World nominal GDP is the sum of value-added in all countries,

$$P_t^y Y_t \equiv \sum_{n=1}^{K} P_{n,t}^y Y_{n,t}$$

where Y_t is world real GDP and P_t^y corresponds to the nominal price. Similar to the definition of country level real GDP growth, world real GDP growth is the weighted sum of real GDP growth in all countries,

$$d \log Y_t = \sum_{n=1}^{K} \phi_n d \log Y_{n,t}$$

where $\phi_n \equiv \frac{P_n^y Y_n}{P^y Y}$ is the share of country n GDP in the world GDP at the steady state. World real GDP growth can also be decomposed into Direct, Income, and Price effect, which can be obtained by substituting the expressions for $d \log Y_{n,t}$ into the equation above. We obtain one key insight from this aggregation to the world level. The contribution of the Price effect to world GDP is zero in result 5 (the proof is in the appendix).

Result 5. *The contribution of the Price effect in the response of world GDP to fiscal spending shocks equals zero.*

$$\sum_{n=1}^{K} \phi_n \sum_{j=1}^{N} \frac{L_{nj}}{L_n} \left(\sum_{k=1}^{K} \tilde{\omega}_{nj,k} d \log P_{k,t}^g \right) + \sum_{n=1}^{K} \phi_n \sum_{j=1}^{N} \frac{L_{nj}}{L_n} \left(\sum_{k=1}^{K} \tilde{\mu}_{nj,k} d \log P_{k,t}^c \right) - \sum_{n=1}^{K} \phi_n d \log W_{n,t} = 0.$$

Intuitively, the price effect represents a balance of network adjusted prices relative to wage costs, and prices are determined only by wages and the exchange rate. When we add all countries together to compute the world Price effect, prices and wages cancel out, as does the exchange rate since we add both Eurozone and the rest of the world together. Therefore, the response of world real GDP to fiscal spending shocks depends only on the Direct effect and the Income effect. Since the Direct effect is nonnegative for all countries, fiscal spending will have a positive effect on the world GDP through the Direct effect.

The Income effect might be positive or negative, depending on consumption adjustment through the intratemporal and intertemporal margin. The international production network will contribute to world GDP growth through both of these two effects. In addition, the zero world Price effect must imply that fiscal spending is a "beggar-thy-neighbor" policy through network adjusted real exchange rate movements.

4.3   An Analytical Example

We can illustrate the role of these three effects by way of a simple example of a three country model in a static environment, with fully sticky nominal wages. Let country 1 and 2 belong to a monetary union, while country 3 constitutes the 'rest of the world', with an independent monetary policy. There is just one sector in each country, but we let production in each country rely on intermediate goods of the other two countries. The details of the model are described fully in Appendix C. We assume that the weight on own goods in consumer preferences of each country is $\beta < 1$, and that on each of the other country's goods is $\frac{1-\beta}{2}$. Likewise, assume that the weight on intermediate goods in the production function is α with a share ω on own goods, and $\frac{1-\omega}{2}$ on each of the other countries goods. Assume also that monetary policy in the monetary union (e.g. euro area) is set so as to stabilize nominal consumption in local currency, and the rest of the world monetary policy stabilizes nominal consumption in rest of the world currency.[14] Finally, the weight on the own good for fiscal spending is defined as β_1, with $\frac{1-\beta_1}{2}$ representing the weight on the other country's goods.

We look at the effect of a fiscal spending shock in country 1, for simplicity starting from an initial condition where government spending is zero. Based on these set of assumptions we can compute the decomposition outlined in the previous section as follows:

Table 1 makes clear a number of features of the impact of fiscal spending in country 1 and the decomposition into Direct, Income, and Price effect. First, when $\beta_1 = 1$ and $\omega = 1$, that is, when fiscal spending is fully concentrated on country 1's good, and there are no international production linkages, then there is just a Direct effect in country 1 equal to $\frac{1}{1-\alpha}$, no Direct effects in country 2 or 3, and no income or price effects in any country. This is in fact a case where monetary policy fully stabilizes nominal consumption in the 'Eurozone', country 1 and 2, and in country 3 separately, the value added

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[14]Monetary authorities target nominal consumption expenditure, $\mathcal{M}_t^{ez} = \sum_{k=1}^{2} P_{k,t} C_{k,t}$ in the monetary union and $\mathcal{M}_t^{row} = P_{3,t}^* C_{3,t}$ in the rest of the world.

Table 1: Effects of fiscal spending in a three-country world economy

	Country 1	Country 2	Country 3
Direct Effect	$\frac{2\beta_1(1-\alpha)+\alpha(1-\omega)}{\Delta}$	$\frac{(1-\alpha)(1-\beta_1)+\alpha(1-\omega)}{\Delta}$	$\frac{(1-\alpha)(1-\beta_1)+\alpha(1-\omega)}{\Delta}$
Income Effect	$-\frac{(3\beta-1)((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{\Delta_1}$	$\frac{(3\beta-1)((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{\Delta_2}$	$\frac{(3\beta-1)((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{\Delta_3}$
Price Effect	$\frac{((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{2\Delta_4}$	$\frac{((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{2\Delta_4}$	$-\frac{((1-\alpha)(1-\beta_1)+\alpha(1-\omega))}{\Delta_4}$

Notes: $\Delta = (1-\alpha)(2(1-\alpha\omega)+\alpha(1-\omega))$, $\Delta_1^{-1} = \frac{((3-\beta)(1-\alpha)+4\alpha(1-\omega))}{2(2(1-\alpha\omega)+\alpha(1-\omega))^2((1-\beta)(1-\alpha)+\alpha(1-\omega))}$, $\Delta_2^{-1} = \frac{((1+\beta)(1-\alpha)+2\alpha(1-\omega))}{2(2(1-\alpha\omega)+\alpha(1-\omega))^2((1-\beta)(1-\alpha)+\alpha(1-\omega))}$, $\Delta_3 = (2(1-\alpha\omega)+\alpha(1-\omega))^2$, $\Delta_4^{-1} = \frac{(1-\alpha)+3((1-\alpha)\beta+\alpha(1-\omega))}{(1-\alpha)(2(1-\alpha\omega)+\alpha(1-\omega))^2}$.

multiplier in country 1 is unity, and there is no change in the exchange rate for country 3. There are no spillovers of any kind, either to country 2 or country 3.

Now take the case where $\beta_1 = 1$, but $\omega < 1$, so there are some production linkages among countries. Then there are positive direct effects for country 2 and 3, working through intermediate goods demand following the increase in demand and output in country 1. Whether there are income effects depends on the degree of home bias in private consumption. If $\beta = \frac{1}{3}$, so that private consumption weights are balanced across each country's good, there are no income effects, even if $\omega < 1$ and $\beta_1 < 1$. The logic comes from the fact that the monetary rules which stabilize consumption in the presence of fixed wages act so as to insulate overall world consumption from the fiscal shock. If world consumption is unchanged, and the pattern of demand given individual consumption is unchanged given $\beta = \frac{1}{3}$, then there is no indirect effect on relative demand for any country's good (or Income effect) through changes in spending. But we note that when $\beta > \frac{1}{3}$, so there is home bias in consumption spending, there will be a negative income effect for country 1 and a positive income effect for country 2 and 3, whenever $\beta_1 < 1$ and/or $\omega < 1$. For any parameter values however, Table 1 establishes that the sum of income effects across countries is zero. This again is a consequence of the monetary policy rules, given sticky wages.

Finally, Table 1 indicates that the price effects are positive for country 1 and 2, while negative for country 3, so long at $\beta_1 < 1$ and/or $\omega < 1$. This implies that the fiscal shock in country 1 will cause a real depreciation for country 1 and 2, while a real appreciation for country 3. Given that $\beta_1 \approx 1$ in most cases, the result is critically tied to the role of the production network. The logic of currency depreciation following the fiscal shock in country 1 is as follows. Recall that monetary policy stabilizes nominal consumption (in local currency) in both the currency area (country 1 and 2) and the rest of the world (country 3). Holding the exchange rate constant, with sticky wages, the CPI would be unchanged

in all countries currency. But a rise in demand for country 3 good following a fiscal expansion in country 1 (through the production network) would ceteris paribus, increase real value added and consumption in country 3, which, given a constant CPI, would be inconsistent with the monetary policy rule which stabilizes nominal consumption. Adjustment must be achieved through an appreciation of country 3's currency which will lead to a combined fall in the foreign currency CPI and a reduction in real value added in country 3.

The overall effect on real value added in each country may be obtained by summing the entries in the column for each country. It is easy to check that the three elements of the decomposition sum to zero for country 3. The positive direct and income effects are exactly offset by the price effect, and real value added is insulated from the fiscal shock in country 1. For country 2 however, all entries are positive. So long as the production network is active, there is a positive Direct effect on demand, but also a positive Income effect (for $\beta > \frac{1}{3}$), and a positive Price effect through the real depreciation. The full effect on country 2 real value added sums to

$$\frac{(1 - \beta_1)(1 - \alpha) + \alpha(1 - \omega)}{(1 - \beta)(1 - \alpha) + \alpha(1 - \omega)} > 0$$

Hence, production networks enhance spillovers within a currency area. For countries outside the currency area however, spillovers are negated by exchange rate adjustment. The impact of the spending shock in country 1 real value added (the own effect) sums from Table 1 to

$$\frac{(\beta_1 - \beta)(1 - \alpha) + (1 - \beta_1)(1 - \alpha) + \alpha(1 - \omega)}{(1 - \beta)(1 - \alpha) + \alpha(1 - \omega)} > 0$$

So long as fiscal spending is more biased towards home production than private spending, this exceeds the spillover effect to country 2.

5 Application to World Input Output Database

In this section, we apply the full dynamic model in an investigation of the size and pattern of fiscal spillovers implied by detailed measures of European production networks. We use an application of the World Input Output Database (WIOD) to the Eurozone. In particular, we explore the quantitative predictions of Eurozone fiscal spillovers by implementing a mapping between the above multi-country

model and the WIOD. Our system of competitive equilibrium can be directly applied to the WIOD in order to calibrate the parameters of the production network, private and government spending shares, and labour shares. Given this calibration we can explore the domestic and spillover effects of government spending shocks both in the aggregate and the sectoral level.

5.1   Calibration

We focus on a data set of 11 euro area countries, belonging to a monetary union and "the Rest of the World" which consists of other countries, over the period 2000-2014 in the WIOD database and 50 main sectors for each country.[15] The focus on the Eurozone allows us to concentrate on the role of production networks in the transmission of fiscal policy without having to take a stand on heterogeneity in monetary policy responses to fiscal shocks. In addition, the Eurozone represents an integrated economic area within which intermediate trading linkages are likely to be substantially greater than among other economies. Moreover, by using the time series of input output tables over the 2000-2014 period, we can investigate how the evolution of production networks within the Eurozone has changed the pattern of fiscal spillovers implied by the model.

To implement the equilibrium model defined by the system of equations in the previous section, we need to calibrate the structural parameters. There are two sets of parameters in the model. The first set of parameters are deep structural parameters, which mainly taken from the literature. We set the inverse of the intertemporal elasticity of substitution to be $\sigma = 2$, and the inverse of Frisch labour supply elasticity to be $\eta = 1$ as in the literature. Since the WIOD is reported at annual frequency, we assume a time period in our model and data is one year, and set $\xi = 0.96$, implying 4% annual real interest rate. To capture wage stickiness at the annual frequency, we set $\psi^w = 100$, which is close to the value used in Devereux, Young and Yu (2019). The bond holding adjustment cost is set to be a small number to generate stationarity of external dynamics.

The second set of parameters include intermediate input coefficients $\omega_{mi,nj}$, the labour income shares

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[15]The 11 euro area countries include Austria, Belgium, Germany, Spain, Finland, France, Greece, Ireland, Italy, Netherlands and Portugal. The last two sectors in the WIOT are sector 55 "Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use" and sector 56 "Activities of extraterritorial organizations and bodies", both of which account for a tiny fraction of gross output. We omit these two sectors due to data availability. In addition, we focus on non-financial sectors in a country, and drop four financial sectors: sector 41 "Financial service activities, except insurance and pension funding", sector 42 "Insurance, reinsurance and pension funding, except compulsory social security", sector 43 "Activities auxiliary to financial services and insurance activities", and sector 44 "Real estate activities".

$1 - \alpha_{nj}$, the consumption spending shares in households preference $\beta_{mi,n}$, government spending shares $\gamma_{mi,n}$, net foreign asset positions b_n, labor income taxes τ_n^c and coefficients in the monetary policies and exogenous government consumption expenditures. Given the assumption of Cobb-Douglas production and unit elasticity of substitution among consumption goods, $\omega_{mi,nj}$, α_{nj}, $\beta_{mi,n}$ and $\gamma_{mi,n}$ can be directly measured from the WIOD.[16]

Column nj row mi in the WIOT Tables gives expenditure by sector j in country n on intermediate inputs from sector i in country m. From the assumption of Cobb-Douglas production, the demand for intermediate input mi by sector nj is $P_{mi}M_{mi,nj} = \alpha_{nj}\omega_{mi,nj}P_{nj}X_{nj}$. Dividing by the total demand for intermediate inputs (using homogeneity), we can write $\omega_{mi,nj} = \frac{P_{mj}M_{mi,nj}}{\sum_{m=1}^{K}\sum_{i=1}^{N}P_{mi}M_{mi,nj}}$. Doing this for all countries and sectors gives us the the input-output matrix Ω_0, following the notation from section above. Note that columns of Ω_0 sum to unity.

The WIOT also gives private consumption expenditure for each sector-country by each country $P_{mi}C_{mi,n}$. In the baseline case, we simply calculate consumption spending share $\beta_{mi,n} = \frac{P_{mi}C_{mi,n}}{\sum_{m=1}^{K}\sum_{i=1}^{N}P_{mi}C_{mi,n}}$ when using the Cobb-Douglas specification. Similarly, to compute government spending we use the column in the WIOT tables reporting final government consumption expenditure by each country on each country-sector, $\gamma_{mi,n} = \frac{P_{mi}G_{mi,n}}{\sum_{m=1}^{K}\sum_{i=1}^{N}P_{mi}G_{mi,n}}$, which describes the share of country n government expenditures going to sector i in country m.[17]

Each parameter above can be calibrated for each year from 2000 to 2014 from the WIOD tables. The composition of the input-output tables did change over this period although, as shown below, the changes did not fundamentally alter the predictions of the model for fiscal spillovers. Hence, we first report the results using an average of all shares over the 2000-2014 period. In the discussion below, we report how the predicted evolution of the effects of fiscal shocks changes year by year over the sample.

Asset markets are incomplete in our baseline model and we consider mainly relatively short-term bonds. At the steady state with zero price and wage inflation, the net foreign asset position of a country

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[16]In the Appendix, we depart from the assumption of Cobb-Douglas production and unit elasticity of substitution in consumption, estimating elasticity parameters directly from the data for each country. The estimation show that these elasticities are very close to one. Huo, Levchenko and Pandalai-Nayar (2020) study productivity in an economy with input-output linkages and obtain a similar estimation of elasticity of substitution among intermediate inputs.

[17]Note that our model does not contain investment and inventory adjustment. To account for this, we add to private consumption expenditure a share of gross fixed capital formation changes in inventories and valuables such that private and government consumption expenditure share are unchanged. As an alternative, we could add changes in inventories and valuables to intermediate goods demand for each sector nj in proportion to the share of demand coming from each country-sector mi, and distribute gross fixed capital formation into public and private sectors. Again using the Cobb-Douglas specification, we obtain an alternative $\beta_{mi,n}$ and $\gamma_{mi,n}$, where private and government consumption are now measured including a share gross fixed capital formation at the sectoral level. The results are similar to the baseline calibration.

is determined by parameter $b_n = \frac{B_n}{P_n^c}$ and bond market clearing condition requires that $\sum_{n=1}^{K} B_n = 0$. In the baseline calibration, we assume that each country has a zero net foreign asset position, $b_n = 0$, to isolate the valuation effect due to interest rate and exchange rate movements when external positions are extremely large.

Fiscal authorities finance government spending by levying an income tax. The labor income tax τ_n^c is set as the total tax wedge net of employer social security contributions in the data of 2007 for the income group as 133 percent of the average wage from the OECD.Stat.[18] The labor income tax varies from 8% in France to 32% in Netherlands, and with an average of 20%. Labor income taxes are not time-varying in our model, and they only affect the steady state of the world economy. In Appendix F, we also consider a case in which government expenditures are only financed by time-varying distortionary labor income taxes.

In the monetary policy rule, the weight for CPI inflation ρ_n in the Taylor rule of the monetary union is calculated based on consumption spending shares in the data. Given the 11 Eurozone countries weighted CPI inflation, we then regress the discount rate for euro area on the weighted CPI inflation and get $\rho_\pi = 1.2$ and set $\rho_r = 0$. For the monetary rule in rest of the world, we use the same set of structural parameters as in the Eurozone.

Government spending shocks are estimated from the data based on the method of Blanchard and Perotti (2002). The identification assumptions and data construction are relegated to Appendix D. For a yearly process of government spending, we set $\rho_g = 0.65$ as in the data. The level of government spending in the model is calibrated in a way such that the ratio of government spending to the sum of consumption and government spending at the steady state in the model matches those in the data.

One clear feature of the input-output tables is the degree of home bias in spending patterns. Appendix E provides an illustration of the share of total spending falling on domestic sectors, for government consumption, private consumption and intermediate imports. For all countries, government spending is heavily biased towards the domestic sector, with a share in excess of 90 percent. Private consumption spending is less home biased than government spending, but the share in all countries exceeds 65 percent. Intermediate input usage is less domestically biased, but for the large European economies intermediate inputs still displays over 70 percent home bias.[19]

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[18]See Table I.5 in OECD.Stat: Average personal income tax and social security contribution rates on gross labour income.

[19]Appendix E also illustrates how home bias has slightly diminished over the sample period, but remains high for all

5.2 A First-Pass Quantitative Exploration

We first look at the effects of fiscal shocks in a special case of the calibrated model. Following the static example above, we assume that instead of the interest rate rules (9), monetary authorities target nominal spending $\mathcal{M}^{ez} = \sum_{k=1}^{K-1} P_{k,t} C_{k,t}$ in the monetary union and $\mathcal{M}^{row} = P_{K,t}^* C_{K,t}$ in the rest of the world. Also, for the moment, we continue to assume fully sticky nominal wages, and we abstract from current account dynamics by assuming very large costs of adjustment in international bond trade. The model dynamics essentially inherit the exogenous government spending shock process.

Figure 1 shows GDP responses and the three-effect decomposition from a one-percent of GDP increase in German government spending. On average GDP increases by about 0.13 percentage points on impact in other 10 Eurozone economies, while it hardly changes in the rest of the world due to its dominant size in the world economy. The fiscal spillovers generated by this static model are in line with empirical estimates from the literature (see figure 8). Note that sectors in the Eurozone and the rest of world are connected through both direct spending and through imported intermediate inputs, so according to our decomposition in equation (13) and result 4, the Direct Effect (blue bars) is positive for all economies responding to an increase in German government spending. Austria, Belgium, Ireland and Netherlands have relatively higher direct effects than others since they are smaller economies and have higher trade intensity in intermediate inputs (see figure A-4 in the Appendix).

Figure 1 indicates that fiscal spillovers through the Income Effect (red bars) are also positive for both the Eurozone and the rest of the world. The shock origin country, Germany, experiences a negative income effect due to the fact that its government spending is financed by domestic income tax. The positive Income Effect for other EZ countries arises because monetary policy implicitly accommodates the fiscal expansion across borders by stabilizing aggregate EZ consumption. Although a rise in German government spending falls mostly on domestically produced goods and partly on imported goods, sectors are interconnected through both domestic and international input output linkages. With fully sticky nominal wages, this leads to increases in output, income and consumption in other countries. Figure 1 shows that the Income Effect accounts for more than one third of output responses in one half of countries in the Eurozone and accounts for around one fourth of output responses in the remaining Eurozone countries. The Income effect also significantly contributes to an output increase even in the

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categories of spending.

rest of the world.

The Price Effect (orange bars) in this example reflects network adjusted real exchange rate movement between the Eurozone and the rest of the world. As in the simple example model, the euro depreciates in response to a positive German government spending shock. A positive Income Effect in the rest of the world requires its currency to appreciate as in the analytical example above, and consequently, the depreciation of the euro generates a positive expenditure switching effect towards the goods produced by countries in the Eurozone, while a negative expenditure switching effect towards the goods produced by the rest of world. Figure 1 shows that this positive expenditure switching effect for the Eurozone is quite sizeable, and even larger than the income effect for most of Eurozone economies (except for Spain and France), while the negative price effect almost offsets the positive direct and income effect in the rest of the world.

Does the international production network facilitate propagation of fiscal shocks across borders? Figure A-2 in the Appendix shows output responses when we shut down international trade in intermediate inputs across borders.[20] Comparing with figure 1, several important differences stand out. First, the Direct Effect is reduced substantially. When firms don't make use of imported inputs and government spending exhibits a strong home bias, the Direct Effect will be generally small as stated in result 4. Second, the Income effect is still prevalent in the euro area but with a large variation across borders. Ireland, Greece, France, Finland and Spain experience higher fiscal spillovers through the Income effect, while other economies face lower fiscal spillovers. Third, the Price effect becomes much smaller for all economies. The reason is that the rest of world contributes to the lion's share of international trade in intermediate inputs, and consequently, once we shut down trade in intermediate inputs, the Income Effect via the Leontief inverse matrix will be substantially reduced in the rest of the world, which in turn diminishes the Price Effect. The overall message is that shutting down intermediate input linkages across borders significantly reduce fiscal spillovers.

The analysis above shows when nominal wages are fully sticky, a fiscal policy shock may generate strong spillovers across borders. What would happen if nominal wages could freely adjust over time? Results in the Appendix show that, without international financial adjustment, fiscal spillovers are essentially zero both in the case with international production network or without international production

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[20]In order to shut down trade in intermediate inputs we set the weights on non-domestic sectors in the production network to zero and reassign the weights on each sector to the relevant sector in the domestic economy. See the calibration section for a detailed description.

network. In the case with international production network, the Direct effect is the only positive component of GDP responses for most of economies. The Income effect is all negative and the price effect is also negative for all economies except for Germany, Italy and Portugal. These negative effects almost completely offset the positive direct effect, which consequently leads to almost zero fiscal spillover.

5.3 Fiscal Spillovers in the Baseline Model

We now extend the analysis to the full dynamic model. As argued by Mountford and Uhlig (2009), and Fisher and Peters (2010), and thoroughly explored by Ramey and Zubairy (2018) based on US historical data, fiscal multipliers should be calculated as the integral of the output response divided by the integral of the government spending response. We consider the responses of the world economy to a government spending shock in a core country c. All nominal variables after the shocks will be deflated by those at the steady state, that is, we use double deflation to calculate the real responses of variables of interest. The cumulative fiscal multiplier and fiscal spillover to country n from core country c for a horizon T, $FM_{nT,c}$, is defined as

$$\text{FM}_{nT,c} \equiv \frac{\sum_{t=1}^{T} d\log(P_{n,t}^y Y_{n,t})}{\frac{\sum_{t=1}^{T} dG_{c,t}P_{c,t}^g}{P_c Y_c}} = \frac{\sum_{t=1}^{T} d\log(Y_{n,t})}{\sum_{t=1}^{T} d\log(G_{c,t})} \frac{P_c Y_c}{P_c^g G_c}.$$

Figure 3 shows the response of real GDP growth to a shock to German government spending approximately equal to one percent of German GDP when monetary authorities follow Taylor rules to stabilize inflation of consumer prices. The figure reports in each case the responses, as well as the decomposition according to equation (13).

The response of German GDP indicates that the own real GDP grows by approximately 0.6 percentage point on impact in figure 3, which translates to an own multiplier of 0.6 in figure 2. The spillover effects to GDP are positive, although the spillovers vary across countries. The highest spillover is to Austria, in which a one percent of GDP spending increase in Germany increases Austrian real GDP growth by about 0.033 of one percent. As expected, the spillover to the rest of the world outside the eurozone is negligible. We note that these spillover magnitudes are much smaller than in the quantitative static economy example of Section 5.2. There are two main reasons for this discrepancy between the purely static model of Section 5.2 and these results. First, in the static model we assume that monetary policy stabilizes nominal Eurozone consumption, while in the current model monetary policy is governed

by an interest rate rule which responds to area wide inflation. This leads to a rise in the policy rate in response to the inflationary effects of the German government spending shock, which in itself dampens both the own effect and spillover effect of the spending shock. Secondly, in the static example, wage rates are assumed to be fully rigid, whereas the current calibration assumes only that labor bundlers face an adjustment cost of increasing wage rates in response to an increase in the fiscal spending shock. Figures A-6 and A-7 in the Appendix show that in the dynamic model, wage and price inflation in all countries rises in response to the German spending shock.

Although spillovers are significantly smaller in the dynamic model, Figure 2 shows that in the absence of cross-country production linkages, the fiscal spillover to other Eurozone countries becomes effectively zero. These results indicate that the cross-country production network does in fact act as a propagation mechanism, increasing the fiscal spillover across countries, although the magnitude of the effect is sensitive to the monetary policy rule followed.

Figure 3 also presents the decomposition of the output response to an increase in German government spending. The blue bars are for the direct effect. Given wages and nominal exchange rate and consumption unchanged, a one-percent of GDP increase in German government spending leads to 0.9 percentage point rise of German GDP on impact through the direct effect. The direct effect for the fiscal spillover in all countries is positive and accounts for about half of the positive response of GDP. We note in fact that direct effect of the spending increase is exactly equivalent to the direct effect in the static model of Section 5.2, since these depend only on the initial share of German government spending in each sector-country, and are independent of the endogenous adjustment in prices or consumption.

The orange bars in figure 3 show that the price effect is negative for the shock origin country – Germany, while it is positive for all other countries. Thus, the price effect generates an expenditure switching away from Germany towards neighbouring countries. The direction of the price effect differs from that of the static example of Section 5.2. In Figure 1, with fully sticky wages, the price effect is driven only by movements in the euro exchange rate against the rest of the world. In this dynamic example with endogenous (although sticky) wage adjustment, the price effect responds to wage changes as well as exchange rate changes. The direction of movement of the price effect indicates that Germany experiences an effective real exchange rate appreciation, driven by a rise in German wages in excess of the network adjusted movements in government and consumer prices, while all other countries experience an effective real depreciation, as network adjusted government and consumer prices rise in excess of

movements in wages. As noted by Result 5 above, the price effect averages to zero when weighted by GDP shares.

While the combination of direct and price effects lead to positive spillovers of fiscal spending in Germany, the income effects move in the other direction in the dynamic model. The red bars in figure 3 show that the income effect in all countries is negative, which may seem surprising at a first glance. For the shock origin country, government spending is financed by income tax, which leads directly to a negative income effect. But the demand effect of the fiscal expansion leads to a rise in inflation, both in the Eurozone countries and the rest of the world. As a result, the monetary response through the Taylor rule implies a rise in real interest rates, and this leads to a fall in current consumption and a negative income effect for all other countries. Thus, again the key difference relative to Section 5.2 lies in the different response of monetary policy to the fiscal spending expansion.

How important is the international production network in generating the fiscal spillovers in this example? Again, following the procedure discussed in Section 5.2, we can shut down production linkages across borders in the model. Figure A-8 in the Appendix shows that the direct effect falls substantially for many economies, except for Ireland, as in the static model. But the price effect is still positive for all countries except for Germany and the income effect is also negative for all countries. But since these secondary effects are endogenously responding to the direct effect, their magnitude also falls relative to the economy with an active international production network. These results indicate that the international production network plays a significant role in propagating fiscal shocks across borders, both through the direct effect and the endogenous price and income effects.

5.4   Fiscal Spillovers at the Zero Lower Bound

During the 2008-09 Global Financial Crisis and the following European debt crisis, the ECB dramatically cut its policy interest rate. The annualized discount rate for euro area declined to 0.3% in 2014 (the end of period of our data sample). As studied by the literature ((see for instance Eggertsson, 2011, Werning, 2011, Woodford, 2011, Christiano, Eichenbaum and Rebelo, 2011, Swanson and Williams, 2014, Gust, Herbst, López-Salido and Smith, 2017)), fiscal spending may have a much stronger impact on output when the nominal interest rate is constrained by an effective lower bound. Here, we extend the multi-country model to allow for a zero bound constraint on the policy rate. Following Cook and Devereux (2019) and Eggertsson, Egiev, Lin, Platzer and Riva (2021), we investigate the responses of

output to an expansionary fiscal spending when the nominal interest response to inflation is temporarily suspended .

Suppose the model world economy begins at its deterministic steady state in period 0. In period 1, all agents and policy makers anticipate that the economy (either the Eurozone or the rest of the world, or the whole world economy) will enter a liquidity trap for τ_z periods due to some anticipated shocks to the natural interest rate. Following this, the economy returns back to its normal state from period $\tau_z + 1$ onwards, in which nominal interest rates are unconstrained and follow the Taylor rules as described above. Period τ_z is known for all agents and policy makers.

Figure 4 shows the response of output and the decomposition in each country responding to one percent of GDP increase in German government spending when the nominal interest rate in the Eurozone is constrained by its lower bound and $\tau_z = 2$. There are a number of striking aspects of the Figure. First, the fiscal spillover effects are much larger than in the baseline model. The spillover effects are in the range of 0.1 to 0.3 percent of GDP and they are particularly large for France, Austria, Netherlands, and Spain. The fiscal spillovers obtained here are quite consistent with those in the empirical literature (see figure 8). Secondly, the own multiplier for Germany increases considerably, and is close to unity in Figure 4. In addition, the multipliers for the rest of the world, while still small, become negative. Finally, as in the baseline model, the international production network plays a substantial role. Recalibrating the model to remove trade in intermediate inputs reduces the spillover multipliers considerably. Furthermore, the surprising feature of the Figure 4 is that the own multiplier is actually higher in the presence of international production networks. This contrasts with the baseline model of section 5.3 above, where the international production network acted as a leakage in the impact of fiscal spending on own GDP. Here, the international spillovers, in the presence of the zero bound constraint on the policy rate and the propagation through the international production network, become large enough that they lead to a 'spillback' effect, generating an additional boost to German GDP that is absent without the international production network.

Figure 4 also shows that for most countries, the fiscal spillover is larger in the presence of the international production network. For Austria, Spain, Finland, France, Italy and Netherlands, the spillover shrinks by about a third of the impact effect in the absence of the international production network. By contrast, the spillover for Greece and Ireland is relatively unaffected by the production network. This points to the increased importance of the endogenous propagation through real interest

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rates in the case of the zero bound constraint, as we discuss below.

Figure 5 provides the decomposition of effects of the fiscal spending shock in the model under the zero bound constraint. As shown in equation (13), the direct effect of government spending on GDP doesn't depend on monetary policies, and therefore, it is identical to figure 3 when the policy interest rate is unconstrained. But the two other effects show a dramatic difference relative to the baseline case. First we see that the income effect is positive for all countries, even for Germany, the origin spending country itself. Intuitively, with a constant policy rate and the inflationary impact of government spending, the fall in the real interest rate stimulates consumption in all countries. Secondly, we see that the price effect is large and positive for all Eurozone countries, whereas it is large and *negative* for the rest of the world. The reason is that the German fiscal spending causes a euro depreciation, due to the lower real interest rate in the Eurozone, and generates a strong expenditure switching towards all Eurozone countries. This is reminiscent of the results of fiscal spending shocks under the zero bound analyzed by Cook and Devereux (2011), who show that fiscal policy may be a beggar thy neighbour policy under the zero bound constraint on monetary policy.

When we again calibrate to remove the international production network (see figure A-9 in the Appendix), we find that the impact is to substantially lower the positive price effect in most eurozone countries, and reduces the negative price effect in the rest of the world. Intuitively, since the fiscal spillovers in the zero lower bound represents a magnification of the direct effect through real interest rates falling, when the direct effect is reduced, the impact on national inflation rates is reduced considerably, reducing the real interest rate channel, and hence reducing the magnitude of the Eurozone real exchange rate depreciation.

5.4.1 Further Discussion

Over the past two decades, nominal interest rates in many advanced economies face an effective lower bound. In the baseline calibration, we assume that only the Eurozone faces a binding constraint on its nominal interest rate in some periods. As an alternative, we consider nominal interest rates in both the Eurozone and the rest of the world are constrained by an effective lower bound in some periods. The results show that fiscal spillovers are quite similar to the baseline case. The reason is that bonds denominated in euro are traded internationally, and therefore when nominal interest rate in the Eurozone

is constrained, fiscal spending in the euro may have larger effect on the world economy.[21]

Do fiscal spending shocks in other large economies in the Eurozone generate similar fiscal spillovers across borders? Does international production network still facilitate fiscal spillovers across borders? Appendix G presents output response and the three-effect decomposition of output response to one percent of GDP increase in either French or Italian government spending. Results show that fiscal spillovers are usually smaller in these two economies than Germany since they are smaller in terms of GDP. Again, when monetary policy is constrained, fiscal policy has a larger spillover to other economies. Shutting down international production network will significantly reduce fiscal spillovers, particularly in large economies.

5.5 Time-Varying Input-Output Linkages

Figure A-5 in the Appendix shows that the countries in our sample increased the share of firm and consumer spending on imported goods after 2003. In the Appendix, we recalibrate the model based on the annual WIOT, and recalculate the implied fiscal multiplier and spillover for each year. Figure 6 shows the impact fiscal multiplier and spillover to German Government spending shocks $FM_{n1,c}$ when monetary authorities stabilize inflation. The own fiscal multiplier in Germany decreases since 2003 and temporarily reverts in 2009. The fiscal spillover varies only slightly across years in other countries. Figure 7 reports a similar pattern for large Eurozone countries and the rest of the world when the Eurozone economy faces an effective lower bound.

5.6 Distortionary Taxes

In the baseline model of the main text, we use a constant labor tax rate and a lump-sum tax to finance government consumption spending in each country. In Appendix F , we allow for time-varying labor income tax rate such that government spending is completely financed by this distortionary labor income tax. Appendix figure A-11 shows in this case that in response to a one percent of GDP increase in German government spending, the own fiscal multiplier becomes much lower than those under the constant labor income tax rate, while other countries have higher spillovers, particularly when the international production network is in place. The logic is that the higher tax rate required to finance

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[21]We also consider only the rest of world faces a lower bound for its nominal interest rate. Results show that fiscal spillovers decrease dramatically. Shutting down international production network further reduces fiscal spillovers.

German government spending depresses labor supply, while for other countries, the opposite applies, since the higher income from the positive fiscal spillover allows for a reduced labor income tax to finance existing government spending, and so the spillover effect is more expansionary. In the case with constrained nominal interest rates, the fiscal spillover with endogenous labor income taxes (shown in figure A-14) become significantly greater even than those outlined in Section 5.4 above. In both cases, however, we show that spillovers are greater with the international production network.

6   An empirical application of Sectoral Responses to Government Spending Shocks

So far we have only looked at aggregate responses to fiscal spending shocks. We now turn to more detailed sectoral responses, both domestic and cross-country. We conduct this exercise using the perspective of the fiscal response decomposition outlined above. Given this, the sectoral response will clearly depend on a) the sector which receives most of the government spending, and b) the linkages, both domestic and international, between these sectors and other sectors.

In this vein, we first explore which sectors a government spends on most and how these sectors are linked with other sectors in the rest of the economy. Figure A-10 in the appendix shows that the governments in the Eurozone and the rest of the world have a similar expenditure pattern. Overall government spending is highly concentrated in a small number of sectors. Three sectors constitute the bulk of government spending: sector 51 "Public administration and defence, compulsory social security", sector 52 "Education" and sector 53 "Human health and social work activities". Other sectors which receive significant but smaller shares are: sector 30 "Retail trade, except of motor vehicles and motorcycles", sector 47 "Scientific research and development" and sector 54 "Other service activities". These sectors in total account for a very large fraction of total government expenditures.

6.1   Sectoral Linkages of Fiscal Responses

We now develop an empirical strategy to explore the impacts of German fiscal shocks at the sectoral level. From the decomposition in equation (13), the growth of sectoral value added responding to government spending shocks in the model can also be decomposed into Direct, Income and Price effect as before, since aggregate value added is the sum of domestic sectoral value added. Growth of real value

added in country-sector nj in period t, $d\log Y_{nj,t}$, responding to a fiscal spending shock in country c alone, can be written as,

$$d\log Y_{nj,t} = \tilde{\omega}_{nj,c} d\log G_{c,t} + \sum_{k=1}^{K} \tilde{\mu}_{nj,k} d\log \tilde{C}_{k,t} + \sum_{k=1}^{K} \tilde{\omega}_{nj,k} d\log P^g_{k,t} + \sum_{k=1}^{K} \tilde{\mu}_{nj,k} d\log P^c_{k,t} - d\log W_{n,t}$$

The results of our calibrated model above suggest that all three effects should play a substantial role in the response of aggregate GDP to fiscal spending shocks. In this section, we focus on the sectoral responses in order to explore how the Direct, Income and Price effect affect sectoral value-added both in the model and data. We specify the relationship as follows

$$\Delta y_{nj,t} = \beta_0 + \beta_D \text{Direct}_{nj,t} + \beta_I \text{Income}_{nj,t} + \beta_P \text{Price}_{nj,t} + \gamma Z_{nj,t} + u_{nj,t} \tag{14}$$

where $\Delta y_{nj,t}$ is the growth of sectoral real value added, $\text{Direct}_{nj,t}$ is a measure for the Direct effect $\tilde{\omega}_{nj,c} d\log G_{c,t}$, $\text{Income}_{nj,t}$ for the Income effect $\sum_{k=1}^{K} \tilde{\mu}_{nj,k} d\log \tilde{C}_{k,t}$, and $\text{Price}_{nj,t}$ for the Price effect $\sum_{k=1}^{K} \tilde{\omega}_{nj,k} d\log P^g_{k,t} + \sum_{k=1}^{K} \tilde{\mu}_{nj,k} d\log P^c_{k,t} - d\log W_{n,t}$. In addition $Z_{nj,t}$ includes other control variables, while $u_{nj,t}$ is an error term. From the decomposition in equation (13), when we have exact measures of these three effects, given fiscal spending shocks alone, the coefficients based on simulated data in our model should be $\beta_D = \beta_I = \beta_P = 1$, and $\beta_0 = \gamma = 0$. Nevertheless, allowing for specification errors, sectoral value-added in the data could be driven by other factors, such as non-fiscal related demand shocks, and productivity shocks, and in addition, we may also face measurement errors since we usually don't have exact measures for all of these three effects in the data.

In order to explore how the three-effect decomposition of sectoral value-added matters in the data, we use the method as in the model to construct variables in the data in specification (14). Due to data limitations, we focus on the 11 Eurozone economies in the empirical analysis. First, the direct effect can be obtained from the Eurozone data directly. We follow the approach of Blanchard and Perotti (2002) and also Ramey and Zubairy (2018), and use quarterly data to estimate government expenditure shocks in Germany. We then aggregate the shocks to the annual frequency $d\log G_{k,t}$, since the WIOD data is annual, and construct the direct effect by $\tilde{\omega}_{nj,c,t-1} d\log G_{c,t}$ in the data. Second, we treat real consumption growth in the 11 Eurozone economies as $d\log \tilde{C}_{k,t}$, for $k = 1, \cdots, K-1$, and then construct $\sum_{k=1}^{K-1} \tilde{\mu}_{nj,k} d\log \tilde{C}_{k,t}$ as a measure of the Income effect. Third, we use the consumer

price index, government consumption price index and labor cost index in the Eurozone to construct $\sum_{k=1}^{K-1} \tilde{\omega}_{nj,k} d \log P_{k,t}^g + \sum_{k=1}^{K-1} \tilde{\mu}_{nj,k} d \log P_{k,t}^c - d \log W_{n,t}$ as a measure of the price effect.[22] Note that variables in the rest of the world are not included in the analysis due to data limitations and all of these omitted terms will show up in the error term in specification (14).

Other control variables include a time trend and macroeconomic variables such as current account to GDP ratio, and real effective exchange rate to capture the time variation of macroeconomies and external dynamics of countries, and also country and sector fixed effects to control for country and sector heterogeneities. The details of data source and variable construction are relegated to Appendix D.

Table 2 shows the regression results. The first column shows that after controlling for a quadratic time trend and country sector fixed effects, the coefficient for the Direct effect is significantly positive when taking into account of country-sector value-added as weight. Column (2) then includes the Income and Price effect to the empirical specification and results show that coefficients for these three effects are significantly positive and moreover they are all around one. A rise in fiscal spending through the direct effect leads to higher sectoral value-added in the Eurozone on average. Sectoral value-added in the data may be driven by non-fiscal policy demand side shocks and supply side shocks as well. In order to control for these factors, we use the current account to GDP ratio and real effective exchange rate to capture country-time heterogeneities. Column (3) shows that after controlling for additional macroeconomic variables, the coefficients for these three effects change slightly and are still around one, while the adjusted R-squared increases a lot. The last three columns present the unweighted regressions as a robustness check. Results are quite similar to the weighted regressions. We also consider French and Italian government spending shocks in Appendix G, and find that the coefficients for the three effects in the decomposition are quite similar to the results in table 2. The main takeaway is that our decomposition are helpful to understand the fiscal multiplier and spillovers both from an aggregate and sectoral perspective.

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[22]There are some other measures, for instance Acemoglu, Akcigit and Kerr (2015) who constructed measures for upstreamness and downstreamness based on input linkages to capture how fiscal shocks are propagated through a production network. But these measures are reduced form and don't have structural interpretation within the context of our model.

Table 2: Government spending in Germany and sectoral value added in the Eurozone

Variables	(1) Weighted	(2) Weighted	(3) Weighted	(4) Unweighted	(5) Unweighted	(6) Unweighted
Direct	2.810***	2.421***	1.487***	6.853***	6.019***	4.313***
	(5.331)	(9.841)	(6.795)	(7.188)	(6.387)	(4.796)
Income		1.392***	1.830***		1.059***	1.231***
		(13.628)	(19.543)		(11.925)	(14.271)
Price		0.457***	0.602***		-0.130*	0.193***
		(5.721)	(8.530)		(-1.737)	(2.668)
CA-GDP			0.144***			0.260***
			(2.666)			(4.378)
REER			-1.884***			-1.668***
			(-40.940)			(-25.064)
Year	-0.034***	-0.027***	-0.005***	-0.043***	-0.035***	-0.018***
	(-14.704)	(-17.171)	(-3.466)	(-21.886)	(-17.278)	(-8.078)
Year^2	0.002***	0.002***	0.000	0.003***	0.002***	0.001***
	(11.032)	(12.948)	(0.122)	(17.102)	(14.263)	(5.450)
Constant	0.131***	0.100***	0.034***	0.144***	0.107***	0.057***
	(8.342)	(9.525)	(3.531)	(12.204)	(8.955)	(4.754)
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Observations	5,929	5,929	5,929	5,929	5,929	5,929
Adjusted R-squared	0.175	0.201	0.380	0.145	0.170	0.250

Notes: This table presents regression results for specification (14) when the shock origin country is Germany. Direct, Income and Price are for the direct effect, income effect and price effect. Year and Year^2 control for a quadratic time trend. CA-GDP is the ratio of current account and GDP, and REER is real effective exchange rate. Column (1)-(3) report results in weighted regressions using sectoral value-added as weight, and column (4)-(6) report results with equal weight. Robust t-statistics in parentheses, with $* * * \, p < 0.01$, $* * \, p < 0.05$, $* \, p < 0.1$.

7 Conclusion

This paper analyzes the impact of fiscal shocks on domestic and foreign productions in a world economy with production network. Using a multi-country multi-sector world economy setting, we first decompose real GDP growth responding to fiscal spending shocks into three effects: direct effect, income effect, and price effect. The direct effect is always nonnegative responding to an expansionary fiscal spending. Price effect reflects network adjusted exchange rate movements and works oppositely for different countries. Income effect depends on both the intratemporal Keynesian consumption adjustment and intertemporal consumption adjustment. The world real GDP growth responding to fiscal spending shocks only depends on the direct and income effect. In another word, fiscal spending is a "beggar-thy-neighbor" policy in the perspective of network adjusted exchange rate movements. International production network affects fiscal spillovers through these effects. Shutting down international trade in intermediate inputs will significantly reduce fiscal spillovers across borders and the global GDP response.

We then explore factors that determine fiscal spillovers in our theoretical framework with alternative monetary policy rules, nominal wage stickiness, international capital mobility, and also international production network. Our model is calibrated by using the World Input Output Database (WIOD) for the Eurozone countries over the period of 2000-2014 and considers German and other large Eurozone economies' government expenditure shocks. In models with using standard Taylor rules or targeting nominal consumption expenditures, the direct effect contributes to around one third of output response to fiscal spending shocks in most of economies. Shutting down international production network significantly reduce fiscal spillovers through the direct effect. The traditional Keynesian adjustment through nominal wage rigidities and constrained response of policy rate mainly work through the income effect. Our analysis shows that certain monetary policy rules such as nominal expenditure targeting and constrained response of interest rate could generate sizable fiscal spillovers across borders.

We finally explore the diffusion of fiscal shocks at the sectoral level, both within and across countries. We measure German and other Eurozone large economies' fiscal policy shocks using the SVAR identification procedure of Blanchard and Perotti (2002), and take our model to the data. Results indicate that our decomposition of three effects are also relevant in the data and sectoral production linkages are helpful to understand fiscal spillovers.

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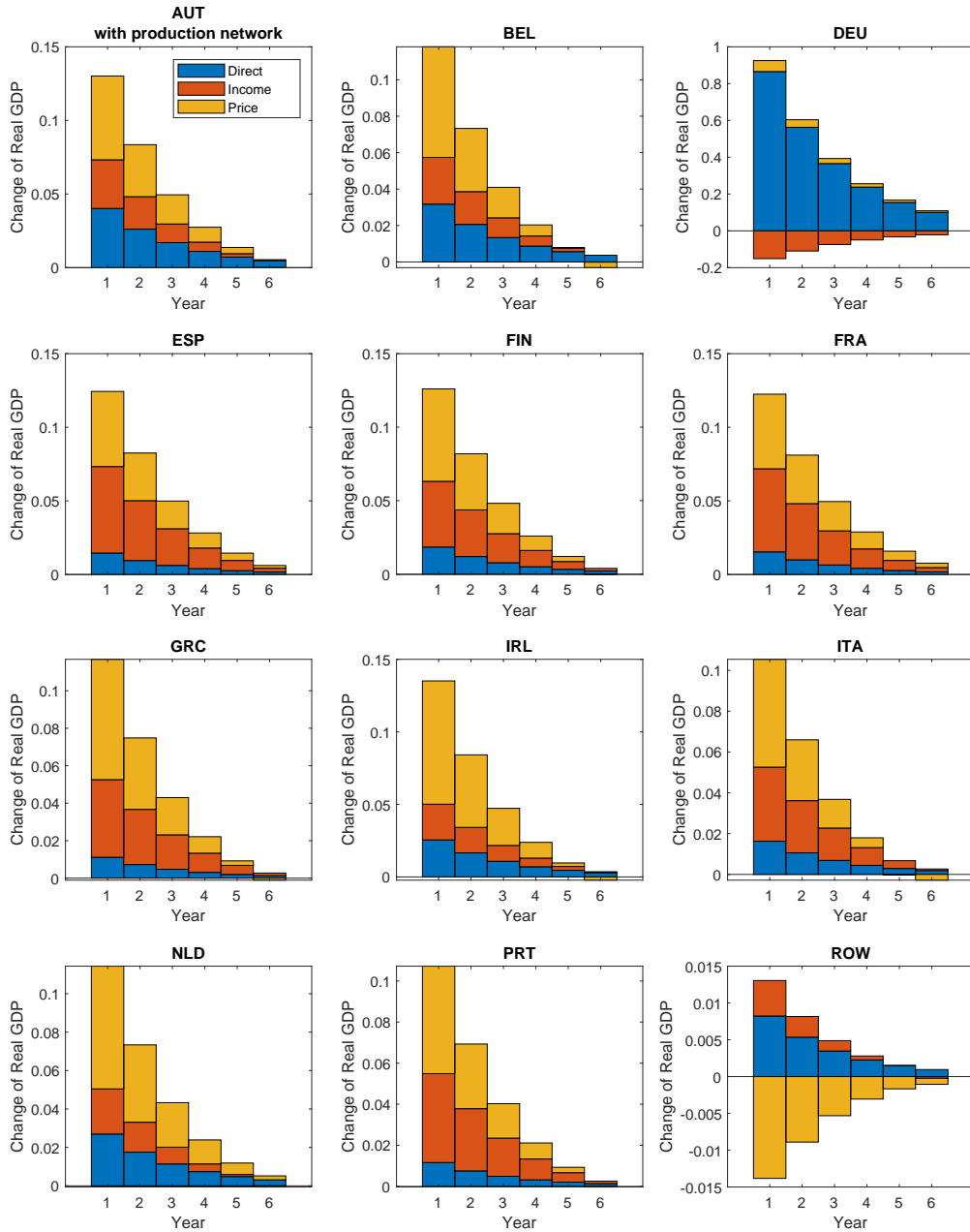
Figure 1: Output responses from a one-percent of GDP increase in German Government spending when nominal wages are fully sticky in national currency. The world economy consists of 11 Eurozone countries and the rest of the world. Monetary authorities target nominal consumption expenditure, $M^{ez} = \sum_{k=1}^{K-1} P_{k,t} C_{k,t}$ in the monetary union and $M^{row} = P_{K,t}^* C_{K,t}$ in the rest of the world. There is no intertemporal adjustment via international borrowing or lending. The total effect of a fiscal spending can be decomposed into three parts: direct effect, income effect and price effect.
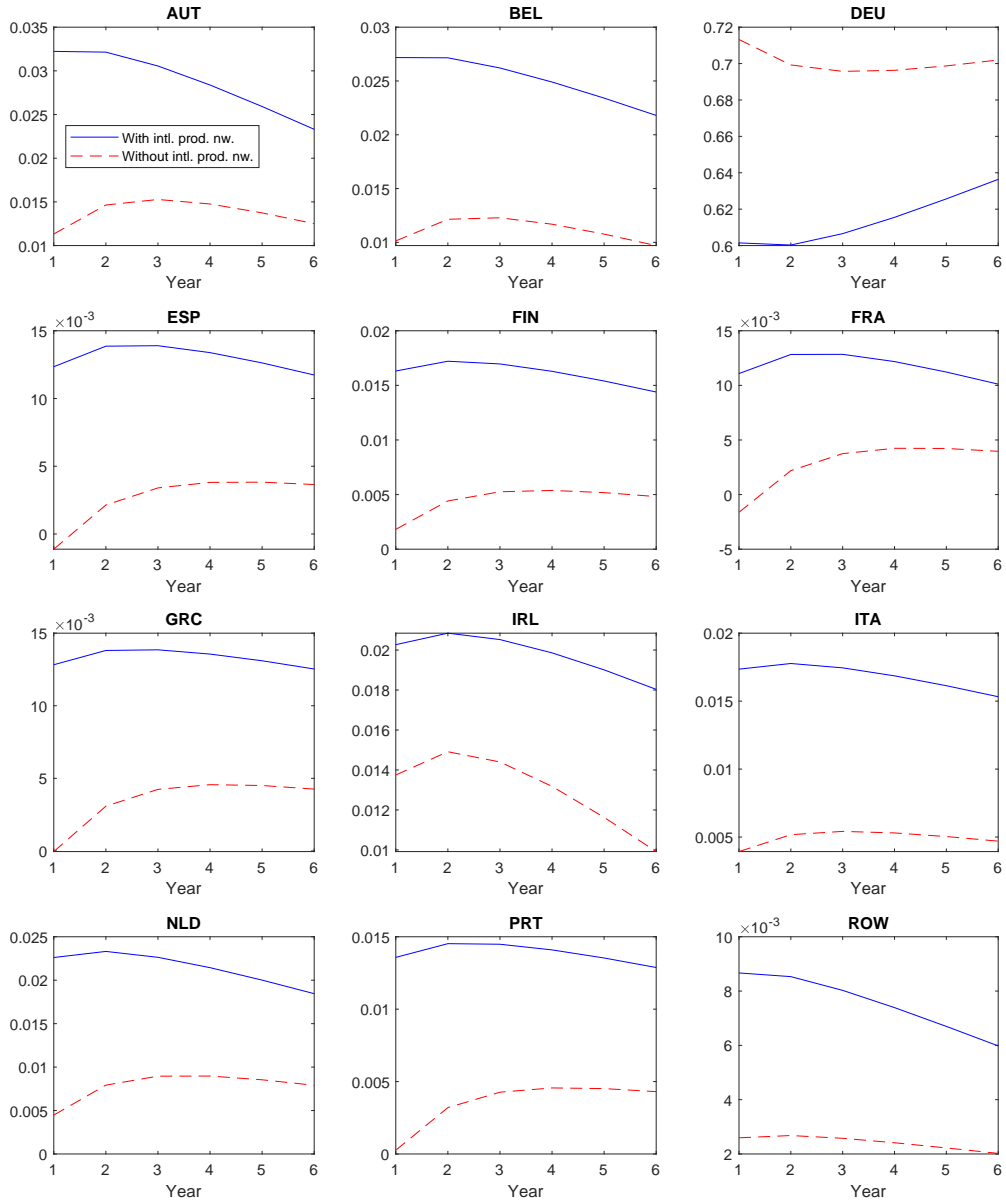
Figure 2: Cumulative responses of real GDP to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation.
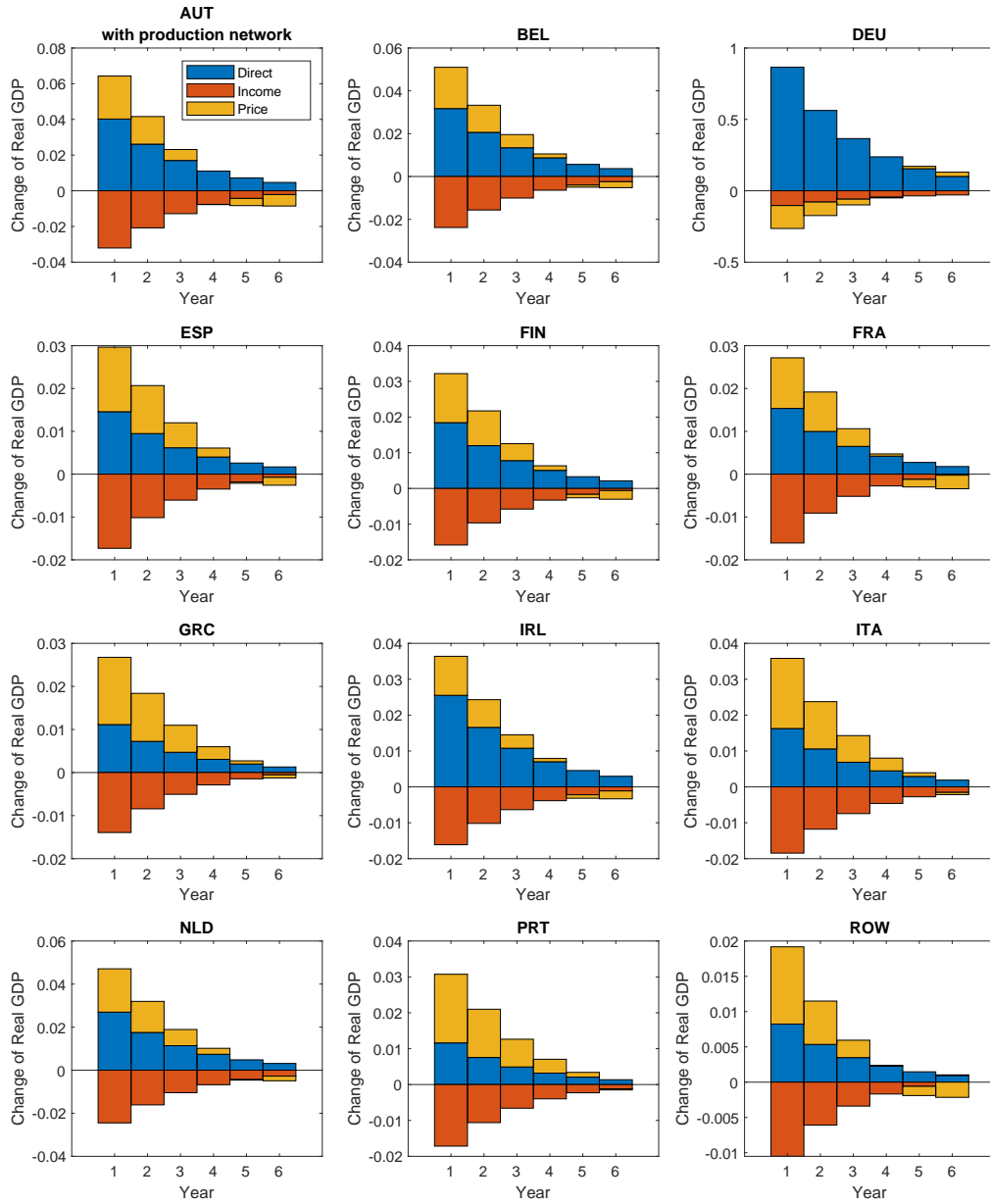
Figure 3: The Direct effect, Income effect and Price effect of the response of real GDP to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation.
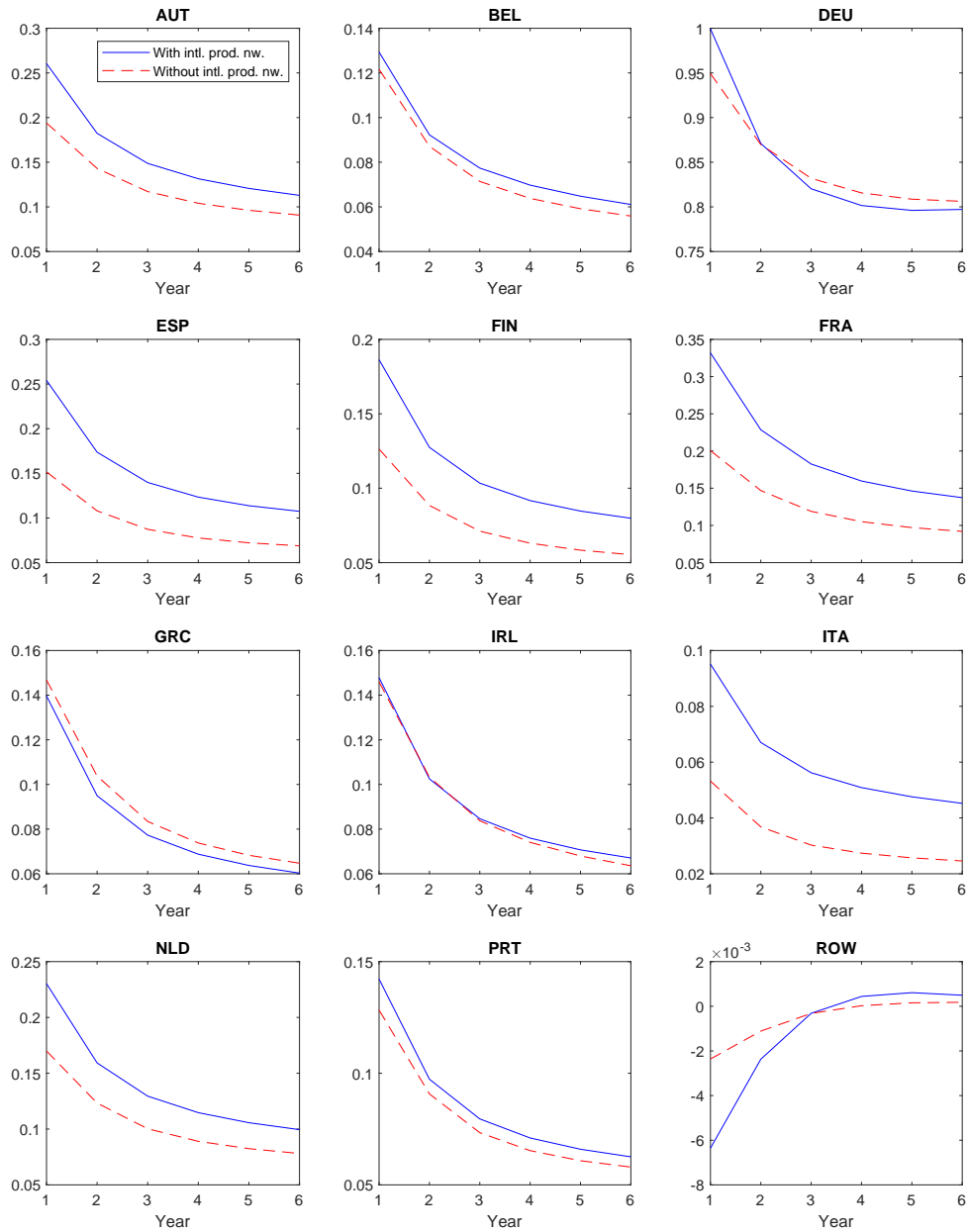
Figure 4: Cumulative responses of real GDP to a one-percent of GDP increase in German Government spending when nominal interest rate in the Eurozone is constrained in period 1 and 2.
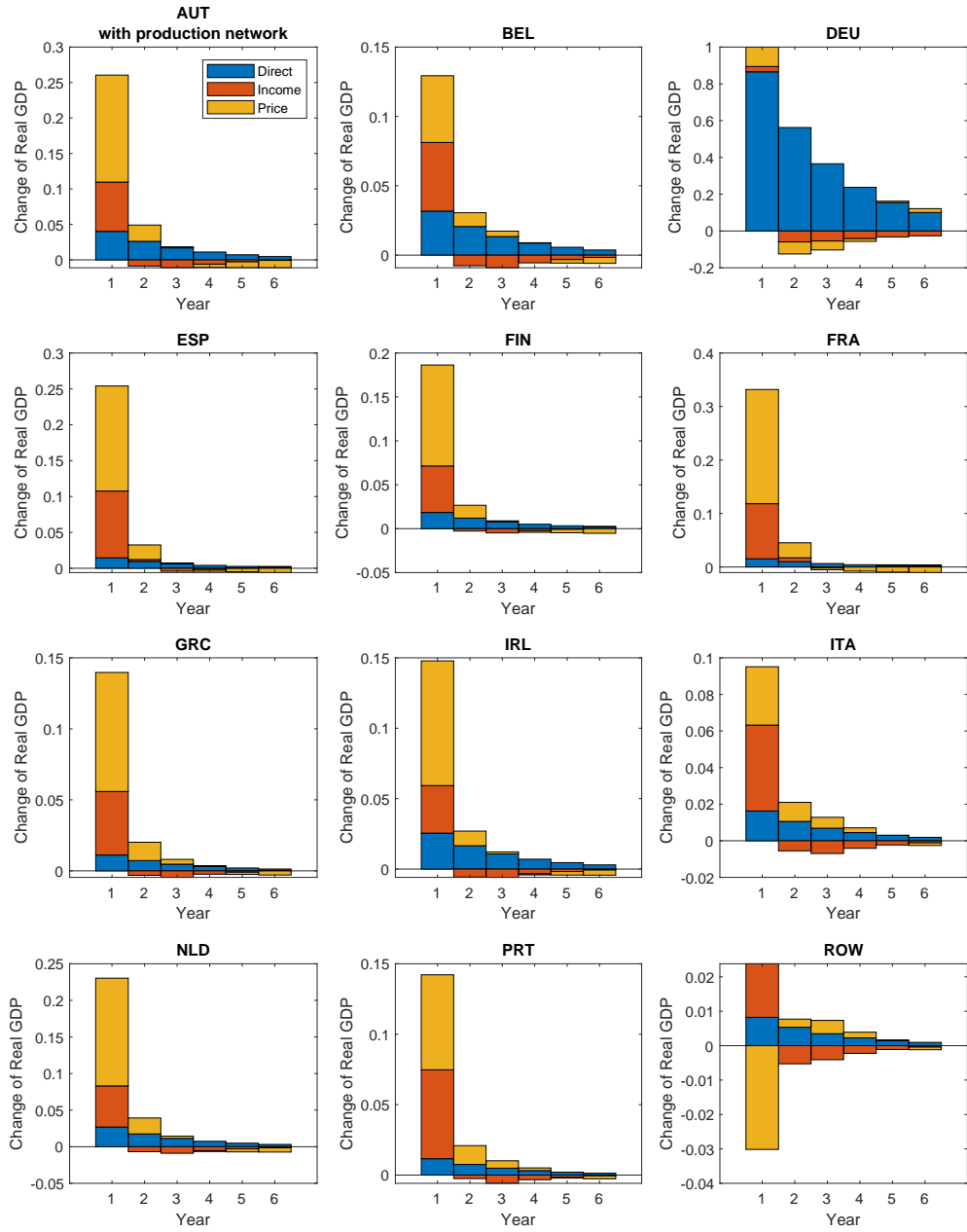
Figure 5: The Direct, Price and Income effect of the response of real GDP to a one-percent of GDP increase in German Government spending when nominal interest rate in the Eurozone is constrained in period 1 and 2.
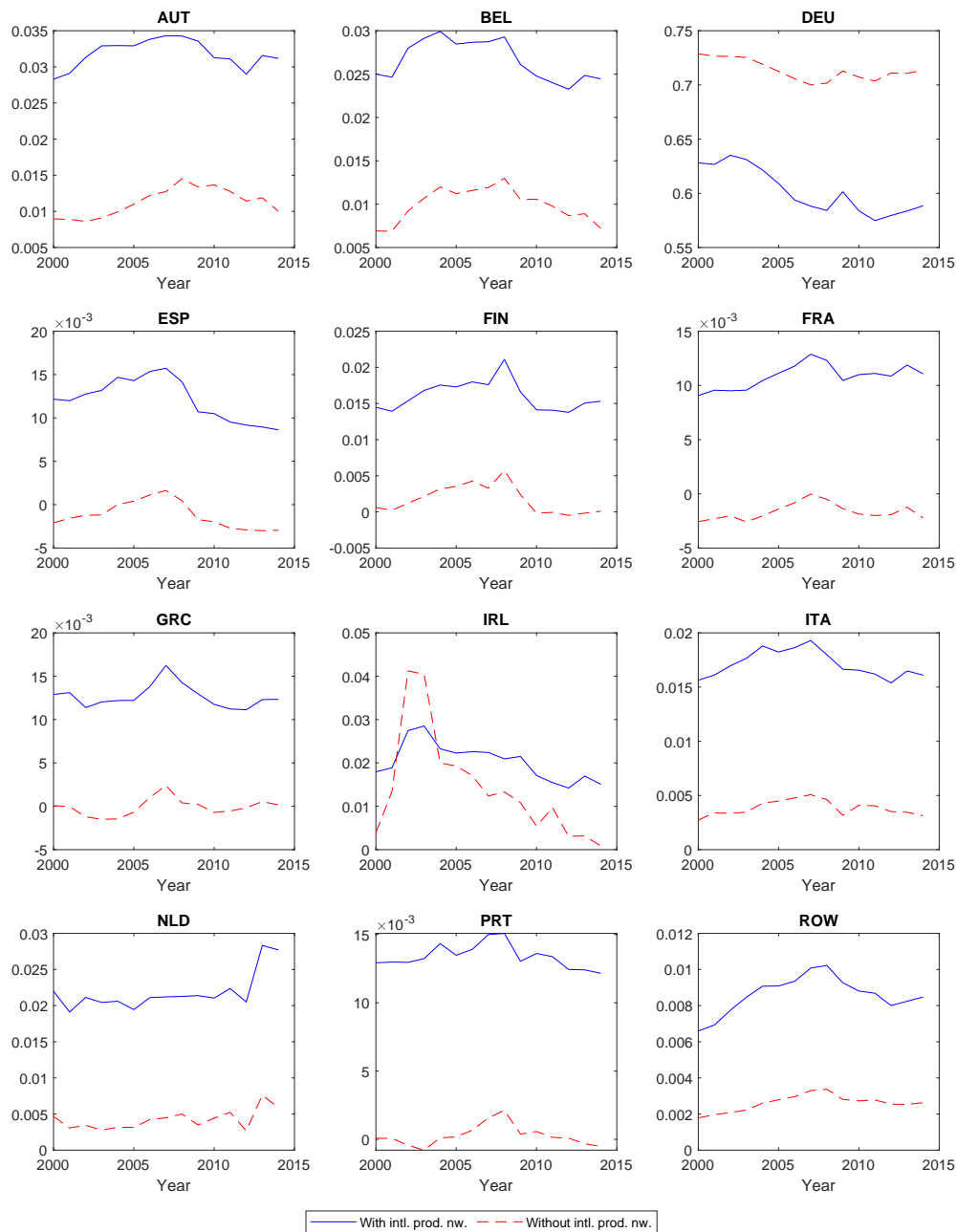
Figure 6: The on impact fiscal multiplier and spillover to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation. We recalibrate production network, consumption and government spending share and labor income share for each year.
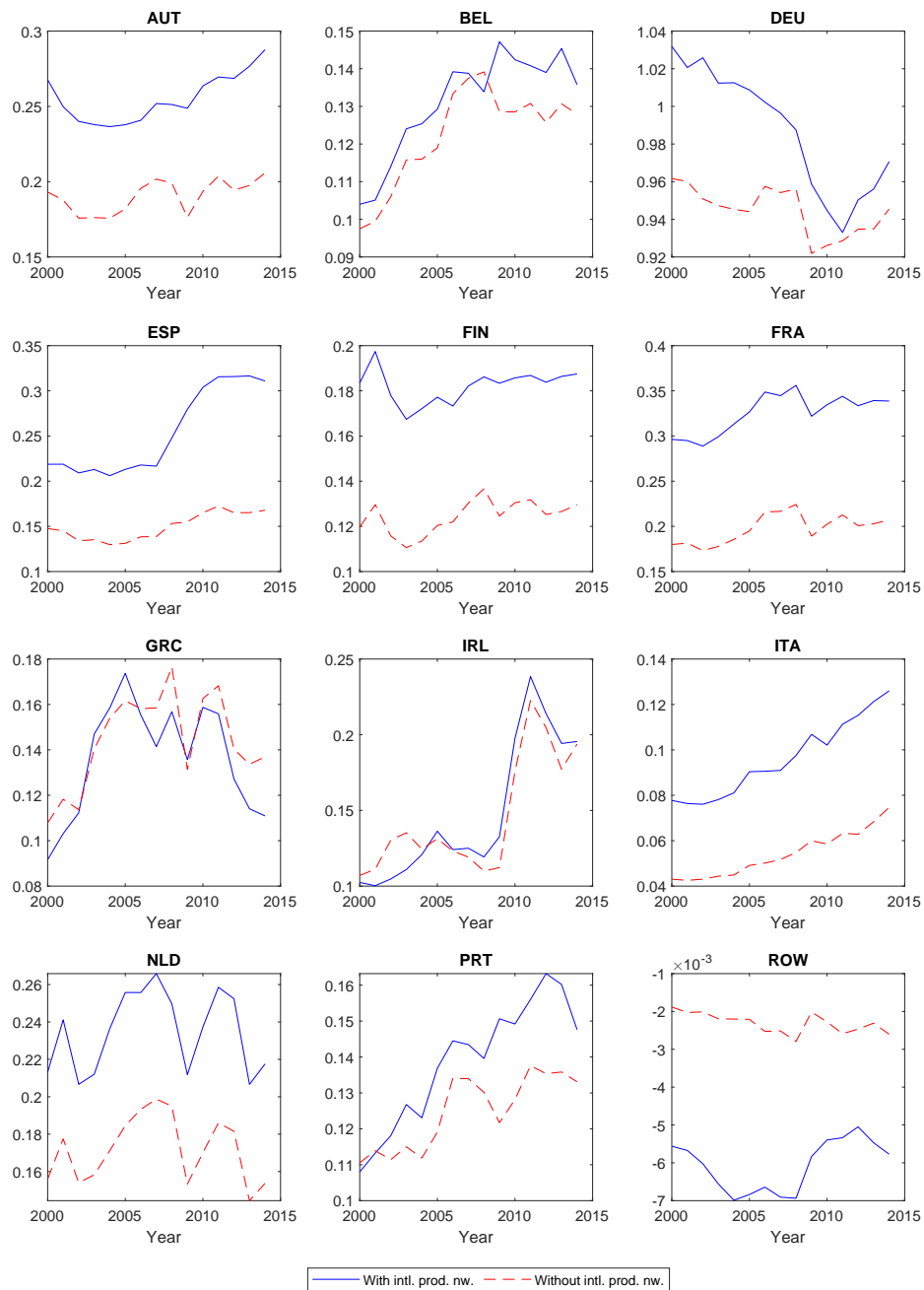
Figure 7: The on impact response of real GDP to a one-percent of GDP increase in German Government spending when nominal interest rate in the Eurozone is constrained for two consecutive periods, while the rest of the world stabilizes its own CPI inflation. We recalibrate production network, consumption and government spending share and labor income share for each year.
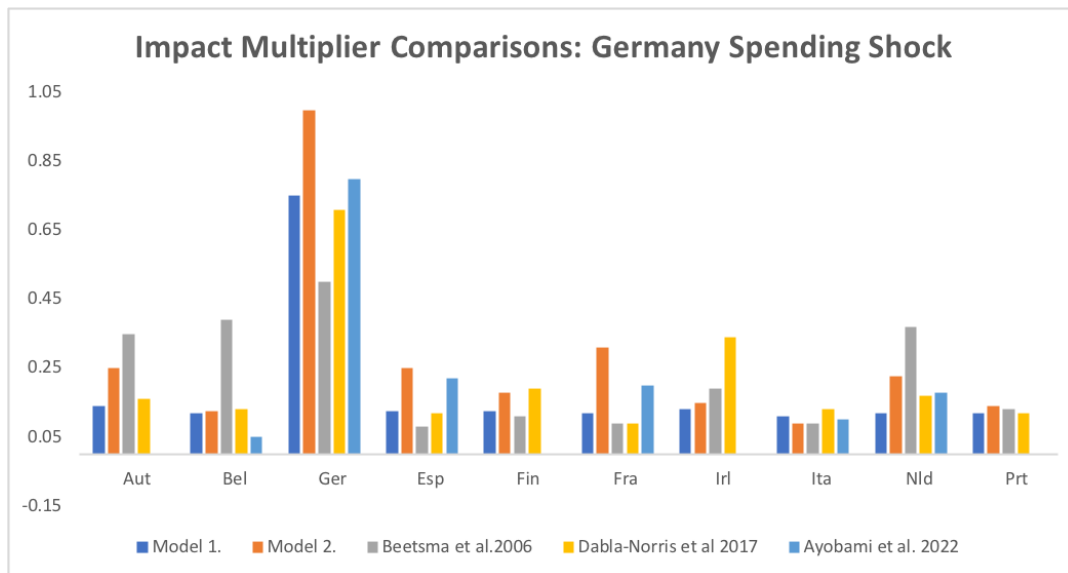
Figure 8: Comparison of Impact Multiplier of German Spending Shock of 1 percent of GDP in static model (Model 1) and model with constrained nominal interest rate (Model 2) with empirical estimates from the literature.

Not For Publication Technical Appendix

A   The System of Competitive Equilibrium in the Dynamic World Economy

The system of equilibrium conditions consists of the following blocks for all sectors $j = 1, 2, \cdots, N$ and all countries $n = 1, 2, \cdots, K$:

The block of production

$$P_{nj,t} = \left(\frac{W_{n,t}}{1 - \alpha_{nj}} \right)^{1 - \alpha_{nj}} \left(\frac{P_{nj,t}^m}{\alpha_{nj}} \right)^{\alpha_{nj}}$$

$$P_{nj,t}^m = \Pi_{m=1}^{K} \Pi_{i=1}^{N} \left(\frac{P_{mi,t}}{\omega_{mi,nj}} \right)^{\omega_{mi,nj}}$$

$$W_{n,t} L_{nj,t} = (1 - \alpha_{nj}) P_{nj,t} X_{nj,t}$$

$$M_{mi,nj,t} P_{mi,t} = \omega_{mi,nj} P_{nj,t}^m M_{nj,t} = \alpha_{nj} \omega_{mi,nj} P_{nj,t} X_{nj,t}$$

The block of households' consumption and saving

$$P_{mi,t} C_{mi,n,t} = \beta_{mi,n} P_{n,t}^c C_{n,t}$$

$$P_{n,t}^c = \Pi_{m=1}^{K} \Pi_{i=1}^{N} \left(\frac{P_{mi,t}}{\beta_{mi,n}} \right)^{\beta_{mi,n}}$$

$$(1 - \tau_n^c) \frac{W_{n,t}^c}{P_{n,t}^c} = \frac{V'(L_{n,t}^c)}{U'(C_{n,t})}$$

$$U'(C_{n,t}) = \mathbb{E}_t \xi U'(C_{n,t+1}) \frac{R_{n,t+1}}{\pi_{n,t+1}^c}$$

$$\frac{1}{R_{n,t+1}} \equiv \frac{1}{R_{t+1}} + \psi_n^b \left(\frac{B_{n,t+1}}{P_{n,t}^c} - b_n \right)$$

$$U'(C_{K,t}) = \mathbb{E}_t \xi U'(C_{K,t+1}) \frac{R_{t+1}^*}{\pi_{K,t+1}^{c*}}$$

$$P_{n,t}^y Y_{n,t} \equiv P_{n,t}^c \tilde{C}_{n,t} + P_{n,t}^g G_{n,t} + \frac{B_{n,t+1}}{R_{t+1}} - B_{n,t} = W_{n,t} L_{n,t}$$

$$\tilde{C}_{n,t} \equiv C_{n,t} + \frac{1}{2} \psi_n^b \left(\frac{B_{n,t+1}}{P_{n,t}^c} - b_n \right)^2 + \frac{\psi_n^w}{2} \left(\pi_{n,t}^w - \pi_n^w \right)^2 \frac{W_{n,t}}{P_{n,t}^c}$$

$$\pi_{K,t+1}^c \equiv \pi_{K,t+1}^{c*} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}, \; W_{K,t} \equiv W_{K,t}^* \mathcal{E}_t$$

Trade balance reads $\text{TB}_{n,t} = \frac{B_{n,t+1}}{R_{t+1}} - B_{n,t}$. Net foreign asset position can be written as $\text{NFA}_{n,t+1} \equiv \frac{B_{n,t+1}}{R_{t+1}}$, and the change of net foreign asset position reads $\Delta \text{NFA}_{n,t+1} = \frac{B_{n,t+1}}{R_{t+1}} - \frac{B_{n,t}}{R_t} = \frac{B_{n,t+1}}{R_{t+1}} - B_{n,t} + B_{n,t}\left(1 - \frac{1}{R_t}\right) = \text{CA}_t$, where CA_t denotes current account.

The block of labor supply

$$L_{n,t}^c = L_{n,t}$$

$$L_{n,t}\theta_n\left(w_{n,t}^r - \chi_n\right) - \psi_n^w \pi_{n,t}^w(\pi_{n,t}^w - \pi_n^w) + \mathbb{E}_{n,t}\left[\Lambda_{n,t,t+1}\psi_n^w \frac{\pi_{n,t+1}^w}{\pi_{n,t+1}^c}\pi_{n,t+1}^w(\pi_{n,t+1}^w - \pi_n^w)\right] = 0, \text{ for } n = 1, \cdots, K-1$$

$$L_{K,t}\theta_K\left(w_{K,t}^r - \chi_K\right) - \psi_K^w \pi_{K,t}^{w*}(\pi_{K,t}^{w*} - \pi_K^{w*}) + \mathbb{E}_{K,t}\left[\Lambda_{K,t,t+1}\psi_K^w \frac{\pi_{K,t+1}^{w*}}{\pi_{K,t+1}^{c*}}\pi_{K,t+1}^{w*}(\pi_{K,t+1}^{w*} - \pi_K^{w*})\right] = 0$$

$$w_{n,t}^r \equiv \frac{W_{n,t}^c}{W_{n,t}}$$

The block of fiscal and monetary policies

$$\frac{R_{t+1}}{R} = \left(\Pi_{n=1}^K \left(\frac{\pi_{n,t}^c}{\pi_n^c}\right)^{\rho_n}\right)^{(1-\rho_r)\rho_\pi} \left(\frac{R_t}{R}\right)^{\rho_r}$$

$$\frac{R_{t+1}^*}{R^*} = \left(\frac{\pi_{K,t}^{c*}}{\pi_K^{c*}}\right)^{(1-\rho_r)\rho_\pi} \left(\frac{R_t^*}{R^*}\right)^{\rho_r}$$

$$P_{mi,t}G_{mi,n,t} = \gamma_{mi,n}P_{n,t}^g G_{n,t}$$

$$P_{n,t}^g = \Pi_{m=1}^K \Pi_{i=1}^N \left(\frac{P_{mi,t}}{\gamma_{mi,n}}\right)^{\gamma_{mi,n}}$$

The block of market clearing conditions

$$L_{n,t} = \sum_{j=1}^N L_{n,j,t}$$

$$X_{nj,t} = \sum_{m=1}^K \tilde{C}_{nj,m,t} + \sum_{m=1}^K G_{nj,m,t} + \sum_{m=1}^K \sum_{i=1}^N M_{nj,mi,t}$$

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$$\sum_{n=1}^{K} B_{n,t+1} = 0, \ B_{t+1}^* = 0$$

The block of exogenous shocks

$$\log\left(\frac{G_{n,t+1}}{\bar{G}_n}\right) = \rho_g \log\left(\frac{G_{n,t}}{\bar{G}_n}\right) + \epsilon_{n,t+1}, \ \text{with} \epsilon_{n,t+1} \sim N(0, \sigma_g^2)$$

One of equations above is redundant according to the Walrus' law.

We can write the equilibrium conditions above in a vector form. First, we choose $W_{1,t} = 1$ as a numeraire. Dividing nominal variables in period t by $W_{1,t}$ yields the corresponding real variables. In the following part, a variable without country index denotes the corresponding vector for that variable in all economies. Note that given nominal wages $W_t = [W_{1,t}, W_{2,t}, \cdots, W_{K,t}]'$, sectoral prices can be written as in a vector form

$$\log \underbrace{P_t^I}_{KN \times 1} = (\log W_t \otimes e_N) \circ (1 - \alpha) + \Omega' \log P_t^I - \text{Const}^m$$

with $\text{Const}^m = (1 - \alpha) \circ \log(1 - \alpha) + \alpha \circ \log \alpha + \alpha \circ [(\Omega_0 \circ \log(\Omega_0))' e_{KN}]$, and $\Omega_0 = [\omega_{mj,ni}]$ with $\sum_{m=1}^{K} \sum_{j=1}^{N} \omega_{mj,ni} = 1$. $\circ$ denotes element wise product (Hadamard product) and $\otimes$ denotes Kronecker product. Re-organizing the equation above, express sectoral prices as a function of nominal wages

$$\log P_t^I = \left(\mathbb{I} - \Omega'\right)^{-1} [(\log W_t \otimes e_N) \circ (1 - \alpha) - \text{Const}^m]$$

$$\underbrace{\log P_t^g}_{K \times 1} = \gamma' \log P_t^I - \text{Const}^g$$

$$\underbrace{\log P_t^c}_{K \times 1} = \beta' \log P_t^I - \text{Const}^c$$

with $\text{Const}^g = (\gamma \circ \log \gamma)' e_{KN}$, $\text{Const}^c = (\beta \circ \log \beta)' e_{KN}$.

From households labor supply, the log version yields,

$$\underbrace{\log C_t}_{K \times 1} = \frac{1}{\sigma} [\log(1 - \tau^c) + \log W_t^c - \log P_t^c - \eta \log L_t]$$

Households nominal consumption spending is defined as $\log S_t^C = \log P_t^c + \log \tilde{C}_t$, and government spend-

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ing $\log S_t^G = \log P_t^g + \log G_t$. Substituting these expressions into product market clearing conditions, yields

$$\underbrace{S_t^I}_{KN\times 1} = \underbrace{(\mathbb{I} - \Omega)^{-1}}_{KN\times KN} \left(\underbrace{\beta}_{KN\times K} \underbrace{S_t^C}_{K\times 1} + \underbrace{\gamma}_{KN\times K} \underbrace{S_t^G}_{K\times 1} \right)$$

Firms labor demand becomes

$$\log \underbrace{L_t^I}_{KN\times 1} = \log(1-\alpha) + \log S_t^I - (\log W_t \otimes e_N)$$

Aggregate labor $L_t = [L_{n,t}] = D^K L_t^I$, where D^K is a block matrix given by

$$\underbrace{D^K}_{K\times KN} = \begin{bmatrix} e_N' & 0 & \cdots & 0 \\ 0 & e_N' & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & e_N' \end{bmatrix} = \mathbb{I}_K \otimes e_N'$$

The Euler equations for optimal bond holdings can be written as

$$C_t^{-\sigma} = \mathbb{E}_{n,t} \xi C_{t+1}^{-\sigma} \circ R_{t+1}^b \circ /\pi_{t+1}^c$$

where the effective nominal return vector $R_{t+1}^b \equiv [R_{n,t+1}]$.

Country resource constraint can be written as

$$\frac{P_{n,t}^c}{W_{1,t}} \tilde{C}_{n,t} + \frac{P_{n,t}^g}{W_{1,t}} G_{n,t} + \frac{B_{n,t+1}}{W_{1,t}} \frac{1}{R_{t+1}} - \frac{B_{n,t}}{W_{1,t-1}} \frac{1}{\pi_{1,t}^w} = \frac{W_{n,t} L_{n,t}}{W_{1,t}}$$

or in a vector form

$$P_t^c \circ \tilde{C}_t + P_t^g \circ G_t + B_{t+1} \frac{1}{R_{t+1}} - B_t \frac{1}{\pi_{1,t}^w} = W_t \circ L_t$$

Relative real wage

$$\log W_t^c = \log w_t^r + \log W_t$$

Monetary policy

$$\log R_{t+1} = \rho_r \log R_t + (1-\rho_r)\rho_\pi \left(\sum_{n=1}^K \rho_n \log \pi_{n,t}^c \right) + \text{Const}^r$$

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$$\log R^*_{t+1} = \rho_r \log R^*_t + (1 - \rho_r)\rho_\pi \pi^{c*}_{K,t} + \text{Const}^{r*}$$

with $\text{Const}^r = (1 - \rho_r)\log R - (1 - \rho_r)\rho_\pi \left(\sum_{n=1}^K \rho_n \log \pi^c_n\right)$, and $\text{Const}^{r*} = (1 - \rho_r)\log R^* - (1 - \rho_r)\rho_\pi \log \pi^{c*}_K$.

Price and wage inflation can be expressed as a function of nominal wages and prices and wage inflation for country $n = 1$, $\pi^w_{1,t}$,

$$\pi^c_{n,t} \equiv \frac{P^c_{n,t}}{P^c_{n,t-1}} = \frac{P^c_{n,t}/W_{1,t}}{P^c_{n,t-1}/W_{1,t-1}}\pi^w_{1,t}, \ \pi^{c*}_{K,t} \equiv \frac{P^{c*}_{K,t}}{P^{c*}_{K,t-1}} = \pi^c_{K,t}\frac{\mathcal{E}_{t-1}}{\mathcal{E}_t}$$

$$\pi^w_{n,t} \equiv \frac{W_{n,t}}{W_{n,t-1}} = \frac{W_{n,t}/W_{1,t}}{W_{n,t-1}/W_{1,t-1}}\pi^w_{1,t}, \ \pi^{w*}_{K,t} \equiv \frac{W^*_{K,t}}{W^*_{K,t-1}} = \pi^w_{K,t}\frac{\mathcal{E}_{t-1}}{\mathcal{E}_t}$$

Then the original equilibrium system can be simplified to a lower dimensional system with unknowns $W_t/W_{1,t}$, C_t, $B_{t+1}/W_{1,t}$, w^r_t, $\pi^w_{1,t}$, $\mathcal{E}_t/\mathcal{E}_{t-1}$, R_{t+1}, R^*_{t+1} given exogenous shocks G_t, endogenous state variables $B_t/W_{1,t-1}$, $P^c_{t-1}/W_{1,t-1}$, $W_{t-1}/W_{1,t-1}$, R_t and R^*_t. The constraints include consumption Euler equation to determine bond holdings B_{t+1} and B^*_{t+1}, households labor supply to determine consumption C_t, the optimal wage setting condition to determine labor cost W^c_t, country resource constraint to determine wage rate W_t (one constraint is redundant), bond market clearing condition to determine R_{t+1} and R^*_{t+1}, and monetary policy to determine inflation $\pi^w_{1,t}$ and change of nominal exchange rate $\mathcal{E}_t/\mathcal{E}_{t-1}$.

A.1 Proof of Result 2

From producers' labor demand, we have

$$L_{nj,t} = \frac{(1 - \alpha_{nj})P_{nj,t}X_{nj,t}}{W_{n,t}} = \frac{(1 - \alpha_{nj})P_{nj,t}X_{nj,t}}{\mathcal{M}_t}\frac{\mathcal{M}_t}{W_{n,t}}$$

where $\mathcal{M}_t = \sum_{k=1}^K P_{k,t}\tilde{C}_{k,t}$ represents the nominal value of total consumption across all countries, expressed in Euro.

Taking log on both sides, yields

$$\log L_{nj,t} = \log(1 - \alpha_{nj}) + \log\left(\frac{P_{nj,t}X_{nj,t}}{\mathcal{M}_t}\right) + \log\left(\frac{\mathcal{M}_t}{W_{n,t}}\right)$$

Substituting it into the expression of real value-added, yields,

$$d \log Y_{n,t} = \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d \log L_{nj,t} = \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d \log \left(\frac{P_{nj,t} X_{nj,t}}{\mathcal{M}_t} \right) - \sum_{j=1}^{N} \frac{L_{nj}}{L_n} d \log \left(\frac{W_{n,t}}{\mathcal{M}_t} \right) \qquad \text{(A.1)}$$

Substituting factor demand into the goods market clearing conditions (10), yields,

$$P_{nj,t} X_{nj,t} = \sum_{m=1}^{K} P_{nj,t} \tilde{C}_{nj,m,t} + \sum_{m=1}^{K} P_{nj,t} G_{nj,m,t} + \sum_{m=1}^{K} \sum_{i=1}^{N} P_{nj,t} M_{nj,mi,t}$$

$$= \sum_{m=1}^{K} \beta_{nj,m} P_{m,t}^{c} \tilde{C}_{m,t} + \sum_{m=1}^{K} \gamma_{nj,m} P_{m,t}^{g} G_{m,t} + \sum_{m=1}^{K} \sum_{i=1}^{N} \alpha_{mi} \omega_{nj,mi} P_{mi,t} X_{mi,t}$$

which can be written in a vector form[A-1],

$$\underbrace{S_t^I}_{KN \times 1} = \underbrace{(\mathbb{I} - \Omega)^{-1}}_{KN \times KN} \left(\underbrace{\beta}_{KN \times K} \underbrace{S_t^C}_{K \times 1} + \underbrace{\gamma}_{KN \times K} \underbrace{S_t^G}_{K \times 1} \right) \qquad \text{(A.2)}$$

The Leontief inverse reflects the direct and indirect impact through the production network of final demand for sectoral output,

$$\mathcal{L} = (\mathbb{I} - \Omega)^{-1} = \mathbb{I} + \Omega + \Omega^2 + \cdots$$

Let $\ell_{nj,mi}$ be the $njmi-$th element of $\mathcal{L}$. Dividing by $\mathcal{M}_t$ on both sides in the equation above, yields

$$\frac{P_{nj,t} X_{nj,t}}{\mathcal{M}_t} = \sum_{k=1}^{K} \frac{P_{k,t}^{c} \tilde{C}_{k,t}}{\mathcal{M}_t} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \beta_{mi,k} + \sum_{k=1}^{K} \frac{P_{k,t}^{g} G_{k,t}}{\mathcal{M}_t} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \gamma_{mi,k}$$

[A-1]Vectors and matrices in equation (A.2) are defined as

$$S_t^I = \begin{bmatrix} P_{1,t} X_{1,t} \\ P_{2,t} X_{2,t} \\ \vdots \\ P_{KN,t} X_{KN,t} \end{bmatrix}, S_t^C = \begin{bmatrix} P_{1,t}^{c} \tilde{C}_{1,t} \\ P_{2,t}^{c} \tilde{C}_{2,t} \\ \vdots \\ P_{K,t}^{c} \tilde{C}_{K,t} \end{bmatrix}, \quad S_t^G = \begin{bmatrix} P_{1,t}^{g} G_{1,t} \\ P_{2,t}^{g} G_{2,t} \\ \vdots \\ P_{K,t}^{g} G_{K,t} \end{bmatrix}, \beta = \begin{bmatrix} \beta_{11,1} & \cdots & \beta_{11,K} \\ \beta_{12,1} & \cdots & \beta_{12,K} \\ \vdots & \vdots & \vdots \\ \beta_{KN,1} & \cdots & \beta_{KN,K} \end{bmatrix}, \quad \alpha = \begin{bmatrix} \alpha_{11} \\ \alpha_{12} \\ \vdots \\ \alpha_{KN} \end{bmatrix}$$

$$\gamma = \begin{bmatrix} \gamma_{11,1} & \cdots & \gamma_{11,K} \\ \gamma_{12,1} & \cdots & \gamma_{12,K} \\ \vdots & \vdots & \vdots \\ \gamma_{KN,1} & \cdots & \gamma_{KN,K} \end{bmatrix}, \Omega_0 = \begin{bmatrix} \omega_{11,11} & \omega_{11,12} & \cdots & \omega_{11,KN} \\ \omega_{12,11} & \omega_{12,12} & \cdots & \omega_{12,KN} \\ \vdots & \vdots & \vdots & \vdots \\ \omega_{KN,11} & \omega_{KN,12} & \cdots & \omega_{KN,KN} \end{bmatrix}, \qquad \Omega = \Omega_0 \circ (e_{KN} \alpha^{'})$$

. e_{KN} is a column vector of length $K \times N$ and each element is one.

$$= \sum_{k=1}^{K} \nu_{k,t} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \beta_{mi,k} + \sum_{k=1}^{K} \frac{P_{k,t}^g G_{k,t}}{\mathcal{M}_t} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \gamma_{mi,k} \qquad (A.3)$$

where $\nu_{k,t} \equiv \frac{P_{k,t}^c \tilde{C}_{k,t}}{\mathcal{M}_t}$, denotes the consumption spending share of country k in the world economy, and $\sum_{k=1}^{K} \nu_{k,t} = 1$. Consumption spending shares may change due to two sources. One is from relative price movements, leading to unequal expenditure switching across borders and the other is from a wealth effect due to a lump-sum transfer which is used to finance fiscal spending. Let $\tilde{\omega}_{nj,k}$ be a weight of a government spending shock from country k to country-sector nj at the steady state,

$$\tilde{\omega}_{nj,k} \equiv \frac{P_k^g G_k}{P_{nj} X_{nj}} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \gamma_{mi,k} \geq 0$$

This weight captures the direct and indirect channel of government spending through the international production network. An increase in government spending in country k leads to higher demand for variety produced by sector i of country m when $\gamma_{mi,k} > 0$, which in turn drives up demand for intermediate input produced by its own sector and other sectors. The compound effect through the production network is captured by the Leontief inverse, with element $\ell_{nj,mi}$, and then summed across all sectors i and countries m.

Consumption share changes may affect sectoral gross output via the following weight

$$\tilde{\mu}_{nj,k} = \frac{P_k^c C_k}{P_{nj} X_{nj}} \sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \beta_{mi,k} \geq 0$$

Similarly to government spending, a rise in consumption share increase sectoral gross output through the international production network as well. Note also that $\sum_{k=1}^{K} (\tilde{\omega}_{nj,k} + \tilde{\mu}_{nj,k}) = 1$.

Taking a log differentiation on both sides of equation (A.3), yields

$$d \log \left(\frac{P_{nj,t} X_{nj,t}}{M_t} \right) = \sum_{k=1}^{K} \tilde{\mu}_{nj,k} d \log \nu_{k,t} + \sum_{k=1}^{K} \tilde{\omega}_{nj,k} d \log \left(\frac{P_{k,t}^g G_{k,t}}{M_t} \right)$$

Substituting the expression above into the aggregate real value-added in a country (A.1), yields the expression in Result 2.

A.2 Proof of Result 4

From the baseline decomposition in the dynamic model, we know that the "direct effect" of output response to fiscal spending shocks in country n can be rewritten as

$$\sum_{j=1}^{N} \frac{1 - \alpha_{nj}}{W_n L_n} \left[\sum_{k=1}^{K} P_k^g G_k \left(\sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \gamma_{mi,k} \right) d \log G_{k,t} \right]$$

$$= \sum_{j=1}^{N} (1 - \alpha_{nj}) \sum_{k=1}^{K} \frac{\nu_k}{\nu_n} \frac{g_k^c}{1 + g_n^c} \left(\sum_{m=1}^{K} \sum_{i=1}^{N} \ell_{nj,mi} \gamma_{mi,k} \right) d \log G_{k,t}$$

where $g_k^c \equiv \frac{P_k^g G_k}{P_k^c C_k}$, and then $\frac{P_k^g G_k}{W_k L_k} = \frac{\nu_k}{\nu_n} \frac{g_k^c}{1+g_n^c}$, $\frac{P_k^c C_k}{W_k L_k} = \frac{\nu_k}{\nu_n} \frac{1}{1+g_n^c}$. We can summarize factors that determine fiscal spillovers as below.

For a given government spending shock by country k, $d \log G_{k,t}$, the "direct effect" is larger when (a) the shock origin country is larger (higher $\frac{\nu_k}{\nu_n}$), (b) fiscal spending relative to consumption is larger (higher g_k^c), (c) higher trade intensity in intermediate inputs (larger off-diagonal elements of Leontiff inverse $\mathcal{L}$), and (d) higher government spending share (higher $\gamma_{mi,k}$).

A.3 Proof of Result 5

Note that price indices expressed in euro can be written as

$$\log P_{n,t}^g = \sum_{m=1}^{K} \sum_{i=1}^{N} \gamma_{mi,n} \log P_{mi,t} - \text{Const}_n^g, \ \log P_{n,t}^c = \sum_{m=1}^{K} \sum_{i=1}^{N} \beta_{mi,n} \log P_{mi,t} - \text{Const}_n^c$$

$$\log P_{nj,t} = (1 - \alpha_{nj}) \log W_{n,t} + \alpha_{nj} \sum_{m=1}^{K} \sum_{i=1}^{N} \omega_{mi,nj} \log P_{mi,t} - \text{Const}_{nj}^m$$

where Const_x denote a constant term with $\text{Const}_n^g \equiv \sum_{m=1}^{K} \sum_{i=1}^{N} \gamma_{mi,n} \log \gamma_{mi,n}$, $\text{Const}_n^c \equiv \sum_{m=1}^{K} \sum_{i=1}^{N} \beta_{mi,n} \log \beta_{mi,n}$, $\text{Const}_{nj}^m \equiv (1 - \alpha_{nj}) \log(1 - \alpha_{nj}) + \alpha_{nj} \log \alpha_{nj} + \alpha_{nj} \sum_{m=1}^{K} \sum_{i=1}^{N} \omega_{mi,nj} \log \omega_{mi,nj}$. We can rewrite the prices in a vector form,

$$d \log P_t^I = (\mathbb{I} - \Omega')^{-1} \left((d \log W_t \otimes e_N) \circ (1 - \alpha) \right)$$

$$d \log P_t^g = \gamma' d \log P_t^I = \gamma' (\mathbb{I} - \Omega')^{-1} \left((d \log W_t \otimes e_N) \circ (1 - \alpha) \right)$$

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$$d\log P_t^c = \beta' d\log P_t^I = \beta' (\mathbb{I} - \Omega')^{-1} ((d\log W_t \otimes e_N) \circ (1 - \alpha))$$

where variables and Greek constants without a country or country-sector index denote the corresponding vectors. Thus, price changes are ultimately tied to changes in the nominal wage rates expressed in euro across all K countries. The price effect in the decomposition of world value-added responding to fiscal spending shocks is written here as

$$\sum_{n=1}^{K} \phi_n \sum_{j=1}^{N} \frac{L_{nj}}{L_n} \left(\sum_{k=1}^{K} \tilde{\omega}_{nj,k} d\log P_{k,t}^g \right) + \sum_{n=1}^{K} \phi_n \sum_{j=1}^{N} \frac{L_{nj}}{L_n} \left(\sum_{k=1}^{K} \tilde{\mu}_{nj,k} d\log P_{k,t}^c \right) - \sum_{n=1}^{K} \phi_n d\log W_{n,t}$$

Let $\tilde{\phi}_{nj} \equiv \phi_n \frac{L_{nj}}{L_n}$ be the share of country-sector nj's value added in the world aggregate value added. Substituting the expressions for $d\log P_t^g$ and $d\log P_t^c$ into the equation above and rewriting it in a vector form

$$\tilde{\phi}' \tilde{\omega} d\log P_t^g + \tilde{\phi}' \tilde{\mu} d\log P_t^c - \tilde{\phi}' (d\log W_t \otimes e_N)$$

$$= \tilde{\phi}' \left[\tilde{\omega}(\gamma' \mathcal{L}') \mathrm{Diag}(1 - \alpha) + \tilde{\mu}(\beta' \mathcal{L}') \mathrm{Diag}(1 - \alpha) - \mathbb{I} \right] (d\log W_t \otimes e_N)$$

where $\mathrm{Diag}(x)$ is a matrix whose diagonal elements are x. The expression $\tilde{\phi}' \left[\tilde{\omega}(\gamma' \mathcal{L}') \mathrm{Diag}(1 - \alpha) + \tilde{\mu}(\beta' \mathcal{L}') \mathrm{Diag}(1 - \alpha) - \mathbb{I} \right]$ is determined only by parameter values at the steady state and we can verify that it is equal to zero. First note that $\tilde{\phi}$ can be treated as country-sector value added when multiplies by the world GDP. The transpose of the expression above reads

$$\mathrm{Diag}(1 - \alpha)(\mathcal{L}\gamma)\tilde{\omega}' \tilde{\phi} + \mathrm{Diag}(1 - \alpha)(\mathcal{L}\beta)\tilde{\mu}' \tilde{\phi} - \tilde{\phi}$$

From the definition of $\tilde{\omega}$ and $\tilde{\mu}$, it follows that $\tilde{\omega}' \tilde{\phi} = S^g$, a vector of government spending, and $\tilde{\mu}' \tilde{\phi} = S^c$, a vector of household consumption spending. From sectoral goods market clearing condition (A.2), we have $\mathcal{L}\gamma S^g + \mathcal{L}\beta S^c = S^I$. Sectoral value added is then equal to $\mathrm{Diag}(1 - \alpha) S^I = \tilde{\phi}$. financial adjustments.

B General CES Specifications

This appendix extends the analysis in the main text to a general specification for production and consumption. We assume that the composite of intermediate inputs $M_{nj,t}$ has a following CES form,

$$M_{nj,t} = \left[\sum_{m=1}^{K} \sum_{i=1}^{N} \omega_{mi,nj}^{\frac{1}{\theta^m}} M_{mi,nj,t}^{1-\frac{1}{\theta^m}} \right]^{\frac{\theta^m}{\theta^m-1}}$$

where θ^m is the elasticity of substitution among intermediate inputs.

The optimality conditions for production read

$$W_{n,t}L_{nj,t} = (1-\alpha_{nj})P_{nj,t}X_{nj,t} \tag{B.1}$$

$$P_{nj,t}^m M_{nj,t} = \alpha_{nj}P_{nj,t}X_{nj,t} \tag{B.2}$$

$$P_{mi,t}M_{mi,nj,t} = \left(\frac{P_{mi,t}}{P_{nj,t}^m} \right)^{1-\theta^m} \alpha_{nj}\omega_{mi,nj}P_{nj,t}X_{nj,t} \tag{B.3}$$

The price for intermediate input composite $M_{nj,t}$ is linked to prices of intermediate inputs as

$$P_{nj,t}^m = \left[\sum_{m=1}^{K} \sum_{i=1}^{N} \omega_{mi,nj}(P_{mi,t})^{1-\theta^m} \right]^{\frac{1}{1-\theta^m}}$$

Similarly, the consumption basket for a representative household has the following CES aggregation,

$$C_{n,t} = \left[\sum_{m=1}^{K} \sum_{i=1}^{N} \beta_{mi,n}^{\frac{1}{\theta^c}} C_{mi,n,t}^{1-\frac{1}{\theta^c}} \right]^{\frac{\theta^c}{\theta^c-1}}$$

θ^c is the elasticity of substitution among varieties in the consumption basket.

The optimality conditions for households in country k become

$$P_{mi,t}C_{mi,n,t} = \left(\frac{P_{mi,t}}{P_{n,t}^c} \right)^{1-\theta^c} \beta_{mi,n}C_{n,t}P_{n,t}^c \tag{B.4}$$

with consumer price index $P_{n,t}^c$,

$$P_{n,t}^c = \left[\sum_{m=1}^{K} \sum_{i=1}^{N} \beta_{mi,n} (P_{mi,t})^{1-\theta^c} \right]^{\frac{1}{1-\theta^c}}$$

B.1 Estimation of Elasticities

We use price information, input output table and private consumption expenditure distribution from WIOD to estimate elasticity of substitution among intermediate inputs and elasticity of substitution in a consumption basket.

The WIOD provides useful information to recover the elasticity parameters θ^m and θ^c. First we define the intermediate input share of sector mi in sector nj in year t

$$IIshare_{mi,nj,t} \equiv \frac{P_{mi,t} M_{mi,nj,t}}{\sum_{m=1}^{K} \sum_{i=1}^{N} P_{mi,t} M_{mi,nj,t}} = \omega_{mi,nj} \left(\frac{P_{mi,t}}{P_{nj,t}^m} \right)^{1-\theta^m}$$

The first expression can be calculated directly from the WIOT and the second equation comes from (B.3).

We define the relative intermediate input share between period t and s as

$$RII_{mi,nj,ts} \equiv \frac{IIshare_{mi,nj,t}}{IIshare_{mi,nj,s}} = \left(\frac{P_{mi,t}/P_{mi,s}}{P_{nj,t}^m/P_{nj,s}^m} \right)^{1-\theta^m}$$

Taking logs on both sides, yields

$$\ln RII_{mi,nj,ts} = (1 - \theta^m) \left[\ln \left(\frac{P_{mi,t}}{P_{mi,s}} \right) - \ln \left(\frac{P_{nj,t}^m}{P_{nj,s}^m} \right) \right] \tag{B.5}$$

We take a similar approach to pin down the elasticity in consumption θ^c. First, we define the share of consumption expenditure on each variety, which can be obtained from WIOT directly

$$CEshare_{mi,n,t} \equiv \frac{P_{mi,t} C_{mi,n,t}}{\sum_{m=1}^{K} \sum_{i=1}^{N} P_{mi,t} C_{mi,n,t}} = \left(\frac{P_{mi,t}}{P_{n,t}^c} \right)^{1-\theta^c} \beta_{mi,n}$$

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The relative consumption expenditure share

$$RCE_{mi,n,ts} \equiv \frac{CEshare_{mi,n,t}}{CEshare_{mi,n,s}} = \left(\frac{P_{mi,t}/P_{mi,s}}{P_{n,t}^c/P_{n,s}^c} \right)^{1-\theta^c}$$

Taking logs on both sides, yields

$$\ln RCE_{mi,n,ts} = (1-\theta^c) \left[\ln \left(\frac{P_{mi,t}}{P_{mi,s}} \right) - \ln \left(\frac{P_{n,t}^c}{P_{n,s}^c} \right) \right] \tag{B.6}$$

The socio-economic database of WIOD provides sectoral price indices for intermediate inputs and gross outputs. We use "price levels gross output (2010=100)", GO-PI, to measure $P_{mi,t}/P_{mi,s}$, and "price levels of intermediate inputs (2010=100) ", II-PI, to measure $P_{nj,t}^m/P_{nj,s}^m$, with $m, n = 1, \cdots, K$, $i, j = 1, \cdots, N$, $t = 2, \cdots, T$. Regressing the left hand side on the right hand side of the equation (B.5) above with controlling sector fixed effects yields the estimate $\hat{\theta^m}$. Taking the country level CPI data to measure $P_{n,t}^c/_{n,s}^c$ (2010=100) from the *Eurostat* database, regressing the left hand side on the right hand side of the equation (B.6) above with controlling sector fixed effects yields the estimate $\hat{\theta}^c$. Figure A-1 shows the estimated $\hat{\theta^m}$ and $\hat{\theta}^c$ based on year by year regressions. The elasticities move around one, with a tight band for $\hat{\theta^m}$. The average value for $\hat{\theta^m} = 0.90$ and $\hat{\theta}^c = 0.82$ in the data.

Note that the constant input-output matrix $\mathbf{\Omega}$ and consumption expenditure shares β in the model are not directly observed from WIOT under general production and preference specifications. But we know that without any shocks, $\omega_{mi,nj}$ captures the steady state input-output linkages and $\beta_{mi,n}$ for the steady state consumption expenditure shares. We use the following information to pin down $\omega_{mi,nj}$ and $\beta_{mi,n}$

$$\omega_{mi,nj} = \frac{\sum_{t=1}^{T} IIshare_{mi,nj,t}}{T}$$

$$\beta_{mi,n} = \frac{\sum_{t=1}^{T} CEshare_{mi,n,t}}{T}$$

Similarly, the average government spending share is also defined as

$$\gamma_{mi,n} = \frac{\sum_{t=1}^{T} Govshare_{mi,n,t}}{T}$$

with

$$Govshare_{mi,n,t} \equiv \frac{P_{mi,t}G_{mi,n,t}}{\sum_{m=1}^{K} \sum_{i=1}^{N} P_{mi,t}G_{mi,n,t}}$$

Similarly we can calibrate other parameters including intermediate income share α_{ki}.

C   Equations for the Example Model

This section provides steps for solving the 3-country world economy described in the main text with international production linkages, sticky wages, and also monetary union in country 1 and 2.

1. Price of good 1 (country 1)

$$p_1 = \omega \, \alpha \, p_1 + \frac{(1-\omega)\,\alpha\,p_2}{2} - \frac{(1-\omega)\,\alpha\,p_3}{2}$$

2. Price of good 2 (country 2)

$$p_2 = \omega \, \alpha \, p_2 + \frac{(1-\omega)\,\alpha\,p_1}{2} + \frac{(1-\omega)\,\alpha\,p_3}{2}$$

3. Price of good 3 (country 3)

$$p_3 = \omega \, \alpha \, pf + \frac{(1-\omega)\,\alpha\,p_1}{2} + \frac{(1-\omega)\,\alpha\,p_2}{2} - (1-\alpha)\,e$$

4. Price indices

$$P_1 := \beta \, p_1 + \frac{(1-\beta)\,p_2}{2} + \frac{(1-\beta)\,p_3}{2}$$

$$P_2 := \beta \, p_2 + \frac{(1-\beta)\,p_1}{2} + \frac{(1-\beta)\,p_3}{2}$$

$$P_3 := \beta \, pf + \frac{(1-\beta)\,p_1}{2} + \frac{(1-\beta)\,p_3}{2}$$

5. Consumption from budget constraints

$$C_1 = p_1 + y1 - \frac{gy\,G}{1-\alpha} - \beta\,p_1 - \frac{(1-\beta)\,p_2}{2} - \frac{(1-\beta)\,p_3}{2}$$

$$C_3 2 = p_2 + y2 - \beta\, p_2 - \frac{(1-\beta)\, p_1}{2} - \frac{(1-\beta)\, p_3}{2}$$

$$C_3 = pf + yf - \beta\, p_3 - \frac{(1-\beta)\, p_1}{2} - \frac{(1-\beta)\, p_2}{2}$$

6. Leontief Inverse Matrix

$$\mathcal{L}_{11} = -\frac{\alpha\,\omega + \alpha - 2}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{12} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{13} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)}$$

$$\mathcal{L}_{21} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{22} = -\frac{\alpha\,\omega + \alpha - 2}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{23} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)}$$

$$\mathcal{L}_{31} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{32} = -\frac{(-1+\omega)\,\alpha}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)} \quad \mathcal{L}_{33} = -\frac{\alpha\,\omega + \alpha - 2}{(\alpha - 1)\,(3\,\alpha\,\omega - \alpha - 2)}$$

7. Goods market clearing for country 1

$$0 = p_1 + y + 1 - \mathcal{L}_{11}gy\beta_1 G - \mathcal{L}_{12}gy((1-\beta_1)(1/2))G - \mathcal{L}_{13}gy((1-\beta_1)(1/2))G$$

$$-\mathcal{L}_{11}(1-\alpha)(\beta C_1+(1/2)(1-\beta)C_2+((1-\beta)(1/2))C_2)-\mathcal{L}_{12}(1-\alpha)(\beta C_2+(1/2)(1-\beta)C_3+((1-\beta)(1/2))C_1)$$

$$-\mathcal{L}_{13}(1-\alpha)(\beta C_3+(1/2)(1-\beta)C_1+((1-\beta)(1/2))C_2)-\mathcal{L}_{11}(1-\alpha)(\beta P_1+((1-\beta)(1/2))P_2+((1-\beta)(1/2))P_3)$$

$$-\mathcal{L}_{12}(1-\alpha)(\beta P_2+((1-\beta)(1/2))P_1+((1-\beta)(1/2))P_3)-\mathcal{L}_{13}(1-\alpha)(\beta P_3+((1-\beta)(1/2))P_2+((1-\beta)(1/2))P_1)$$

8. Goods market clearing for country 2

$$0 = p_2 + y_2 - \mathcal{L}_{21}gy\beta_1 G - \mathcal{L}_{22}gy((1-\beta_1)(1/2))G - \mathcal{L}_{23}gy((1-\beta_1)(1/2))G$$

$$-\mathcal{L}_{21}(1-\alpha)(\beta C_1+(1/2)(1-\beta)C_3+((1-\beta)(1/2))C_2)-\mathcal{L}_{22}(1-\alpha)(\beta C_2+(1/2)(1-\beta)C_3+((1-\beta)(1/2))C_1)$$

$$-\mathcal{L}_{23}(1-\alpha)(\beta C_3+(1/2)(1-\beta)C_1+((1-\beta)(1/2))C_2)-\mathcal{L}_{21}(1-\alpha)(\beta P_1+((1-\beta)(1/2))P_2+((1-\beta)(1/2))P_3)$$

$$-\mathcal{L}_{22}(1-\alpha)(\beta P_2+((1-\beta)(1/2))P_1+((1-\beta)(1/2))P_3)-\mathcal{L}_{23}(1-\alpha)(\beta P_3+((1-\beta)(1/2))P_2+((1-\beta)(1/2))P_1)$$

D Estimating Government Spending Shocks

We follow the SVAR approach of Blanchard and Perotti (2002) and Ramey and Zubairy (2018) to estimate fiscal shocks in the Eurozone. The quarterly VAR specification reads

$$Y_t = A(L, q)Y_{t-1} + U_t$$

with $Y_t \equiv [T_t, G_t, X_t]'$, with net taxes T_t, government expenditures G_t, economic activity X_t, GDP. $A(L, q)$ is a polynomial capturing four-quarter lags. The residual from the reduced form VAR, $U_t \equiv [t_t, g_t, x_t]'$, can be specified as functions of structural shocks e_t^t, e_t^g, e_t^x,

$$t_t = a_1 x_t + a_2 e_t^g + e_t^t$$

$$g_t = b_1 x_t + b_2 e_t^t + e_t^g$$

$$x_t = c_1 t_t + c_2 g_t + e_t^x$$

The identification steps follow Blanchard and Perotti (2002):

- $b_1 = 0$. Discretionary fiscal policy doesn't respond contemporaneously to unexpected changes in output in quarterly data.

- a_1. Tax elasticity measures the automatic response of tax revenues to economic activity, and is usually estimated by using narrative shocks (see proxy SVAR as in Mertens and Ravn (2014)) and forecast error shocks. Blagrave, Ho, Koloskova and Vesperoni (2017) present tax elasticities for the USA (3.13), the UK (1.61), Germany (0.7), France (1.8), and Japan (1.3). We estimate the shocks for the eurozone countries using the values for Germany, Japan, and the USA, which cover the range of current estimations.

- Let $t_t' \equiv t_t - a_1 x_t$, $g_t' \equiv g_t - b_1 x_t = g_t$. t_t' and g_t' are instruments for t_t and g_t to pin down c_1 and c_2 by regressing x_t on t_t and g_t.

- a_2 and b_2. We consider two alternative identifications: (a) $a_2 = 0$ when taxes are ordered first or (b) $b_2 = 0$ when government expenditures are ordered first.

D.1 Data Construction

We use quarterly data from Eurostat. All data are in local currency units (Euro), seasonally adjusted and annualized. The data are converted into log per capita real terms with base year in 2010 and then detrended.

The country coverage, range of periods and variables are defined as follows.

- Country coverage (the 11 eurozone countries in the main text and other eurozone countries): Austria (AUT), Belgium (BEL), Cyprus (CYP), Germany (DEU), Spain (ESO), Estonia (EST), Finland (FIN), France (FRA), Greece (GRC), Ireland (IRL)M Italy (ITA), Luxembourg (LUX), Latvia (LVA), Lithuania (LTU), Malta (MLT), Netherlands (NLD), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), and Sweden (SWW).

- National Accounts

    - Quarterly nominal GDP at market prices (B1GQ) in euros seasonally and calendar adjusted from "Quarterly GDP and main components (output, expenditure, income)".

    - Quarterly GDP (B1GQ) chainlinked volumes, index 2010 = 100 seasonally and calendar adjusted. This is the GDP deflator, from "Quarterly GDP and main components (output, expenditure, income)".

    - Yearly average population, from "Population Change - Demographic Balance and Crude rates at national level".

- Government Expenditure

    - **Definition of total general government expenditure (definition 1):** comprises all transactions recorded under positive uses in the European System of Accounts framework, and subsidies payable in the current accounts as well as transactions (gross capital formation, acquisition less disposals pf non-financial non-produced assets plus capital transfers payable) in the capital account of the government.

It comprises the following categories

> intermediate consumption
>
> +gross capital formation
>
> +compensation of employess, payable
>
> +other taxes on productio, payable
>
> +subsidies payable
>
> +property income, payable
>
> +current taxes on income, wealth, etc. payable
>
> +social benefits other than social transfers in kind
>
> +social transfers in kind - purchased market production
>
> +other current transfers
>
> +adjustments for the change in pension entitlements
>
> +capital transfers payable
>
> +acquistions less disposals of non-financial non-produced assets

– **Reduced definition of Government Expenditure (definition 2):** real per capita "Final Consumption Expenditure of General Government (P3-S13)" + "Gross Fixed Capital Formation" (P51G). Both variables are nominal, and seasonally and calendar adjusted.

– **Reduced definition of Government Expenditure (definition 2):** real per capita "Final Consumption Expenditure of General Government (P3-S13)" + "Gross Fixed Capital Formation of General Government" (P51G). Both variables are nominal, and seasonally and calendar adjusted.

• Taxes

– **Definition of total general government revenue (definition 2) following the Euro-**

pean System of Accounts

> Sales of market output
>
> +Sales of output for own final use
>
> +Sales of payments for non-market output
>
> +taxes on production and imports, receivable
>
> +other subsidies on production, receivable
>
> +property income, receivable
>
> +current taxes on income, wealth, etc. receivable
>
> +net social constributions
>
> +other current transfers, receivable and
>
> +capital transfers, receivable

- **Reduced definition of Tax Revenue (definition 2):** real per capita "Current Taxes on Income, Wealth, etc. receivable (D5)" + "Taxes on production and imports (D2)" + "Capital Taxes (D91)". Variables are nominal, and don't have seasonal adjustment, from "Quarterly non-financial accounts for general government".
- We convert these tax series to a non-seasonal version running a regression with quarter dummies and adding to the residual the mean from the original series.

Other aspects to consider include:

- Trends are removed under a linear and a quadratic specification.

- Variables are expressed in logarithms for the SVAR.

- Blanchard and Perotti use for taxes a measure of revenue minus transfers.

D.2 Other aggregate data

In the sectoral value-added analysis, real sectoral value-added is calculated by nominal sectoral value-added from the world input output tables divided by sectoral output prices from the Socio-Economic Accounts of the WIOD. We also use some macroeconomic variables for the Eurozone economies. GDP

and its decomposition are taken from the National Accounts - Analysis of Main Aggregates (AMA) of United Nations. Inflation and current account are taken from World Economic Outlook. Real effective exchange rate is taken from World Development Indicators and from Bruegel. Government financial consumption expenditure in current and constant price is taken from World Development Indicators, which are used to back out the price index for government consumption expenditure. Wage inflation is the change of Labor Cost Index (compensation of employees plus taxes minus subsidies) for the main activities (industry, construction and services) from the Eurostat. Eurostat has an imbalanced coverage on labor cost index during 2000-2014. Labor cost index for France during 2000-2008 comes from Insee for main economic activities. Labor cost index is missing for Austria during 2000-2009, we fill these missing values by using the average change of labor cost index in other Eurozone countries.

E   Figures and Tables
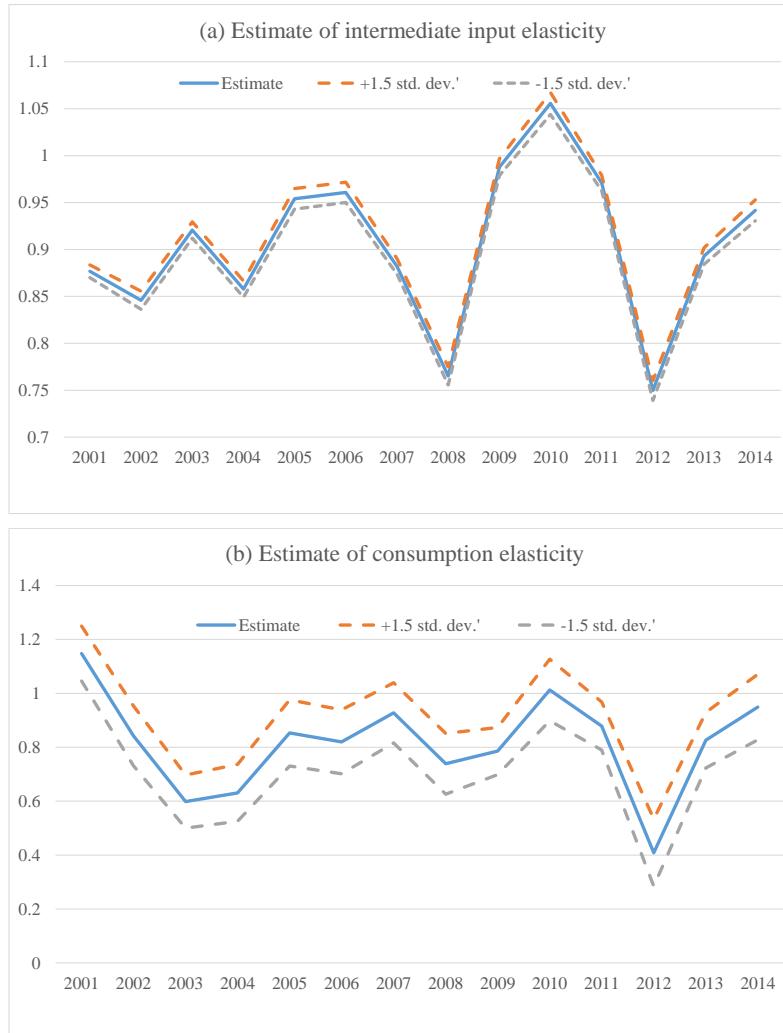
Figure A-1: Estimation of elasticities. Panel (a) shows the empirical estimate of elasticity of substitution between intermediate inputs in production $\hat{\theta^m}$, and panel (b) shows the empirical estimate of elasticity of substitution between varieties in consumption $\hat{\theta^c}$.
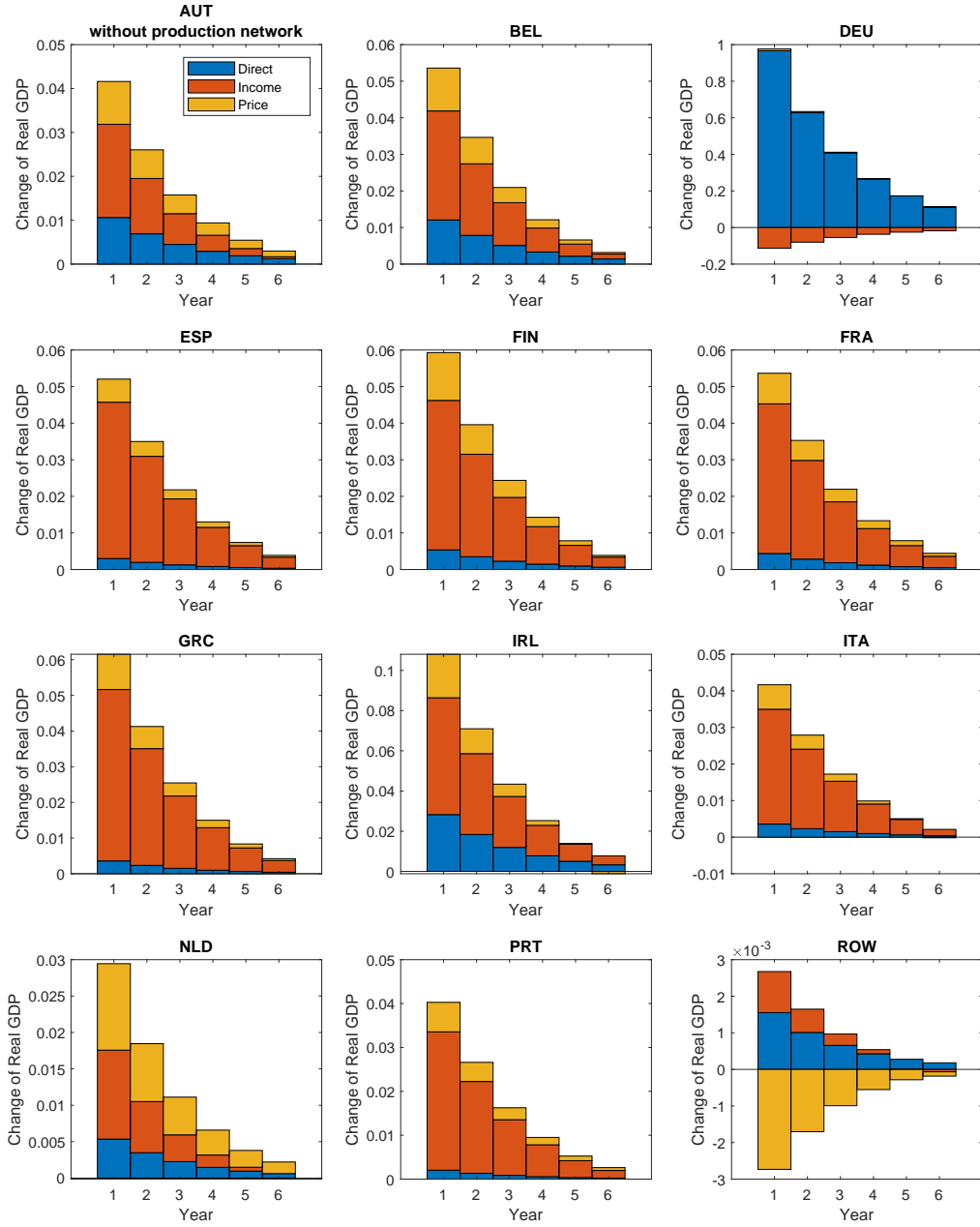
Figure A-2: Output responses from a one-percent of GDP increase in German Government spending when nominal wages are fully sticky in national currency, but firms don't use imported intermediate inputs to produce. The world economy consists of 11 Eurozone countries and the rest of the world. Monetary authorities target nominal consumption expenditure, $M^{ez} = \sum_{k=1}^{K-1} P_{k,t} C_{k,t}$ in the monetary union and $M^{row} = P_{K,t}^* C_{K,t}$ in the rest of the world. There is no intertemporal adjustment via international borrowing or lending. The total effect of a fiscal spending can be decomposed into three parts: direct effect, income effect and price effect.
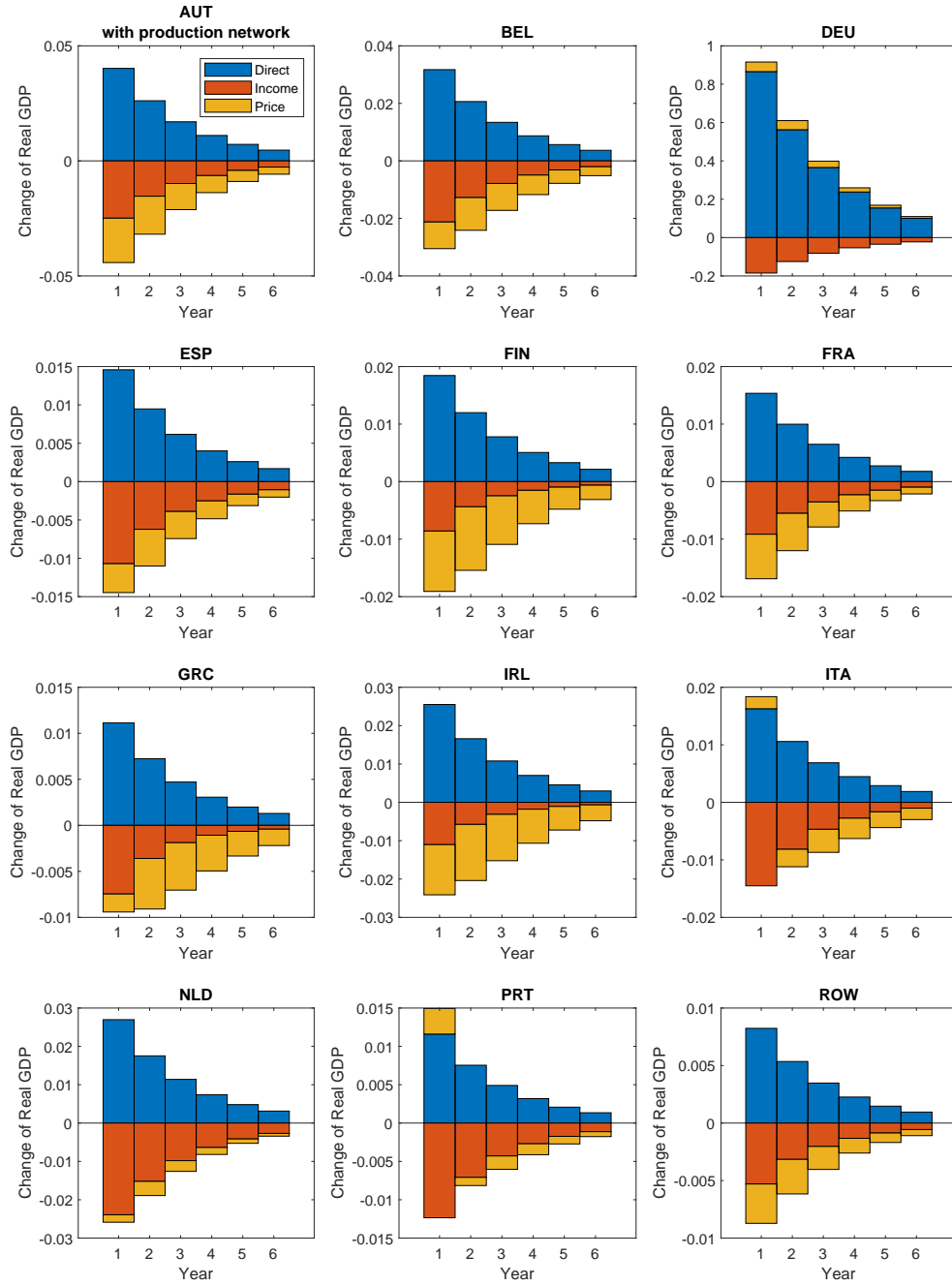
Figure A-3: Output responses from a one-percent of GDP increase in German Government spending when nominal wages are flexible. The world economy consists of 11 Eurozone countries and the rest of the world. Monetary authorities target nominal consumption expenditure, $M^{ez} = \sum_{k=1}^{K-1} P_{k,t}C_{k,t}$ in the monetary union and $M^{row} = P^*_{K,t}C_{K,t}$ in the rest of the world. There is no intertemporal adjustment via international borrowing or lending. The total effect of a fiscal spending can be decomposed into three parts: direct, income and price effect.
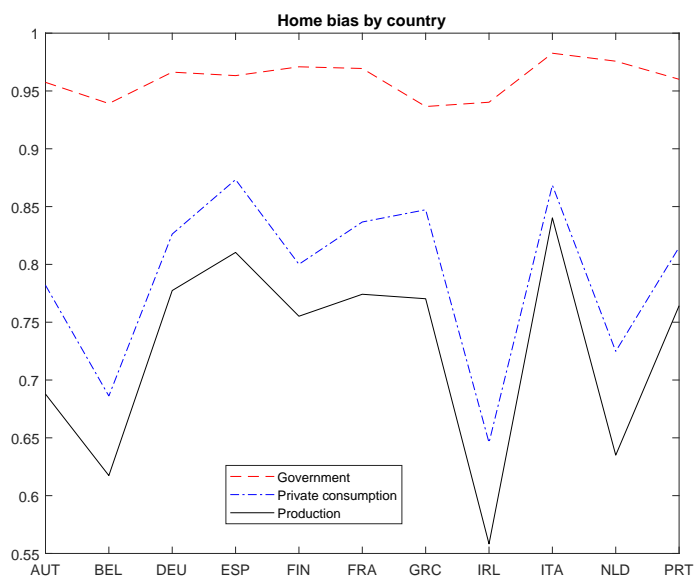
Figure A-4: Shares of government spending, private consumption spending, intermediate input spending falling on domestic sectors, listed by country.
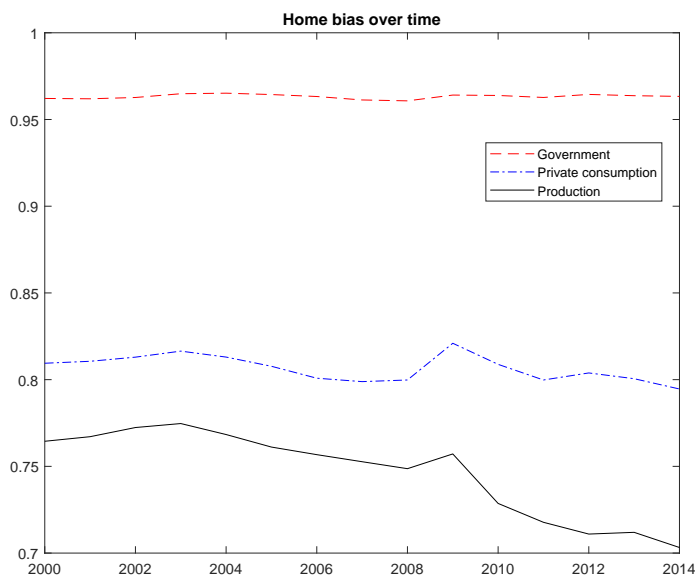
Figure A-5: Shares of government spending, private consumption spending and intermediate input spending falling on domestic sectors, by year, averaged over countries.
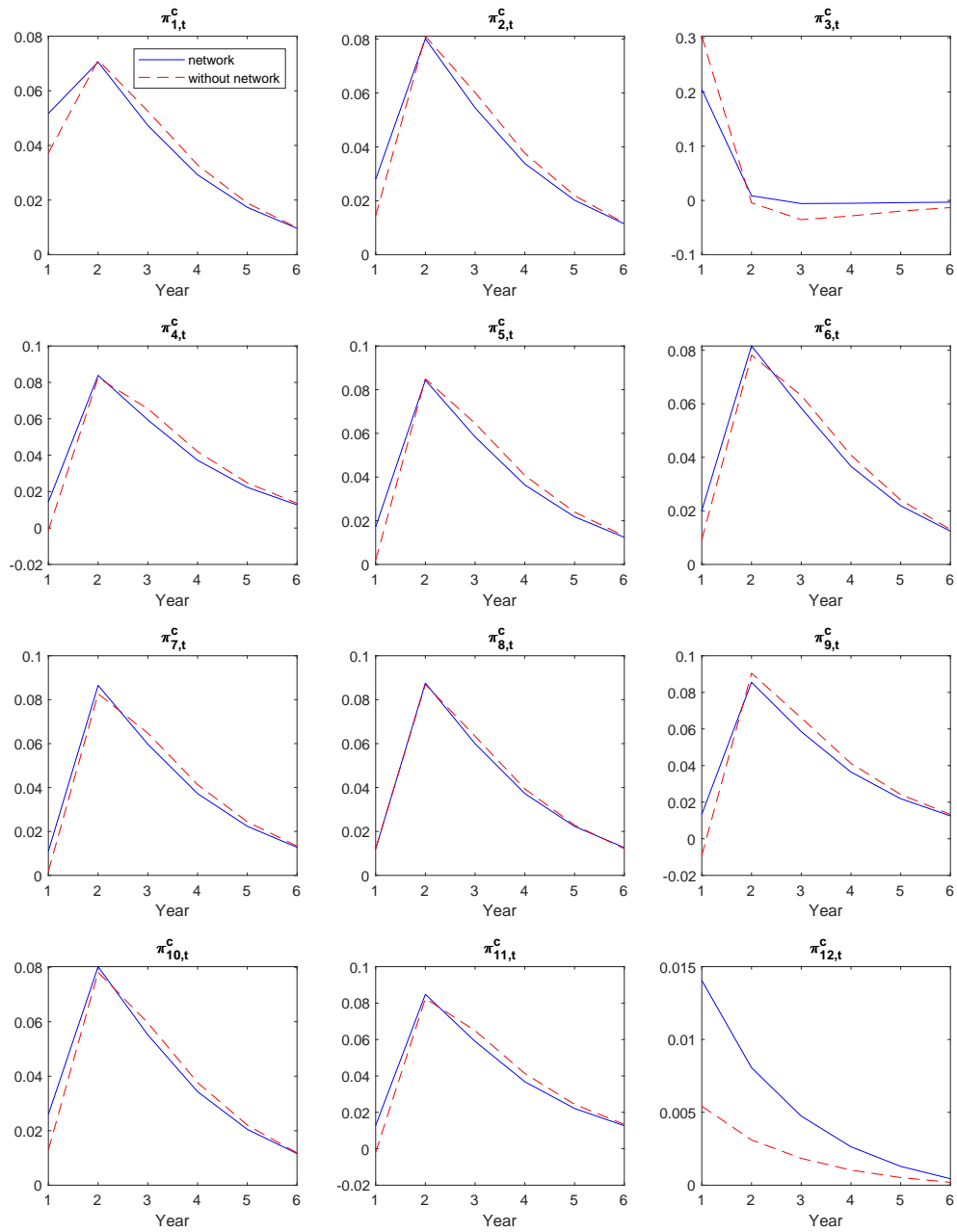
Figure A-6: The response of CPI inflation to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation.
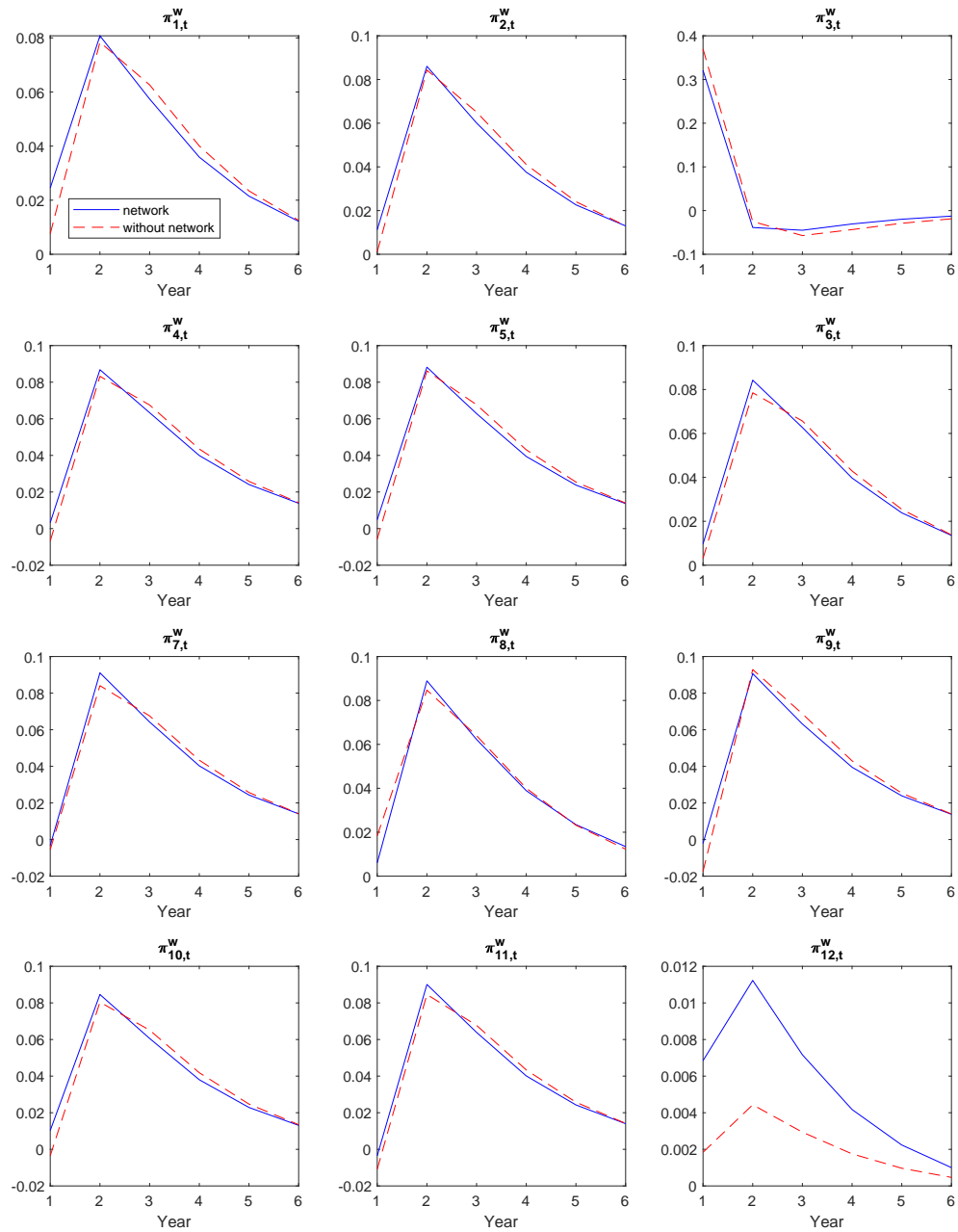
Figure A-7: The response of wage inflation to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation.
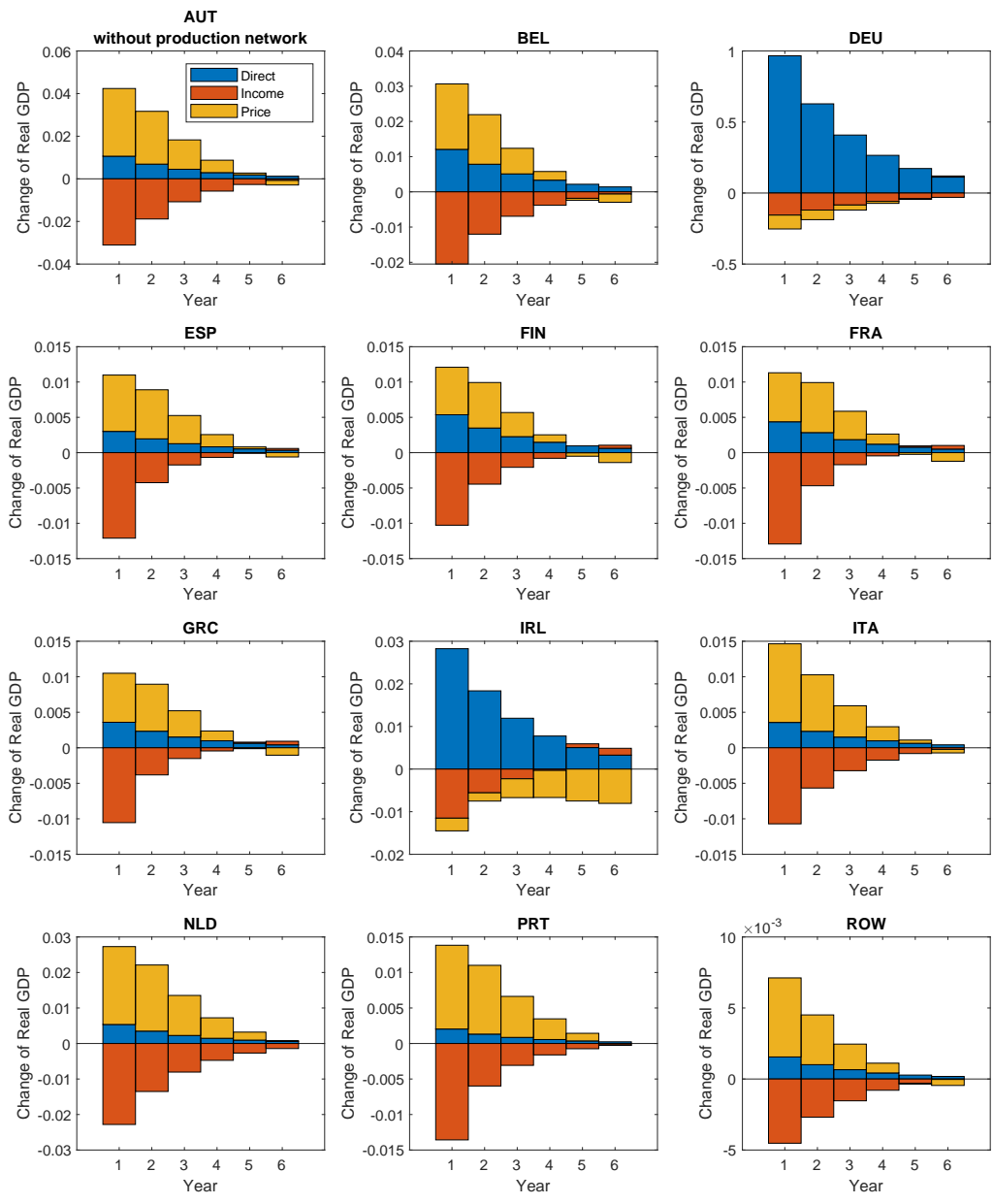
Figure A-8: The Direct, Income and Price effect of the response of real GDP to a one-percent of GDP increase in German Government spending when monetary authorities stabilize CPI inflation. There is no international trade in intermediate inputs.
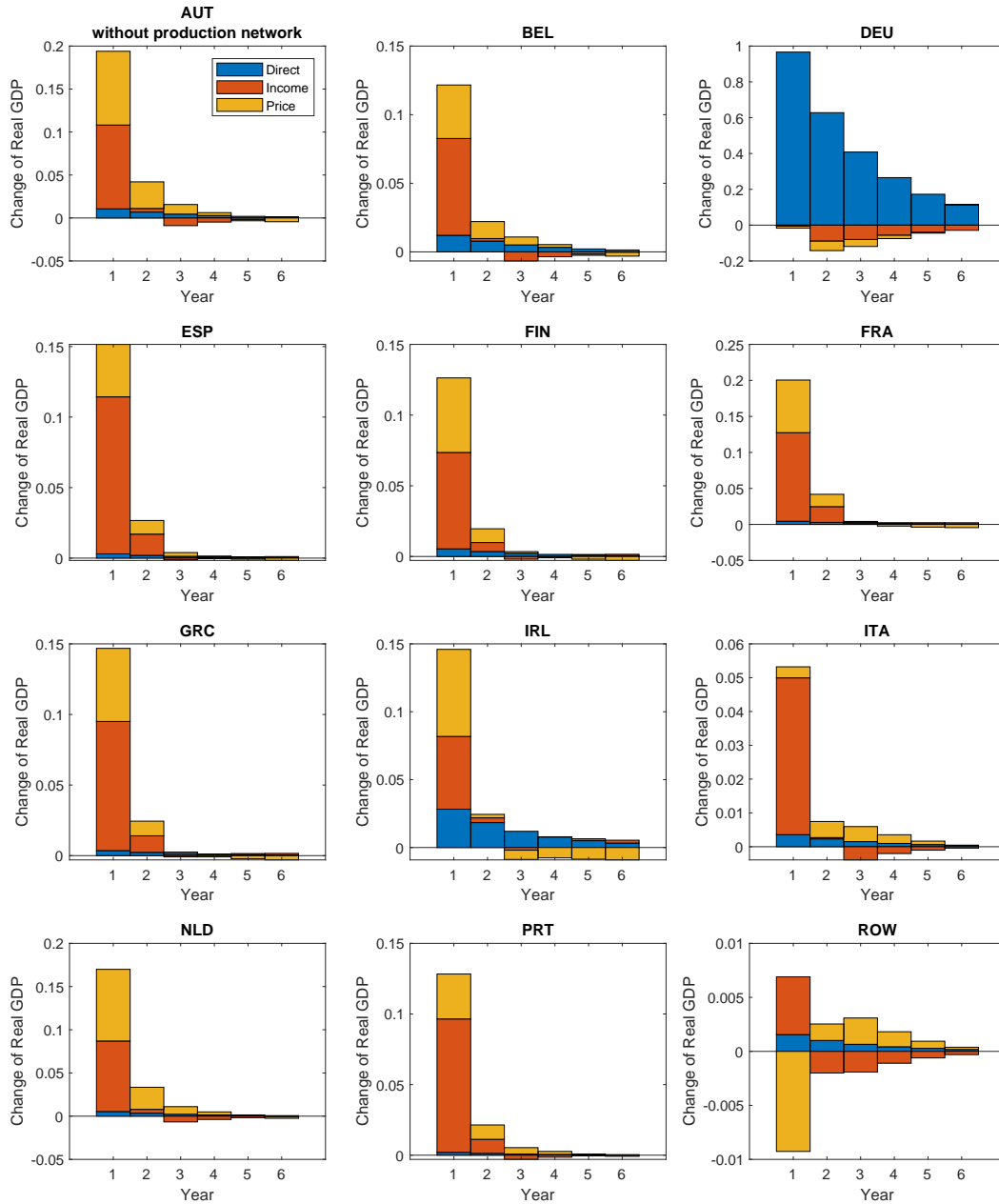
Figure A-9: The Direct, Income and Price effect of the response of real GDP to a one-percent of GDP increase in German Government spending when shutting down international production network and nominal interest rate in the Eurozone is constrained in period 1 and 2.
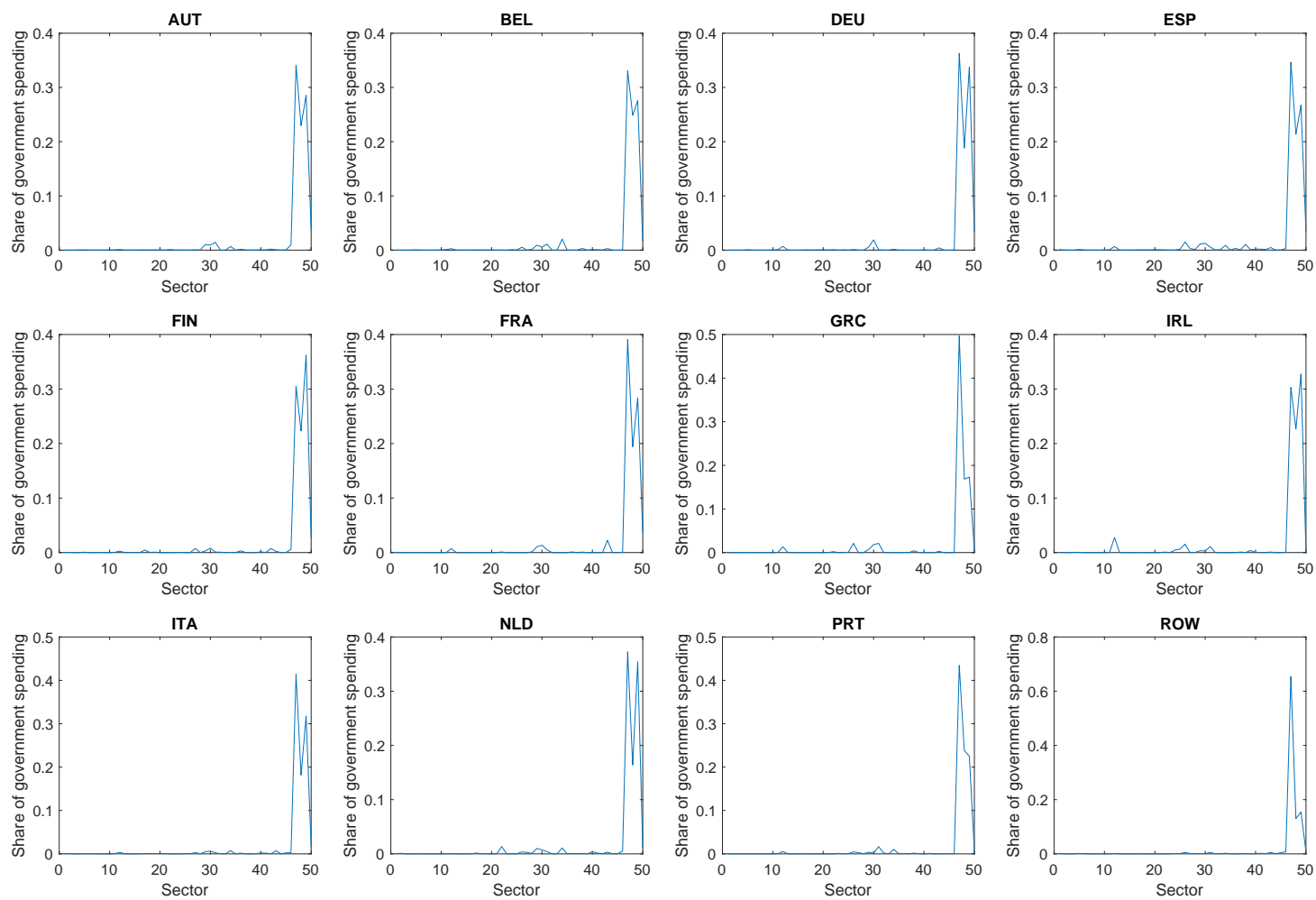
Figure A-10: Government expenditure shares in domestic sectors in the euro 11 countries and the rest of the world based on the average WIOD from 2000-2014.

F   Distortionary Income Taxes

In the baseline model of the main text, we use a constant labor tax rate and a lump-sum tax to finance government consumption spending in each country. The labor income tax only affects the steady state of the economy. In this section, we allow for time-varying labor income tax rate such that government spending is completely financed by this distortionary labor income tax, then $T^g_{n,t} = 0$. Here we only write equations that are different from the baseline model. First, households labor supply reads

$$(1 - \tau^c_{n,t}) \frac{W^c_{n,t}}{P^c_{n,t}} = \frac{V'(L^c_{n,t})}{U'(C_{n,t})} = (C_{n,t})^\sigma (L^c_{n,t})^\eta$$

and the labor income tax rate satisfies

$$\tau^c_{n,t} \equiv \frac{G_{n,t} P^g_{n,t}}{W^c_{n,t} L^c_{n,t}}$$

The other equilibrium conditions are the same as in the baseline model. We then recalculate the steady state and it turns out that $\tau^c_{n,t}$ at steady state are quite similar to those for most of countries in the data.

One key difference between constant labor income tax rate and distortionary labor income tax rate is that for the shock origin country, an increase in government consumption must be financed by a higher labor income tax rate, which in turn depresses labor supply and may reduce the own fiscal multiplier, while other countries with a positive spillover under constant labor income tax rate may experience higher fiscal spillover under distortionary labor income tax since higher labor income induced by fiscal spillover leads to lower distortionary labor income tax rate given domestic government spending unchanged. Figure A-11 shows output responses to one percent of GDP increase in German government spending when fiscal spending is financed by a distortionary labor income tax rate. German own fiscal multiplier becomes much lower than those under the constant labor income tax rate, while other countries have higher spillovers, particularly when international production network is in place. Figure A-12 shows the three-effect decomposition of output responses to fiscal spending shocks. Note that the direct effect doesn't depend on how government spending is financed. As in the baseline case in the main text, income effect is negative in all countries, but the price effect becomes larger and outweighs the income effect in most of economies. Figure A-13 shows that shutting down international production network substantially reduces fiscal spillovers.

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This logic also applies to the world economy with constrained nominal interest rates. The reduced labor income tax rate due to positive spillover in the shock recipient countries further increase the labor response to an expansionary German fiscal spending. Figure A-14 shows output responses to one percent of GDP increase in German fiscal spending when nominal interest rates are constrained in period 1 and 2. Fiscal spillovers increase as more than twice as those in the baseline model with constant labor income tax rate. Figure A-15 presents that both the price and income effects in the shock recipient Eurozone countries become much larger than those under constant labor income tax rate, while the rest of the world experiences a much higher adverse price effect. Figure A-16 shows that once we shut down international production network, both the income and price effects reduce substantially.

G Fiscal Spillovers from France and Italy

This section presents fiscal spillovers from French and Italian fiscal spending shocks. Figure A-17 shows output responses to one percent of GDP increase in French government spending when monetary authorities stabilize CPI inflation. Results indicate that under the standard Taylor rules, fiscal spillovers are relatively small, but the spillovers dramatically decrease once shutting down international trade in intermediate inputs, as output responses to German fiscal spending shocks in the main text. In addition, fiscal spillovers are smaller responding to French government spending shocks. Figure A-18 and A-19 report three effects of decomposition of output response to the same size of French fiscal spending shocks. Patterns are quite similar to those responding to German fiscal spending shocks. The direct effect is positive in all countries, and income effect is negative in all countries as well since the shock-origin country faces a negative income tax to finance government spending, while the other countries cut current consumption due to higher real interest rate. The price effect is negative for the shock-origin country, while it is positive for all other countries due to this oppositive movement of network adjusted real exchange rates.

Figure A-20 shows output response to one percent of GDP increase in French government spending when nominal interest rates are constrained in the Eurozone for two periods (period 1 and 2). Results indicate that fiscal multiplier and spillovers increase substantially. Shutting down international input linkages significantly reduce fiscal spillovers, particularly for large economies. Figure A-21 and A-22 show the three-effect decomposition for the same fiscal spending shocks in France. Results show that

when monetary policy is constrained, expansionary fiscal policy in France will drive down real interest rate due to higher inflation, and the income and price effect will significantly outweigh the direct effect and generate higher spillovers across borders.

Similarly, figure A-23 presents output responses to one percent of GDP increase in Italian government spending when monetary authorities stabilize CPI inflation. Fiscal spillovers are relatively small and international production network strengthens fiscal spillovers. Figure A-24 shows the three-effect decomposition of output responses with international production network, and figure A-25 describes the decomposition of output responses without international production network. These results are similar to output responses to French and German fiscal spending shocks.

Figure A-26 shows output responses to one percent of GDP increase in Italian government spending when nominal interest rates are constrained by a lower bound in period 1 and 2. Figure A-27 and A-28 shows the three-effect decomposition of output responses with and without international production network when nominal interest rates are constrained. When nominal interest rates are constrained, expansionary fiscal spending pushes up inflation and consequently leads to lower real interest rate, which in turn raises consumption and therefore the income and price effect go up to a large amount. In this case, the fiscal spillovers are not higher with international production networks for all countries. The reason is that the real exchange rate in Italy appreciates much less with international production network than that without it, and the rest of Eurozone economies experience less real exchange depreciation with international production network.

Table A-1 and A-2 report regression results for fiscal spending shocks in France and Italy on the Eurozone sectoral value-added. Results show that the coefficients for Direct, Income and Price effects are all significantly positive and around one, which is consistent with our model predictions.

Table A-1: Government spending in France and sectoral value added in the Eurozone

Variables	(1) Weighted	(2) Weighted	(3) Weighted	(4) Unweighted	(5) Unweighted	(6) Unweighted
Direct	1.171**	1.192***	1.007***	2.885***	2.641***	2.269***
	(2.491)	(5.300)	(5.223)	(3.458)	(3.222)	(2.948)
Income		1.533***	1.911***		1.205***	1.378***
		(16.633)	(24.201)		(14.950)	(18.160)
Price		0.481***	0.666***		-0.007	0.300***
		(6.556)	(10.606)		(-0.109)	(4.576)
CA-GDP			0.129***			0.289***
			(2.937)			(5.670)
REER			-2.002***			-1.721***
			(-51.588)			(-31.154)
Year	-0.031***	-0.030***	0.002**	-0.033***	-0.030***	-0.002
	(-14.657)	(-25.628)	(2.013)	(-21.748)	(-20.034)	(-0.889)
Year^2	0.001***	0.001***	-0.000***	0.001***	0.001***	-0.000
	(10.139)	(17.648)	(-5.184)	(14.114)	(13.992)	(-1.568)
Constant	0.163***	0.144***	0.014	0.160***	0.132***	0.022**
	(11.136)	(14.835)	(1.542)	(14.746)	(12.175)	(1.984)
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Observations	7,006	7,006	7,006	7,006	7,006	7,006
Adjusted R-squared	0.241	0.271	0.474	0.188	0.217	0.313

Notes: This table presents regression results for specification (14) when the shock origin country is France. Direct, Income and Price are for the direct effect, income effect and price effect. Year and Year^2 control for a quadratic time trend. CA-GDP is the ratio of current account and GDP, and REER is real effective exchange rate. Column (1)-(3) report results in weighted regressions using sectoral value-added as weight, and column (4)-(6) report results with equal weight. Robust t-statistics in parentheses, with $***\ p < 0.01$, $**\ p < 0.05$, $*\ p < 0.1$.

Table A-2: Government spending in Italy and sectoral value added in the Eurozone

Variables	(1) Weighted	(2) Weighted	(3) Weighted	(4) Unweighted	(5) Unweighted	(6) Unweighted
Direct	1.641***	1.362***	1.090***	3.394***	2.880***	2.520***
	(4.570)	(6.137)	(5.775)	(5.063)	(4.360)	(4.072)
Income		1.499***	1.888***		1.185***	1.362***
		(16.240)	(23.867)		(14.690)	(17.919)
Price		0.426***	0.617***		-0.024	0.284***
		(5.815)	(9.830)		(-0.356)	(4.323)
CA-GDP			0.157***			0.297***
			(3.617)			(5.825)
REER			-2.001***			-1.719***
			(-51.582)			(-31.136)
Year	-0.032***	-0.030***	0.003**	-0.033***	-0.030***	-0.002
	(-14.684)	(-25.704)	(2.108)	(-21.884)	(-20.123)	(-0.909)
Year^2	0.001***	0.001***	-0.000***	0.001***	0.001***	-0.000
	(10.223)	(17.691)	(-5.408)	(14.257)	(14.083)	(-1.566)
Constant	0.163***	0.144***	0.013	0.161***	0.133***	0.022**
	(11.153)	(14.848)	(1.437)	(14.783)	(12.197)	(1.975)
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Observations	7,006	7,006	7,006	7,006	7,006	7,006
Adjusted R-squared	0.244	0.272	0.474	0.190	0.218	0.314

Notes: This table presents regression results for specification (14) when the shock origin country is Italy. Direct, Income and Price are for the direct effect, income effect and price effect. Year and Year^2 control for a quadratic time trend. CA-GDP is the ratio of current account and GDP, and REER is real effective exchange rate. Column (1)-(3) report results in weighted regressions using sectoral value-added as weight, and column (4)-(6) report results with equal weight. Robust t-statistics in parentheses, with $*** p < 0.01$, $** p < 0.05$, $* p < 0.1$.
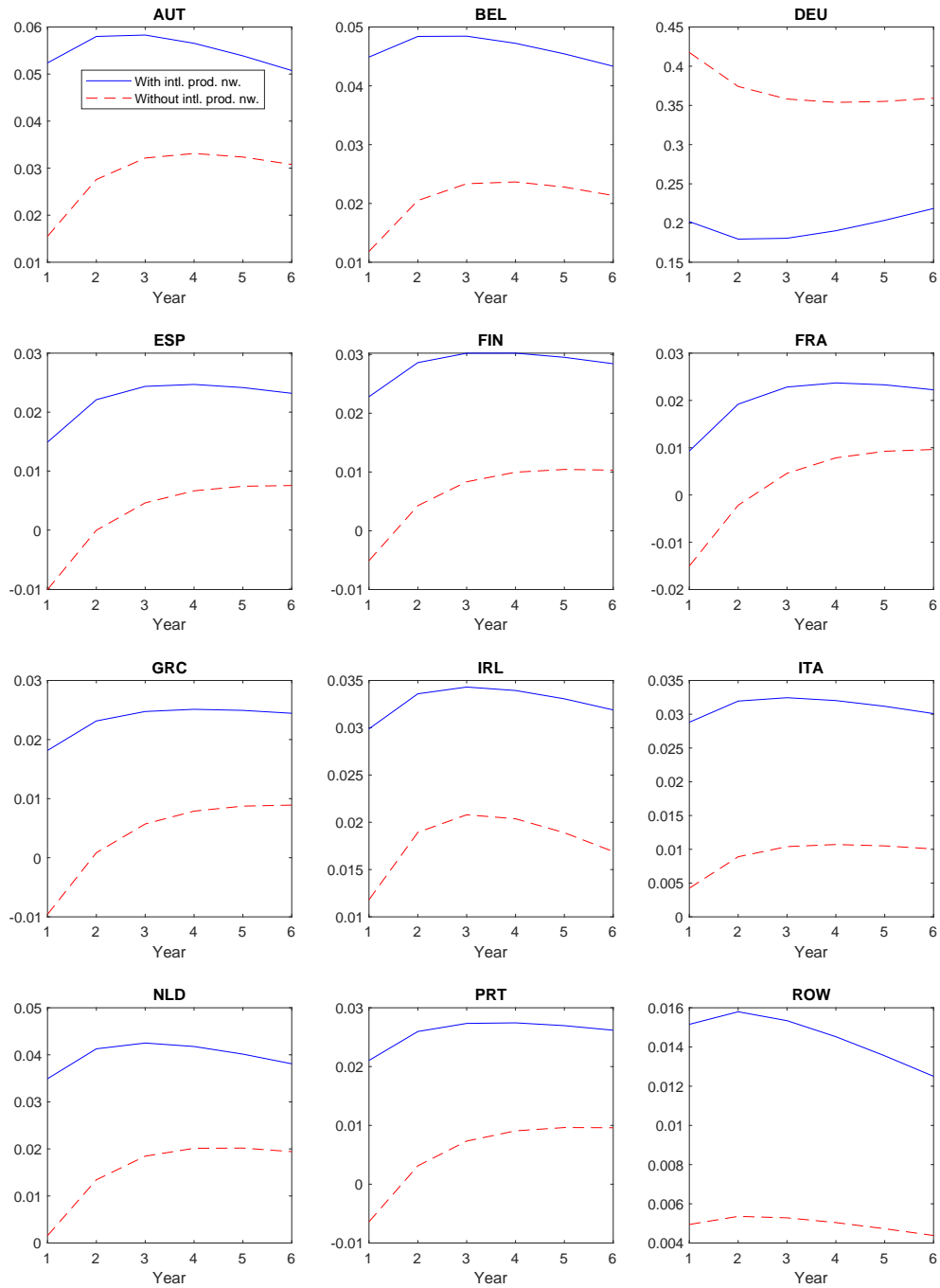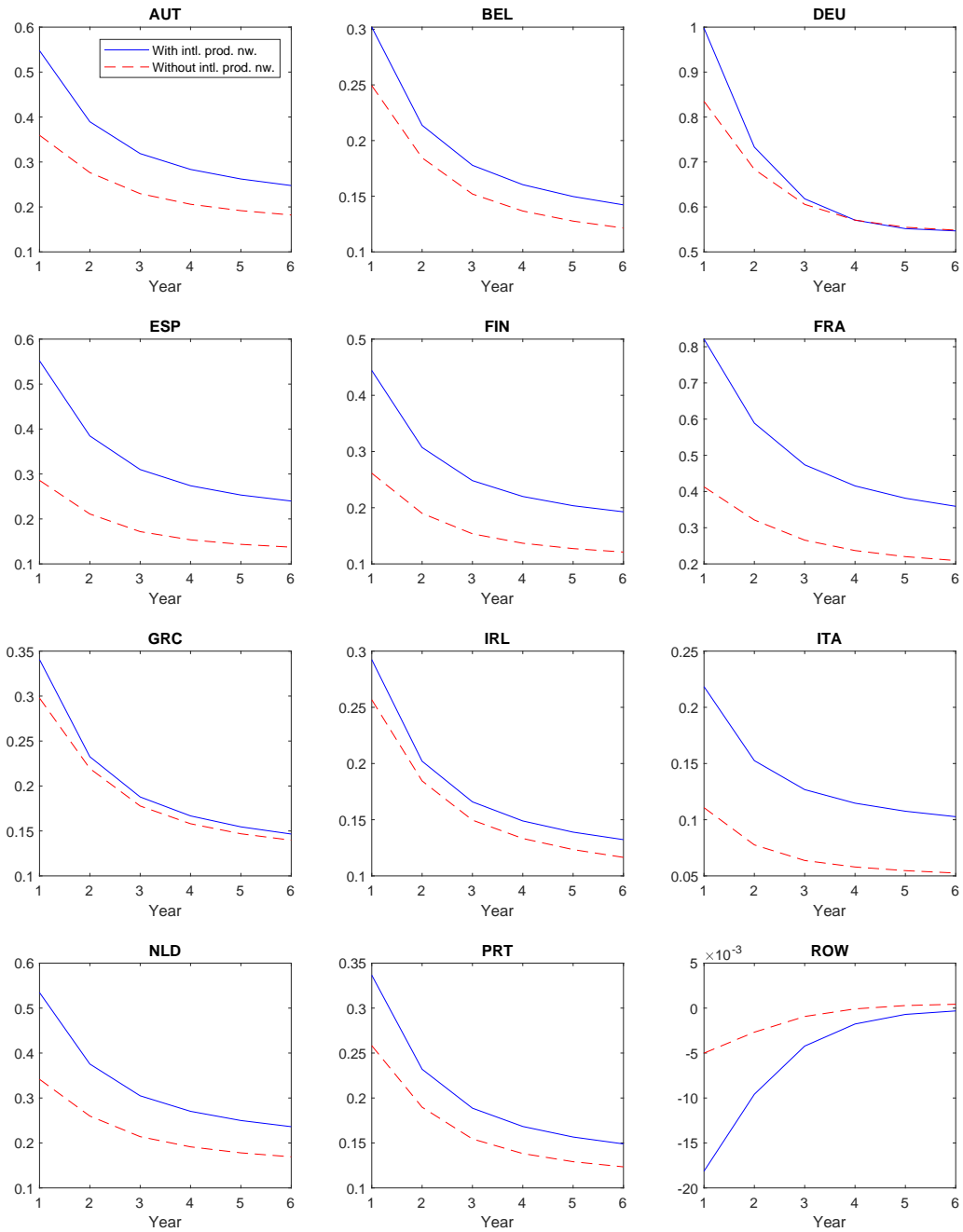
Figure A-11: Fiscal multiplier and fiscal spillover to one percent of GDP increase in German government spending when monetary authorities stabilize CPI inflation and fiscal spending is financed by distortionary labor income tax.
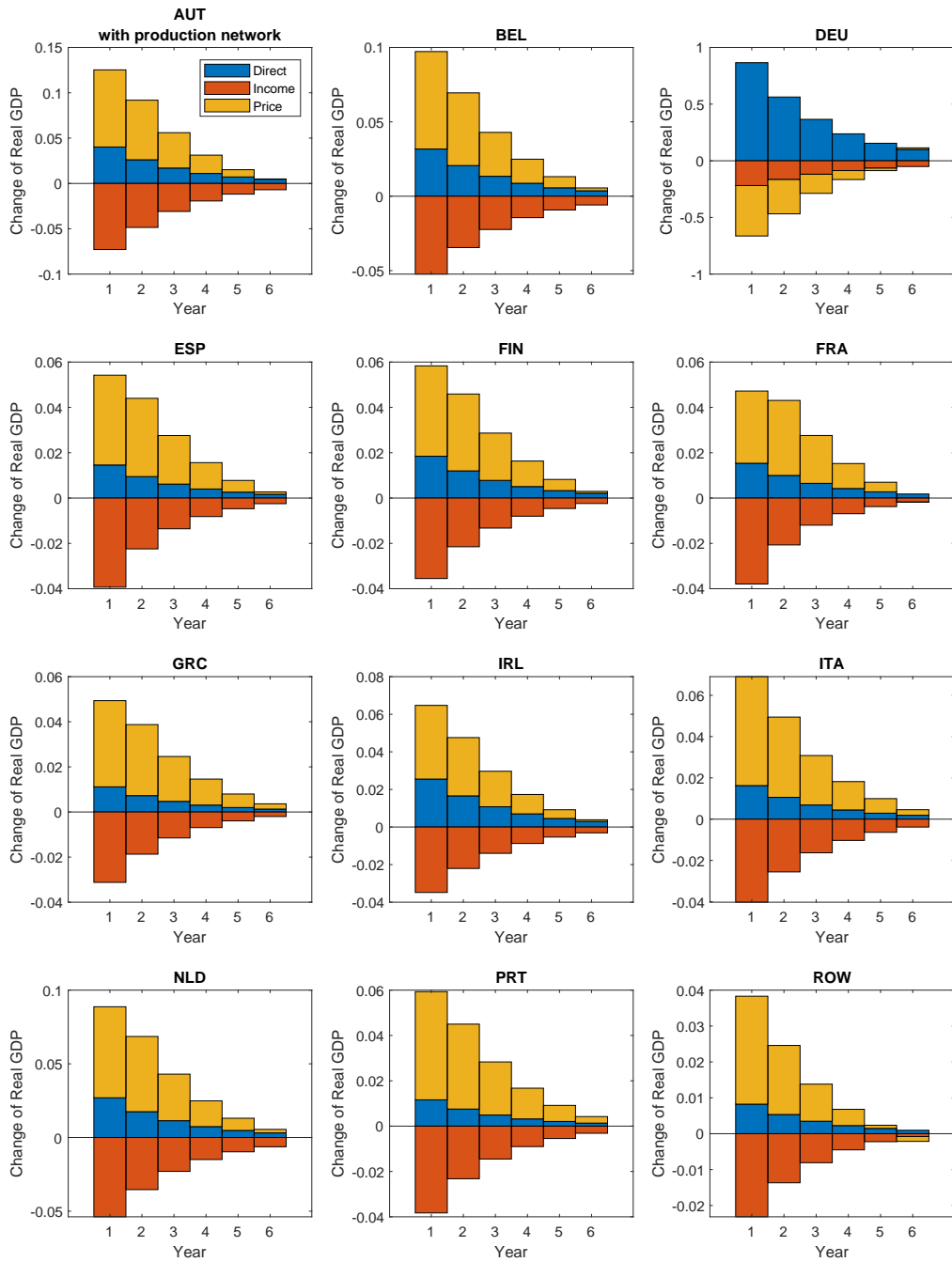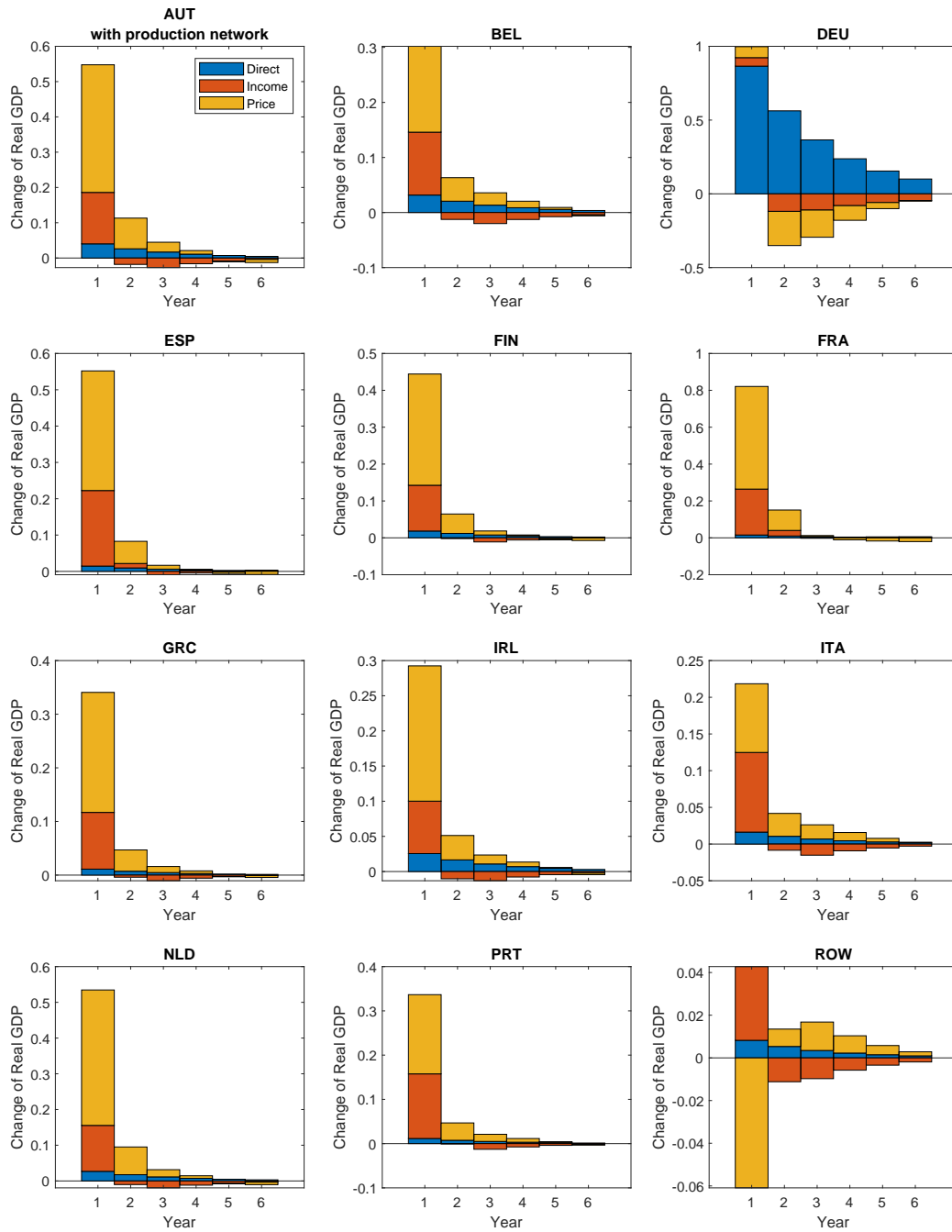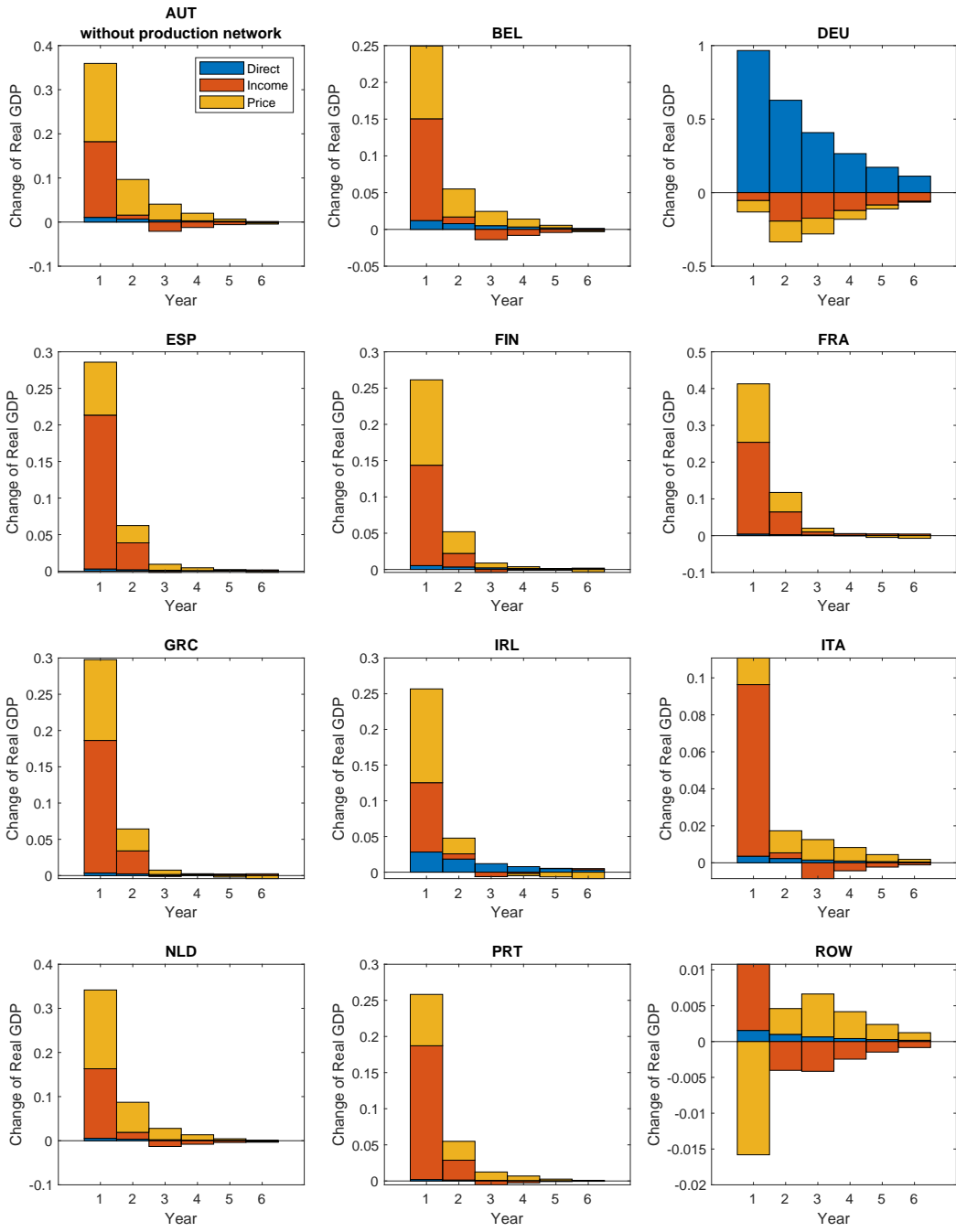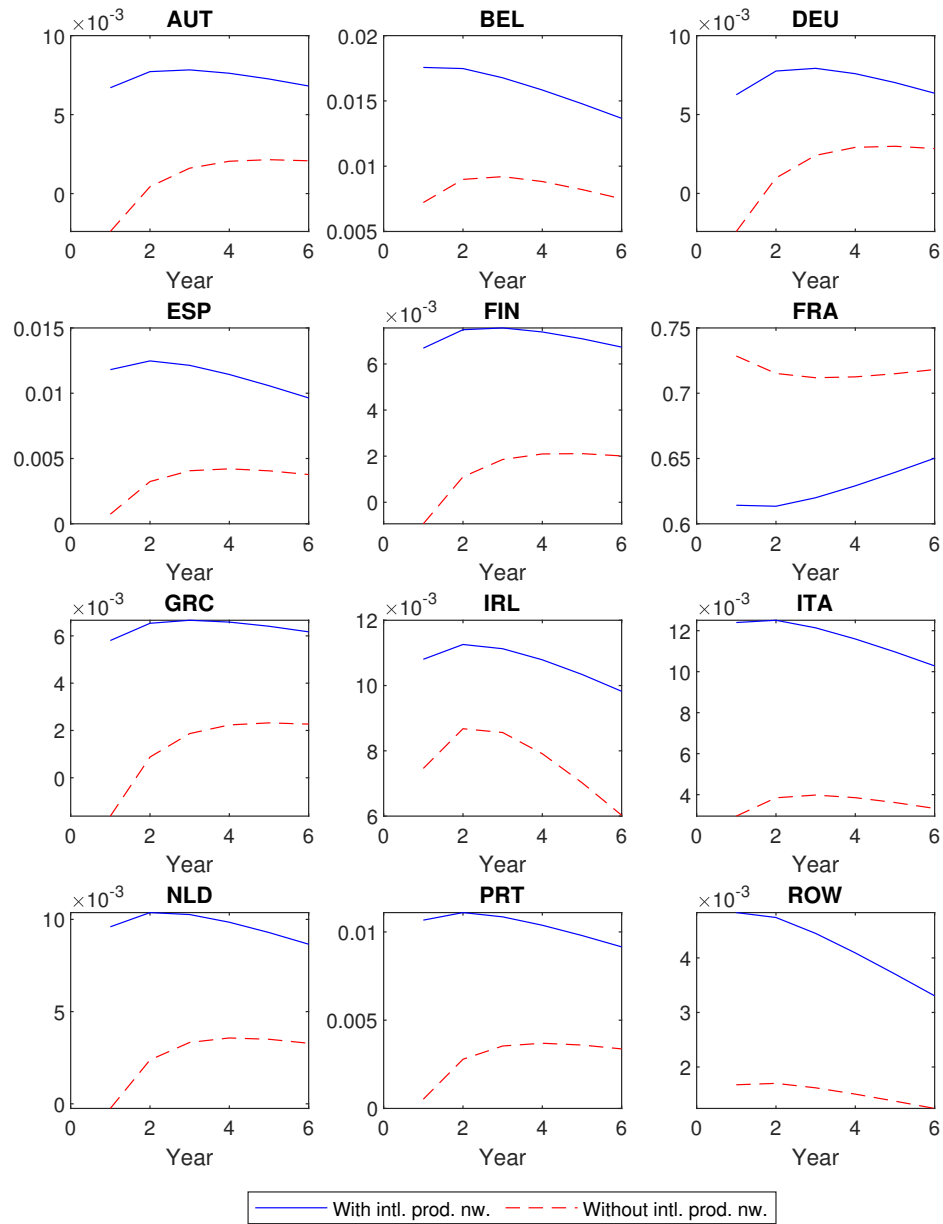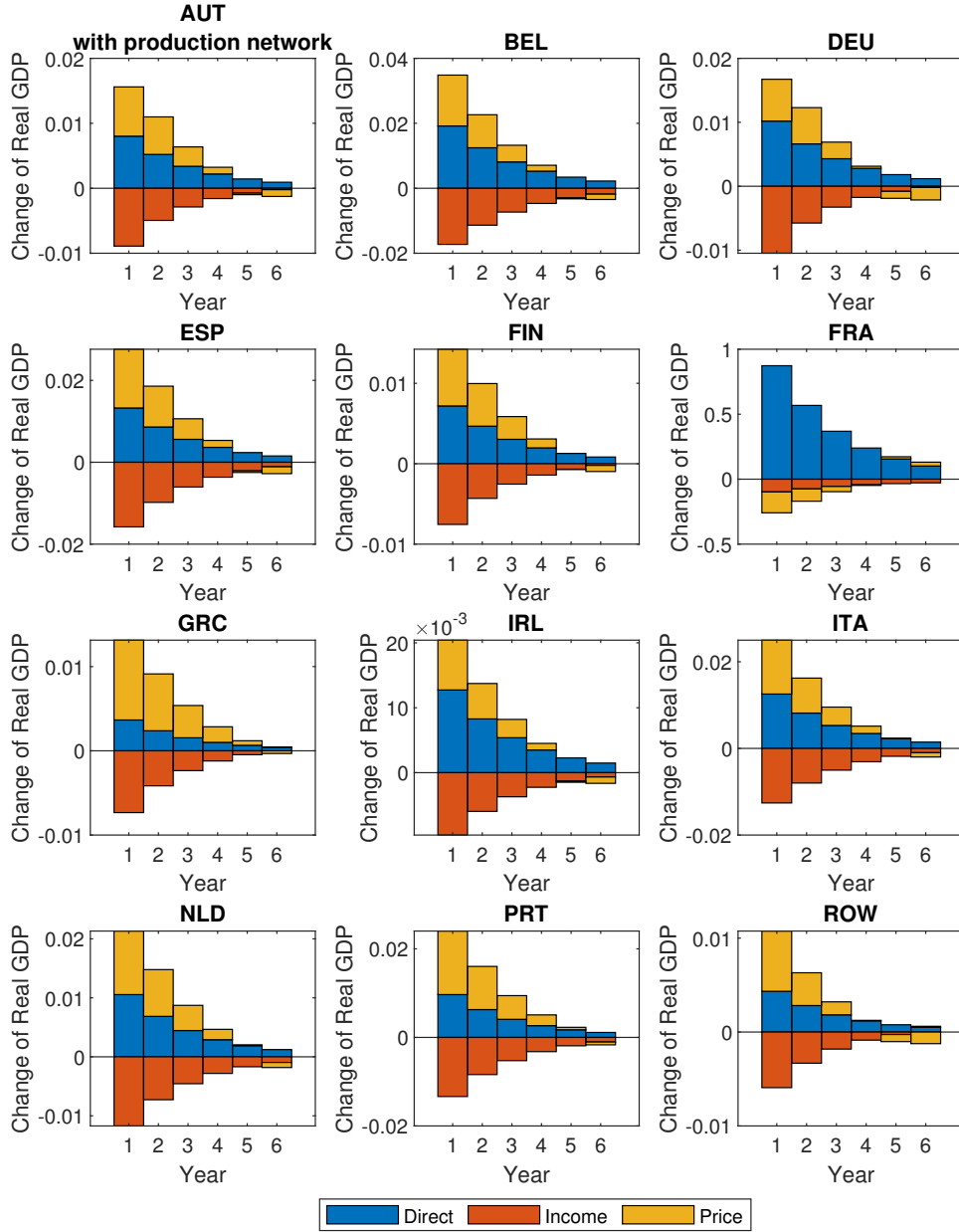
Figure A-12: GDP response to one percent of GDP increase in German government spending, and three-effect decomposition when monetary authorities stabilize CPI inflation and fiscal spending is financed by distortionary labor income tax.
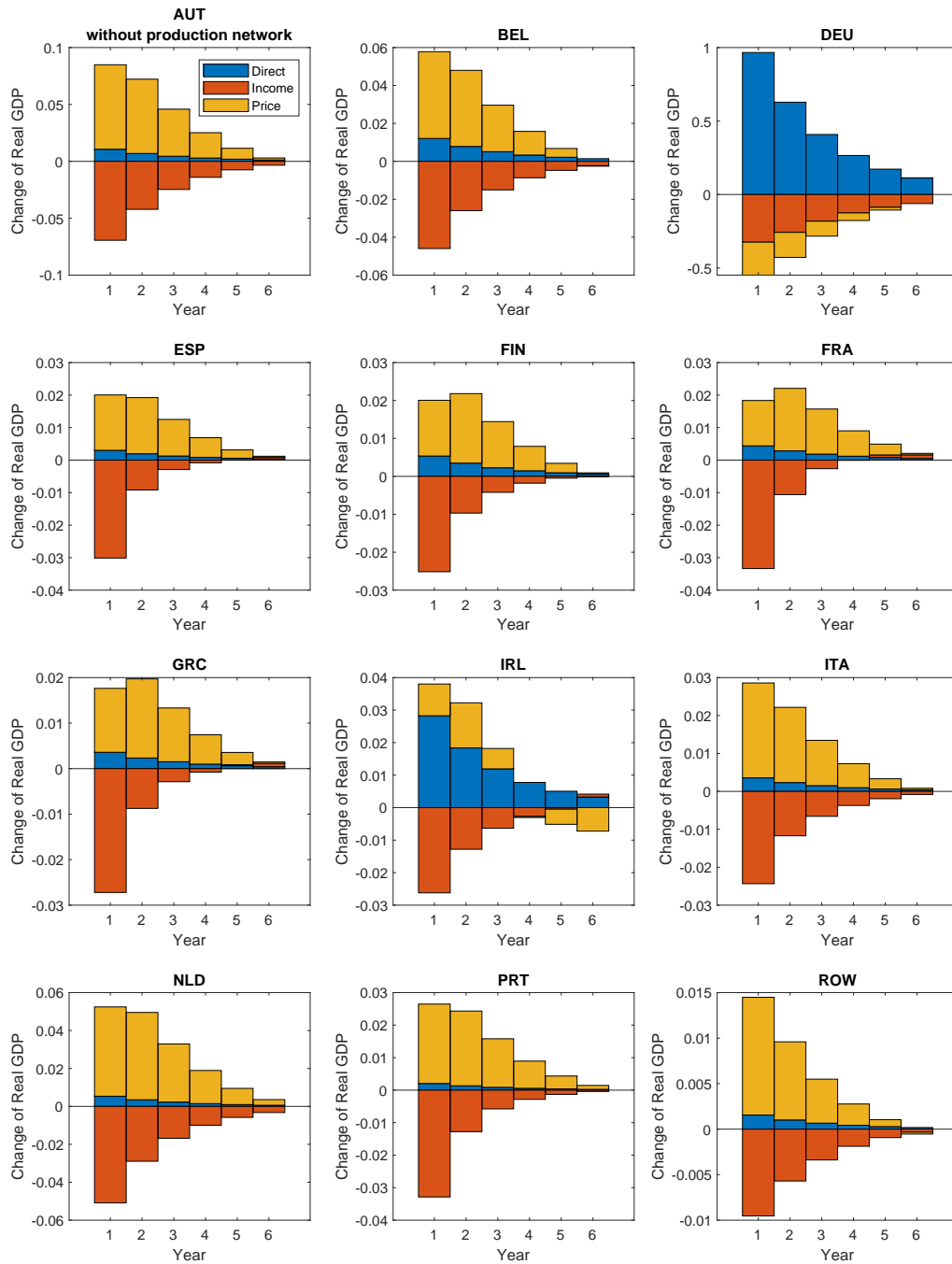
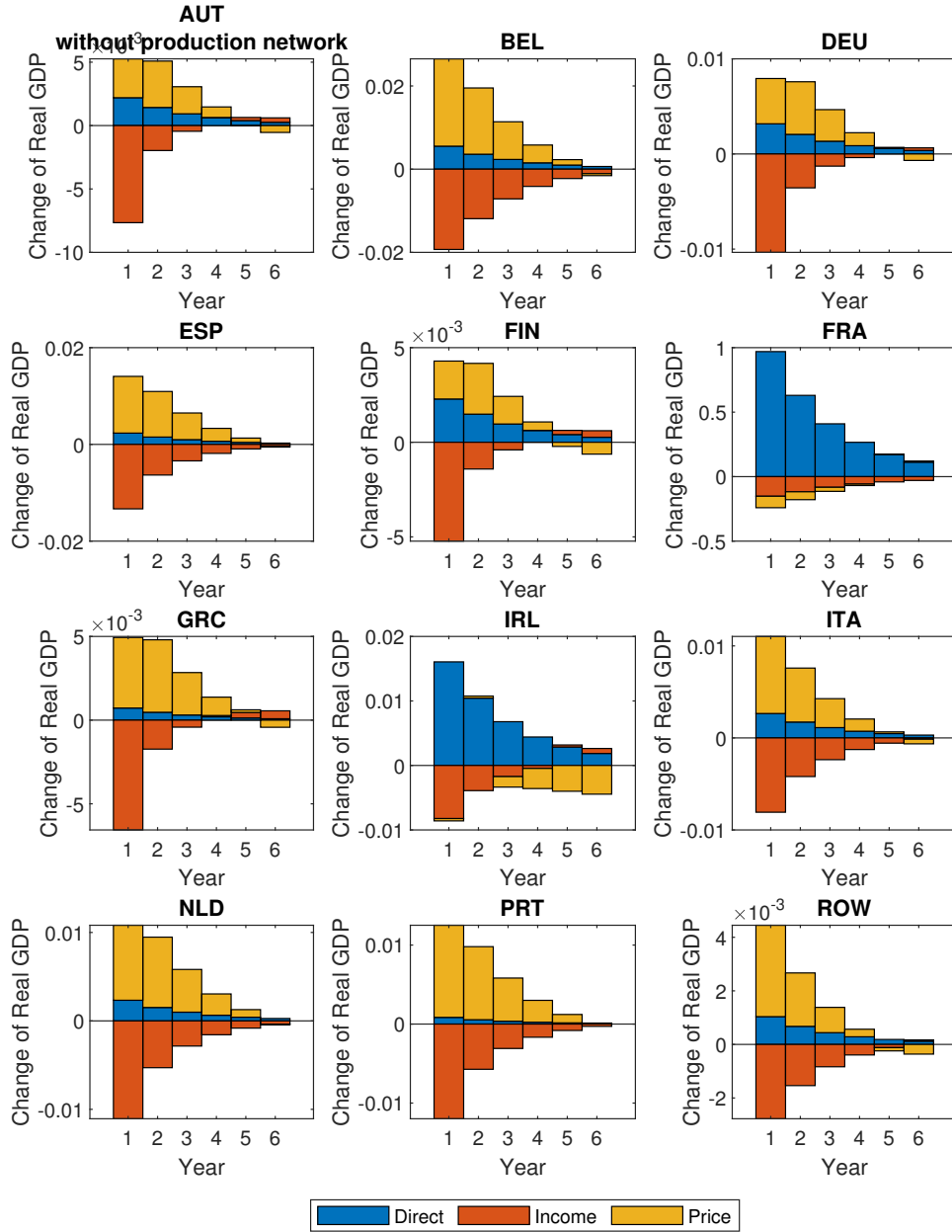Figure A-13: GDP response to one percent of GDP increase in German government spending, and three-effect decomposition when monetary authorities stabilize CP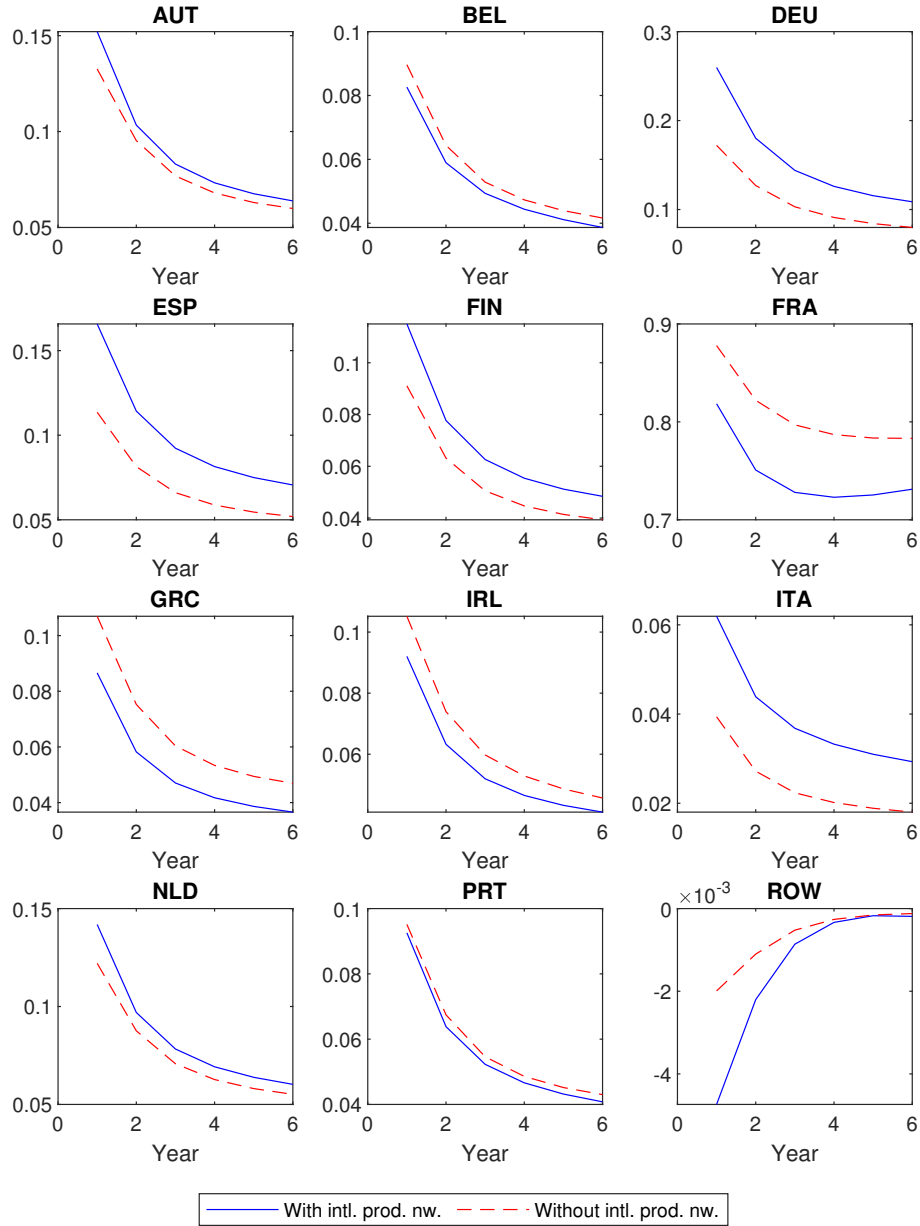I inflation and there is no international production network, and fiscal spending is financed by distortionary labor income tax.

Figure A-14: Fiscal multiplier and fiscal spillover to one percent of GDP increase in French government spending when nominal inter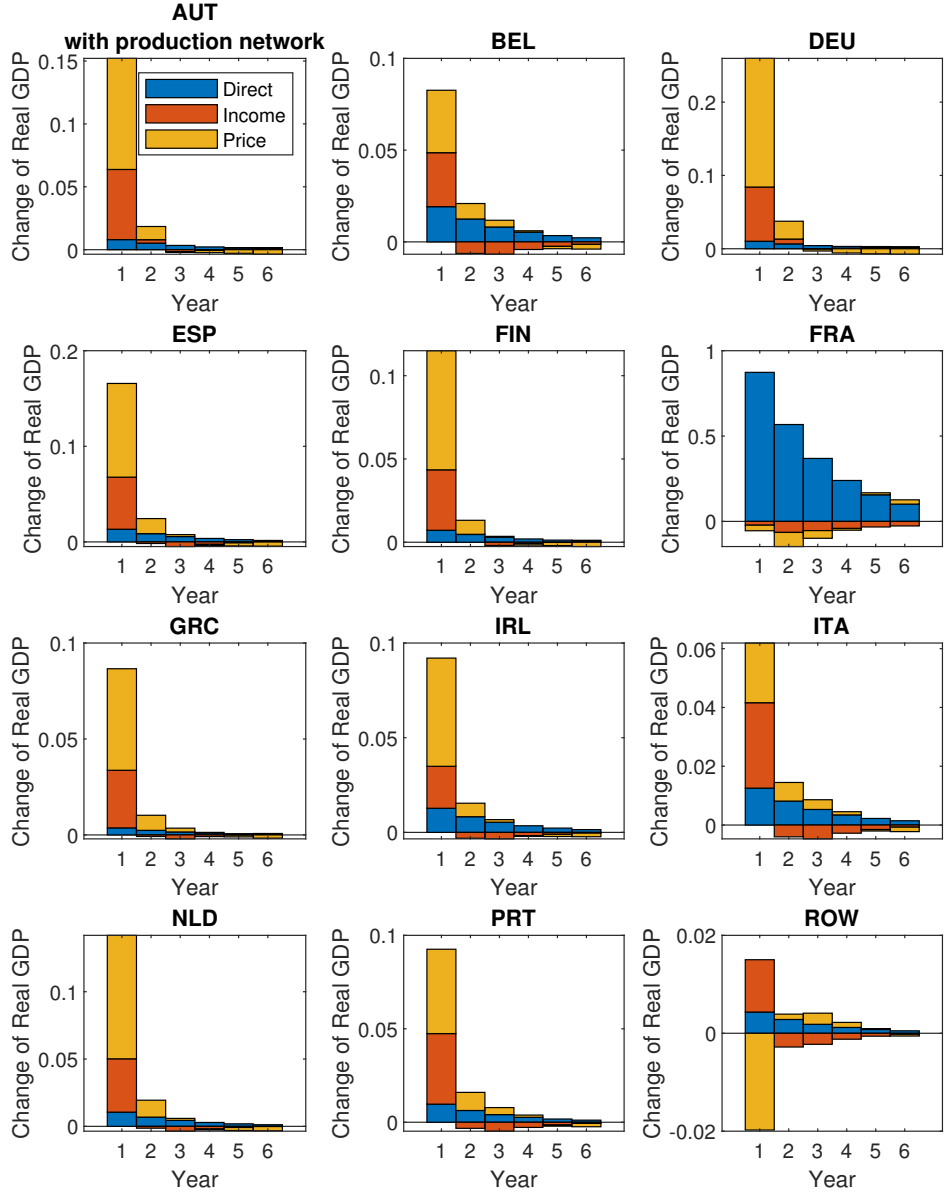est rates are constrained by a lower bound in period 1 and 2, and fiscal spending is financed by distortionary labor income tax.

Figure A-15: GDP response to one percent of GDP increase in German government spending, and three-effect decomposition when nominal interest rates are constrained by a lower bound in period 1 and 2, and fiscal spending is financed by distortionary labor income tax.

Figure A-16: GDP response to one percent of GDP increase in German government spending, and three-effect decomposition when nominal inter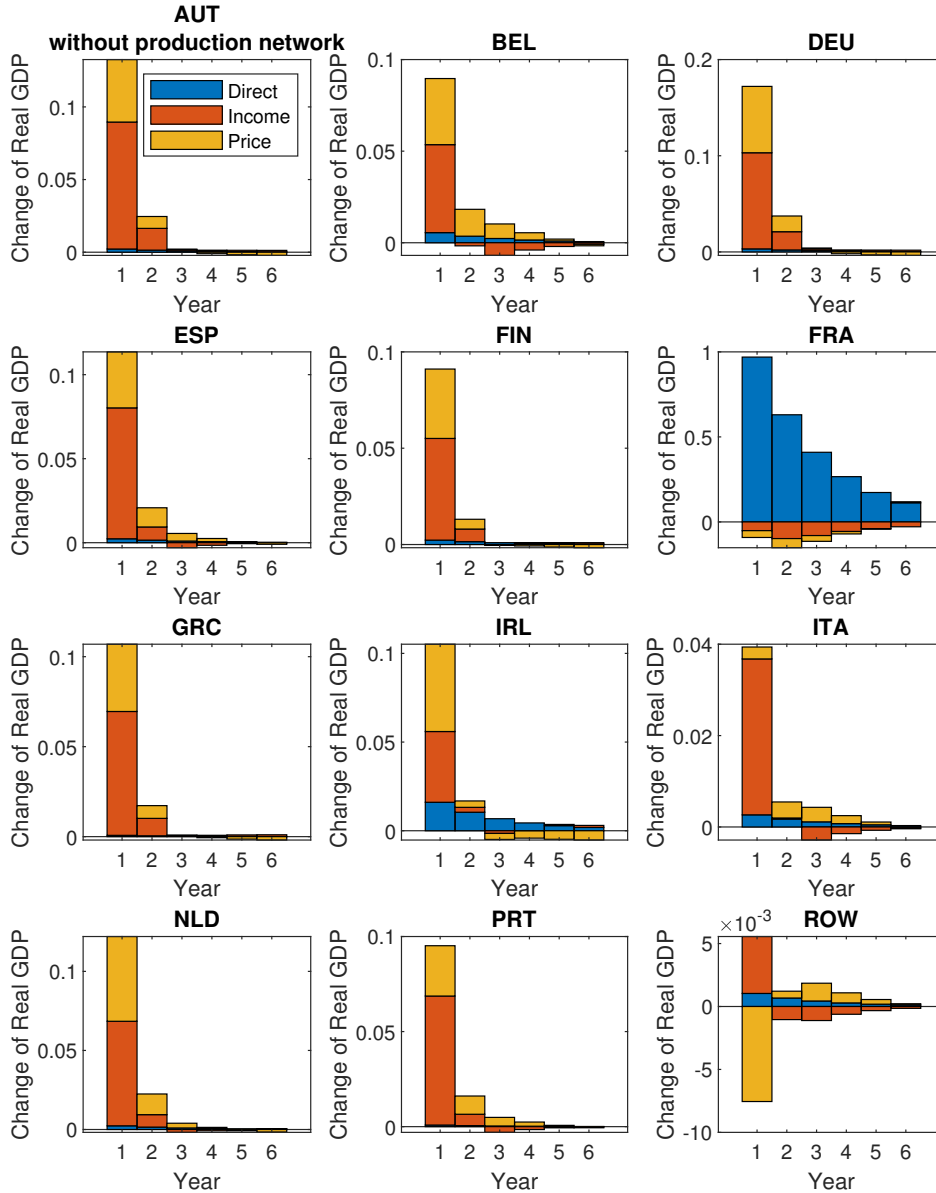est rates are constrained by a lower bound in period 1 and 2, and fiscal spending is financed by distortionary labor income tax, and there is no international production network.
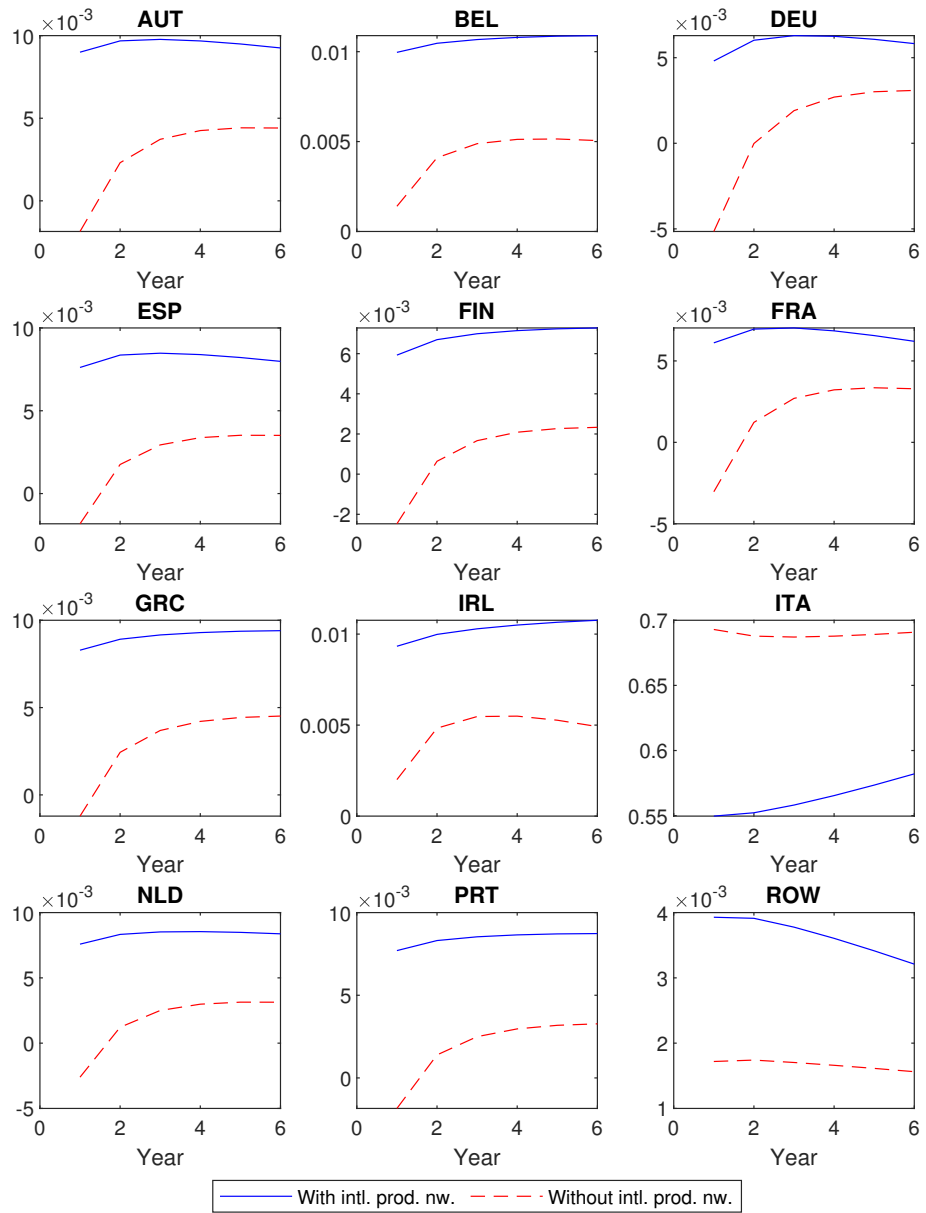
Figure A-17: Fiscal multiplier and fiscal spillover to one percent of GDP increase in French government spending when monetary authorities stabilize CPI inflation.

Figure A-18: GDP response to one percent of GDP increase in French government spending, and three-effect decomposition when monetary authorities stabilize CPI inflation.

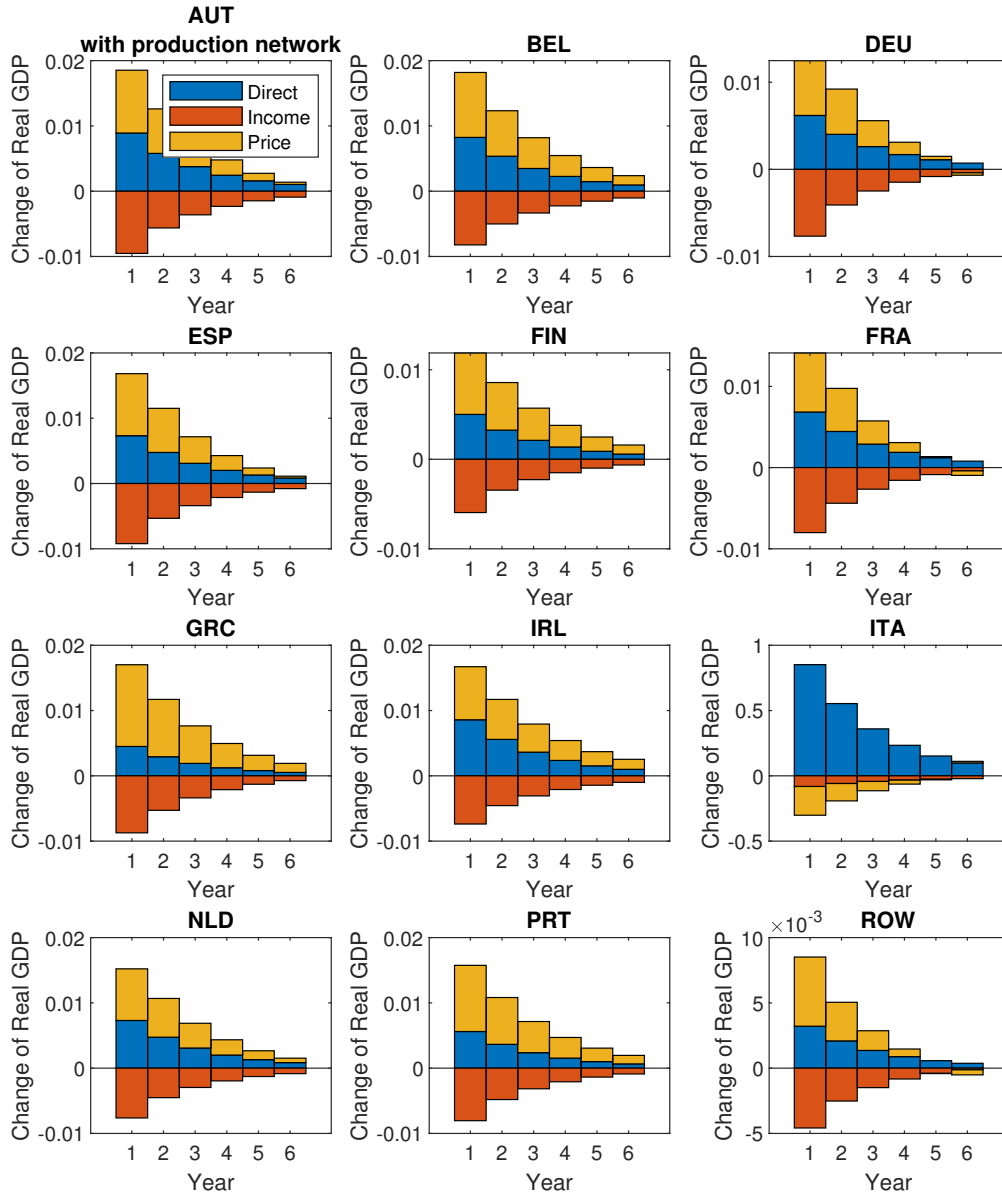Figure A-19: GDP response to one percent of GDP increase in French government spending, and three-effect decomposition when monetary authorities stabilize CPI inflation and there is no international production network.
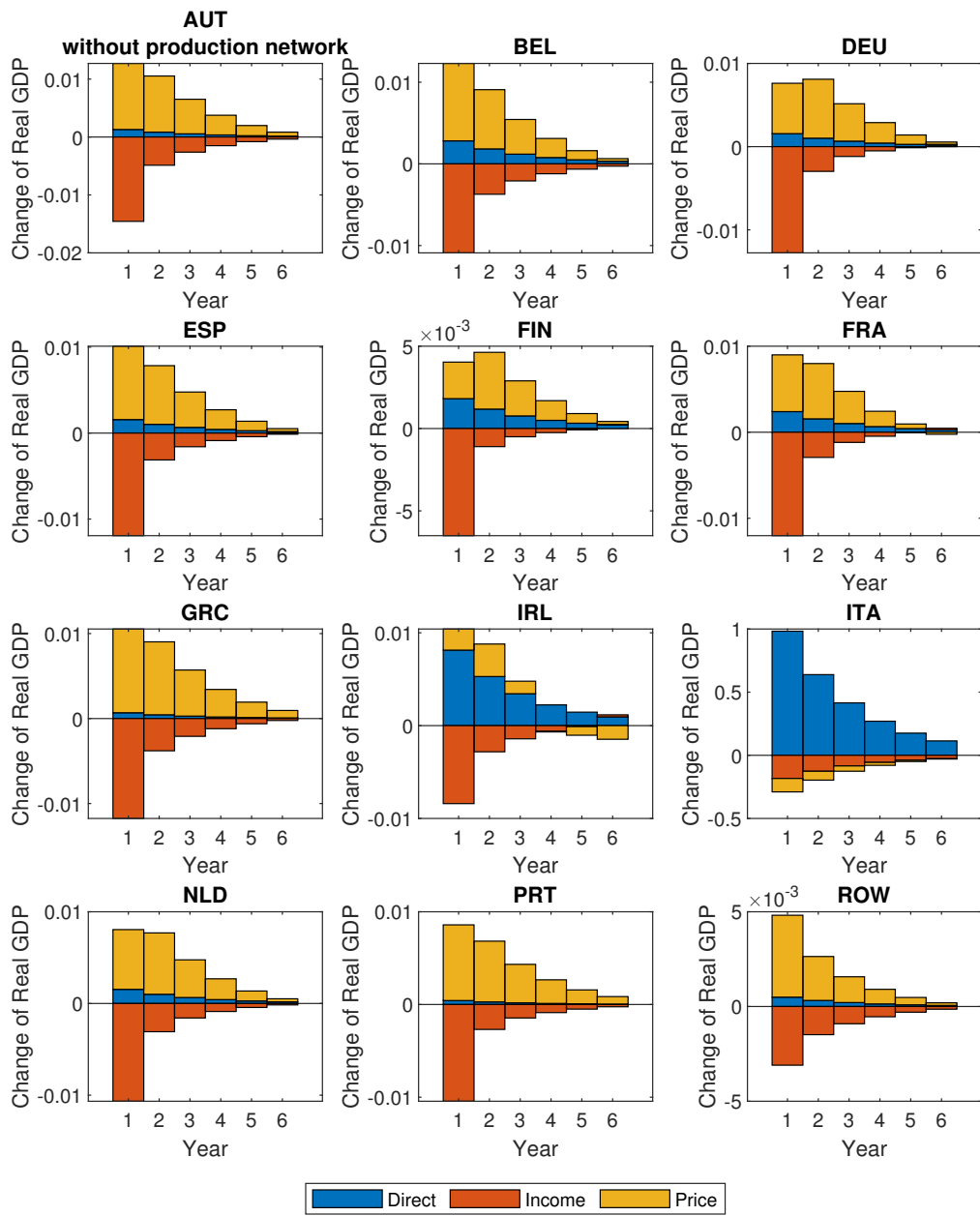
Figure A-20: Fiscal multiplier and fiscal spillover to one percent of GDP increase in French government spending when nominal interest rates are constrained by a lower bound in period 1 and 2.

Figure A-21: GDP response to one percent of GDP increase in French government spending, and three-effect decomposition when nominal interest rates are constrained by a lower bound in period 1 and 2.

Figure A-22: GDP response to one percent of GDP increase in French government spending, and three-effect decomposition when nominal interest rates are constrained by a lower bound in period 1 and 2 and there is no international production network.

Figure A-23: Fiscal multiplier and fiscal spillover to one percent of GDP increase in Italian government spending when monetary authorities stabilize CPI inflation.

Figure A-24: GDP response to one percent of GDP increase in Italian government spending, and three-effect decomposition when monetary authorities stabilize CPI inflation.

Figure A-25: GDP response to one percent of GDP increase in Italian government spending, and three-effect decomposition when monetary authorities stabilize CPI inflation and there is no international production network.
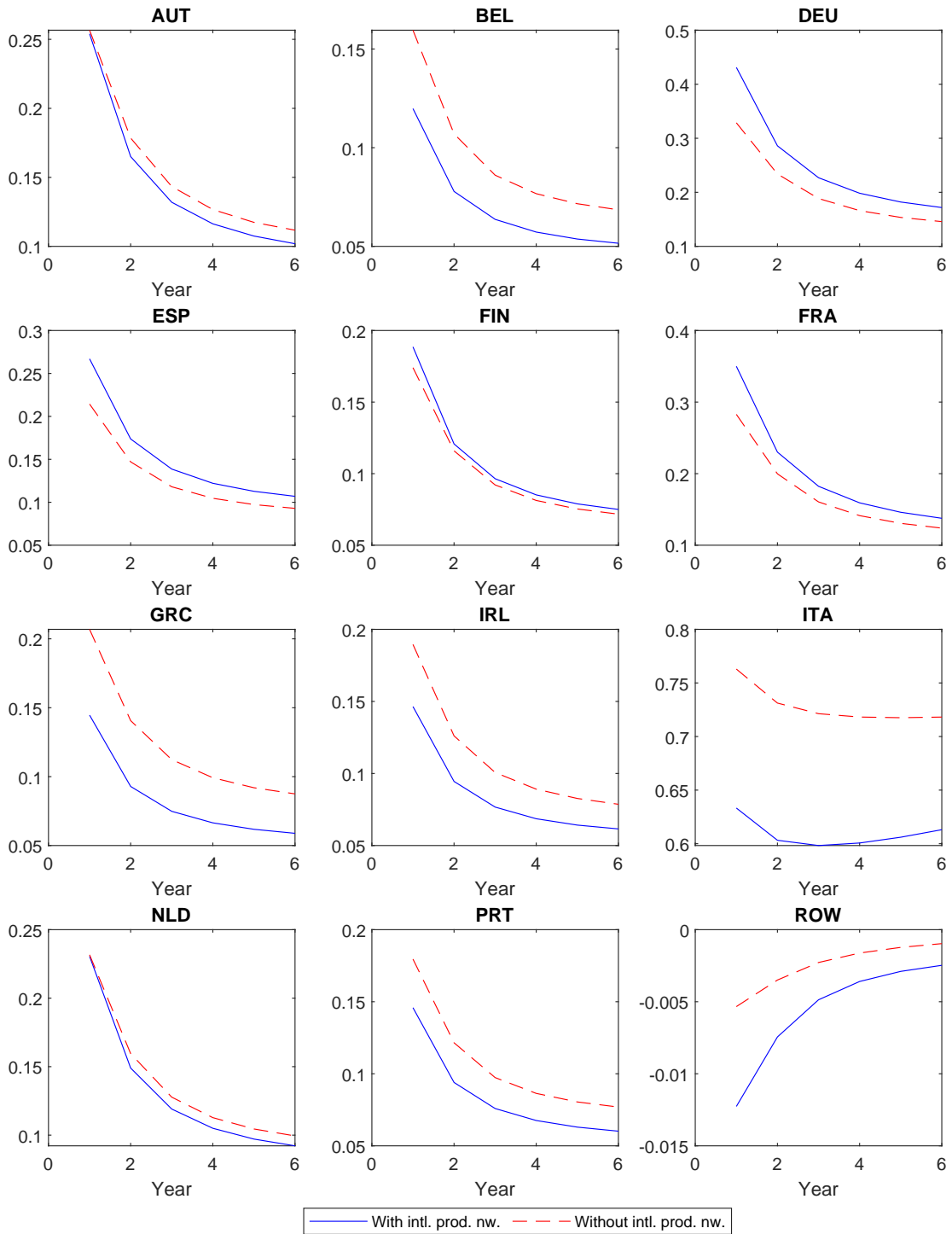
Figure A-26: Fiscal multiplier and fiscal spillover to one percent of GDP increase in Italian government spending when nominal interest rates are constrained by a lower bound in period 1 and 2.
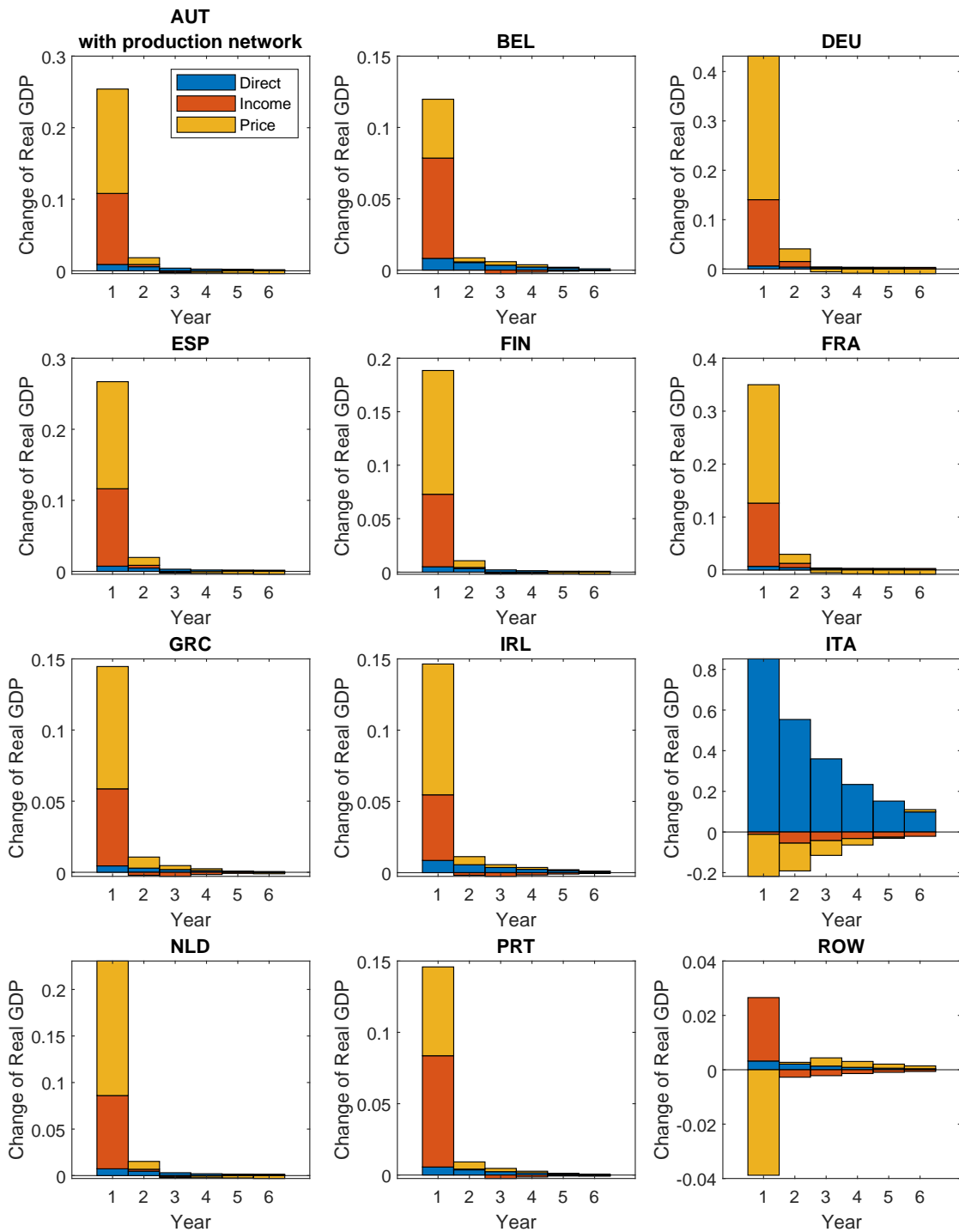
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Figure A-27: GDP response to one percent of GDP increase in Italian government spending, and three-effect decomposition when nominal interest rates are constrained by a lower bound in period 1 and 2.
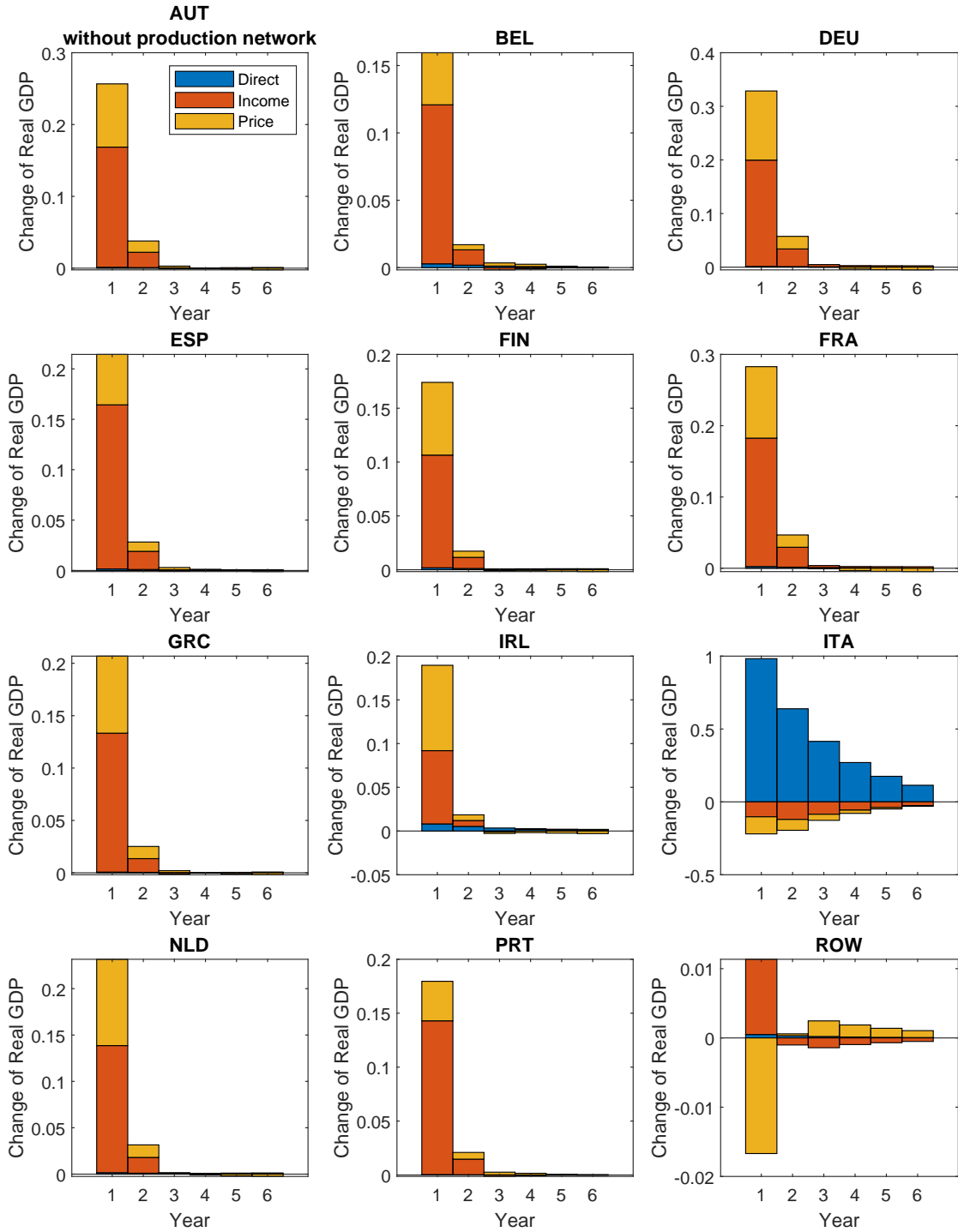
Figure A-28: GDP response to one percent of GDP increase in Italian government spending, and three-effect decomposition when nominal interest rates are constrained by a lower bound in period 1 and 2 and there is no international production network.