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The Sectoral Origins of the Spending Multiplier *

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Abstract

The aggregate spending multiplier crucially depends on the sectoral origin of government purchases. To establish this result, we characterize analytically the response of aggregate output to sector-specific government spending shocks in a tractable production-network economy. The response is larger when government purchases originate in sectors with a relatively small contribution to private final demand and in downstream industries. These findings hinge on the pivotal role of relative-price changes. In the special case where price adjustment is inhibited, the response of aggregate output is invariant to the origin of the spending shock. Using a quantitative multi-sector model, we show that the heterogeneity across U.S. industries translates into significant dispersion in the aggregate spending multiplier associated with sectoral government purchases. Finally, we illustrate how differences in the sectoral composition of purchases across U.S. government levels (i.e., general, federal, and state and local) lead to sizable differences in the spending multiplier.

JEL classification: E62, H32.

Key words: Government Spending Multiplier, Relative Prices, Input-Output Matrix, Sectoral Heterogeneity, Spillover Effects.

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1 Introduction

Government purchases of goods and services from the private sector are heterogeneously distributed across highly diverse industries.[1] This basic observation is largely overlooked by theoretical studies of fiscal policy, which tend to condense the entire economy into a representative sector, and lump government purchases from the different industries into a single aggregate. By construction, the one-sector framework cannot address the role of sectoral characteristics and inter-sectoral linkages in the transmission of government spending shocks. This limitation becomes even more severe when assessing large stimulus plans, which typically target specific industries.

This paper takes a bottom-up approach to study the aggregate implications of sectoral government purchases. A large literature has examined the role of sectoral heterogeneity and production networks in shaping aggregate fluctuations caused by idiosyncratic/sectoral disturbances.[2] Surprisingly, however, little is known about how the aggregate effects of sector-specific government spending shocks map into the intrinsic characteristics of the sector being shocked and its position in the supply chain. We tackle this question both analytically and quantitatively, conveying a central message: the aggregate spending multiplier depends on the sectoral origin of government purchases.

A key contribution of this paper is to derive – in the context of a tractable production-network economy – a formula that characterizes the response of aggregate value added to a sectoral spending shock. Our expression involves the product of two factors pertaining to the sector being shocked: the response of its relative price, and a loading factor, which decreases in the sectoral contribution to private final demand. Crucially, the response of aggregate output is independent of the origin of the shock when relative prices do not adjust.

To highlight the pivotal role of relative-price changes, our model conveniently encompasses situations in which sectoral relative prices adjust, as well as the limiting case considered by Acemoglu et al. (2015), in which relative prices are unresponsive to demand shocks. Acemoglu et al. (2015) show that sectoral government shocks propagate upstream through the production network, from downstream to input-supplying industries, while crowding out private demand from all sectors. Our formula, however, reveals that both the sectors' position in the network and their contribution to private final demand are irrelevant for the response of aggregate output when relative-price adjustment is inhibited. The reason is that price unresponsiveness reflects

[1] The standard deviation of sectoral government purchases is 45 percent larger than that of sectoral value added. The correlation between the sectoral contribution to government purchases and sectoral value added is 0.39. These figures are based on information from the 2018 U.S. Input-Output Tables at the 3-digit level of the North American Industry Classification System (NAICS).

[2] E.g., Long and Plosser (1983), Horvath (1998, 2000), Foerster et al. (2011), Gabaix (2011), Acemoglu et al. (2012), Carvalho (2014), Di Giovanni et al. (2014, 2018), Atalay (2017), and Bigio and La'O (2020).

the fact that sectoral real marginal costs are independent of the demand side of the economy, which makes the allocation of production inputs across the different industries immaterial for aggregate quantities. As a result, the response of aggregate output is invariant to the sectoral origin of spending shocks.

This conclusion need not hold in the empirically relevant scenario in which relative prices adjust. In this case, government spending in a given sector raises its relative price, diverting consumption away from the shocked sector and towards the other industries, whose goods have become relatively cheaper. For a given relative-price change, the magnitude of this channel depends negatively on the shocked sector's contribution to private final demand: as the consumption share of the recipient industry increases – thereby compressing the share of the remaining sectors – a change in its relative price brings about weaker sectoral spillovers and reduces the response of aggregate output.

When relative prices adjust asymmetrically across the recipient industries, the response of aggregate output depends on the origin of the spending shock even for a given contribution to final demand. In particular, aggregate value added reacts more when the government raises its demand for goods from downstream industries. Underlying this result is the way in which the production network shapes the response of sectoral prices: the relative price of the shocked sector rises more when spending originates in a downstream sector than when it originates in an otherwise identical upstream sector. Intuitively, the increase in the price level of an upstream industry is passed through the marginal cost of production – and thus the price level – of its customer (downstream) industries. Therefore, the change in the *relative* price of the upstream sector is dampened. This cost pass-through channel is absent when spending occurs in a downstream sector, so that its relative price exhibits a larger response, *ceteris paribus*.

Assessing the empirical plausibility of our analytical results requires to identify sectoral government spending shocks. Existing identification approaches, however, enable one to estimate the cross-industry effects of sectoral government purchases, but preclude any mapping from sectoral to aggregate elasticities.[3] Consequently, we cannot directly evaluate the implications of our formula for the response of aggregate value added. For this reason, we opt for an indirect test, exploiting the variation in relative prices, which is the necessary condition for the response of aggregate output to depend on the sectoral origin of the shock. Specifically, we build on the empirical approach proposed by Nekarda and Ramey (2011), and test the theoretical prediction that an increase in government spending in a given sector not only raises its relative price, but does so to a larger extent when the recipient industry is located downstream in the production

[3]Typically, sectoral spending shocks are identified in panel settings that include time fixed effects. These time dummies subsume any general-equilibrium force that is common across sectors, such as the response of monetary policy to government spending shocks (e.g., Nakamura and Steinsson, 2014; Chodorow-Reich, 2019, 2020).

chain. Based on a panel of 274 manufacturing industries, we find robust empirical support for this prediction.

We then re-examine our analytical findings within a quantitative multi-sector model that features multiple sources of sectoral heterogeneity and a complex production network, calibrated to 57 industries of the U.S. economy. The main insights from our formula continue to hold in this richer setting. To the extent that prices adjust, the response of the sectoral relative price and the aggregate value-added multiplier are larger when spending shocks originate in sectors with a relatively small contribution to consumption and investment, and in downstream industries.

Having confirmed the main conclusions from our theoretical analysis, we leverage the quantitative model to determine whether the heterogeneity across U.S. industries translates into substantial cross-sectional variation in the aggregate spending multiplier associated with sectoral government purchases. Doing so allows us to quantify the extent to which the aggregate effects of government purchases depend on their sectoral origin, and – by the same token – helps identify the industries associated with a large "bang for the buck". We find significant dispersion in the size of the multiplier, which ranges from 0.19 to 1.20. Overall, the output response is lower when the government buys from upstream industries with a large contribution to investment, like manufacturing and transportation. On the other hand, it is larger when the government raises its demand for goods produced by downstream industries, such as retail trade, and educational and health-care services.

The heterogeneity in the aggregate effects of sector-specific spending shocks implies that the aggregate spending multiplier varies with the sectoral allocation of government purchases. To illustrate this implication and measure its quantitative relevance, we exploit the differences in the sectoral composition of purchases across layers of the U.S. government – general, federal (defense and non-defense), and state and local.[4] While the aggregate value-added multiplier of the general government amounts to 0.74, this figure masks substantial heterogeneity across government levels, ranging from a relatively low value of 0.41 for federal defense spending, to 0.88 for the state and local government. Likewise, we find significant differences in the aggregate consumption multiplier, which is negative (-0.24) for defense spending, but positive (0.14) for the state and local government. This variation is due to the fact that defense spending is concentrated in upstream industries that mostly provide investment goods, whereas state and local government spending is tilted towards downstream sectors. Importantly, these findings contribute to explaining the large dispersion in the empirical estimates of the effects of government spending: studies that rely on federal defense spending tend to report small output multipliers and a crowding-out of consumption (e.g., Barro and Redlick, 2011; Ramey, 2011);

[4]We study otherwise identical versions of the model that only differ in the sectoral composition of government spending. More specifically, we consider different linear combinations of sectoral spending shocks, where the weights replicate the sectoral composition of purchases at each U.S. government level.

instead, measuring spending at the general-government level typically leads to large output multipliers and a crowding-in of consumption (e.g., Blanchard and Perotti, 2002; Auerbach and Gorodnichenko, 2012).

Our paper builds on the large literature that studies the spending multiplier, focusing predominantly on government consumption in the form of purchases of goods and services from the private sector (see Ramey, 2019 for a recent survey). We contribute to this work by proposing a bottom-up approach that maps the aggregate effects of government spending shocks into their sectoral origins. Our results highlight that the spending multiplier is contingent on the sectoral composition of public purchases. In this respect, we complement the strand of the literature that shows that the aggregate effects of government spending are not invariant to considerations such as the financing scheme (e.g., Leeper et al., 2010), the stance of monetary policy (e.g., Christiano et al., 2011), and the state of the economy (e.g., Auerbach and Gorodnichenko, 2012).

Very few papers have examined the effects of government spending within multi-sector models with production networks.[5] In a companion paper (Bouakez et al., 2020), we evaluate the role of sectoral heterogeneity and input-output interactions in amplifying the output effects of an aggregate spending shock relative to the one-sector framework, taking as given the sectoral composition of government purchases. Acemoglu et al. (2015) examine the propagation of sectoral spending shocks via the production network, but their framework inhibits relative-price adjustment, implying that inter-sectoral linkages are irrelevant for the aggregate spending multiplier. Devereux et al. (2019) build on Acemoglu et al. (2015) to study the cross-country spillovers of government spending shocks through international production networks. Dong and Wen (2019) compare the transmission of money injections via the production network with that of sectoral technology and government spending shocks. None of these contributions, however, relates the aggregate spending multiplier to its sectoral origins. An exception is Baqaee and Farhi (2019), who emphasize that the spending multiplier depends on the sectoral composition of government purchases when workers with different marginal propensities to consume are heterogeneously distributed across industries.

Finally, this paper connects to the applied work that studies highly disaggregated public purchases and estimates their effects at the industry/firm level (e.g., Nekarda and Ramey, 2011; Acemoglu et al., 2015; Slavtchev and Wiederhold, 2016; Coviello et al., 2019; Auerbach et al., 2020; Cox et al., 2020; Hebous and Zimmermann, 2020; Kim and Nguyen, 2020). These studies typically adopt identification strategies that difference out the aggregate general-equilibrium effects of sectoral shocks, thus preventing a clear mapping between the estimated cross-industry

[5]The first work on the effects government spending within a multi-sector model is Ramey and Shapiro (1998), which shows that costly capital reallocation across sectors alters the spending multiplier relative to the one-sector framework. This paper, however, abstracts from production networks.

multipliers of government purchases and their aggregate counterparts. Our paper complements this strand of the literature by developing a structural framework that allows to take into account the general-equilibrium interactions shaping the aggregate effects of sector-specific government spending shocks.

The rest of the paper is organized as follows. Section 2 presents a stylized model that yields analytical results about the propagation of sectoral government spending shocks and their effects on aggregate output. Section 3 provides empirical evidence supporting the model's predictions about the response of relative prices to sector-specific spending shocks. Section 4 validates the main insights from the stylized model within a quantitative multi-sector economy. In Section 5, we use the quantitative model to document the differences in the aggregate multiplier implied by the sectoral composition of purchases across the different levels of the U.S. government. Section 6 concludes.

2 The Aggregate Effects of Sectoral Government Spending in a Stylized Model

The purpose of this section is to characterize analytically the aggregate effects of sectoral government spending, relating them to the attributes of the sector in which spending originates and to its position in the production network. To this end, we develop a stylized flexible-price model with two inter-connected sectors that use labor and intermediate inputs to produce, and sell goods both to consumers and to the government. The two sectors are heterogeneous along two dimensions. First, they differ in their contribution to private final demand, as they are characterized by different sectoral shares in aggregate consumption. Second, they differ in their position in the production network. To capture this feature in a tractable and parsimonious way, we consider an upstream sector, denoted by u, which supplies all the intermediate inputs used by both sectors, and a downstream sector, denoted by d, which demands intermediate inputs, but provides none. We focus on these sectoral characteristics because they prove to be the most pertinent factors accounting for the cross-sectional heterogeneity in the aggregate effects of sectoral government spending in the context of a highly disaggregated multi-sector model of the U.S. economy, as we show in the quantitative analysis of Section 4.[6]

The model allows for imperfect labor mobility across sectors, and nests the limiting case in which labor is perfectly mobile. The degree of labor mobility has crucial implications for the adjustment of sectoral relative prices to changes in government spending, which in turn has an important bearing on the results.

Because the model has no endogenous state variable, it can be solved period by period.

[6]The structure of the model is graphically summarized by Figure A.1 in Appendix A.

Thus, we drop the time subscript in the remainder of this section.

2.1 The environment

2.1.1 Households

The representative household has a utility function that is logarithmic in consumption, C, and linear in total labor, N:

$$u(C,N) = \log C - \theta N, \qquad \theta > 0. \tag{1}$$

The linearity of the utility function with respect to labor means that the latter is indivisible, as in Hansen (1985), which in turn implies that the Frisch elasticity of labor supply is infinite.

To allow for imperfect labor mobility across sectors, we follow Huffman and Wynne (1999), Horvath (2000), and Bouakez et al. (2009), and posit that the total amount of labor provided by the household is a CES function of the labor supplied to each sector, that is,[7]

$$N = \left[\omega_{N,u}^{-\frac{1}{\nu_N}} N_u^{\frac{1+\nu_N}{\nu_N}} + \omega_{N,d}^{-\frac{1}{\nu_N}} N_d^{\frac{1+\nu_N}{\nu_N}}\right]^{\frac{\nu_N}{1+\nu_N}}, \tag{2}$$

where $\omega_{N,u} + \omega_{N,d} = 1$, with $\omega_{N,s}$ being the weight attached to labor provided to sector s ($s = u, d$), and ν_N denotes the elasticity of substitution of labor across sectors. This specification nests the special case in which $\nu_N \to \infty$, so that labor is perfectly mobile and, as a result, nominal wages are equalized across sectors. Under fully flexible prices, this also implies that sectoral relative prices are unresponsive to demand shocks. Instead, as long as $\nu_N < \infty$, labor is imperfectly mobile and sectoral wages and relative prices can differ.[8]

The household's supply of labor to sector s is given by

$$N_s = \omega_{N,s}\left(\frac{W_s}{W}\right)^{\nu_N} N, \qquad s = u, d, \tag{3}$$

where W_s denotes the nominal wage in sector s, and $W = \left[\omega_{N,u} W_u^{1+\nu_N} + \omega_{N,d} W_d^{1+\nu_N}\right]^{\frac{1}{1+\nu_N}}$ is the aggregate nominal wage index, which satisfies $W_u N_u + W_d N_d = WN$.

The household pays a nominal lump-sum tax, T, to the government, so that its budget

[7]Note that this assumption does not contradict labor indivisibility, as one can think of the representative household as a family consisting of two members, each working in a different sector.

[8]Empirically, imperfect labor mobility across sectors is certainly a more plausible characterization of the labor market than perfect mobility. Lee and Wolpin (2006) find that labor adjusts very sluggishly in response to shocks, and is reallocated imperfectly across sectors in the short and medium run. Moreover, Krueger and Summers, (1988), Gibbons and Katz (1992), and Neumuller (2015), among others, document large sectoral wage differentials. Finally, Katayama and Kim (2018) show that imperfect labor mobility provides a better account of the comovement between output and hours worked than alternative explanations based on the wealth effects associated with labor supply.

constraint is given by

$$PC + T = WN, \tag{4}$$

where P denotes the consumption-price index.

2.1.2 Firms

Producers In each sector, there is a representative producer that uses the following Cobb-Douglas technology:

$$Z_s = {N_s}^{1-\alpha_H} {H_{s,u}}^{\alpha_H}, \qquad s = u, d, \tag{5}$$

where Z_s is the gross output of producer s, N_s is its use of labor, and $H_{s,u}$ denotes the intermediate inputs it buys from sector u. The parameter $\alpha_H \in [0, 1]$ measures the gross-output-based intensity of intermediate inputs.

The production of the two sectors is sold as final goods both to a representative consumption-good retailer and to the government. The goods produced by the upstream sector are also sold as intermediate inputs to producers in both industries. This yields the following market-clearing conditions at the sectoral level:[9]

$$Z_u = C_u + G_u + H_{u,u} + H_{d,u}, \tag{6}$$

$$Z_d = C_d + G_d, \tag{7}$$

where C_s denotes the retailer's purchase of consumption goods from sector s, and G_s denotes government purchases from sector s.

Consumption-good retailers A representative consumption-good retailer purchases goods from each sector and assembles them into a consumption bundle sold to households. Its technology is given by

$$C = C_u^{\omega_{C,u}} C_d^{\omega_{C,d}}, \tag{8}$$

where $\omega_{C,u} + \omega_{C,d} = 1$, with $\omega_{C,s}$ being the consumption share of sector s. The retailer's optimal demand for the good produced by sector s is

$$C_s = \omega_{C,s} \left(\frac{P_s}{P} \right)^{-1} C, \qquad s = u, d, \tag{9}$$

where P_s denotes the nominal price of the good produced in sector s. The zero-profit condition of the consumption-good retailer implies that $P = \omega_{C,u}^{-\omega_{C,u}} \omega_{C,d}^{-\omega_{C,d}} P_u^{\omega_{C,u}} P_d^{\omega_{C,d}}$.

[9] These market-clearing conditions reflect the assumption that the input-output matrix has a column of ones and a column of zeros, as the upstream sector provides intermediates inputs to itself and to the downstream sector, whereas the latter provides none. This structure is the most parsimonious way to allow for differences in the sectors' positions in the production network while holding constant all the remaining sectoral attributes.

2.1.3 Government

Government purchases from the two sectors are exogenously determined and are financed through lump-sum taxes paid by the household, which implies the following budget constraint for the government:

$$P_u G_u + P_d G_d = T. \tag{10}$$

2.1.4 Aggregation and auxiliary assumptions

Defining $Q_s \equiv \frac{P_s}{P}$ as the real price of the good produced by sector s, real value added in this sector is obtained by subtracting the real cost of the intermediate inputs it uses from the real value of its gross output:

$$Y_s = Q_s Z_s - Q_u H_{s,u}, \qquad s = u, d. \tag{11}$$

By consolidating the household's and government's budget constraints, one can then express aggregate real value added as

$$Y \equiv Y_u + Y_d = C + Q_u G_u + Q_d G_d. \tag{12}$$

To solve the model, we log-linearize the equilibrium conditions around a non-stochastic steady state that features two convenient properties. First, sectoral nominal wages are equal. This property, which we obtain by equating the sectoral weights $\omega_{N,s}$ to the steady-state ratios of sectoral to total labor, N_s^*/N^*, ensures that versions of the model with different degrees of labor mobility share the same steady state.[10] Second, we assume that the two sectors contribute equally to total public spending in the steady state, by imposing that $Q_u^* G_u^*/Y^* = Q_d^* G_d^*/Y^*$. While it would be straightforward to extend the model (and results) to allow for different steady-state sectoral contributions to total government spending, we abstract from this source of sectoral heterogeneity because – as we show in Section 4 – it turns out to be quantitatively irrelevant in accounting for differences in the aggregate effects of sectoral spending shocks, *ceteris paribus*.

Based on the log-linear model, we derive analytical results regarding the propagation of sectoral government spending shocks and their aggregate effects, which we relate to the characteristics of the sector being shocked and its position in the network. In the remainder of this section, lowercase variables denote percentage deviations of their uppercase counterparts from their steady-state values.

[10] Steady-state variables are denoted by an asterisk. Appendix A reports the list of non-linear equilibrium conditions, the steady-state equilibrium, and the log-linearized equations.

2.2 Own and spillover effects of sectoral spending shocks

Substituting the sectoral market-clearing conditions (6) and (7) into the definition of sectoral real value added (11), and exploiting the optimal-demand equations for intermediate inputs (Equations A.10–A.13 in Appendix A), leads – after log-linearization – to the following expressions for y_u and y_d:

$$y_u = \frac{\gamma}{2\left(1-\left(1-\alpha_H\right)\mu_d\right)} g_u + \frac{\left(1-\gamma\right)\omega_{C,u}}{1-\left(1-\alpha_H\right)\mu_d} c_u + \frac{\alpha_H \mu_d}{1-\left(1-\alpha_H\right)\mu_d} h_{d,u} + q_u, \tag{13}$$

$$y_d = \frac{\gamma}{2\mu_d} g_d + \frac{\left(1-\gamma\right)\omega_{C,d}}{\mu_d} c_d + q_d, \tag{14}$$

where γ is the steady-state share of total government spending in aggregate value added, and $\mu_d = \left(1-\gamma\right)\omega_{C,d} + \frac{\gamma}{2}$ is the steady-state contribution of sector d to total final demand. Equation (13) states that changes in the value added of the upstream sector reflect changes in government demand, g_u, consumer demand, c_u, demand for intermediate inputs from the downstream sector, $h_{d,u}$, as well as changes in the relative price, q_u. Equation (14) provides an analogous decomposition of the downstream sector's value added, which reflects the fact that no inputs are supplied to the upstream sector.

It is instructive to decompose the change in aggregate value added resulting from a sectoral government spending shock into the change in the value added of the sector in which the shock has originated – the *own effect* – and the change in the value added of the other sector – the *spillover effect*. Based on the expressions above, it can be shown that

$$\frac{dy}{dg_u} = \underbrace{\frac{\gamma}{2} + \left(1-\gamma\right)\omega_{C,u}\frac{dc_u}{dg_u} + \alpha_H\mu_d\frac{dh_{d,u}}{dg_u} + \frac{dq_u}{dg_u}}_{\text{own effect}} + \underbrace{\left(1-\gamma\right)\left(1-\alpha_H\right)\omega_{C,d}\frac{dc_d}{dg_u} + \frac{dq_d}{dg_u}}_{\text{spillover effect}},$$

$$\frac{dy}{dg_d} = \underbrace{\frac{\gamma}{2}\left(1-\alpha_H\right) + \left(1-\gamma\right)\left(1-\alpha_H\right)\omega_{C,d}\frac{dc_d}{dg_d} + \frac{dq_d}{dg_d}}_{\text{own effect}} + \underbrace{\left(1-\gamma\right)\omega_{C,u}\frac{dc_u}{dg_d} + \alpha_H\mu_d\frac{dh_{d,u}}{dg_d} + \frac{dq_u}{dg_d}}_{\text{spillover effect}}.$$

These expressions show that changes in relative prices affect the own and spillover effects associated with sectoral spending shocks both directly, through the valuation of sectoral production, and indirectly, through their influence on the demand from consumers and intermediate-good users.

Absent relative-price adjustment, the change in the consumption of a given good only reflects the resource-constraint effect, that is, the fall in consumption resulting from the increase in the tax burden required to finance the increase in government spending. In fact, it is straightforward to show that consumption changes by the same percentage in both sectors (and so does

aggregate consumption), regardless of their position in the network.[11] On the other hand, higher government demand for the good produced by the downstream sector generates higher demand for intermediate goods from the upstream sector, whereas spending shocks originating in the upstream sector do not generate any spillover via the production network. This upstream propagation of spending shocks through the network was first highlighted by Acemoglu et al. (2015). As we show below in Section 2.3, however, input-output linkages are irrelevant for the response of aggregate value added when relative prices do not adjust.

When relative prices change, both the own and spillover effects are modified in a way that matters for the response of aggregate value added. In what follows, we dissect these effects by characterizing the response of relative prices, sectoral consumption, and demand for intermediate inputs following a change in sectoral government purchases. In Section 2.3, we show how these different channels collapse into a simple expression that relates the aggregate output effect of a spending shock in a given sector to the response of that sector's relative price.

2.2.1 The response of relative prices to sectoral spending shocks

Proposition 1 below shows how relative prices respond to sectoral government spending shocks.

Proposition 1 *Sectoral government spending shocks have no effect on relative prices if labor is perfectly mobile. Under imperfect labor mobility, an increase in government spending in a given sector raises its relative price and lowers the relative price of the other sector, regardless of the sectors' positions in the network. That is, for* $s, x = u, d$ *and* $s \neq x$,

$$\begin{aligned} \frac{dq_s}{dg_s} &= \frac{dq_s}{dg_x} = 0 \quad \textit{if } \nu_N \to \infty, \\ \frac{dq_s}{dg_s} &> 0 \quad \textit{and} \quad \frac{dq_s}{dg_x} < 0 \quad \textit{otherwise.} \end{aligned}$$

Proof. See Appendix A. ■

Under perfect labor mobility, sectoral nominal wages are equalized across sectors. In this case, the assumptions of price flexibility and constant returns to scale in the sectoral production functions imply that relative prices are independent of the demand side of the economy, and are therefore unresponsive to government spending shocks, as is also shown by Acemoglu et al. (2015). When labor is imperfectly mobile, however, an increase in spending in a given sector

[11] In the general case where the Frisch elasticity of labor supply is finite, the (sectoral and aggregate) consumption response to spending shocks is strictly negative when relative prices do not adjust. Our simplifying assumption of an infinite Frisch elasticity implies that aggregate consumption only depends on the aggregate real wage and is unrelated to labor. Under this condition, the resource-constraint effect vanishes and, absent changes in relative prices, consumption remains unchanged in response to a spending shock in either sector. Abstracting from the resource-constraint effect greatly simplifies the algebra without altering our conclusions. The assumption of infinite Frisch elasticity of labor supply is relaxed in the quantitative analysis presented in Section 4.

raises its real wage and, in turn, its relative price. In this respect, assuming imperfect mobility of labor inputs between sectors allows us to consider the empirically relevant case in which relative prices respond to demand shocks, in the spirit of Ramey and Shapiro (1998).

2.2.2 The response of consumption to sectoral spending shocks

When relative prices adjust, the response of sectoral consumption reflects an expenditure-switching effect whereby consumption is diverted away from the more expensive good and towards the cheaper good. This channel is summarized in the proposition below.

Proposition 2 *Sectoral government spending shocks have no effect on sectoral (and aggregate) consumption if labor is perfectly mobile. Under imperfect labor mobility, an increase in government spending in a given sector lowers the consumption of the good produced by that sector and raises the consumption of the good produced by the other sector. That is, for* $s, x = u, d$ *and* $s \neq x$,

$$\begin{aligned} \frac{dc_s}{dg_s} &= \frac{dc_s}{dg_x} = 0 \quad \textit{if } \nu_N \to \infty, \\ \frac{dc_s}{dg_s} &< 0 \quad \textit{and} \quad \frac{dc_s}{dg_x} > 0 \quad \textit{otherwise.} \end{aligned}$$

Proof. See Appendix A. ■

Everything else constant, the expenditure-switching motive mitigates the own effect and reinforces the spillover effect of sectoral government spending shocks. It is important to emphasize, however, that the existence of this channel is independent of the network; it operates even in the absence of input-output linkages. Section 2.2.3 establishes the role of network linkages in the transmission of government spending shocks.

2.2.3 The response of the demand for intermediate goods to sectoral spending shocks

Proposition 3 shows how the demand for intermediate inputs by the downstream sector is affected by sectoral government spending shocks.

Proposition 3 *A government spending shock originating in the upstream sector has no effect on the demand for intermediate goods by the downstream sector if labor is perfectly mobile. Under imperfect labor mobility, an increase in government spending in the upstream sector lowers the demand for intermediate goods by the downstream sector. That is,*

$$\begin{aligned} \frac{dh_{d,u}}{dg_u} &= 0 \quad \textit{if } \nu_N \to \infty, \\ \frac{dh_{d,u}}{dg_u} &< 0 \quad \textit{otherwise.} \end{aligned}$$

In addition, a government spending shock originating in the downstream sector generates a larger increase in its demand for intermediate goods under imperfectly mobile labor than under perfect labor mobility. That is,

$$\left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N<\infty} > \left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N\to\infty} > 0.$$

Proof. See Appendix A. ■

Let us first focus on the implications of a government spending shock in the upstream sector. Under perfect labor mobility, relative prices remain constant, such that an increase in government purchases from the upstream sector does not induce any change in the demand for intermediate goods by the downstream sector. Under imperfect labor mobility, the relative price of the upstream sector rises, inducing producers in the downstream sector to cut their use of intermediate inputs.[12] Everything else equal, this channel mitigates the own effect of shocks originating in the upstream sector.

An increase in government spending in the downstream sector, instead, raises the demand for intermediate goods, even absent changes in relative prices. However, the magnitude of this upstream propagation of government spending is strengthened by the behavior of relative prices, *ceteris paribus*. Under imperfect labor mobility, the relative price of the downstream sector increases, raising further the demand for intermediate goods, whose relative price has fallen.

2.3 Determinants of the aggregate output effects of sectoral spending shocks

As stated above, sectors u and d in our stylized economy differ only along two dimensions: their contribution to private consumption and their position in the production network. The purpose of the subsequent analysis is to determine how the aggregate output response to spending shocks originating in a given sector depends on these two attributes.

2.3.1 A sufficient-statistic formula

The response of aggregate output to a sectoral spending shock depends on the balance of its own and spillover effects, which are ultimately shaped by the adjustment of sectoral relative prices. We exploit this insight to derive a sufficient-statistic formula that maps the response of aggregate value added into the response of the relative price of the sector being shocked. Proposition 4 states the result.

[12] To meet the higher consumer demand for their goods, induced by the fall in their relative price, producers in the downstream sector substitute labor for intermediate inputs. In other words, the output of the downstream sector rises despite the fall in the use of intermediate inputs.

Proposition 4 *The response of aggregate value added to a spending shock in sector s is given by*

$$\frac{dy}{dg_s} = \frac{\gamma}{2} + \varkappa_s \frac{dq_s}{dg_s}, \tag{15}$$

where $\varkappa_s = \frac{\gamma(2-\gamma)\left(\frac{1}{2}-\omega_{C,s}\right)}{1-\omega_{C,s}}$ *for* $s = u, d$.

Proof. See Appendix A. ■

Equation (15) shows that the response of aggregate value added to a spending shock originating in sector s can be fully characterized by the product of two sector-specific sufficient statistics: a loading factor, $\varkappa_s$, which depends negatively on the sector's consumption share, $\omega_{C,s}$, and the response of its relative price. The formula highlights the pivotal role of relative-price adjustment, which is a necessary condition for the response of aggregate output to depend on the sectoral origin of the shock.

Below, we show how the response depends on the consumption share of the recipient sector and its position in the network. In both comparative-static exercises, we highlight the importance of relative-price adjustment. Given that at the disaggregation level considered in the quantitative part of the paper, no sector is large enough to represent half of the economy, we hereafter focus on the case in which the consumption share of the sector being shocked is smaller than one half (i.e., $\omega_{C,s} < \frac{1}{2}$, with s denoting the sector being shocked).[13]

2.3.2 On the role of the sectoral consumption share

To isolate the role of the sectoral consumption share, we abstract from the use of intermediate inputs (i.e., we set $\alpha_H = 0$), thus neutralizing input-output linkages between the two sectors. Equation (15) shows that the consumption share affects the response of aggregate value added both directly – through $\varkappa_s$ – and indirectly – through the response of the relative price of the shocked sector. The proposition below shows how the latter depends on the sector's share in aggregate consumption. Since we know from Proposition 1 that this response is nil under perfect labor mobility, we only focus on the case of imperfect labor mobility.

Proposition 5 *Consider a spending shock in sector s. Under imperfect labor mobility, the response of the relative price of sector s is decreasing in its consumption share. That is, for $s = u, d$,*

$$\frac{\partial\left(\frac{dq_s}{dg_s}\right)}{\partial \omega_{C,s}} \quad < \quad 0 \quad \text{if } \nu_N < \infty.$$

Proof. See Appendix A. ■

[13] Note, however, that our main result, stated in Proposition 8, holds even when the consumption share of the shocked sector is strictly lager than $\frac{1}{2}$.

The intuition behind this result can be easily understood from the discussion in subsection 2.2. To the extent that relative prices change, government purchases from a given sector raise its relative price and reduce consumer demand for the good it produces. Hence, value added decreases more in the sector with the highest consumption share. This, in turn, mitigates the increase in its relative price.

The proposition below states the result regarding the relationship between the response of aggregate value added to a spending shock in a given sector and that sector's share in total consumption.

Proposition 6 *Consider a spending shock in sector s. The response of aggregate value added is independent of the consumption share of sector s when labor is perfectly mobile, and is decreasing in it when labor is imperfectly mobile. That is, for $s = u, d$,*

$$\begin{aligned} \frac{\partial \left(\frac{dy}{dg_s}\right)}{\partial \omega_{C,s}} &= 0 \quad \textit{if } \nu_N \to \infty, \\ \frac{\partial \left(\frac{dy}{dg_s}\right)}{\partial \omega_{C,s}} &< 0 \quad \textit{otherwise.} \end{aligned}$$

Proof. See Appendix A. ■

As the consumption share of the sector being shocked increases – thus compressing the share of the other sector – a given change in its relative price triggers weaker inter-sectoral spillovers, leading to a smaller response of aggregate value added. This response if further mitigated by the reaction of the shocked sector's relative price, which decreases in $\omega_{C,s}$, as enunciated in Proposition 5. Under perfect labor mobility, prices do not move and there is no expenditure switching, thus implying that the response of aggregate value added is independent of the consumption share of the affected sector.

2.3.3 On the role of the production network

Equation (15) shows that the mapping from the response of the relative price to that of aggregate value added is isomorphic across sectors. In particular, the formula does not attribute an explicit role to trade in intermediate inputs. Does this mean that the production network is irrelevant for the response of aggregate value added? The answer is no, as long as the relative price of the affected sector responds asymmetrically depending on whether it is located upstream or downstream. The proposition below shows how the production network affects the response of sectoral relative prices in the relevant case of imperfect labor mobility.

Proposition 7 *Consider a sectoral spending shock. Under imperfectly mobile labor, the relative price of the shocked sector rises more when spending originates in the downstream sector than*

when it originates in the upstream sector, for a given sectoral consumption share. That is,

$$\left.\frac{dq_d}{dg_d}\right|_{\omega_{C,d}=\omega} > \left.\frac{dq_u}{dg_u}\right|_{\omega_{C,u}=\omega} \quad \text{if } \nu_N < \infty.$$

Proof. See Appendix A. ■

Intuitively, the increase in the price level of a good produced by the upstream industry is passed through the marginal cost of production in the downstream sector, which contributes to raising its price level. As a result, the change in the *relative* price of the upstream sector is dampened. This cost pass-through channel is absent when spending occurs in the downstream sector, so that its relative prices exhibits a larger response, *ceteris paribus*.

Proposition 8 below fleshes out the role of the network in shaping the response of aggregate value added to sectoral government spending shocks.

Proposition 8 *Consider a sectoral spending shock. For a given consumption share, the response of aggregate value added is (i) independent of the origin the shock if labor is perfectly mobile, and (ii) strictly larger when the shock originates in the downstream sector than when it originates in the upstream sector, if labor is imperfectly mobile. That is,*

$$\begin{aligned}
\left.\frac{dy}{dg_d}\right|_{\omega_{C,d}=\omega} &= \left.\frac{dy}{dg_u}\right|_{\omega_{C,u}=\omega} && \text{if } \nu_N \to \infty, \\
\left.\frac{dy}{dg_d}\right|_{\omega_{C,d}=\omega} &> \left.\frac{dy}{dg_u}\right|_{\omega_{C,u}=\omega} && \text{otherwise.}
\end{aligned}$$

Proof. See Appendix A. ■

Consider first the case of perfect labor mobility. Because the upstream sector does not use intermediate goods, absent any change in its relative price, a 1 percent increase in government purchases from that sector increases its value added by $\frac{\gamma}{2}$ percent. On the other hand, a 1 percent increase in spending on the good produced by the downstream sector translates into a $\frac{\gamma}{2}(1-\alpha_H)$ percent increase in its value added, while the output of the upstream sector rises by $\frac{\gamma}{2}\alpha_H$ percent. Thus, aggregate value added responds identically across the two shocks. Critical to this result is the assumption of constant returns to scale in production which – under equal sectoral *nominal* wages – induces sectoral relative prices to be unresponsive to demand shocks. As a consequence, sectoral *real* wages are equalized, such that the allocation of labor across the different industries is immaterial for aggregate quantities.

This is no longer the case, however, under imperfect labor mobility. For a given sectoral consumption share, the rise in the relative price is larger when spending originates in the downstream sector, as established in Proposition 7. In turn, this generates larger inter-sectoral spillovers, which translate into a larger increase in aggregate output.

To sum up, the production network matters for the aggregate effects of sectoral spending shocks, but only indirectly through the way it shapes the response of sectoral relative prices. Input-output linkages are irrelevant at the aggregate level when relative prices do not respond to the shocks. Given the pivotal role of relative-price adjustment, the next section provides empirical support for our theoretical predictions along this dimension. Section 4 then re-examines the main insights from our sufficient-statistic formula (15) in the context of a quantitative multi-sector model.

3 Empirical Evidence

In this section, we test our theoretical predictions in the data. We cannot directly evaluate the implications of our sufficient-statistic formula for the response of aggregate value added, as existing approaches to identify sectoral government spending shocks cannot back out their aggregate effects. These methods identify government spending shocks by saturating the regressions with time fixed effects, which absorb any general-equilibrium force that is common across sectors (e.g., Nakamura and Steinsson, 2014; Chodorow-Reich, 2019, 2020). For this reason, the estimated partial-equilibrium cross-industry elasticities do not map into their aggregate counterparts. Thus, we opt for an indirect test, exploiting the variation in relative prices, which is the necessary condition for the response of aggregate output to depend on the sectoral origin of the shock. Specifically, we test the prediction that an increase in government spending in a given sector not only raises its relative price, but does so to a larger extent when the recipient industry is located downstream in the production chain, as stated in Proposition 7.

We build on the approach proposed by Nekarda and Ramey (2011), and use their dataset merging the Bureau of Economic Analysis (BEA) Input-Output tables with the NBER-CES Manufacturing database. This allows us to construct an annual panel of relative prices, shipments, and government defense spending across 274 U.S. industries, from 1958 to 2005. To rank the sectors' positions in the production network, we construct the Katz-Bonacich measure of centrality for each industry.[14] According to this measure, more central industries are those located upstream in the network, supplying most of the intermediate inputs to the other industries. Instead, sectors with low levels of centrality are mainly users of intermediate inputs and are therefore located downstream.

[14]The vector of Katz-Bonacich centralities c is computed as

$$\mathbf{c} = \frac{\alpha_H}{S} \left(\mathbf{I} - \alpha_H \mathbf{W}'\right)^{-1} \mathbf{1},$$

where α_H is the average gross-output intensity of intermediate inputs, S is the number of sectors, $\mathbf{I}$ is a diagonal matrix, $\mathbf{W} = \{\omega_{H,s,x}\}_{s,x=1}^{S}$ characterizes the Input-Output matrix of economy, and $\mathbf{1}$ is a vector of ones.

Using the constructed series, we estimate the following regression:

$$\Delta \log Q_{s,t} = \beta_1 \Delta \log \tilde{G}_{s,t} + \beta_2 \left(\Delta \log \tilde{G}_{s,t} \times \text{Centrality}_s \right) + \beta_3 \Delta \log Q_{s,t-1} + \delta_s + \delta_t + \epsilon_{s,t}, \quad (16)$$

where the dependent variable, $\Delta \log Q_{s,t}$, is the log-change in the relative price of sector s, measured as either the sectoral gross-output or value-added deflator, divided by the aggregate value-added deflator, $\Delta \log \tilde{G}_{s,t}$ is the defense spending shock in sector s, $\Delta \log \tilde{G}_{s,t} \times \text{Centrality}_s$ is a term that interacts the spending shock in sector s with its centrality. The regression also includes lagged values of the sectoral relative price, as well as sector fixed effects, δ_s, and year fixed effects, δ_t.

Since sectoral defense purchases, $G_{s,t}$, could depend on the economic conditions of the recipient industry, we identify the sectoral shocks by assuming that the allocation of aggregate defense spending across sectors remains constant over time. Specifically, we closely follow Nekarda and Ramey (2011) and Acemoglu et al. (2015) by constructing the series of defense spending shocks as

$$\Delta \log \tilde{G}_{s,t} = \theta_s \times \Delta \log G_t, \quad (17)$$

where G_t is the aggregate series of real defense spending, and θ_s is the sample average of the ratio between sectoral defense spending in sector s and sectoral total shipments, $Z_{s,t}$, that is

$$\theta_s = \frac{1}{T} \sum_{t=1}^{T} \frac{G_{s,t}}{Z_{s,t}}. \quad (18)$$

While the common practice of using military spending as a proxy for government expenditure relies on the premise that the U.S. do not embark in a war because national value added is low (Barro and Redlick, 2011; Ramey, 2011), our approach implies a much weaker identifying condition, by requiring that the U.S. do not embark in a war when the output of a given sector – and thus its relative price – is lower than that of all the other industries.

In this setting, the coefficient β_1 denotes the elasticity of the relative price of sector s – relative to the elasticity of the relative prices of all the other industries – to a 1 percent increase in real defense spending in sector s. The coefficient β_2 measures the extent to which the response of the relative price of sector s is larger if that sector is located downstream. Based on the theoretical predictions, we therefore expect β_1 to be positive and β_2 to be negative.

Table 1 reports the estimation results based on our two alternative measures of the relative price. In each case, we consider a basic regression that excludes the interaction term, and one that corresponds exactly to equation (16). Starting with the results based on the gross-output deflator, Column (1) shows that the basic regression yields a positive and statistically significant estimate of β_1 (0.08). When we allow the government spending shock to interact with centrality, in Column (2), we obtain a larger estimate of β_1 (0.16) and a negative and

Table 1: The Response of Relative Prices and Centrality in the Data.

	Sectoral Gross-Output Deflator		Sectoral Value-Added Deflator	
	(1)	(2)	(3)	(4)
$\Delta \log \tilde{G}_{s,t}$	0.08**	0.16*	0.07**	0.16*
	(0.04)	(0.09)	(0.04)	(0.09)
$\Delta \log \tilde{G}_{s,t} \times \text{Centrality}_s$		-0.58*		-0.56*
		(0.33)		(0.33)
$\Delta \log Q_{s,t-1}$	0.11***	0.11***	0.12***	0.12***
	(0.03)	(0.03)	(0.03)	(0.03)
Industry Fixed Effect	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES
R^2	0.34	0.34	0.34	0.34
N. Obs.	12,536	12,536	12,536	12,536

Notes: The table reports the estimates of a panel regression across 274 U.S. manufacturing industries using annual data from 1958 to 2005. In Columns (1) and (2), the dependent variable is the log-change in the sectoral gross-output deflator. In Columns (3) and (4), the dependent variable is the log-change in the sectoral value-added deflator. In all regressions, the independent variables are the log-change in sectoral government spending, $\Delta \log \tilde{G}_{s,t}$, its interaction with sector centrality, $\Delta \log \tilde{G}_{s,t} \times \text{Centrality}_s$, the lagged values of the sectoral relative prices, as well as sector and year fixed effects. We closely follow Nekarda and Ramey (2011) and Acemoglu et al. (2015) by constructing the series of defense spending shocks as $\Delta \log \tilde{G}_{s,t} = \theta_s \times \Delta \log G_t$, where G_t is aggregate government spending, and θ_s is the the sample average of the ratio between sectoral defense spending and sectoral total shipments. Standard errors clustered at the sector level are reported in parentheses.

statistically significant estimate of β_2 (-0.58). The corresponding results based on the value-added deflator, reported in Columns (3) and (4), respectively, are extremely similar. These results imply that an exogenous increase in government spending in a given sector not only raises its relative price, but does so to a larger extent when the recipient industry is located downstream in the production chain, in accordance with the theoretical predictions.

4 Quantitative Analysis

The stylized model considered in Section 2 provides sharp insights into how the response of aggregate value added to sector-specific government spending shocks depends on the intrinsic characteristics of the sector being shocked and its position in the supply chain. The analyt-

ical tractability of the stylized model, however, requires abstracting from certain features – including other dimensions of sectoral heterogeneity – that might be empirically relevant for the propagation of government spending and their aggregate effects. In this section, we develop a quantitative highly disaggregated multi-sector model that allows for multiple sources of sectoral heterogeneity and a complex production network.

The purpose of the quantitative model, which we calibrate to the U.S. economy, is threefold. The first is to confirm that the analytical results based on the stylized model continue to hold in a richer and more realistic setting. The second is to identify the sector-specific characteristics that are quantitatively relevant in accounting for the heterogeneity in the response of aggregate value added across sector-specific government spending shocks. The third is to document the dispersion in the response of aggregate value added to sectoral shocks, and identify the industries that are associated with a sizable "bang for the buck".

4.1 A quantitative multi-sector model

We consider a New Keynesian economy with S production sectors, inter-connected through an Input-Output matrix. The model incorporates several dimensions of sectoral heterogeneity, as industries differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to consumption, investment, and government purchases. Households accumulate physical capital, which they rent to firms, and producers face price-setting frictions that give rise to nominal price stickiness. Both features make the model dynamic in nature.

We describe below the key distinctive features of the economy (relative to the stylized model), and refer to Appendix B for a thorough discussion of its structure. The parameter restrictions under which the multi-sector model nests exactly the one presented in Section 2 are specified in Appendix B.5.[15]

4.1.1 Households

We alter household preferences in three ways. First, the representative household receives utility not only from private consumption but also from the sum of government purchases from all sectors, where the two arguments enter the utility function in a non-separable manner, as in Bouakez and Rebei (2007).[16] Second, we allow the elasticity of intertemporal substitution to be different from 1 by adopting a general CRRA function (over total consumption) rather

[15]The structure of the model is graphically summarized by Figure B.1 in Appendix B.

[16]As we show in Bouakez et al (2020), assuming that private and public consumption spending are complements is helpful to generate aggregate spending multipliers that are in line with those reported in the empirical literature. In Appendix D, however, we show that this feature mainly exerts a level effect, as there is close-to-perfect correlation between the aggregate spending multipliers implied by the models with and without complementarity.

than a logarithmic one. Third, we relax the assumption of linear disutility of labor, allowing the Frisch elasticity to be finite. We also assume that the representative household trades one-period nominal bonds. In each period, the household purchases investment goods, which increase the undepreciated stock of capital subject to convex adjustment costs.

As in the stylized model, we allow for imperfect labor mobility across sectors by assuming that total labor is given by:

$$N_t = \left[\sum_{s=1}^{S} \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}}\right]^{\frac{\nu_N}{1+\nu_N}}, \tag{19}$$

where $\sum_{s=1}^{S} \omega_{N,s} = 1$. Analogously, we assume that the total capital stock supplied by the representative household, K_t, is a CES aggregator of the capital stocks it rents to all the sectors, with ν_K being the elasticity of substitution of capital across sectors, and $\omega_{K,s}$ denoting the weight attached to the capital provided to sector s, such that $\sum_{s=1}^{S} \omega_{K,s} = 1$. As is the case for labor, this assumption allows capital to be imperfectly mobile across sectors, consistently with its sluggish reallocation across industries over the business cycle (e.g., Lanteri, 2018).[17]

4.1.2 Production

The production process is split in two stages. A continuum of monopolistically competitive producers, indexed by $j \in [0,1]$, combine labor, capital, and a bundle of intermediate inputs to produce differentiated varieties of goods. These varieties are then aggregated into a single good in each sector by a representative perfectly competitive wholesaler.

Producer j in sector s has the following Cobb-Douglas production technology:

$$Z_{s,t}^{j} = \left(N_{s,t}^{j}{}^{\alpha_{N,s}} K_{s,t}^{j}{}^{1-\alpha_{N,s}}\right)^{1-\alpha_{H,s}} H_{s,t}^{j}{}^{\alpha_{H,s}}, \tag{20}$$

where $Z_{s,t}^{j}$ denotes gross output, and $N_{s,t}^{j}$, $K_{s,t}^{j}$, and $H_{s,t}^{j}$ denote labor, capital, and the bundle of intermediate inputs used by the producer. The parameters $\alpha_{N,s}$ and $\alpha_{H,s}$ are the value-added-based labor intensity and the gross-output-based intensity of intermediate inputs, respectively. Producers face price-setting frictions, such that they can reset their prices according to a Calvo-type mechanism, with ϕ_s being the sector-specific probability of not changing prices.

The representative wholesaler in sector s aggregates (using a CES technology) the different varieties supplied by the producers into a single final good, $Z_{s,t}$, which is then sold to consumption-good, investment-good, and intermediate-input retailers, as well as to the fiscal

[17] Miranda-Pinto and Young (2019) show that a model with imperfect mobility of capital across industries can fit well both the volatility of aggregate output and the comovement of sectoral output.

authority. Thus, the following market-clearing condition holds for sector s:

$$Z_{s,t} = C_{s,t} + I_{s,t} + \sum_{x=1}^{S} H_{x,s,t} + G_{s,t}, \tag{21}$$

where $C_{s,t}$ and $I_{s,t}$ denote, respectively, the retailers' purchases of consumption and investment goods from the wholesaler of sector s, $H_{x,s,t}$ denotes the intermediate inputs produced by sector s and used in the production of sector x, and $G_{s,t}$ denotes government purchases from sector s.

4.1.3 Consumption-good, investment-good, and intermediate-input retailers

The consumption-good retailer differs from that of the stylized model in that the elasticity of substitution of consumption across sectors is allowed to be non-unitary. More specifically, we assume that

$$C_t = \left[\sum_{s=1}^{S} \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C - 1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C - 1}}, \tag{22}$$

where ν_C is the elasticity of substitution of consumption across sectors, and $\omega_{C,s}$ denotes the weight of good s in the consumption bundle, such that $\sum_{s=1}^{S} \omega_{C,s} = 1$. Analogously, we consider a representative investment-good retailer, which assembles the aggregate investment good, I_t, that is then sold to the household. In this case, the elasticity of substitution is ν_I, while the sectoral weights are denoted by $\omega_{I,s}$.

Finally, a representative intermediate-input retailer assembles the goods supplied by the wholesalers of all sectors into a bundle of intermediate inputs destined exclusively to the producers of a specific sector. The representative intermediate-input retailer that sells exclusively to sector s produces the bundle $H_{s,t}$ using the CES technology

$$H_{s,t} = \left[\sum_{x=1}^{S} \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H - 1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H - 1}}, \tag{23}$$

where $H_{s,x,t}$ is the quantity of goods purchased from the wholesaler of sector x, ν_H is the elasticity of substitution of intermediate inputs across sectors, and $\omega_{H,s,x}$ is the weight of the intermediate inputs produced by sector x in the total amount of intermediate inputs used by firms in sector s, such that $\sum_{x=1}^{S} \omega_{H,s,x} = 1$.

4.1.4 Government

The government consists of a monetary and a fiscal authority. The monetary authority sets the nominal interest rate following a standard Taylor rule that responds to aggregate inflation and the aggregate output gap. The fiscal authority purchases goods from each sector. The amount

of government spending in sector s is governed by the following auto-regressive process:

$$\log G_{s,t} = (1-\rho)\log G_s^* + \rho \log G_{s,t-1} + \upsilon_{s,t}, \tag{24}$$

where $\rho \in (0,1)$ measures the persistence of the process. Sectoral government spending changes over time following the realizations of the unique source of uncertainty in the model: sectoral government spending shocks, $\upsilon_{s,t}$, which are zero-mean innovations. As in the stylized model, government purchases are financed through lump-sum taxes paid by the households.

4.2 Calibration

We calibrate the model to the U.S. economy, assuming that it consists of $S = 57$ sectors, which roughly correspond to the 3-digit level of the NAICS code list.[18] Throughout the analysis, we assume that one period in the model corresponds to a quarter. In what follows, we describe the calibration of the parameters that govern sectoral heterogeneity and interaction in the model, as well as those characterizing the exogenous process of government spending. Appendix C describes the calibration of the remaining parameters.

We set the elasticity of substitution of consumption across sectors to $\nu_C = 2$, in line with the estimates reported by Hobijn and Nechio (2019) based on the 2-digit and 3-digit levels of disaggregation of the expenditure categories included in the calculation of the Harmonized Index of Consumer Prices. The same value is assigned to the elasticity of substitution of investment across industries, i.e., $\nu_I = 2$. We set the elasticity of substitution of intermediate inputs across sectors following the estimates of Barrot and Sauvagnat (2016), Atalay (2017), and Boehm et al. (2019), who find a strong degree of complementarity across industries, and do not reject the hypothesis that the aggregator of intermediate inputs is a Leontief function. Accordingly, we set $\nu_H = 0.1$.

We calibrate the sectoral weights $\omega_{C,s}$, $\omega_{I,s}$, and $\omega_{H,s,x}$ using the information of the Input-Output Tables of the U.S. economy provided by the BEA. The consumption weights, $\omega_{C,s}$, target the average contribution of each sector to personal consumption expenditures over the period 1997-2015. Analogously, the investment weights, $\omega_{I,s}$, and the intermediate-input weights, $\omega_{H,s,x}$, target the average contribution of each sector to nonresidential private fixed investment in structures and in equipment, and the average use of intermediate inputs from sector x in the production of sector s, respectively.[19] The joint calibration of $\omega_{C,s}$, $\omega_{I,s}$, and $\omega_{H,s,x}$ allows the model to match the sectoral shares in private final demand.

To set the factor intensities, $\alpha_{N,s}$ and $\alpha_{H,s}$, we use information from the Input-Output Tables on value added, labor compensation, and use of intermediate inputs. More specifically, we posit

[18] The list of sectors is reported in Appendix C.

[19] The calibration of the sectoral weights is conditional on the values of the elasticities ν_C, ν_I, and ν_H.

that the gross output of each sector equals the sum of the compensation of employees, the gross operating surplus, and the cost of intermediate inputs.[20] Since we consider a constant-return-to-scale Cobb-Douglas production function for gross output, we can compute $\alpha_{H,s}$ as the sectoral share of intermediate inputs in gross output (net of the share accrued to the markup). Analogously, we set $\alpha_{N,s}$ as the sectoral share of the compensation of employees in value added. To assign values to the sectoral Calvo probabilities, ϕ_s, we match our sectors with the items/industries analyzed by Nakamura and Steinsson (2008) and Bouakez et al. (2014), and rely on their estimates of the sectoral durations of price spells to back out the values of ϕ_s.

Following Horvath, we set the elasticity of substitution of labor across sectors to $\nu_N = 1$.[21] Analogously, we set the elasticity of substitution of capital across sectors to $\nu_K = 1$. We calibrate the weights $\omega_{N,s}$ and $\omega_{K,s}$ such that the model features identical real wages and rental rates of capital across sectors in the steady state. To do so, we set $\omega_{N,s} = \frac{N_s^*}{N^*}$ and $\omega_{K,s} = \frac{K_s^*}{K^*}$.

We normalize total government spending such that it sums up to 20 percent of aggregate value added in the steady state. Finally, we set the autoregressive parameter of the sectoral processes of government spending to $\rho = 0.90$, and calibrate the steady-state sectoral government purchases, G_s^*, using information from the Input-Output Tables on the average contribution of each industry to general government purchases.

4.3 On the role of the sectoral characteristics: counterfactual experiments

We start by evaluating the way in which a government spending shock in a given sector affects the response of its relative price and aggregate value added, depending on that sector's characteristics. Since our sufficient-statistic formula implies that the response of aggregate output is larger when the spending shock occurs in sectors with a relatively small contribution to private final demand and those located downstream, we study the role of the consumption weight, $\omega_{C,s}$, investment weight, $\omega_{I,s}$, and position in the network (i.e., centrality). In addition, we examine the role of two other sources of sectoral heterogeneity from which we have abstracted in the stylized model: the steady-state sectoral level of public spending, G_s^*, and the sectoral degree of price stickiness, ϕ_s. The latter is of particular interest, given that it fares prominently in the literature on the aggregate implications of demand shocks. For instance, several contributions have emphasized the importance of sectoral heterogeneity in price stickiness in amplifying the aggregate effects of monetary and fiscal policy shocks (e.g., Carvalho, 2006; Nakamura and Steinsson, 2010; Bouakez et al., 2014; Bouakez et al., 2020; Cox et al. 2020).

[20] We leave out taxes and subsidies from the computation of gross output.

[21] Our calibration choice for ν_N and ν_K implies a larger extent of labor and capital reallocation across sectors than in the case where these inputs are either firm- or sector-specific (e.g., Matheron, 2006; Altig et al., 2011; Carvalho and Nechio, 2016).

To take into consideration the dynamic nature of the response of aggregate value added to spending shocks, we henceforth follow the standard practice of measuring this response as a multiplier, which we compute as the present-value change in aggregate output resulting from a dollar increase in government purchases from a given sector (e.g., Uhlig, 2010). That is, for a spending shock originating in sector s, the aggregate value-added multiplier is given by[22]

$$\mathcal{M}_{G_s} = \frac{\sum_{j=0}^{\infty} \beta^j \left(Y_{t+j} - Y^*\right)}{\sum_{j=0}^{\infty} \beta^j \left(Q_{s,t} G_{s,t+j} - Q_s^* G_s^*\right)}, \qquad s = 1, \ldots, S. \tag{25}$$

We perform counterfactual simulations by computing the spending multiplier in a sequence of model versions that allow for one dimension of sectoral heterogeneity at a time, while imposing symmetry in all the remaining sectoral attributes. In doing so, we consider the scenarios of perfect and imperfect labor and capital mobility across sectors. The scatter plots relating the response of the sectoral relative price and the aggregate multiplier to the sectoral characteristics are depicted in Figures 1 and 2.

Under perfectly mobile labor and capital, a sector's contribution to consumption, investment, and government spending, as well as its degree of centrality, are irrelevant for the response of its relative price (which is nil) and for the aggregate spending multiplier. When we allow for heterogeneity in price stickiness, the sectoral relative price and the aggregate multiplier, albeit not constant, are barely sensitive to the sectoral degree of price rigidity.

Under imperfect factor mobility, instead, the model predicts that an increase in spending in a given sector raises its relative price. Moreover, the aggregate spending multiplier strongly correlates with the response of the relative price, except when conditioning on the degree of price rigidity. Heterogeneity in price rigidity also appears to be quantitatively irrelevant in this case: while the sectoral Calvo probabilities span almost the entire range of possible values, the response of the sectoral price varies from 0.01 to 0.03 percent, while the aggregate multiplier varies from 0.69 to 0.74. Furthermore, the responses of the sectoral relative price and aggregate value added are flat over most of the spectrum of the sectoral Calvo probabilities.[23]

Figures 1 and 2 also indicate that both the response of the sectoral relative price and the aggregate value-added multiplier are larger when spending shocks originate in sectors with relatively small consumption and investment weights, and in sectors located downstream in the production network. These findings corroborate the analytical results discussed in Section 2,

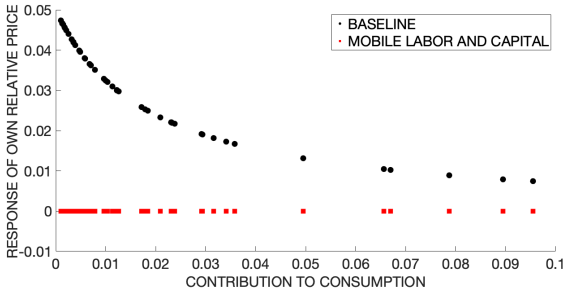
[22]Thus, the effects quantified in this section correspond to those of an additional dollar spent by the government, whereas those discussed in the analytical results are those of an additional unit of good purchased by the government.

[23]In a companion paper (Bouakez et al., 2020), we show that heterogeneity in the sectoral degree of price rigidity raises the size of the aggregate multiplier relative to an economy with a common average duration of prices across industries. Hence, this dimension of sectoral heterogeneity acts mainly as a level shifter, but has little bearing on the heterogeneity in the spending multipliers associated with sector-specific shocks.

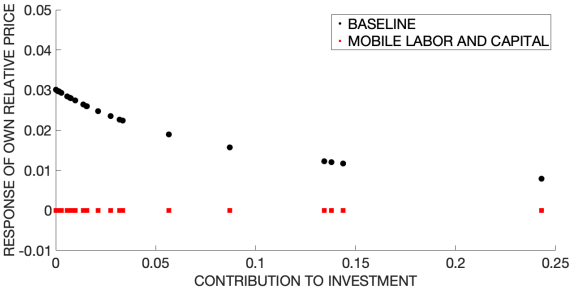
Figure 1: Role of Sectoral Characteristics.

Sectoral Relative Price

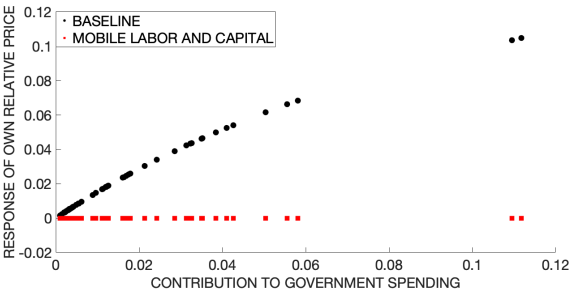
(a) Contribution to Consumption



(c) Contribution to Investment

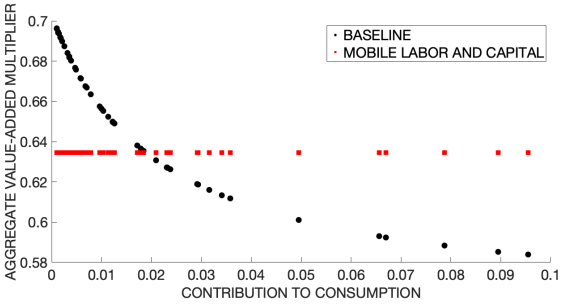


(e) Contribution to Government Spending

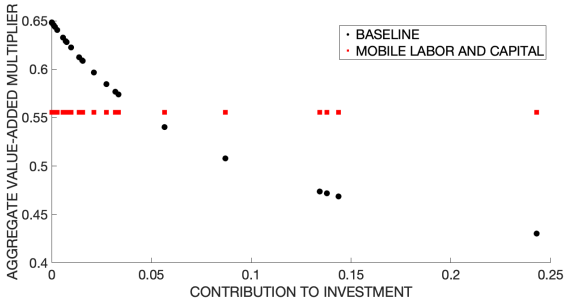


Aggregate Value-Added Multiplier

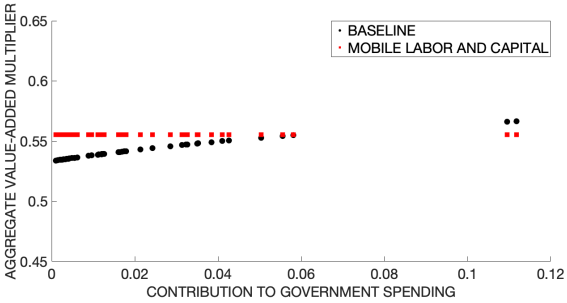
(b) Contribution to Consumption



(d) Contribution to Investment

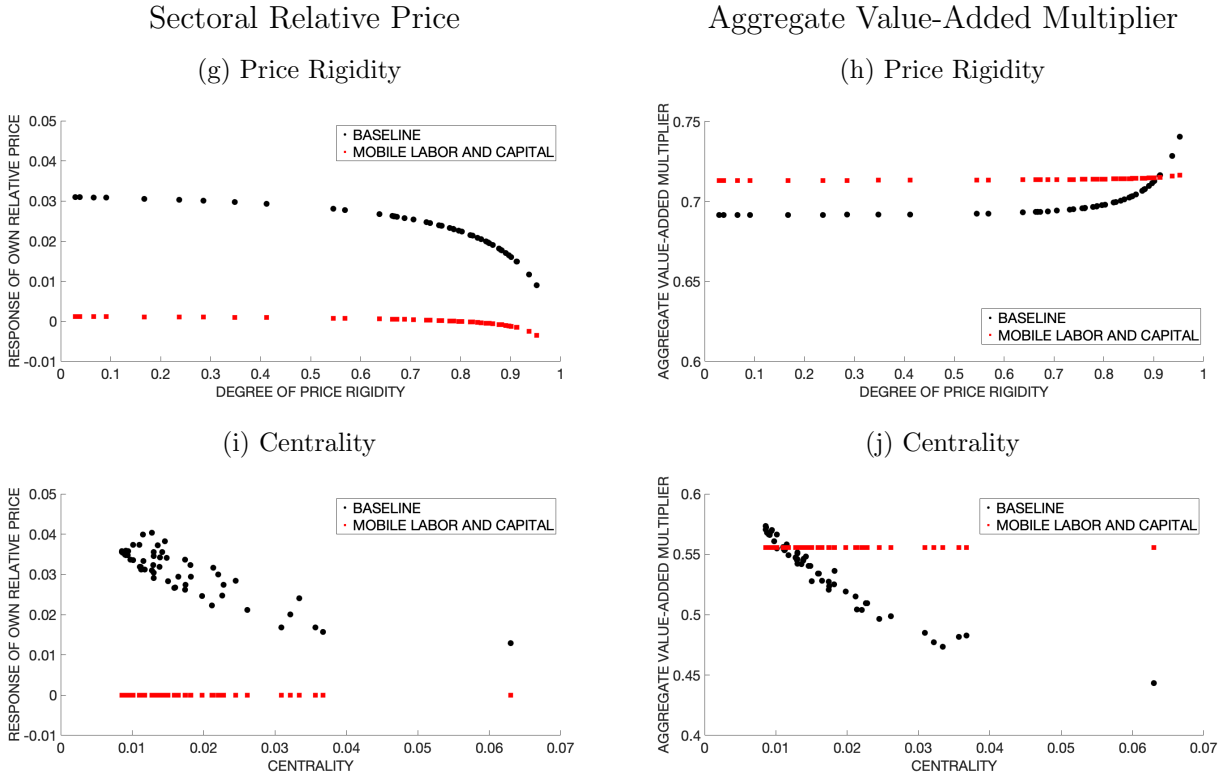


(f) Contribution to Government Spending



Notes: The figure reports the cumulative relative price response (left column) and the aggregate value-added multiplier (right column) in three counterfactual economies in which we allow for one dimension of sectoral heterogeneity at a time, while imposing symmetry in all the remaining sectoral attributes. The dimensions we consider are: the consumption weight ($\omega_{C,s}$) in Panels a and b, the investment weight ($\omega_{I,s}$) in Panels c and d, and the steady-state sectoral government purchases (G_s^*) in Panels e and f. In the two latter cases, the x-axis reports the steady-state sectoral shares in total government spending, $\frac{Q_s^* G_s^*}{\sum_{x=1}^{S} Q_x^* G_x^*}$. We consider both a scenario of perfect mobility of labor and capital (red squares), as well as one of imperfect mobility (black dots). Each dot/square represents one of the 57 sectors of the economy.

Figure 2: Role of Sectoral Characteristics (Cont.).



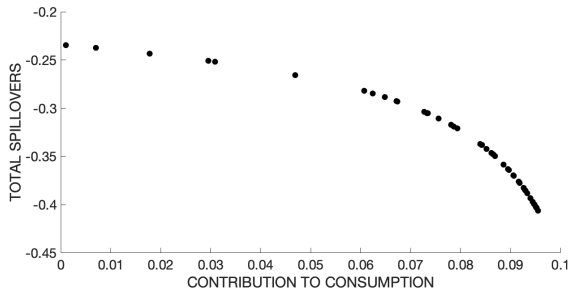
Notes: The figure reports the cumulative relative price response (left column) and the aggregate value-added multiplier (right column) in two counterfactual economies in which we allow for one dimension of sectoral heterogeneity at a time, while imposing symmetry in all the remaining sectoral attributes. The dimensions we consider are: the degree of price rigidity (ϕ_s) in Panels g and h, and the degree of centrality, which depends on the set of parameters $\omega_{H,s,x}$, in Panels i and j. We consider both a scenario of perfect mobility of labor and capital (red squares), as well as one of imperfect mobility (black dots). Each dot/square represents one of the 57 sectors of the economy.

which map the aggregate output effect of a spending shock in a given sector into that sector's contribution to private final demand and its degree of centrality. The multiplier varies from roughly 0.58 to 0.7 as a function of the consumption weight, from 0.43 to 0.65 as a function of the investment weight, and from 0.44 to 0.57 as a function of centrality. Instead, heterogeneity in the sectors' steady-state contribution to total government spending generates only a negligible variation in the aggregate multiplier, which ranges from 0.53 to 0.56.

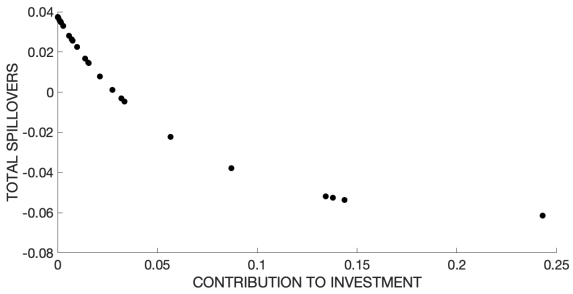
Our discussion in Section 2 suggests that the aggregate multiplier associated with a sectoral spending shock tends to be large when that shock induces large inter-sectoral spillovers. Figure 3 substantiates this claim by showing that the total spillovers generated by a sectoral shock depends on the sector's characteristics and position in the network in the same way as does the aggregate output multiplier. In particular, spillovers decrease with the sectoral contribution to private consumption and investment, and with centrality. This observation, in turn, implies that the aggregate multiplier is likely to be highly correlated with total spillovers when all the sources of sectoral heterogeneity are simultaneously accounted for. We validate this conjecture

Figure 3: Sectoral Characteristics and Total Spillovers.

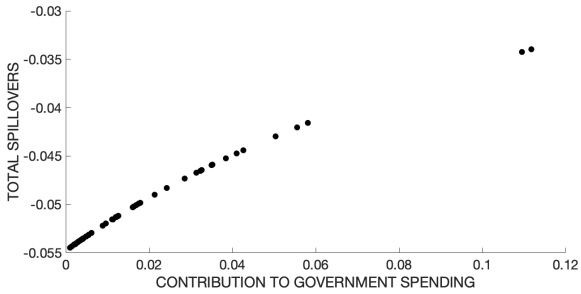
(a) Contribution to Consumption



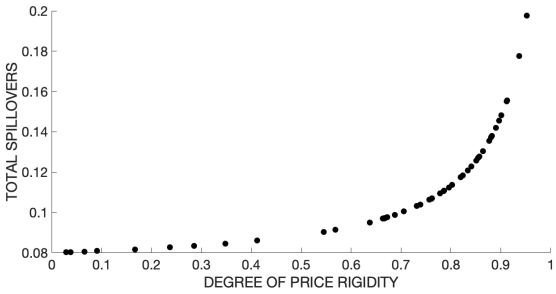
(b) Contribution to Investment



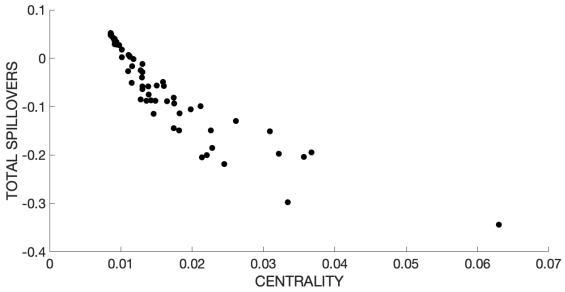
(c) Contribution to Government Spending



(d) Price Rigidity



(e) Centrality



Notes: The figure reports total spillovers in five counterfactual economies in which we allow for one dimension of sectoral heterogeneity at a time, while imposing symmetry in all the remaining sectoral attributes. The dimensions we consider are: the consumption weight (Panel a), the investment weight (Panel b), the steady-state sectoral government purchases (Panel c), the degree of price rigidity (Panel d), and the degree of centrality (Panel e). Each dot represents one of the 57 sectors of the economy.

in the next subsection.

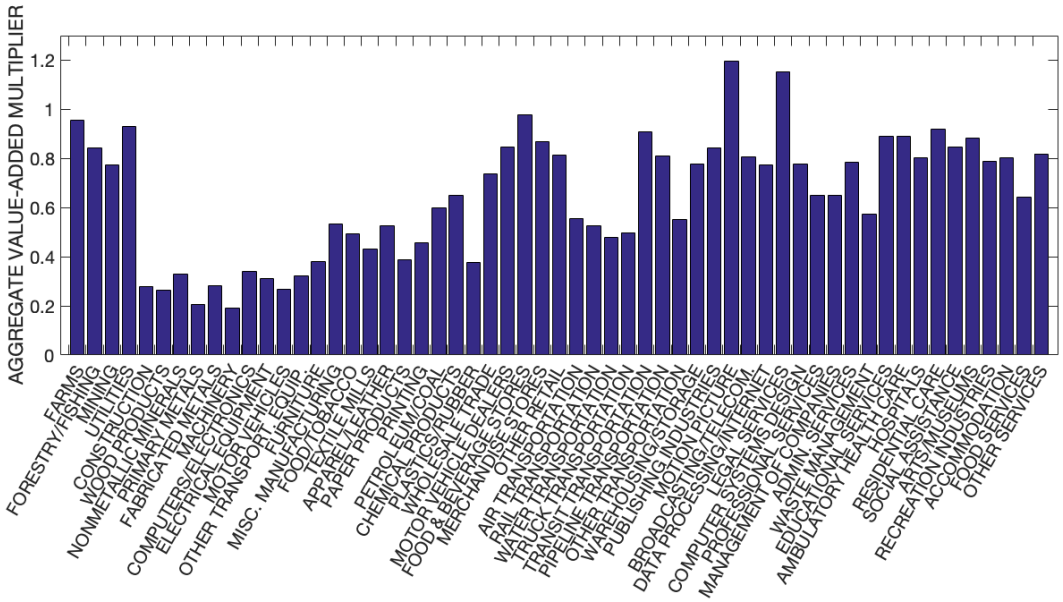
4.4 Dispersion of the aggregate spending multiplier

So far, we have studied the aggregate effects of sectoral spending shocks in environments that only allow for one source of sectoral heterogeneity at a time. In what follows, we leverage the fully-fledged structure of the model to determine whether the heterogeneity across U.S. industries implies substantial dispersion in the size of the aggregate spending multiplier associated with sectoral government purchases. Such an exercise is not only useful to quantify the extent

to which the aggregate effects of government purchases depend on their sectoral origin, but also to identify the industries associated with a large "bang for the buck". In that regard, our findings can inform policymakers about the industries they should target to maximize the aggregate spending multiplier.

Figure 4 presents a scatter of the aggregate multipliers obtained by raising government purchases in each sector in isolation. The multiplier ranges from 0.19 when government spending originates in machinery manufacturing to 1.20 when it originates in motion picture and sound recording industries. In general, the multiplier is lower when the government buys from upstream industries with a relatively large contribution to final demand, like manufacturing and transportation. On the other hand, it is larger when the government raises its demand for goods produced by downstream industries and those with a low contribution to investment, such as retail trade, and educational and health-care services.

Figure 4: Aggregate Output Response to Sectoral Government Spending Shocks.

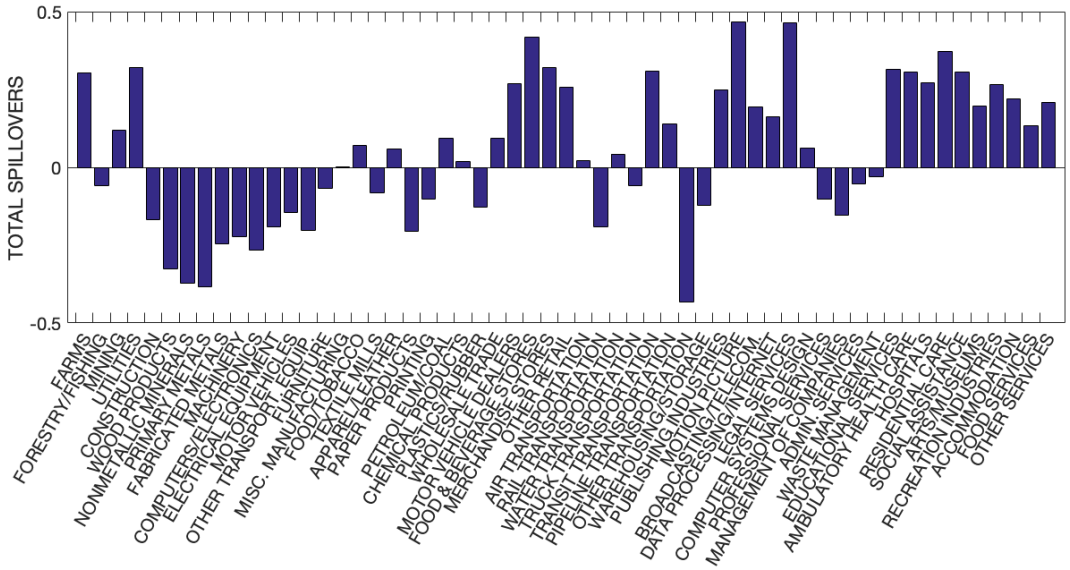


Notes: The figure plots the aggregate value-added multiplier associated with each sectoral government spending shock, obtained from the fully-heterogeneous economy.

Figure 5 shows equally significant dispersion in the degree of spillovers generated by the sectoral spending shocks, which is highly correlated with the aggregate output multiplier – the correlation between the two is 0.87. Consistent with the predictions of our stylized model, spending shocks in upstream sectors with a relatively large contribution to final demand tend to give rise to negative spillovers, whereas shocks to downstream sectors tend to generate positive and large spillovers.

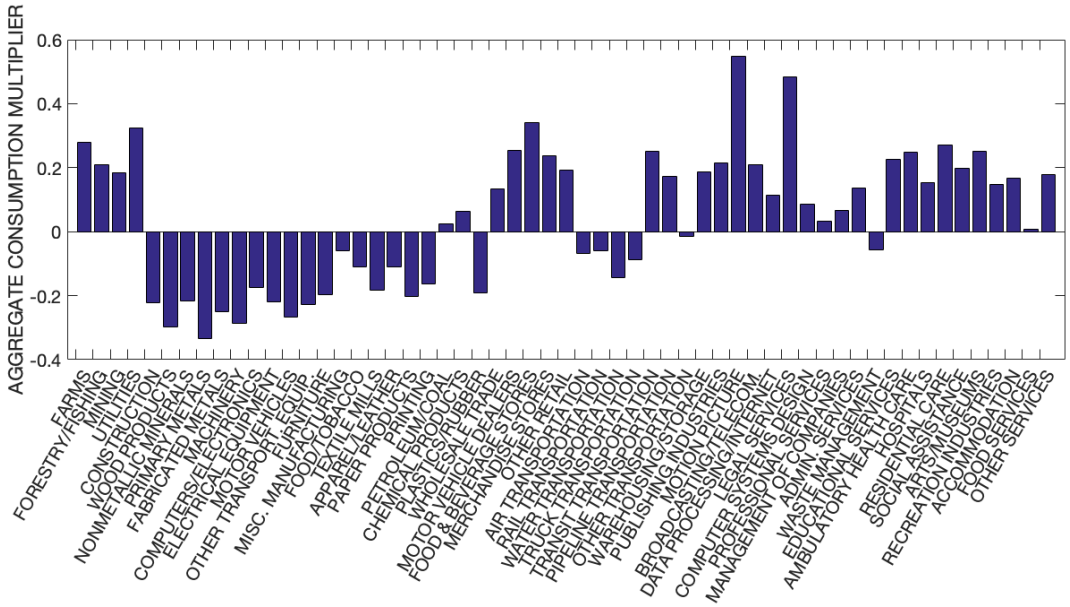
Figures 6 and 7 report the bar plots associated with the aggregate consumption and investment multipliers. While both multipliers are correlated with that of aggregate output, the

Figure 5: Total Spillovers from Sectoral Government Spending Shocks.



Notes: The figure plots the total spillovers generated by each sectoral government spending shock, obtained from the fully-heterogeneous economy.

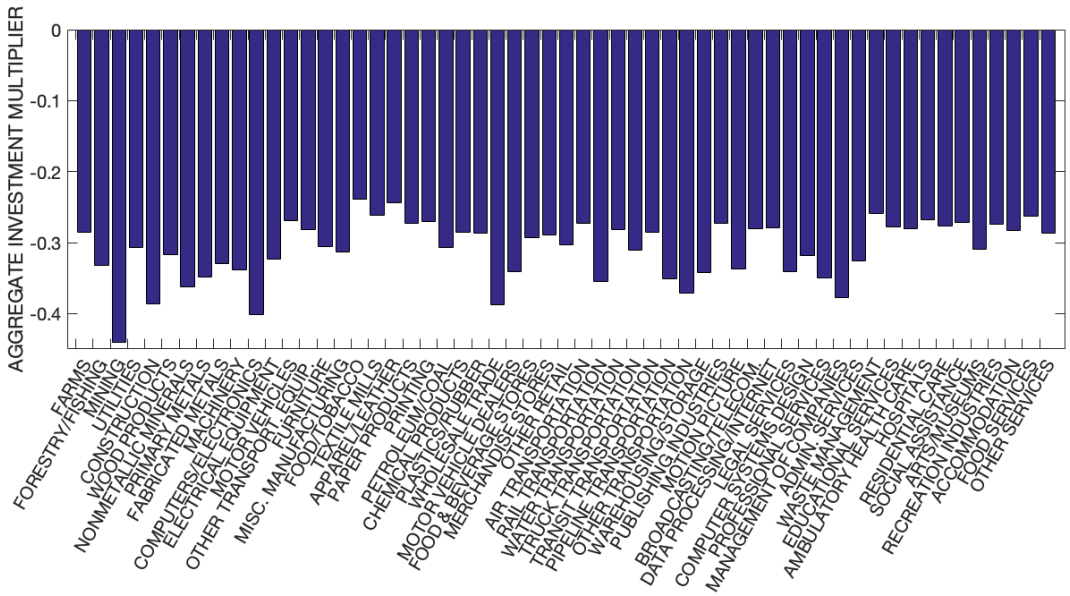
Figure 6: Aggregate Consumption Response to Sectoral Government Spending Shocks.



Notes: The figure plots the aggregate consumption multiplier associated with each sectoral government spending shock, obtained from the fully-heterogeneous economy.

consumption multiplier exhibits much larger dispersion across the sectoral spending shocks – as compared with the investment multiplier – with values ranging from -0.33 in primary metals manufacturing to 0.55 in motion picture and sound recording industries. Interestingly, our assumption of complementarity between aggregate consumption and total government purchases

Figure 7: Aggregate Investment Response to Sectoral Government Spending Shocks.



Notes: The figure plots the aggregate investment multiplier associated with each sectoral government spending shock, obtained from the fully-heterogeneous economy.

does not affect the dispersion of the aggregate multipliers, as it only shifts upward the response of aggregate variables to all sectoral shocks (see Figures D.3–D.4 in Appendix D).[24] In doing so, however, it generates heterogeneity in the sign of the response of aggregate consumption, implying a negative consumption multiplier for 24 of the 57 sectoral spending shocks. Instead, the aggregate investment multiplier is uniformly negative across all sectoral shocks, and ranges from -0.23 in food and tobacco manufacturing to -0.44 in mining.

These findings underscore the importance of conditioning on the nature of government purchases when estimating their macroeconomic effects. Depending on the sectoral origin of the spending shock, the output multiplier can be small or large, and the response of aggregate consumption can be either positive or negative. From this perspective, our approach has the potential to reconcile divergent views about the effectiveness of spending-based fiscal policy. The next section sheds further light on this issue.

5 The Sectoral Composition of Government Purchases across Government Levels

The heterogeneity in the size of the aggregate spending multiplier across sectoral spending shocks implies that changes in the sectoral allocation of government spending translate into

[24]The correlation between the aggregate output multipliers of sectoral spending implied by the models with and without complementarity is 0.97.

changes in the multiplier. To measure the extent to which the sectoral composition of government spending matters, we evaluate the aggregate output and consumption multipliers associated with public purchases at the different layers of the U.S. government – general, federal (defense and non-defense), and state and local. For each of these levels, the shares of government spending pertaining to the 57 sectors are computed based on the entries of the Input-Output Tables of the BEA, averaged over the period 1997–2015. In evaluating the aggregate multipliers associated with the different government levels, we consider otherwise identical versions of the quantitative model that differ only in the spending shares assigned to the different sectors outside the steady state.[25] In this way, we can isolate differences in the multipliers that are to be attributed to differences in the sectoral composition of the government spending shock (i.e., spending in excess of its steady-state level).[26,27]

Figure 8 reports the aggregate output and consumption multipliers associated with the different levels of the U.S. government. An additional dollar spent by the general government raises aggregate value added by 77 cents. This value, however, masks substantial heterogeneity in the output effects of spending across government levels. The aggregate output multiplier associated with the state and local government amounts to 0.88, and is 61 percent larger than the multiplier of the federal government, which equals 0.54. There is large variation in the output multipliers even within the federal government: the one associated with non-defense spending amounts to 0.75, and is almost twice as large as that associated with defense spending, which equals 0.41.

A similar pattern holds for the aggregate consumption multiplier, which is close to 0 when measured at the general-government level, but negative (-0.12) for the federal government and positive (0.14) for the state and local government. A large disparity in the consumption multiplier is also observed when federal purchases are split into defense and non-defense spending. The multiplier amounts to -0.24 for the former and 0.06 for the latter.

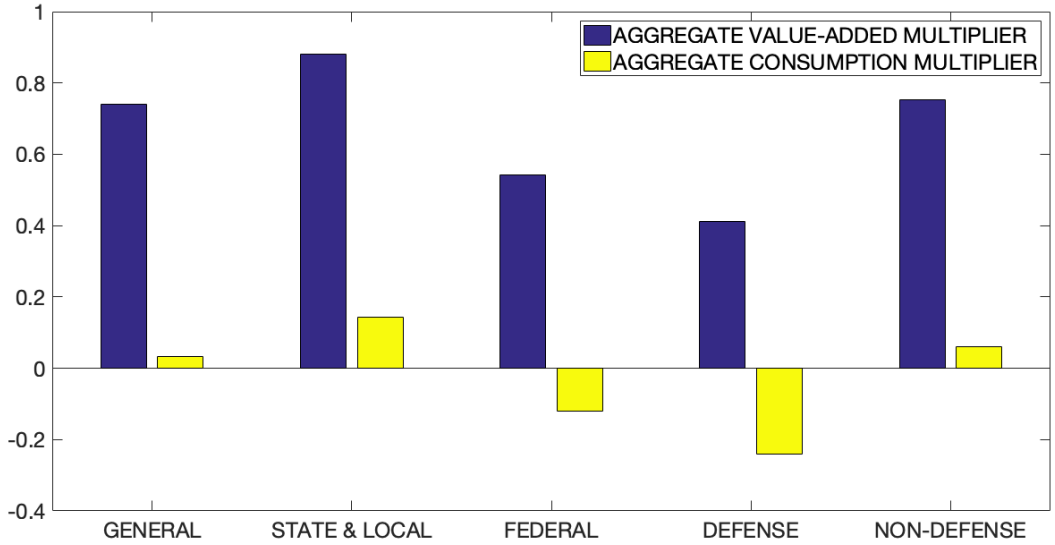
To understand the large variation in the aggregate output multiplier across the different levels of the U.S. government, Figure 9 reports the sectoral composition of state and local,

[25] All the deep parameters are calibrated identically across the model versions we consider, which therefore share the same steady state. We compute the spending multipliers associated with different linear combinations of sectoral spending shocks, where the weights replicate the average sectoral composition of purchases at each of the U.S. government levels.

[26] It should be emphasized that our analysis is strictly positive in nature, and does not imply ranking the sectoral allocations of government spending at the different levels of the U.S. government in terms of their desirability from a welfare perspective.

[27] In Appendix E, we report the results from a similarly devised exercise, in which we compare the aggregate output and consumption multipliers implied by the quantitative model based on the sectoral composition of national government spending in 28 OECD countries. We show that the spending multiplier of the U.S. economy could be as low as 0.54 if additional spending by the U.S. government had the same sectoral composition as that of the general government of Slovakia, and as high as 0.95 if it reflected the sectoral composition of purchases of the United Kingdom's general government.

Figure 8: The Aggregate Spending Multiplier across Government Levels.



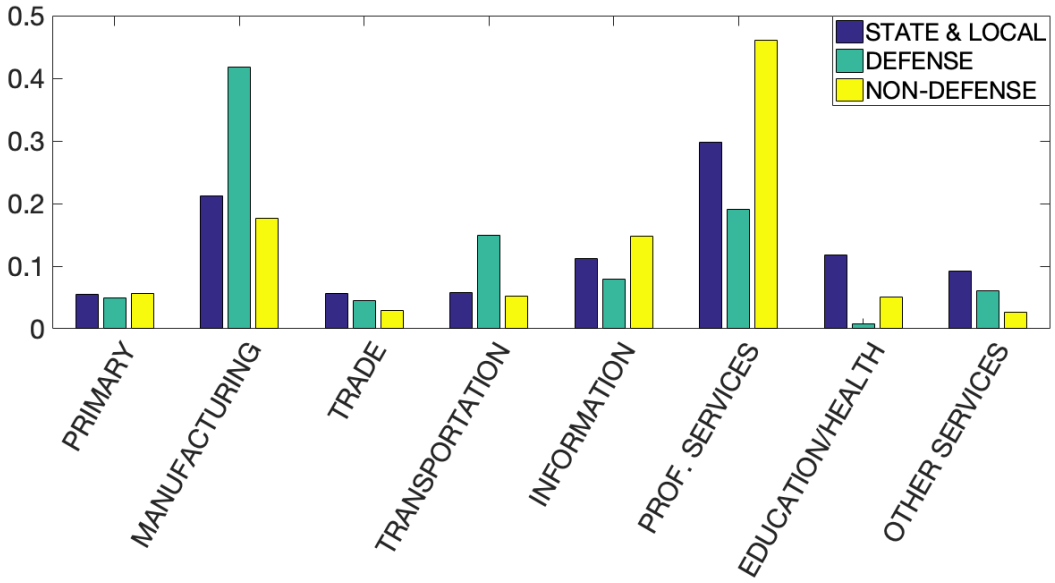
Notes: The figure reports the aggregate value-added multipliers across the different levels of the U.S. government. The multipliers are computed from otherwise identical economies that only differ the sectoral composition of the government spending shock, which is calibrated based on the Input-Output Tables of the U.S. Bureau of Economic Analysis.

federal non-defense, and defense spending. For expositional simplicity, we look at eight macro industries: primary (including agriculture, mining, utilities, and construction), manufacturing, trade, transportation, information, professional services, education and health-care services, and other services (including arts, recreation services, and food and hotel services). Defense spending is largely concentrated in manufacturing and transportation industries, for which we found lower multipliers. Instead, both federal non-defense and state and local spending are tilted towards industries with relatively large multipliers, such as professional, educational, and health-care services.

These results imply that the spending multiplier crucially depends on the sectoral composition of government purchases. This observation has consequential implications for empirical work on the effects of fiscal policy. First, it may provide a rationale for the wide range of estimates of the spending multiplier reported in the literature: Studies that rely on federal defense spending tend to report small output multipliers and a crowding-out of consumption (e.g., Barro and Redlick, 2011; Ramey, 2011); instead, measuring spending at the general-government level typically leads to large output multipliers and a crowding-in of consumption (e.g., Blanchard and Perotti, 2002; Auerbach and Gorodnichenko, 2012).[28] Second, our analysis poses yet

[28]While our analysis controls for the financing scheme and the stance of monetary policy when comparing the aggregate multipliers associated with the different sectoral shocks, these considerations can play a role in explaining the difference in the empirical estimates reported in the literature.

Figure 9: The Sectoral Composition of Government Spending in the United States.



Notes: The figure reports the sectoral shares of government spending at the different levels of the U.S. government across eight macro-industries. Primary refers to farms, forestry, mining, utilities, and construction. Other services include arts, recreation industries, accommodation services, and food services. The shares are computed based on the Input-Output Tables of the U.S. Bureau of Economic Analysis.

another challenge for the identification of government spending shocks based on times-series data, which should not only exploit exogenous shifts in total government spending, but also control for time variation in the sectoral allocation of public expenditure.

6 Conclusion

This paper has explored the role of sectoral characteristics and network linkages in shaping the aggregate effects of sector-specific government spending shocks. Based on a tractable multi-sector model, we have derived a sufficient-statistic formula that characterizes the response of aggregate output to an increase in government purchases from a given sector. Our analytical results indicate that sectoral spending shocks tend to have larger aggregate output effects when they originate in sectors that have a relatively small contribution to private final demand, and in those located downstream in the production network. These insights carry over to a quantitative multi-sector model that incorporates several realistic dimensions of sectoral heterogeneity and input-output interactions, which we calibrate to the U.S. economy. The model implies substantial heterogeneity in the aggregate output and consumption multipliers of sectoral spending shocks. It also reveals sizable differences in the aggregate multipliers across the different layers of the U.S. government. Together, these findings have important implications regarding the sectoral composition of spending-based stimulus plans that aim at generating sizeable "bangs

for the buck".

As in the vast majority of papers studying the spending multiplier, we have focused on a specific component of government consumption: purchases of goods and services from the private sector. While a branch of the literature studies the aggregate effects of government employment/wages (e.g., Finn, 1998; Pappa, 2009; Chang et al., 2020), little is known, however, about the government aggregate production function that regulates the interaction between public employment and public purchases. In the spirit of Baqaee and Farhi (2018), our bottom-up approach could in principle help micro-found such a construct. Unfortunately, data on public employment are not available at the same level of sectoral disaggregation as for government purchase, precluding researchers from pursuing this line of inquiry.[29]

Finally, while this paper proposes a novel perspective to think about the transmission of government spending, the analysis has remained positive in nature. The marked heterogeneity in the aggregate effects of sectoral public spending, however, suggests that, from a normative standpoint, an optimizing fiscal authority needs to determine not only the optimal level of government spending, but also its composition. We leave this issue for future research.

References

Acemoglu, D., U. Akcigit, and W. Kerr. 2015. Networks and the Macroeconomy: An Empirical Exploration. *NBER Macroeconomics Annual* , 30, 273-335.

Acemoglu, D., V. Carvalho, A. Ozdaglar, and A. Tahbaz-Salehi. 2012. The Network Origins of Aggregate Fluctuations. *Econometrica*, 80, 1977-2016.

Altig, D., L. Christiano, M. Eichenbaum, and J. Linde. 2011. Firm-Specific Capital, Nominal Rigidities and the Business Cycle. *Review of Economic Dynamics*, 14, 225-247.

Atalay, E. 2017. How Important Are Sectoral Shocks? *American Economic Journal: Macroeconomics*, 9, 254-280.

Auerbach, A., and Y. Gorodnichenko. 2012. Measuring the Output Responses to Fiscal Policy. *American Economic Journal: Economic Policy*, 4, 1-27.

Auerbach, A., Y. Gorodnichenko, and D. Murphy. 2020. Local Fiscal Multipliers and Fiscal Spillovers in the United States. *IMF Economic Review*, 68, 195-229.

Baqaee, D., and E. Farhi. 2018. The Microeconomic Foundations of the Aggregate Production Function. *Journal of the European Economic Association*, 17, 1337-1392.

Baqaee, D., and E. Farhi. 2019. Macroeconomics with Heterogeneous Agents and Input-Output Networks. *Mimeo.*

[29]This data limitation might explain why only a handful of papers allow for the interaction between public purchases and public employment through an aggregate production function of the government (e.g., Moro and Rachedi, 2020).

Barro, R., and C. Redlick. 2011. Macroeconomic Effects from Government Purchases and Taxes. *Quarterly Journal of Economics*, 126, 51-102.

Barrot, J., J. Sauvagnat. 2016. Input Specificity and the Propagation of Shocks in Production Networks. *Quarterly Journal of Economics*, 131, 1543-1592.

Bigio, S., and J. La'O. 2020. Distortions in Production Networks. *Quarterly Journal of Economics*, 135, 2187-2253.

Blanchard, O., and R. Perotti. 2002. An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. *Quarterly Journal of Economics*, 117, 1329-1368.

Boehm, C., A. Flaaen, and N. Pandalai-Nayar. 2019. Input Linkages and the Transmission of Shocks: Firm Level Evidence from the 2011 Tohoku Earthquake. *Review of Economics and Statistics*, 101, 60-75.

Bouakez, H., E. Cardia, and F. Ruge-Murcia. 2009. The Transmission of Monetary Policy in a Multi-Sector Economy. *International Economic Review, 50*, 1243-1266.

Bouakez, H., E. Cardia, and F. Ruge-Murcia. 2014. Sectoral Price Rigidity and Aggregate Dynamics. *European Economic Review*, 65, 1-22.

Bouakez, H., O. Rachedi, and E. Santoro. 2020. The Government Spending Multiplier in a Multi-Sector Economy. *Mimeo*.

Bouakez, H. and N. Rebei. 2007. Why Does Private Consumption Rise After a Government Spending Shock? *Canadian Journal of Economics*, 40, 954-979.

Carvalho, C. 2006. Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks. *B.E. Journal of Macroeconomics*, 2, 1-56.

Carvalho, C., and F. Nechio. 2016. Factor Specificity and Real Rigidities. *Review of Economic Dynamics*, 22, 208-222.

Carvalho, V. 2014. From Micro to Macro via Production Networks. *Journal of Economic Perspective*, 28, 23-48.

Chang, J., H. Lin, N. Traum, and S. Yang. 2020. Fiscal Consolidation with Public Wages. *Journal of Money, Credit and Banking*, forthcoming.

Chetty, R., A. Guren, D. Manoli, and A. Weber. 2013. Does Indivisible Labor Explain the Difference Micro and Macro Elasticities? A Meta-Analysis of Extensive Margin Elasticities. *NBER Macroeconomics Annual*, 27, 1-56.

Chodorow-Reich, G. 2019. Geographic Cross-Sectional Fiscal Multipliers: What Have We Learned? *American Economic Journal: Economic Policy*, 11, 1-34.

Chodorow-Reich, G. 2020. Regional Data in Macroeconomics: Some Advice for Practitioners. *Journal of Economic Dynamics and Control* , 115, 103875.

Christiano, L., M. Eichenbaum, and S. Rebelo. 2011. When is the Government Spending Multiplier Large? *Journal of Political Economy*, 119, 78-121.

Clarida, R., J. Galí, and M. Gertler. 2000. Monetary Policy Rules And Macroeconomic Stability: Evidence And Some Theory. *Quarterly Journal of Economics*, 115, 147-180.

Cox, L., G. Muller, E. Pasten, R. Schoenle, and M. Weber. 2020. Big G. *Mimeo.*

Coviello, D., I. Marino, T. Nannicini, and N. Persico. 2019. Effect of a Fiscal Demand Shock on Firm Investment. *Mimeo.*

De Loecker, J., J. Eeckhout, and G. Unger. 2020. The Rise of Market Power and the Macroeconomic Implications. *Quarterly Journal of Economics*, 135, 561-644.

Devereux, M., K. Gente, and C. Yu. 2019. Production Networks and International Fiscal Spillovers. *Mimeo.*

Di Giovanni, J., A. Levchenko, and I. Mejean. 2014. Firms, Destinations, and Aggregate Fluctuations. *Econometrica*, 82, 1303-1340.

Di Giovanni, J., A. Levchenko, and I. Mejean. 2018. The Micro Origins of International Business-Cycle Comovement. *American Economic Review*, 108, 82-108.

Dong, F., and Y. Wen. 2019. Long and Plosser Meet Bewley and Lucas. *Journal of Monetary Economics*, 102, 70-92.

Fève, P., J. Matheron, and J. Sahuc. 2013. Pitfall with Estimated DSGE-Based Government Spending Multipliers. *American Economic Journal: Macroeconomics*, 5, 141-178.

Finn, M. 1998. Cyclical Effects of Government's Employment and Goods Purchases. *International Economic Review*, 39, 635-657.

Foerster, A., P. Sarte, and M. Watson. 2011. Sectoral versus Aggregate Shocks: A Structural Factor Analysis of Industrial Production. *Journal of Political Economy*, 119, 1-38.

Gabaix, X. 2011. The Granular Origins of Aggregate Fluctuations. *Econometrica*, 79, 733-772.

Gibbons, R., and L. Katz. 1992. Does Unmeasured Ability Explain Inter-Industry Wage Differentials. *Review of Economic Studies*, 59, 515-535.

Hebous, S., and T. Zimmermann. 2020. Can Government Demand Stimulate Private Investment? Evidence from U.S. Federal Procurement. *Journal of Monetary Economics*, forthcoming.

Hobijn, B., and F. Nechio. 2019. Sticker Shocks: Using VAT Changes to Estimate Upper-Level Elasticities of Substitution. *Journal of the European Economic Association*, 17, 799-833.

Horvath, M. 1998. Cyclicality and Sectoral Linkages: Aggregate Fluctuations From Sectoral Shocks. *Review of Economic Dynamics*,1, 781-808.

Horvath, M. 2000. Sectoral Shocks and Aggregate Fluctuations. *Journal of Monetary Economics*, 45, 69-106.

Huffman, G., and M. Wynne. 1999. The Role of Intratemporal Adjustment Costs in a Multisector Economy. *Journal of Monetary Economics*, 43, 317-350.

Katayama, M., and K. H. Kim. 2018. Intersectoral Labor Immobility, Sectoral Comove-

ment, and News Shocks. *Journal of Money, Credit and Banking*, 50, 77-114.

Kim, T., and Q. Nguyen. 2020. The Effect of Public Spending on Private Investment. *Review of Finance*, 24, 415-451.

Krueger, A., and L. Summers. 1988. Efficiency Wages and the Inter-Industry Wage Structure. *Econometrica*, 56, 259-293.

Lanteri, A. 2018. The Market for Used Capital: Endogenous Irreversibility and Reallocation over the Business Cycle. *American Economic Review*, 108, 2383-2419.

Lee, D., and K. Wolpin. 2006. Intersectoral Labor Mobility and the Growth of the Service Sector. *Econometrica*, 74, 1-46.

Leeper, E., M. Plante, and N. Traum. 2010. Dynamics of Fiscal Financing in the United States. *Journal of Econometrics*, 156, 304-321.

Leeper, E., N. Traum, and T. Walker. 2017. Clearing Up the Fiscal Multiplier Morass. *American Economic Review*, 107, 2409-2454.

Long, J., and C. Plosser. 1983. Real Business Cycles. *Journal of Political Economy*, 91, 39-69.

Matheron, J. 2006. Firm-Specific Labor and Firm-Specific Capital: Implications for the Euro-Data New Phillips Curve. *International Journal of Central Banking*, 4, 33-64.

Miranda-Pinto, J., and E. Young. 2019. Comparing Dynamic Multisector Models. *Economic Letters*, 181, 28-32.

Moro, A., and O. Rachedi. 2020. The Changing Structure of Government Consumption Spending. *Mimeo*.

Nakamura, E., and J. Steinsson. 2008. Five Facts about Prices: A Reevaluation of Menu Cost Models. *Quarterly Journal of Economics*, 123, 1415-1464.

Nakamura, E., and J. Steinsson. 2010. Monetary Non-Neutrality in a Multi-Sector Menu Cost Model. *Quarterly Journal of Economics*, 125, 961-1013.

Nakamura, E., and J. Steinsson. 2014. Fiscal Stimulus in a Monetary Union: Evidence from US Regions. *American Economic Review*, 104, 753-792.

Nekarda, C., and V. Ramey. 2011. Industry Evidence on the Effects of Government Spending. *American Economic Journal: Macroeconomics*, 3, 36-59.

Neumuller, S. 2015. Inter-Industry Wage Differentials Revisited: Wage Volatility and the Option Value of Mobility. *Journal of Monetary Economics*, 76, 38-54.

Pappa, E. 2009. The Effects of Fiscal Shocks on Employment and the Real Wage. *International Economic Review*, 50, 400-421.

Ramey, V. 2011. Identifying Government Spending Shocks: It's All in the Timing. *Quarterly Journal of Economics*, 126, 1-50.

Ramey, V. 2019. Ten Years after the Financial Crisis: What Have We Learned from the Renaissance in Fiscal Research? *Journal of Economic Perspective*, 33, 89-114.

Ramey, V., and M. Shapiro. 1998. Costly Capital Reallocation and the Effects of Government Spending. *Carnegie-Rochester Conference Series on Public Policy*, 48, 145-194.

Sims, E., and J. Wolff. 2018. The Output and Welfare Effects of Government Spending Shocks over the Business Cycle. *International Economic Review*, 59, 1403-1435.

Slavtchev, V., and S. Wiederhold. 2016. Does the Technological Content of Government Demand Matter for Private R&D? Evidence from US States. *American Economic Journal: Macroeconomics*, 8, 45-84.

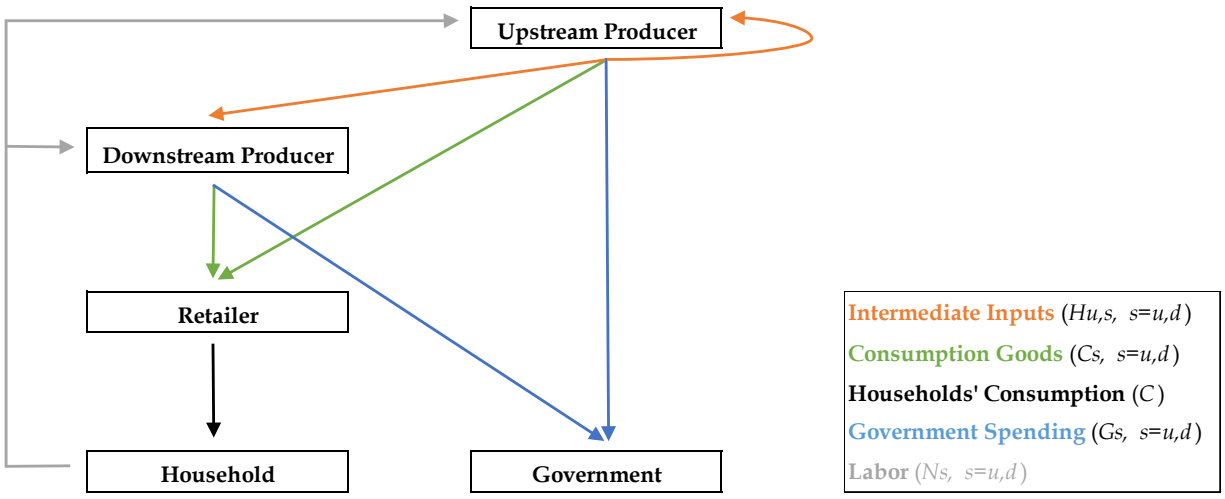
Uhlig, H. 2010. Some Fiscal Calculus. *American Economic Review*, 100, 30-34.

Appendix

A Stylized Model

This appendix solves the stylized model employed to derive the analytical results discussed in Section 2, and reports the proofs to the propositions contained therein.

Figure A.1: Structure of the Stylized Model.



A.1 Non-linear economy

This subsection reports the necessary set of equations to solve the stylized model. From households' optimal allocation between consumption and labor hours we obtain:

$$\theta = C^{-1}W. \tag{A.1}$$

The optimal consumption demand for the goods produced by the two sectors are given by

$$C_u = \omega_{C,u}\frac{C}{Q_u}, \tag{A.2}$$

$$C_d = \omega_{C,d}\frac{C}{Q_d}, \tag{A.3}$$

where $Q_{s,t} = \frac{P_s}{P}$ for $s = u, d$, and

$$P = \omega_{C,d}^{-\omega_{C,d}}\omega_{C,u}^{-\omega_{C,u}}P_d^{\omega_{C,d}}P_u^{\omega_{C,u}}. \tag{A.4}$$

Households' supply of labor to the two sectors is given by

$$N_u = \omega_{N,u}\left(\frac{W_u}{W}\right)^{\nu_N} N, \tag{A.5}$$

$$N_d = \omega_{N,d}\left(\frac{W_d}{W}\right)^{\nu_N} N, \tag{A.6}$$

where

$$W = \left[\omega_{N,d} W_d^{1+\nu_N} + \omega_{N,u} W_u^{1+\nu_N}\right]^{\frac{1}{1+\nu_N}}. \tag{A.7}$$

Recall that the sectoral production technologies read as

$$Z_u = N_u^{1-\alpha_H} H_{u,u}^{\alpha_H}, \tag{A.8}$$

$$Z_d = N_d^{1-\alpha_H} H_{d,u}^{\alpha_H}. \tag{A.9}$$

Thus, producers' profit-maximization returns the following first-order conditions:

$$W_u = (1-\alpha_H)\, Q_u \frac{Z_u}{N_u}, \tag{A.10}$$

$$1 = \alpha_H \frac{Z_u}{H_{u,u}}, \tag{A.11}$$

$$W_d = (1-\alpha_H)\, \frac{Q_d Z_d}{N_d}, \tag{A.12}$$

$$Q_u = \alpha_H \frac{Q_d Z_d}{H_{d,u}}. \tag{A.13}$$

Finally, the model is closed by the sectoral resource constraints:

$$Z_u = C_u + G_u + H_{u,u} + H_{d,u}, \tag{A.14}$$

$$Z_d = C_d + G_d. \tag{A.15}$$

A.2 Steady state

This sub-section describes the steady state. Steady-state variables are denoted by an asterisk. We start by rearranging the production function of sector u as

$$1 = \left(\frac{N_u^*}{Z_u^*}\right)^{1-\alpha_H} \left(\frac{H_{u,u}^*}{Z_u^*}\right)^{\alpha_H}. \tag{A.16}$$

From (A.10) and (A.11), we have

$$\frac{N_u^*}{Z_u^*} = (1-\alpha_H)\, \frac{Q_u^*}{W_u^*} \qquad \text{and} \qquad \frac{H_{u,u}^*}{Z_u^*} = \alpha_H, \tag{A.17}$$

which can combined with (A.16) to obtain

$$\left(\frac{W_u^*}{Q_u^*}\right)^{1-\alpha_H} = (1-\alpha_H)^{1-\alpha_H}\,\alpha_H^{\alpha_H}. \tag{A.18}$$

Analogously, the following result holds for sector d:

$$\left(\frac{W_d^*}{Q_d^*}\right)^{1-\alpha_H} = (1-\alpha_H)^{1-\alpha_H}\,\alpha_H^{\alpha_H}\left(\frac{Q_d^*}{Q_u^*}\right)^{\alpha_H}. \tag{A.19}$$

Under our calibration $\omega_{N,s}{=}\frac{N_s^*}{N^*}$ for $s = u, d$, (A.5) and (A.6) imply that $W_u^* = W_d^* = W^*$. Therefore, (A.18) and (A.19) lead to

$$Q_u^* = Q_d^*,$$

which in turn implies that

$$\frac{C_u^*}{C_d^*} = \frac{\omega_{C,u}}{\omega_{C,d}}. \tag{A.20}$$

Because public spending is split equally between the two sectors, we have $\frac{Q_u^*G_u^*}{Q_u^*G_u^*+Q_d^*G_d^*} = \frac{1}{2}$. Letting $\gamma = \frac{Q_u^*G_u^*+Q_d^*G_d^*}{Y^*}$ denote the share of total government spending in total value added, Y^*, it follows that

$$Q_u^*G_u^* = Q_d^*G_d^* = \frac{\gamma}{2}Y^*, \tag{A.21}$$

and

$$Q_d^*C_d^* = \omega_{C,d}\,(1-\gamma)\,Y^*, \tag{A.22}$$

$$Q_u^*C_u^* = \omega_{C,u}\,(1-\gamma)\,Y^*. \tag{A.23}$$

Noting that $Y_d^* = Q_d^*Z_d^* - Q_u^*H_{d,u}^* = (1-\alpha_H)\,Q_d^*Z_d^* = (1-\alpha_H)\,(Q_d^*C_d^* + Q_d^*G_d^*)$ and using the fact that $\frac{Y_u^*}{Y^*} + \frac{Y_d^*}{Y^*} = 1$, we obtain the following expression for the sectoral value added as a fraction of aggregate value added:

$$\frac{Y_u^*}{Y^*} = 1-(1-\alpha_H)\,\mu_d, \tag{A.24}$$

$$\frac{Y_d^*}{Y^*} = (1-\alpha_H)\,\mu_d, \tag{A.25}$$

where $\mu_d = \frac{Q_d^*C_d^*+Q_d^*G_d^*}{Y^*} = (1-\gamma)\,\omega_{C,d} + \frac{\gamma}{2}$ is the steady-state contribution of sector d to total final demand.

Moreover, (A.10) and (A.12) imply that $\frac{N_u^*}{Q_u^*Z_u^*} = \frac{N_d^*}{Q_d^*Z_d^*}$. Since $Y_d^* = (1-\alpha_H)\,Q_d^*Z_d^*$ and

$Y_u^* = (1-\alpha_H)\, Q_u^* Z_u^*$, it follows that $\frac{N_u^*}{Y_u^*} = \frac{N_d^*}{Y_d^*} = \frac{N^*}{Y^*}$, which implies that

$$\frac{N_u^*}{N^*} = 1-(1-\alpha_H)\,\mu_d, \tag{A.26}$$

$$\frac{N_d^*}{N^*} = (1-\alpha_H)\,\mu_d. \tag{A.27}$$

Finally, to determine the ratio $\frac{Q_u^* H_{d,u}^*}{Y^*}$, we combine the expression for the sectoral value added of sector u (i.e., $Y_u^* = Q_u^* Z_u^* - Q_u^* H_{u,u}^*$) with its resource constraint, obtaining

$$\frac{Y_u^*}{Y^*} = \frac{Q_u^* C_u^* + Q_u^* G_u^*}{Y^*} + \frac{Q_u^* H_{d,u}^*}{Y^*}. \tag{A.28}$$

Letting $\mu_u = \frac{Q_u^* C_u^* + Q_u^* G_u^*}{Y^*} = (1-\gamma)\,\omega_{C,u} + \frac{\gamma}{2}$, noting that $\mu_u + \mu_d = 1$, and using (A.24), we get

$$\frac{Q_u^* H_{d,u}^*}{Y^*} = \alpha_H \mu_d. \tag{A.29}$$

A.3 Log-linear economy

We solve the model by log-linearizing its equilibrium conditions around the non-stochastic steady state. The log-linearized counterparts of equations (A.1)–(A.15) are, respectively:

$$c = w, \tag{A.30}$$

$$c_u = c - q_u, \tag{A.31}$$

$$c_d = c - q_d, \tag{A.32}$$

$$q_d = -\frac{\omega_{C,u}}{\omega_{C,d}} q_u, \tag{A.33}$$

$$n_u = \nu_N (w_u - w) + n, \tag{A.34}$$

$$n_d = \nu_N (w_d - w) + n, \tag{A.35}$$

$$w = [1-(1-\alpha_H)\,\mu_d]\, w_u + (1-\alpha_H)\,\mu_d w_d, \tag{A.36}$$

$$z_u = (1-\alpha_H)\, n_u + \alpha_H h_{u,u}, \tag{A.37}$$

$$z_d = (1-\alpha_H)\, n_d + \alpha_H h_{d,u}, \tag{A.38}$$

$$w_u = q_u + z_u - n_u, \tag{A.39}$$

$$h_{u,u} = z_u, \tag{A.40}$$

$$w_d = q_d + z_d - n_d, \tag{A.41}$$

$$h_{d,u} = z_d + q_d - q_u, \tag{A.42}$$

$$z_u = \frac{\gamma}{2\,[1-(1-\alpha_H)\,\mu_d]} g_u + \frac{(1-\gamma)\,\omega_{C,u}}{1-(1-\alpha_H)\,\mu_d} c_u + \frac{\alpha_H \mu_d}{1-(1-\alpha_H)\,\mu_d} h_{d,u}, \tag{A.43}$$

$$z_d = \frac{\gamma}{2\mu_d} g_d + \frac{(1-\gamma)\,\omega_{C,d}}{\mu_d} c_d. \tag{A.44}$$

A.4 Proofs

Proof of Proposition 1. Using (A.38) to substitute for z_d in (A.41) and (A.42) and combining the resulting two equations yields

$$q_d = (1-\alpha_H)\, w_d + \alpha_H q_u. \tag{A.45}$$

Together with (A.33), this gives

$$w_d = -\frac{1-(1-\alpha_H)\,\omega_{C,d}}{(1-\alpha_H)\,\omega_{C,d}} q_u. \tag{A.46}$$

Equations (A.37) and (A.40) imply that $z_u = h_{u,u} = n_u$. Thus, in light of (A.39), $w_u = q_u$. We plug the latter and (A.46) into (A.36), obtaining

$$w = \frac{\omega_{C,d} - \mu_d}{\omega_{C,d}} q_u. \tag{A.47}$$

Combining (A.33) and (A.42) to obtain $h_{d,u} = z_d - \frac{1}{\omega_{C,d}} q_u$, and substituting the latter into (A.38), we get

$$z_d = n_d - \frac{\alpha_H}{(1-\alpha_H)\,\omega_{C,d}} q_u. \tag{A.48}$$

Inserting this expression into (A.44) returns

$$n_d = \frac{\gamma}{2\mu_d} g_d + \frac{(1-\gamma)\,(1-\alpha_H)\,\mu_u \omega_{C,d} + \alpha_H \mu_d}{(1-\alpha_H)\,\mu_d \omega_{C,d}} q_u. \tag{A.49}$$

The next step consists in combining $n_u = z_u$ with (A.43) and

$$h_{d,u} = n_d - \frac{1}{(1-\alpha_H)\,\omega_{C,d}} q_u, \tag{A.50}$$

where the latter obtains from the combination of (A.42) with (A.48). Following these steps takes us to

$$n_u = \frac{\gamma}{2\left[1-\mu_d\,(1-\alpha_H)\right]} g_u + \frac{(1-\gamma)\,(1-\alpha_H)\,\mu_d \omega_{C,u} - \alpha_H \mu_d}{(1-\alpha_H)\left[1-(1-\alpha_H)\,\mu_d\right]\omega_{C,d}} q_u + \frac{\alpha_H \mu_d}{1-(1-\alpha_H)\,\mu_d} n_d. \tag{A.51}$$

The last equation is then combined with (A.33), (A.34), (A.46), (A.47), and (A.49) implying

$$n = \frac{\gamma}{2\mu_u} g_u - \frac{(1-\gamma)\,(1-\alpha_H)\,\mu_d \omega_{C,u} + \alpha_H \mu_d + (1-\alpha_H)\,\nu_N \mu_u \mu_d \omega_{C,d}}{(1-\alpha_H)\,\mu_d \omega_{C,d}} q_u. \tag{A.52}$$

We then combine (A.33), (A.35), (A.46), (A.47), and (A.49) to obtain

$$n = \frac{\gamma}{2\mu_d} g_d + \frac{(1-\gamma)\,(1-\alpha_H)\,\mu_u \omega_{C,u} + \alpha_H \mu_d + \left[1-\mu_d\,(1-\alpha_H)\right]\nu_N \mu_d}{(1-\alpha_H)\,\mu_d \omega_{C,d}} q_u. \tag{A.53}$$

By equating (A.52) and (A.53), we finally obtain the solution for the relative price of sector u as a function of the two sectoral spending shocks:

$$q_u = \frac{1}{\Upsilon}\left(\frac{1}{\mu_u}g_u - \frac{1}{\mu_d}g_d\right), \tag{A.54}$$

where

$$\Upsilon \equiv \frac{2}{\gamma}\left[\frac{1-\gamma}{\omega_{C,d}}\frac{\mu_u^2\omega_{C,d}+\mu_d^2\omega_{C,u}}{\mu_u\mu_d} + \frac{\alpha_H}{(1-\alpha_H)\,\mu_u\omega_{C,d}} + \frac{[1-(1-\alpha_H)\,\mu_d]\,\nu_N}{(1-\alpha_H)\,\mu_u\omega_{C,d}}\right] > 0.$$

In the case of perfect labor mobility (i.e., $\nu_N \to \infty$), $\Upsilon \to \infty$, so that $q_u = 0$, and $q_d = -\frac{\omega_{C,u}}{\omega_{C,d}}q_u = 0$. In the case of imperfect labor mobility (i.e., $\nu_N < \infty$), since $\mu_d, \mu_u > 0$, it is immediate to prove that

$$\begin{aligned}
\frac{dq_u}{dg_u} &= \frac{1}{\Upsilon\mu_u} > 0,\\
\frac{dq_d}{dg_d} &= -\frac{\omega_{C,u}}{\omega_{C,d}}\frac{dq_u}{dg_d} = \frac{\omega_{C,u}}{\omega_{C,d}}\frac{1}{\Upsilon\mu_d} > 0,
\end{aligned}$$

and

$$\begin{aligned}
\frac{dq_u}{dg_d} &= -\frac{1}{\Upsilon\mu_d} < 0,\\
\frac{dq_d}{dg_u} &= -\frac{\omega_{C,u}}{\omega_{C,d}}\frac{dq_u}{dg_u} = -\frac{\omega_{C,u}}{\omega_{C,d}}\frac{1}{\Upsilon\mu_u} < 0.
\end{aligned}$$

■

Proof of Proposition 2. Combining (A.30) with (A.47) yields

$$c = \frac{\omega_{C,d}-\mu_d}{\omega_{C,d}}q_u. \tag{A.55}$$

Thus, from (A.31), (A.32), and (A.33):

$$c_u = -\frac{\mu_d}{\omega_{C,d}}q_u, \tag{A.56}$$

$$c_d = -\frac{\mu_u}{\omega_{C,u}}q_d. \tag{A.57}$$

Therefore, in light of Proposition 1, it is immediate to show that under perfect labor mobility, $\frac{dc_s}{dg_s} = \frac{dc_s}{dg_x} = 0$, for $s \neq x$, since sectoral relative prices do not react to the shocks. Under imperfect labor mobility, using Proposition 1, it is also straightforward to verify that $\frac{dc_s}{dg_s} < 0$ and $\frac{dc_s}{dg_x} > 0$, for $s \neq x$.

■

Proof of Proposition 3. Combining equations (A.49) and (A.50) yields

$$h_{d,u} = \frac{\gamma}{2\mu_d} g_d + \frac{(1-\gamma)\,\mu_u \omega_{C,d} - \mu_d}{\omega_{C,d}\mu_d} q_u. \tag{A.58}$$

Using (A.54) to substitute for q_u, we get:

$$h_{d,u} = \frac{1}{\mu_d}\left(\frac{\gamma}{2} + \frac{\Phi}{\Upsilon}\right) g_d - \frac{\Phi}{\Upsilon \mu_u} g_u. \tag{A.59}$$

where

$$\Phi \equiv \frac{(1-\gamma)\,\mu_d \omega_{C,d} + \frac{\gamma}{2}}{\mu_d \omega_{C,d}} > 0.$$

Under perfect labor mobility, $\frac{dh_{d,u}}{dg_u} = 0$ since $\Upsilon \to \infty$. Under imperfectly mobile labor, $\frac{dh_{d,u}}{dg_u} < 0$. Finally, since $\left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N < \infty} = \frac{1}{\mu_d}\left(\frac{\gamma}{2} + \frac{\Phi}{\Upsilon}\right)$ and $\left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N \to \infty} = \frac{\gamma}{2\mu_d}$, it is immediate to see that

$$\left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N < \infty} > \left.\frac{dh_{d,u}}{dg_d}\right|_{\nu_N \to \infty} > 0.$$

■

Proof of Proposition 4. We first derive the two expressions for sectoral value added. Thus, we insert y_d and y_u into the expression that weighs them into the aggregate value added:

$$y = \left[1 - \mu_d\,(1-\alpha_H)\right] y_u + \mu_d\,(1-\alpha_H)\, y_d. \tag{A.60}$$

After some algebraic steps, we can show that

$$y = \frac{\gamma}{2} g_u + \frac{\gamma}{2} g_d + (1-\gamma)\, c + \frac{\omega_{C,d} - \mu_d}{\omega_{C,d}} q_u. \tag{A.61}$$

Replacing c with w in the expression above and exploiting (A.47) returns

$$y = \frac{\gamma}{2} g_u + \frac{\gamma}{2} g_d + (2-\gamma)\,\frac{\omega_{C,d} - \mu_d}{\omega_{C,d}} q_u. \tag{A.62}$$

Recalling that $\mu_d = (1-\gamma)\,\omega_{C,d} + \frac{\gamma}{2}$ and $\omega_{C,u} + \omega_{C,d} = 1$, we obtain

$$\frac{dy}{dg_u} = \frac{\gamma}{2} + \frac{\gamma\,(2-\gamma)\left(\frac{1}{2} - \omega_{C,u}\right)}{1 - \omega_{C,u}} \frac{dq_u}{dg_u}. \tag{A.63}$$

An isomorphic expression can be derived for $\frac{dy}{dg_d}$, by considering that $q_d = -\frac{\omega_{C,u}}{\omega_{C,d}} q_u$:

$$\frac{dy}{dg_d} = \frac{\gamma}{2} + \frac{\gamma\,(2-\gamma)\left(\frac{1}{2} - \omega_{C,d}\right)}{1 - \omega_{C,d}} \frac{dq_d}{dg_d}. \tag{A.64}$$

■

Proof of Proposition 5. Setting $\alpha_H = 0$ to highlight the role of the consumption share implies that the two sectors are structurally identical. Thus, we examine only sector u, and rely on symmetry arguments to extend the proof to sector d. Based on (A.54), we compute

$$\frac{\partial\left(\frac{dq_u}{dg_u}\right)}{\partial\omega_{C,u}} = -\frac{1}{\Upsilon\mu_u}\left(\frac{\frac{\partial\Upsilon}{\partial\omega_{C,u}}}{\Upsilon} + \frac{\frac{\partial\mu_u}{\partial\omega_{C,u}}}{\mu_u}\right). \tag{A.65}$$

When $\alpha_H = 0$, we have

$$\Upsilon = \frac{2\left(1-\gamma\right)}{\gamma}\left[\frac{\mu_u^2\omega_{C,d} + \mu_d^2\omega_{C,u}}{\mu_d\mu_u\omega_{C,d}} + \frac{\nu_N}{\left(1-\gamma\right)\omega_{C,d}}\right].$$

Therefore:

$$\frac{\partial\Upsilon}{\partial\omega_{C,u}} = \frac{2\left(1-\gamma\right)}{\gamma}\left[\frac{1}{\mu_u\mu_d}\Upsilon + \left(\frac{1}{\omega_{C,d}^2}\right)\left(\frac{\mu_d}{\mu_u} + \frac{\nu_N}{1-\gamma}\right)\right] > 0.$$

Combining this result with the fact that $\frac{\partial\mu_u}{\partial\omega_{C,u}} = 1-\gamma > 0$, it follows that

$$\frac{\partial\left(\frac{dq_u}{dg_u}\right)}{\partial\omega_{C,u}} < 0.$$

■

Proof of Proposition 6. Recall that our sufficient-statistic formula implies

$$\frac{dy}{dg_s} = \frac{\gamma}{2} + \varkappa_s\frac{dq_s}{dg_s}, \tag{A.66}$$

where $\varkappa_s = \frac{\gamma(2-\gamma)\left(\frac{1}{2}-\omega_{C,s}\right)}{1-\omega_{C,s}}$, for $s = u, d$. We therefore have

$$\frac{\partial\left(\frac{dy}{dg_s}\right)}{\partial\omega_{C,s}} = \frac{\partial\varkappa_s}{\partial\omega_{C,s}}\frac{dq_s}{dg_s} + \varkappa_s\frac{\partial\left(\frac{dq_s}{dg_s}\right)}{\partial\omega_{C,s}}, \tag{A.67}$$

where $\frac{\partial\varkappa_s}{\partial\omega_{C,s}} = -\frac{\gamma(2-\gamma)}{2\left(1-\omega_{C,s}\right)^2} < 0$.

Under perfect labor mobility, $\frac{dq_s}{dg_s} = 0$ (see Proposition 1) and thus $\frac{\partial\left(\frac{dy}{dg_s}\right)}{\partial\omega_{C,s}} = 0$. Under imperfect labor mobility, we know that $\frac{dq_s}{dg_s} > 0$. Thus, a sufficient condition to prove the result is that $\varkappa_s\frac{\partial\left(\frac{dq_s}{dg_s}\right)}{\partial\omega_{C,s}} < 0$. In light of Proposition 4 – which states that $\frac{\partial\left(\frac{dq_s}{dg_s}\right)}{\partial\omega_{C,s}} < 0$ – this is always the case for $\omega_{C,s} < \frac{1}{2}$, which ensures $\varkappa_s > 0$.

■

Proof of Proposition 7. Given (A.54) and $q_u = -\frac{\omega_{C,d}}{\omega_{C,u}} q_d$, we have

$$\left.\frac{dq_d}{dg_d}\right|_{\omega_{C,d}=\omega} = \frac{1-\omega}{\omega\mu}\frac{1}{\Upsilon_{\omega_{C,d}=\omega}}, \tag{A.68}$$

and

$$\left.\frac{dq_u}{dg_u}\right|_{\omega_{C,u}=\omega} = \frac{1}{\mu\Upsilon_{\omega_{C,u}=\omega}}, \tag{A.69}$$

where $\mu = \omega(1-\gamma) + \frac{\gamma}{2}$ and

$$\begin{aligned}
\Upsilon_{\omega_{C,d}=\omega} &\equiv \frac{2}{\gamma}\left[\frac{1-\gamma}{\omega}\frac{\omega(1-\mu)^2 + (1-\omega)\mu^2}{\mu(1-\mu)} + \frac{\alpha_H}{\omega(1-\alpha_H)(1-\mu)} + \frac{[1-(1-\alpha_H)\mu]\nu_N}{\omega(1-\alpha_H)(1-\mu)}\right], \\
\Upsilon_{\omega_{C,u}=\omega} &\equiv \frac{2}{\gamma}\left[\frac{1-\gamma}{1-\omega}\frac{(1-\omega)\mu^2 + \omega(1-\mu)^2}{\mu(1-\mu)} + \frac{\alpha_H}{\mu(1-\omega)(1-\alpha_H)} + \frac{[1-(1-\alpha_H)(1-\mu)]\nu_N}{\mu(1-\omega)(1-\alpha_H)}\right].
\end{aligned}$$

Thus, we need to prove that

$$\frac{1-\omega}{\omega}\frac{1}{\Upsilon_{\omega_{C,d}=\omega}} > \frac{1}{\Upsilon_{\omega_{C,u}=\omega}}.$$

After some algebra we can show that this inequality reduces to

$$\frac{2\mu-1}{\omega\mu(1-\alpha_H)(1-\mu)}\left[\alpha_H + \frac{(1+\omega-\alpha_H)\nu_N}{\omega}\right] < 0,$$

which holds true for $\omega < \frac{1}{2}$.

■

Proof of Proposition 8. Recall that

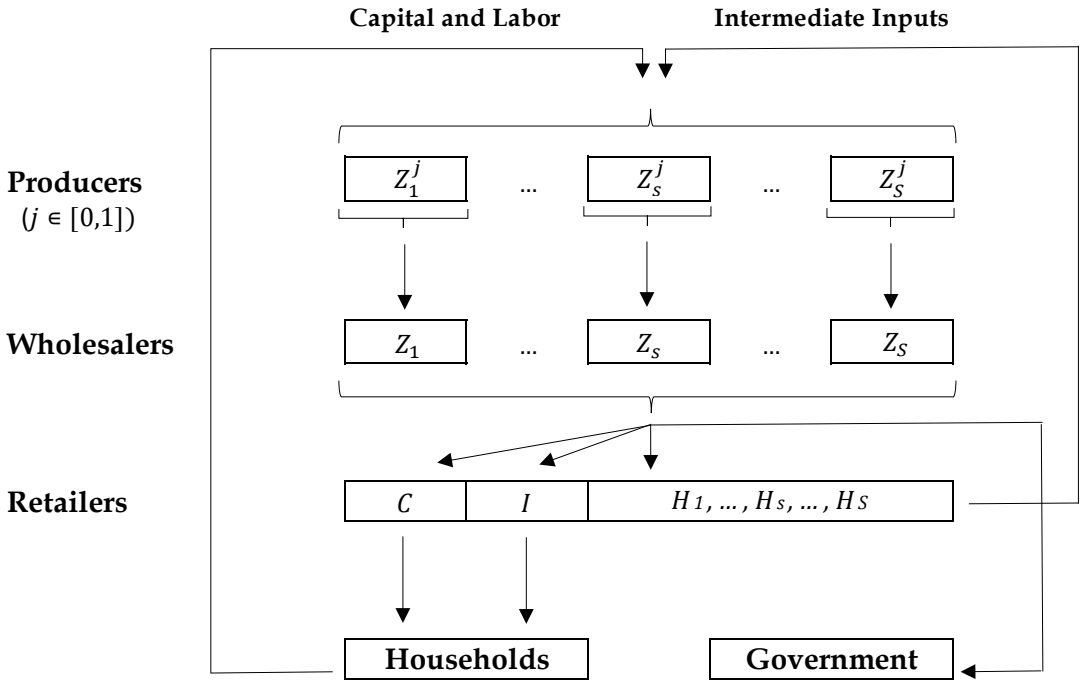
$$\frac{dy}{dg_s} = \frac{\gamma}{2} + \varkappa_s \frac{dq_s}{dg_s}, \quad s = u, d. \tag{A.70}$$

It is immediate to verify that $\left.\frac{dy}{dg_d}\right|_{\omega_{C,d}=\omega} = \left.\frac{dy}{dg_u}\right|_{\omega_{C,u}=\omega}$ under perfect labor mobility, as $\frac{dq_s}{dg_s} = 0$. Otherwise, under imperfect labor mobility, we know from Proposition 6 that $\left.\frac{dq_d}{dg_d}\right|_{\omega_{C,d}=\omega} > \left.\frac{dq_u}{dg_u}\right|_{\omega_{C,u}=\omega}$. As $\varkappa_s > 0$, it follows that $\left.\frac{dy_d}{dg_d}\right|_{\omega_{C,d}=\omega} > \left.\frac{dy_u}{dg_u}\right|_{\omega_{C,u}=\omega}$.

■

B Full Description of the Quantitative Model

Figure B.1: Structure of the Quantitative Model.



B.1 Households

The economy is populated by an infinitely-lived representative household that has preferences over aggregate consumption, C_t, the sum of government purchases from all sectors, G_t, and aggregate labor, N_t, so that its expected lifetime utility is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{X_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right\}, \tag{B.1}$$

$$X_t = \left[\zeta^{\frac{1}{\xi}} C_t^{\frac{\xi-1}{\xi}} + (1-\zeta)^{\frac{1}{\xi}} G_t^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}, \tag{B.2}$$

where β is the subjective time discount factor, σ captures the degree of risk aversion, θ is a preference parameter that affects the disutility of labor, and η is the inverse of the Frisch elasticity of labor supply. As in Bouakez and Rebei (2007), preferences are non-separable in consumption and government services. In this specification, the parameter ζ denotes the weight of aggregate consumption in total consumption services, X_t, whereas ξ is the elasticity

of substitution between aggregate consumption and aggregate government services.

The household enters period t with a stock of nominal bonds, B_t, and a stock of physical capital, K_t. During the period, it receives the principal and the interest on its bonds holdings – with R_t denoting the gross nominal interest rate – provides labor and rents physical capital to the intermediate-good producers in exchange of a nominal wage rate, W_t, and a nominal rental rate, $R_{K,t}$. It also receives nominal profits from intermediate-good producers in all sectors, $\sum_{s=1}^{S} D_{s,t}$, and pays a nominal lump-sum tax, T_t, to the government. The household purchases a bundle of consumption goods at price $P_{C,t}$, and one of investment goods, I_t, at price $P_{I,t}$, and allocates its remaining income to the purchase of new bonds. Its budget constraint is therefore given by

$$P_{C,t}C_t + P_{I,t}I_t + B_{t+1} + T_t = W_t N_t + R_{K,t}K_t + B_t R_{t-1} + \sum_{s=1}^{S} D_{s,t}. \tag{B.3}$$

Investment is subject to convex adjustment costs, so that the stock of physical capital evolves over time according to

$$K_{t+1} = (1-\delta)\,K_t + I_t\left[1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right], \tag{B.4}$$

where δ is the depreciation rate and Ω captures the magnitude of the adjustment cost. The household chooses C_t, N_t, I_t, K_{t+1}, and B_{t+1} to maximize life-time utility (B.1) subject to the budget constraint (B.3), the accumulation equation (B.4), and a no-Ponzi-game condition.

The total amount of labor provided by the household is a CES function of the labor supplied to each sector, that is

$$N_t = \left[\sum_{s=1}^{S} \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}}\right]^{\frac{\nu_N}{1+\nu_N}}, \tag{B.5}$$

where $\omega_{N,s}$ is the weight attached to labor provided to sector s, and ν_N denotes the elasticity of substitution of labor across sectors. When $\nu_N \to \infty$, labor is perfectly mobile and nominal wages are equalized across sectors. Instead, as long as $\nu_N < \infty$, labor is imperfectly mobile and sectoral wages can differ. The nominal wage rate is defined as a function of the nominal sectoral wages, $W_{s,t}$, and reads as

$$W_t = \left[\sum_{s=1}^{S} \omega_{N,s} W_{s,t}^{1+\nu_N}\right]^{\frac{1}{1+\nu_N}}. \tag{B.6}$$

Analogously, the total amount of physical capital is given by the CES function

$$K_t = \left[\sum_{s=1}^{S} \omega_{K,s}^{-\frac{1}{\nu_K}} K_{s,t}^{\frac{1+\nu_K}{\nu_K}}\right]^{\frac{\nu_K}{1+\nu_K}}, \tag{B.7}$$

where $\omega_{K,s}$ is the weight attached to capital provided to sector s, and ν_K is the elasticity of substitution of capital across sectors. The aggregate nominal rental rate of capital is defined as

$$R_{K,t} = \left[\sum_{s=1}^{S} \omega_{K,s} {R_{K,s,t}}^{1+\nu_K} \right]^{\frac{1}{1+\nu_K}}, \tag{B.8}$$

where $R_{K,s,t}$ is the nominal rental rate of capital in sector s.

B.2 Firms

In each sector, there is a continuum of producers that assemble differentiated varieties of output using labor, capital, and a bundle of intermediate inputs. These varieties are then aggregated into a single good in each sector by a representative wholesaler. The goods produced by the S representative wholesalers are then purchased by the retailers, who assemble them into consumption and investment bundles sold to the households, and intermediate-input bundles sold to the producers.

B.2.1 Producers

In each sector, there is a continuum of monopolistically competitive producers, indexed by $j \in [0, 1]$, that use labor, capital, and a bundle of intermediate inputs to assemble a differentiated variety using the Cobb-Douglas technology

$$Z_{s,t}^{j} = \left({N_{s,t}^{j}}^{\alpha_{N,s}} {K_{s,t}^{j}}^{1-\alpha_{N,s}} \right)^{1-\alpha_{H,s}} {H_{s,t}^{j}}^{\alpha_{H,s}}, \tag{B.9}$$

where $Z_{s,t}^{j}$ is the gross output of the variety of producer j, $N_{s,t}^{j}$, $K_{s,t}^{j}$, and $H_{s,t}^{j}$ denote labor, capital, and the bundle of intermediate inputs used by this producer. The parameters $\alpha_{N,s}$ and $\alpha_{H,s}$ are the value-added labor intensity and the gross-output intensity of intermediate inputs, respectively.

As producer j sells its output $Z_{s,t}^{j}$ at price $P_{s,t}^{j}$ to the wholesalers, hires labor at the wage $W_{s,t}$, rents capital at the rate $R_{K,s,t}$, and purchases intermediate inputs at the price $P_{H,s,t}$, its nominal profits equal

$$D_{s,t}^{j}\left(P_{s,t}^{j}\right) = P_{s,t}^{j} Z_{s,t}^{j} - W_{s,t} N_{s,t}^{j} - R_{K,s,t} K_{s,t}^{j} - P_{H,s,t} H_{s,t}^{j}. \tag{B.10}$$

Producers set their price according to a Calvo-type pricing protocol. The Calvo probability that the price remains fixed from one period to the next is constant and identical across producers within the same sector. However, we allow this probability to differ across sectors, and denote it by ϕ_s. By the law of large numbers, a fraction $1 - \phi_s$ of producers are able to reset their prices in each period.

B.2.2 Wholesalers

In each sector, perfectly competitive wholesalers aggregate the different varieties supplied by the producers into a single final good. The representative wholesaler in sector s has the following CES production technology:

$$Z_{s,t} = \left[\int_0^1 {Z_{s,t}^j}^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{B.11}$$

where $Z_{s,t}$ is the output of sector s, and ϵ is the elasticity of substitution across varieties within the sector, which is assumed to be constant across sectors.[30] The price of the final good s is then given by

$$P_{s,t} = \left[\int_0^1 {P_{s,t}^j}^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}. \tag{B.12}$$

The final good of sector s is sold to consumption, investment, and intermediate-input retailers, as well as to the fiscal authority. This yields the following market-clearing condition:

$$Z_{s,t} = C_{s,t} + I_{s,t} + \sum_{x=1}^{S} H_{x,s,t} + G_{s,t}, \tag{B.13}$$

where $C_{s,t}$ and $I_{s,t}$ denote, respectively, the retailer's purchase of consumption and investment goods from the wholesaler of sector s, $H_{x,s,t}$ denotes the intermediate inputs produced by sector s and used in the production of sector x, and $G_{s,t}$ denotes government purchases from sector s.

B.2.3 Consumption-good retailers

Perfectly competitive consumption-good retailers purchase goods from the wholesalers of each sector and assemble them into a consumption bundle sold to households. The representative consumption-good retailer uses the following CES technology:

$$C_t = \left[\sum_{s=1}^{S} \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C-1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C-1}}, \tag{B.14}$$

where ν_C is the elasticity of substitution of consumption across sectors, and $\omega_{C,s}$ denotes the weight of good s in the consumption bundle, such that $\sum_{s=1}^{S} \omega_{C,s} = 1$. The consumption bundle is sold to the households at the equilibrium price $P_{C,t}$, defined as

$$P_{C,t} = \left[\sum_{s=1}^{S} \omega_{C,s} P_{s,t}^{1-\nu_C} \right]^{\frac{1}{1-\nu_C}}. \tag{B.15}$$

[30] Assuming a symmetric elasticity of substitution is inconsequential for our results, as in a Calvo-pricing economy this parameter vanishes when we log-linearize the model around the steady state. The model, however, still accommodates heterogeneity in sectoral markups through heterogeneity in sectoral price rigidity.

B.2.4 Investment-good retailers

Investment-good retailers behave analogously to the consumption-good retailers. The representative investment-good retailer buys goods from the representative wholesaler of each sector and assembles them into an investment bundle using the CES technology

$$I_t = \left[\sum_{s=1}^{S} \omega_{I,s}^{\frac{1}{\nu_I}} I_{s,t}^{\frac{\nu_I - 1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I - 1}}, \tag{B.16}$$

where ν_I is the elasticity of substitution of investment across sectors, and $\omega_{I,s}$ denotes the weight of good s in the investment bundle, such that $\sum_{s=1}^{S} \omega_{I,s} = 1$. The investment bundle is sold to the households at the equilibrium price $P_{I,t}$, defined as

$$P_{I,t} = \left[\sum_{s=1}^{S} \omega_{I,s} P_{s,t}^{1-\nu_I} \right]^{\frac{1}{1-\nu_I}}. \tag{B.17}$$

B.2.5 Intermediate-input retailers

Perfectly competitive intermediate-input retailers transform the goods assembled by the wholesale producers of all sectors into a bundle of intermediate inputs destined exclusively to the producers of a specific sector. The representative intermediate-input retailer that sells exclusively to sector s produces the bundle $H_{s,t}$ using the CES technology

$$H_{s,t} = \left[\sum_{x=1}^{S} \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H - 1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H - 1}}, \tag{B.18}$$

where $H_{s,x,t}$ is the quantity of goods purchased from the wholesaler of sector x, ν_H is the elasticity of substitution of intermediate inputs across sectors, and $\omega_{H,s,x}$ is the weight of the intermediate inputs produced by sector x in the total amount of intermediate inputs used by firms in sector s, such that $\sum_{x=1}^{S} \omega_{H,s,x} = 1$. The intermediate-input bundle is sold to firms in sector s at the equilibrium price $P_{H,s,t}$, which satisfies

$$P_{H,s,t} = \left[\sum_{x=1}^{S} \omega_{H,s,x} P_{x,t}^{1-\nu_H} \right]^{\frac{1}{1-\nu_H}}. \tag{B.19}$$

B.3 Government

The government consists of a monetary and a fiscal authority. The monetary authority sets the nominal interest rate, R_t, according to the Taylor rule

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\varphi_R} \left[(1+\pi_t)^{\varphi_\Pi} \left(\frac{Y_t}{Y_t^{\text{flex}}}\right)^{\varphi_Y}\right]^{1-\varphi_R}, \tag{B.20}$$

where R^* denotes the steady-state nominal interest rate, φ_R is the degree of interest rate inertia, Y_t is aggregate real value added, Y_t^{flex} is the aggregate real value added of a counterfactual economy with fully flexible prices, φ_Π and φ_Y measure the degree to which the monetary authority adjusts the nominal interest rate in response to changes in aggregate inflation π_t and the output gap $\frac{Y_t}{Y_t^{\text{flex}}}$, respectively. The aggregate inflation is derived over the GDP deflator P_t, that is, $\pi_t = \frac{P_t}{P_{t-1}} - 1$.

Government purchases from sector s are governed by the following auto-regressive process:

$$\log G_{s,t} = (1-\rho)\log G_s^* + \rho \log G_{s,t-1} + \upsilon_{s,t}, \tag{B.21}$$

where ρ measures the persistence of the process. Sectoral government spending changes over time following the realizations of the unique source of uncertainty in the model: sectoral government spending shocks, $\upsilon_{s,t}$, which are zero-mean innovations. Once the spending shocks are realized, the government purchases goods from the representative wholesaler at price $P_{s,t}$. Government purchases are financed through lump-sum taxes paid by the household, which implies the following budget constraint for the government:

$$\sum_{s=1}^{S} P_{s,t} G_{s,t} = T_t. \tag{B.22}$$

B.4 Aggregation

Let $\mathcal{Y}_{s,t}$ denote the nominal value added of producer j in sector s, defined as the value of gross output produced by the producer less the cost of the intermediate inputs it uses. That is,

$$\mathcal{Y}_{s,t}^j = P_{s,t}^j Z_{s,t}^j - P_{H,s,t} H_{s,t}^j. \tag{B.23}$$

Aggregating the nominal value added of all the producers in sector s yields

$$\mathcal{Y}_{s,t} = \int_0^1 \mathcal{Y}_{s,t}^j dj = P_{s,t} Z_{s,t} - P_{H,s,t} H_{s,t}. \tag{B.24}$$

Moreover, summing up nominal dividends across firms within sector s yields

$$\begin{aligned} D_{s,t} &= \int_0^1 D_{s,t}^j dj = P_{s,t} Z_{s,t} - W_{s,t} N_{s,t} - R_{K,s,t} K_{s,t} - P_{H,s,t} H_{s,t} \\ &= \mathcal{Y}_{s,t} - W_{s,t} N_{s,t} - R_{K,s,t} K_{s,t}. \end{aligned} \tag{B.25}$$

Aggregating nominal dividends across sectors and substituting into the households' budget constraint (B.3), we obtain[31]

$$\mathcal{Y}_t = \sum_{s=1}^{S} \mathcal{Y}_{s,t} = P_{C,t} C_t + P_{I,t} I_t + \sum_{s=1}^{S} P_{s,t} G_{s,t}. \tag{B.26}$$

Equation (B.26) states that aggregate nominal value added, $\mathcal{Y}_t$, equals the sum of the nominal values of consumption, investment, and government spending.

Aggregate real value added is defined as the ratio between aggregate nominal value added and the GDP deflator:

$$Y_t = \frac{\mathcal{Y}_t}{P_t}. \tag{B.27}$$

Using an analogous definition for sectoral real value added, $Y_{s,t}$, aggregate real value added satisfies the following identity:

$$Y_t = \frac{\sum_{s=1}^{S} \mathcal{Y}_{s,t}}{P_t} = \sum_{s=1}^{S} Y_{s,t}. \tag{B.28}$$

B.5 Nesting the stylized economy

The multi-sector model collapses to the stylized two-sector economy of Section 2 under the following parameter restrictions:

1. The economy consists of two sectors: $S = 2$, and $s = u, d$;
2. The upstream sector (u) supplies all the intermediate inputs, whereas the downstream sector (d) demands intermediate inputs, but provides none: $\omega_{H,u,u} = \omega_{H,d,u} = 1$;
3. Cobb-Douglas consumption-good aggregator: $\nu_C = 1$;
4. No capital in the production function: $\alpha_{N,u} = \alpha_{N,d} = 1$;
5. Equal gross-output factor intensities across sectors: $\alpha_{H,u} = \alpha_{H,d} = \alpha_H$;
6. Fully flexible prices: $\phi_u = \phi_d = 0$;
7. Infinite elasticity of demand: $\epsilon \to \infty$;
8. Equal steady-state ratio of the sectoral contribution to government spending to aggregate value added: $\frac{Q_u^* G_u^*}{Y^*} = \frac{Q_d^* G_d^*}{Y^*}$;

[31] To derive this equation, we have used the market clearing conditions $N_{s,t} = \int_0^1 N_{s,t}^j dj$, $K_{s,t} = \int_0^1 K_{s,t}^j dj$, and $H_{s,t} = \int_0^1 H_{s,t}^j dj$, the government budget constraint (B.22), the retailers' zero-profit conditions $\sum_s W_{s,t} N_{s,t} = W_t N_t$ and $\sum_s R_{K,s,t} K_{s,t} = R_{K,t} K_t$, as well as the fact that the net supply of private bonds equals zero in equilibrium: $B_t = 0, \ \forall t$.

9. Households receive no utility from government spending: $\zeta = 1$;

10. Logarithmic preference over consumption: $\sigma = 1$;

11. Infinite Frisch elasticity of labor supply: $\eta = 0$.

C More on the Calibration of the Quantitative Model

This section presents further information on the calibration of the quantitative model. Tables C.1 – C.3 report the list of the 57 production sectors we consider. This level of disaggregation roughly corresponds to the three-digit level of the NAICS codes.

In what follows, we discuss the calibration of the parameters that are common to all sectors and we have not mentioned in Section 4.2. All these values are also reported in Table C.4, together with the target or the source that disciplines our calibration choice. We calibrate the time discount factor to $\beta = 0.995$, such that the annual steady-state nominal interest rate equals 2 percent, while the risk-aversion parameter is set to the standard value of $\sigma = 2$. Moreover, we choose $\eta = 1.25$, such that the Frisch elasticity equals 0.8, in line with the estimate of the labor supply elasticity derived by Chetty et al. (2013). We set $\theta = 41.57$, such that the steady-state level of total hours, N, equals 0.33. We choose the elasticity of substitution between consumption and government spending to be $\xi = 0.3$, in line with the estimates of Bouakez and Rebei (2007) and Sims and Wolf (2018),[32] and the relative weight of consumption to be $\zeta = 0.7$, which corresponds to the ratio of the nominal value of consumption expenditures over the sum of consumption and government expenditures.

We set $\delta = 0.025$, which implies that physical capital depreciates by 10 percent on an annual basis. We calibrate the investment-adjustment-cost parameter such that the response of aggregate inflation to a common government spending shock peaks after eight quarters, in line with the empirical evidence of Blanchard and Perotti (2002). Accordingly, we set $\Omega = 25$.

We calibrate the elasticity of substitution across varieties within a sector to $\epsilon = 4$, which implies a steady-state mark-up of 33 percent, in line with the average mark-up that De Loecker et al. (2020) estimate at the firm-level over the recent decades.

As for the Taylor rule, we use the estimates of Clarida et al. (2000): we set the degree of interest-rate inertia to $\varphi_R = 0.8$, and the responsiveness to changes in the inflation rate and to the output gap to $\varphi_\Pi = 1.5$ and $\varphi_Y = 0.2$, respectively.

Finally, the tables that report the parameters that vary across sectors (i.e., the contribution to the final consumption good, the contribution to the final investment good, the contribution to government spending, the entire Input-Output matrix, the factor intensities, and the degree of price rigidity) are available upon request.

[32] Consumption and government spending are therefore Edgeworth complements in utility. This assumption is supported by the empirical evidence reported by Fève et al. (2013) and Leeper et al. (2017).

Table C.1: Sectors 1-20.

1	Farms
2	Forestry, fishing, and related activities
3	Mining
4	Utilities
5	Construction
6	Wood products
7	Nonmetallic mineral products
8	Primary metals
9	Fabricated metal products
10	Machinery
11	Computer and electronic products
12	Electrical equipment, appliances, and components
13	Motor vehicles, bodies and trailers, and parts
14	Other transportation equipment
15	Furniture and related products
16	Miscellaneous manufacturing
17	Food and beverage and tobacco products
18	Textile mills and textile product mills
19	Apparel and leather and allied products
20	Paper products

Table C.2: Sectors 21-40.

21	Printing and related support activities
22	Petroleum and coal products
23	Chemical products
24	Plastics and rubber products
25	Wholesale trade
26	Motor vehicle and parts dealers
27	Food and beverage stores
28	General merchandise stores
29	Other retail
30	Air transportation
31	Rail transportation
32	Water transportation
33	Truck transportation
34	Transit and ground passenger transportation
35	Pipeline transportation
36	Other transportation and support activities
37	Warehousing and storage
38	Publishing industries, except internet (includes software)
39	Motion picture and sound recording industries
40	Broadcasting and telecommunications

Table C.3: Sectors 41-57.

41	Data processing, internet publishing, and other information services
42	Legal services
43	Computer systems design and related services
44	Miscellaneous professional, scientific, and technical services
45	Management of companies and enterprises
46	Administrative and support services
47	Waste management and remediation services
48	Educational services
49	Ambulatory health care services
50	Hospitals
51	Nursing and residential care facilities
52	Social assistance
53	Performing arts, spectator sports, museums, and related activities
54	Amusements, gambling, and recreation industries
55	Accommodation
56	Food services and drinking places
57	Other services, except government

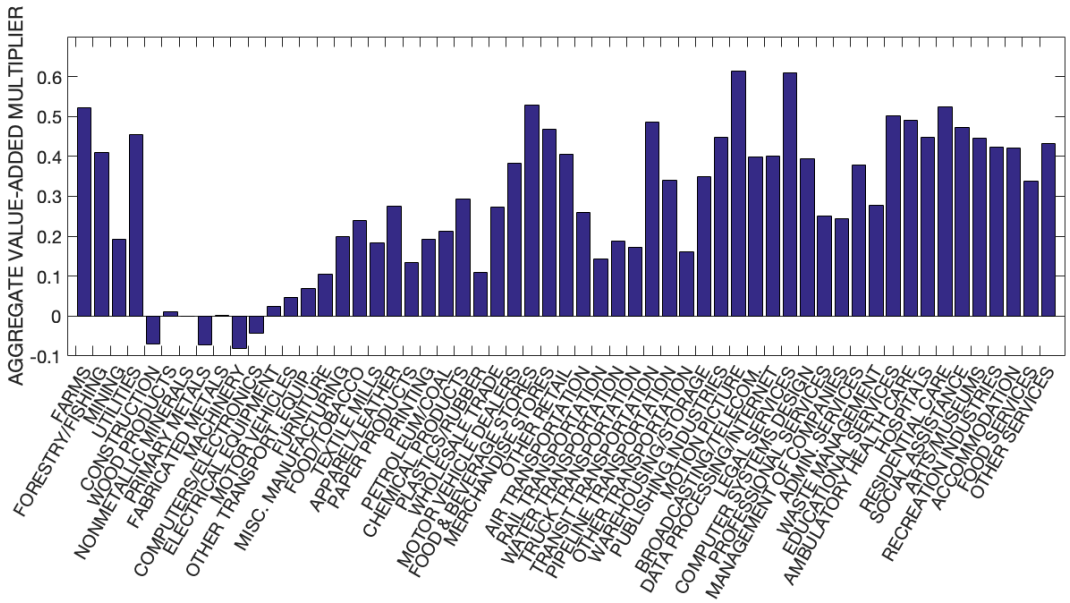
Table C.4: Calibration of Economy-Wide Parameters.

Parameter	Target/Source
$\beta = .995$	2% Steady-State Annual Interest Rate R
$\sigma = 2$	Standard Value
$\theta = 41.01$	0.33 Steady-State Total Hours N
$\eta = 1/0.8$	Chetty et al. (2013)
$\xi = 0.3$	Bouakez and Rebei (2007), Sims and Wolff (2018)
$\zeta = 0.7$	Ratio of nominal value of consumption expenditures over the sum of consumption and government expenditures
$\delta = 0.025$	10% Annual Depreciation Rate
$\Omega = 20$	8 Quarters Peak Response of Investment
$\nu_C = 2$	Hobijn and Nechio (2019)
$\nu_I = 2$	$\nu_I = \nu_C$
$\nu_H = 0.1$	Barrot and Sauvagnat (2016), Atalay (2017), Boehm et al. (2019)
$\nu_N = 1$	Horvath (2000)
$\nu_K = 1$	$\nu_K = \nu_N$
$\epsilon = 4$	33% Steady-State Mark-Up
$\varphi_R = 0.8$	Clarida et al. (2000)
$\varphi_\Pi = 1.5$	Clarida et al. (2000)
$\varphi_Y = 0.2$	Clarida et al. (2000)
$\rho = 0.9$	Standard Value

D Aggregate Effects of Eectoral Spending Shocks in the Absence of Complementarity between C_t and G_t

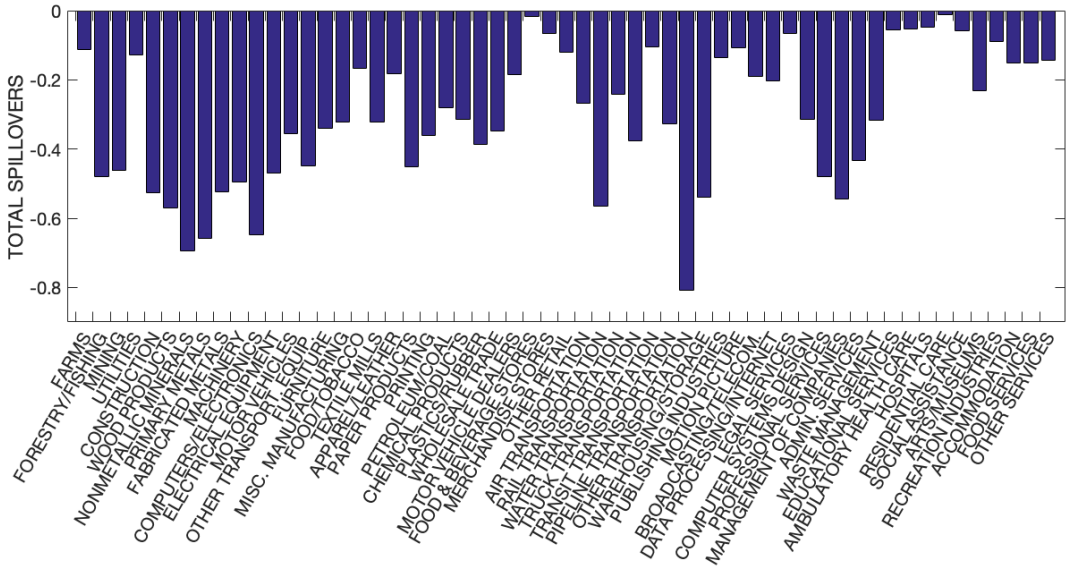
Below, we report the aggregate implications of sectoral spending shocks, obtained from a version of the quantitative model in which government spending does not enter directly into the utility function. This is achieved by assuming $\zeta = 1$. Figures D.1–D.4 report, respectively, the value-added multipliers, the total spillovers, the consumption multipliers, and the investment multipliers associated with spending shocks in each of the 57 sectors. These figures show that abstracting from complementarity between private consumption and government spending in preferences reduces the magnitude of the aggregate effects of sectoral spending shocks and their inter-sectoral spillovers. Intuitively, when government spending no longer raises the marginal utility of private consumption, labor supply increases by a smaller amount in response to an increase in public purchases, leading to a larger (negative) resource-constraint effect. Figures D.1–D.4 indicate, however, that the complementarity between private and public spending affects the aggregate implications of sectoral spending shocks essentially through a *level* effect. A version of the model that abstracts from this feature still generates sizable heterogeneity in the aggregate spending multiplier across sectoral spending shocks.

Figure D.1: Aggregate Output Response to Sectoral Government Spending Shocks.



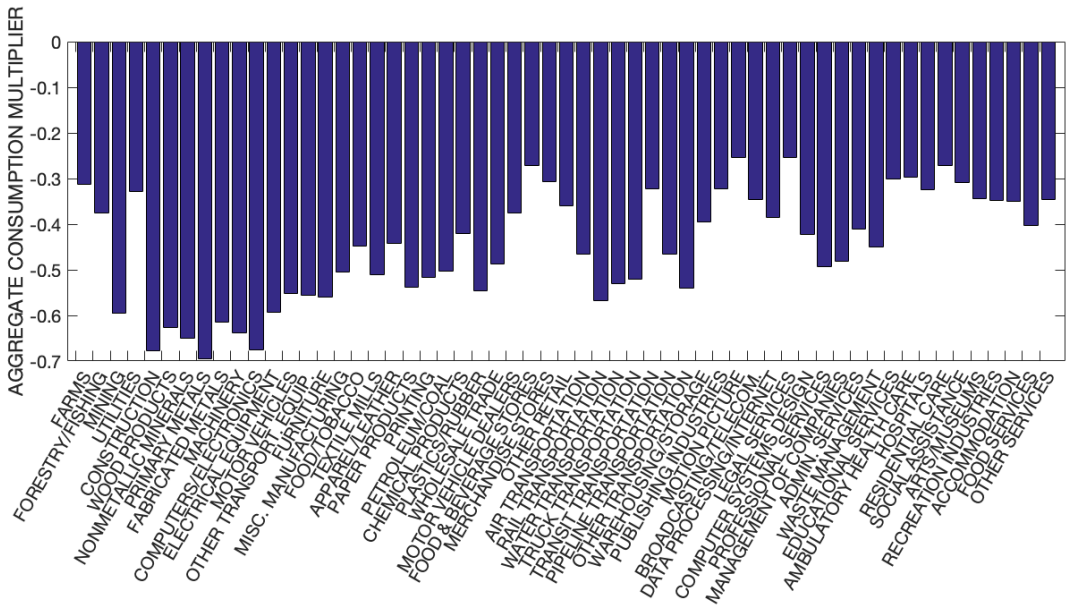
Notes: The figure plots the aggregate value-added multiplier associated with each sectoral government spending shock, obtained from a version of the fully-heterogeneous economy in which government spending does not enter into the utility function.

Figure D.2: Total Spillovers from Sectoral Government Spending Shocks.



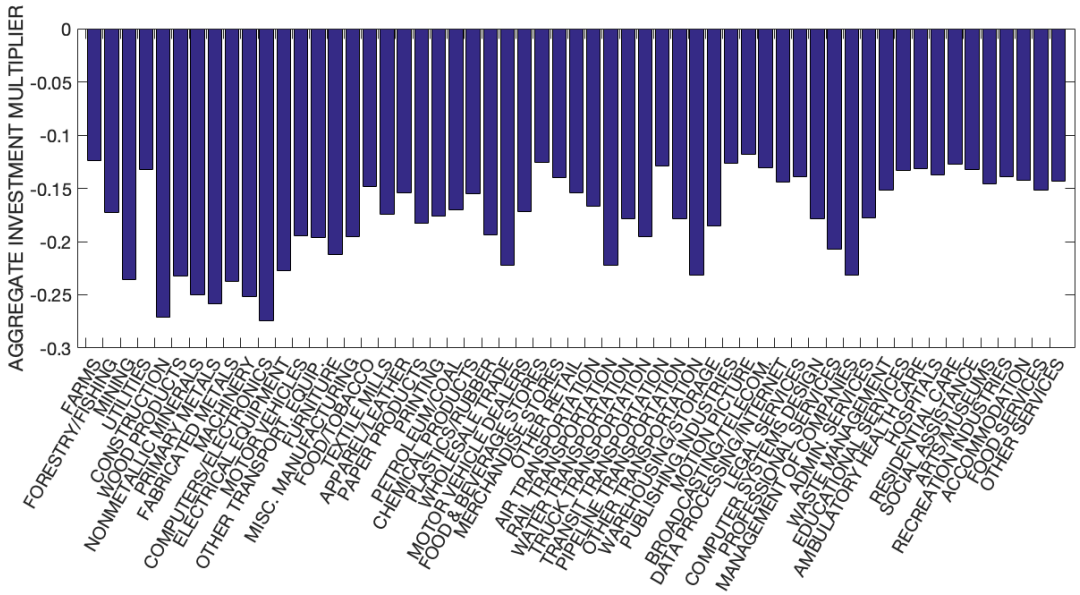
Notes: The figure plots the total spillovers generated by each sectoral government spending shock, obtained from a version of the fully-heterogeneous economy in which government spending does not enter into the utility function.

Figure D.3: Aggregate Consumption Response to Sectoral Government Spending Shocks.



Notes: The figure plots the aggregate consumption multiplier associated with each sectoral government spending shock, obtained from a version of the fully-heterogeneous economy in which government spending does not enter into the utility function.

Figure D.4: Aggregate Investment Response to Sectoral Government Spending Shocks.



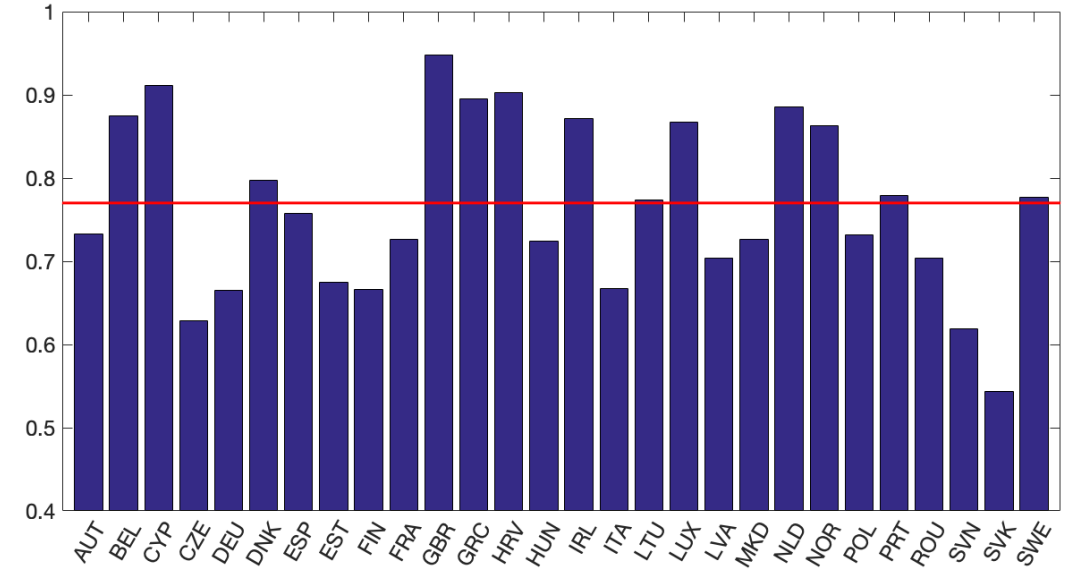
Notes: The figure plots the aggregate investment multiplier associated with each sectoral government spending shock, obtained from a version of the fully-heterogeneous economy in which government spending does not enter into the utility function.

E The Sectoral Composition of Government Purchases across Countries

In this section, we use the 2014 Input-Output Tables of the OECD to derive the sectoral composition of national government spending for a set of 28 countries: Austria, Belgium, Cyprus, Croatia, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Latvia, Lithuania, Luxembourg, Macedonia, the Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden, and the United Kingdom. As in Section 5, we consider a sequence of economies, one for each country, that feature the same steady state (based on the U.S. economy) and differ only in the calibration of the sectoral composition of the government spending shocks. Note that because the specific blend of sectoral government spending in a given country is, to a large extent, endogenous to its economic conditions, we do not seek to measure the spending multiplier in each of the 28 countries based on the model calibrated to the U.S. economy. Instead, we would like to determine what the government spending multiplier in the U.S. would be, should the calibration reflect the sectoral composition of government spending of other advanced economies.

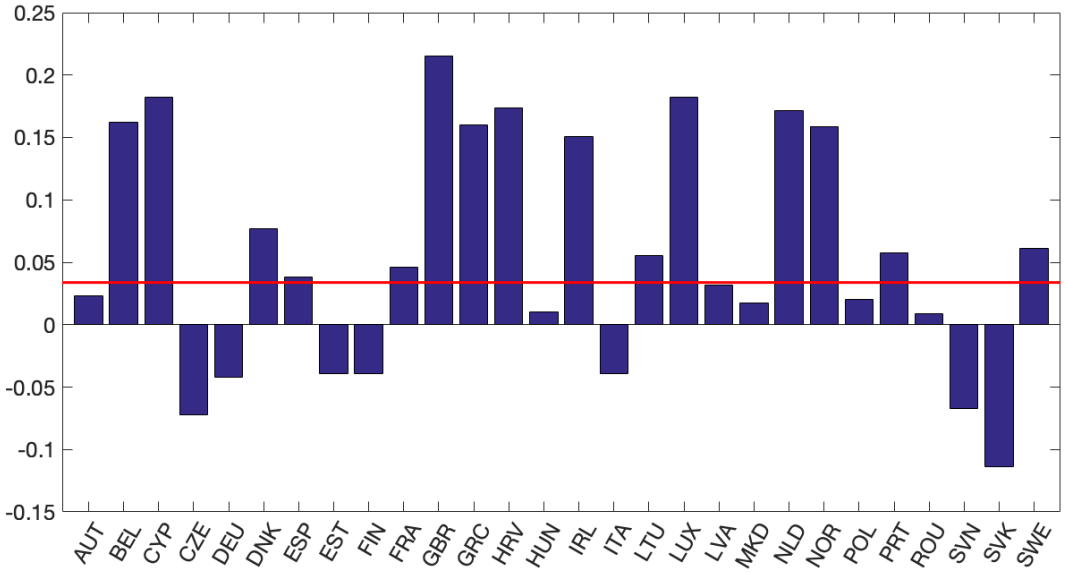
Allowing for variation in the sectoral composition of spending of the general government across countries leads to large differences in the size of the government spending multiplier. Figures E.1 and E.2 respectively report the output and consumption multipliers associated with spending shocks whose sectoral split is calibrated to the U.S. and each of the 28 OECD countries we consider. The output multiplier ranges between 0.54 in the case of Slovakia and 0.95 for the United Kingdom. These differences are driven by the fact that the general government in (low-multiplier) countries such as Czech Republic, Slovakia, and Slovenia tends to concentrate its spending relatively more in manufacturing and transportation industries, whereas the general government of (high-multiplier) economies such as Croatia, Cyprus, and the United Kingdom spends relatively more in professional, educational, and health-care services. As for consumption, we observe – once again – strong heterogeneity, with both crowding-in and crowding-out effects associated with different countries/compositions of the public spending shock. The general picture emerging from this exercise is that the multiplier associated with the sectoral composition of government spending in the U.S. is lower than those implied by the sectoral composition of public purchases in at least a dozen of OECD countries.

Figure E.1: The Aggregate Value-Added Multiplier across Countries.



Notes: The figure reports the aggregate value-added multiplier based on the sectoral composition of general government spending in twenty-eight OECD countries. The red line corresponds to the value of the aggregate value-added multiplier in the United States. All the multipliers are obtained from otherwise identical economies that only differ in the sectoral composition of the government spending shock, which is calibrated based the Input-Output table of each country.

Figure E.2: The Aggregate Consumption Multiplier across Countries.



Notes: The figure reports the aggregate consumption multiplier based on the sectoral composition of general government spending in twenty-eight OECD countries. The red line corresponds to the value of the aggregate consumption multiplier in the United States. All the multipliers are obtained from otherwise identical economies that only differ in the sectoral composition of the government spending shock, which is calibrated based the Input-Output table of each country.

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