

Sectoral Heterogeneity, Production Networks, and the Effects of Government Spending*

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Abstract

We study the effects of government spending shocks in an economy with multiple interconnected production sectors that differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. The cumulative aggregate output multiplier associated with an aggregate government spending shock is 84% larger than that obtained in the average one-sector economy. This amplification is mainly driven by sectoral heterogeneity in price rigidity and the presence of input-output linkages. We also document substantial heterogeneity in the aggregate effects of sector-specific government spending shocks, and identify the key factors that account for it. Government spending shocks tend to have larger effects on aggregate output when they originate in sectors that have relatively rigid prices and high labor shares in value added, and are located downstream in the production network.

Key Words: Government Spending Multiplier, Input-Output Matrix, Price Rigidity, Spillover Effects.

JEL Classification Codes: E62, H32.

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1 Introduction

Fiscal packages involve purchases of goods and services produced by heterogeneous and interconnected industries. For instance, the 2009 American Recovery and Reinvestment Act provisioned a \$228 billion increase in government spending, of which \$144 billion were allocated to educational services, transportation projects, and energy programs. This fact, however, is largely overlooked by theoretical studies of fiscal policy, which tend to rely on one-sector models (e.g., Aiyagari et al., 1992; Baxter and King, 1993; Burnside et al., 2004; Christiano et al., 2011; Woodford, 2011; Leeper et al., 2017). To the extent that sectoral heterogeneity and inter-sectoral linkages affect the aggregate implications of public expenditure, the assumptions of symmetry and absence of production networks embedded in the one-sector framework can be an important source of bias when evaluating the government spending multiplier.

In this paper, we study the effects of government spending in the context of a multi-sector sticky-price model featuring input-output linkages. The sectors differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. The model consists of 58 sectors, which roughly correspond to the 3-digit level of the North American Industry Classification System (NAICS) sectoral codes, and is calibrated based on the actual Input-Output matrix of the U.S. economy, as well as on available estimates of sectoral price rigidity. Although the model incorporates input-output linkages and numerous dimensions of heterogeneity, it represents a natural extension of the standard New Keynesian model, which it nests as a limiting case.

Our first contribution is to determine how and to what extent sectoral heterogeneity and input-output interactions affect the aggregate effects of government spending relative to the benchmark one-sector economy. We find that the long-run cumulative value-added multiplier associated with a spending shock that is common to all sectors is 84 percent larger in the multi-sector economy than in the average one-sector economy. This amplification is mainly due to sectoral heterogeneity in price rigidity and the presence of input-output interactions. To shed light on the mechanisms underlying this result, we provide some analytical insights based on a stripped-down version of the model, which isolates the role of intermediate inputs and sectoral heterogeneity in price rigidity. Both features raise the size of the government spending multiplier by acting as sources of real rigidity.

Fiscal packages are typically devised to target some specific industries. Accounting for this fact is of paramount importance when evaluating the spending

multiplier. In this respect, our second contribution is to study the implications of the sectoral allocation of government spending for aggregate outcomes. We do so by analyzing the economy-wide response to sector-specific spending shocks. Relating the aggregate effects of a shock to a given sector to its characteristics and position in the production network also enables us to unveil the propagation channels of government spending.

We document substantial dispersion in the effects of sector-specific government spending shocks on aggregate value added, with a cumulative multiplier ranging from 0.27 to 0.89 at the 1-year horizon, and from 0.32 to 0.75 in the long run. This heterogeneity is not limited to aggregate output; it also extends to consumption, investment, employment, inflation, and the real wage. The dispersion in the response of the aggregate wage, in particular, is not only in terms of magnitude but also in terms of sign, especially at short horizons. For instance, the 1-year cumulative wage response is negative when the spending shock occurs in 30 out of the 58 sectors. This result implies that the response of the real wage to a government spending shock cannot be used to discriminate between competing theories of aggregate fluctuations, as it has been argued in the literature (e.g., Perotti, 2008 and Nekarda and Ramey, 2011).

We then ask: which factors drive the observed heterogeneity in the response of aggregate variables to sectoral spending shocks? We find larger effects on aggregate output when shocks originate in sectors that have relatively rigid prices and high labor shares in value added (for given shares of intermediate inputs in gross output). Heterogeneity in price stickiness and labor intensity across production sectors introduces an additional shift term in the aggregate labor demand schedule. This shifter is larger when spending increases in sectors that have relatively rigid prices and are labor intensive, thus leading to higher equilibrium levels of aggregate employment and output.

In addition to these two sectoral intrinsic characteristics, we show that a sector's position in the production network is a key determinant of the aggregate effects of a dollar spent on its goods. More specifically, the aggregate value-added multiplier tends to be large when spending occurs in sectors that are located downstream in the production network.¹ Downstreamness implies positive spillovers from the sector impacted by the shock to its input-supplying industries, as the affected sector demands more intermediate inputs to meet the increase in demand from the

¹Downstream sectors are located at the bottom of the supply chain, demanding intermediate inputs from many industries and selling most of their output to final consumers. In contrast, upstream sectors are located at the top of the supply chain, selling most of their output as intermediate inputs to other industries.

government. These positive spillovers outweigh the negative ones resulting from the increase in the relative price of the affected sector, which makes its product relatively more expensive for its customer industries.

In sum, our findings highlight the fact that the size of the spending multiplier crucially depends on the sectoral composition of government purchases. This observation poses yet another challenge for empirical research on fiscal multipliers, as the identification of shocks to government spending should also control for changes in the allocation of public expenditure across sectors. At the same time, it can rationalize (at least partially) the marked dispersion in the available estimates of the spending multiplier. In light of our analysis, studies that exploit military build-ups (e.g., Barro and Redlick, 2011 and Ramey, 2011) tend to find relatively low multipliers likely because they focus on a component of public spending that is concentrated in few manufacturing industries, characterized by low price rigidity and labor intensity, and an upstream position in the production network. Conversely, studies focusing on local spending, which is highly concentrated in education and health care services (e.g., Schoag, 2010), tend to estimate larger multipliers likely because they exploit changes in government purchases that involve sectors that have rigid prices, are labor intensive, and are located downstream in the production network.

This paper relates to the literature that studies the fiscal multipliers associated with broad categories of government spending, which either compares government investment to government consumption (e.g., Baxter and King, 1993; Boehm, 2018; Bouakez et al., 2018), or disaggregates government consumption into wages of government employees and purchases of private-sector goods (e.g., Lane and Perotti, 2003; Pappa, 2009; Auerbach and Gorodnichenko, 2012; Chang et al., 2017; Bouakez et al., 2018; Moro and Rachedi, 2018). We focus on government consumption spending that consists in purchases of goods and services. In doing so, our model allows for inter-sectoral linkages and a much more comprehensive degree of heterogeneity than existing studies that examine the effects of public consumption within two-sector models.² As we show, these features are crucial to understand the aggregate implications of government spending shocks and their propagation.

Our paper also relates to the vast literature on sectoral heterogeneity and production networks. First, it is connected with studies that emphasize the role of sectoral heterogeneity in price rigidity in amplifying the degree of monetary non-neutrality

²In these studies, sectors differ regarding their tradability (e.g., Monacelli and Perotti, 2010), production technology (e.g., Alonso, 2016), or the degree of capital specialization (e.g., Ramey and Shapiro, 1998). Nekarda and Ramey (2011) empirically evaluate the implications of industry-level government purchases at a high level of disaggregation (274 industries), but do not estimate their aggregate effects.

(e.g., Carvalho, 2006; Nakamura and Steinsson, 2010; Bouakez et al., 2014; Pasten et al., 2018). We show that an analogous result holds in the case of government spending shocks. Second, our paper ties in closely with existing work on the implications of production networks for the propagation of shocks (e.g., Horvath, 1998, 2000; Bouakez et al., 2009, 2011; Acemoglu et al., 2012, 2015; Carvalho, 2014; Pasten et al., 2017, 2018; Petrella et al., 2018). This strand of the literature has focused exclusively on technology and monetary policy shocks, with the notable exception of Acemoglu et al. (2015), who empirically investigate the short-run propagation of government spending through the Input-Output matrix. We build on and extend the work of Acemoglu et al. (2015) by developing a New Keynesian model in which government spending shocks propagate both upstream and downstream through the production network and changes in relative prices. Our paper also differs from theirs in that it documents heterogeneity in the aggregate effects of sector-specific spending shocks, and identifies the features that account for it.

Finally, we complement the literature that examines the implications of heterogeneity across households for fiscal multipliers (e.g., Galí et al., 2007; Brinca et al., 2016; Hagedorn et al., 2018). While we retain the convenience of the representative-household framework, we highlight the role of heterogeneity on the production side of the economy.

The rest of this paper is organized as follows. Section 2 presents the model. Section 3 discusses the calibration. Section 4 studies the role of sectoral heterogeneity and input-output interactions in amplifying the government spending multiplier. Section 5 studies the propagation of sector-specific shocks, first by documenting the cross-sectional dispersion in their aggregate effects, then by examining the determinants of this dispersion, with a particular focus on the role of production networks. Section 6 concludes.

2 Model

We build a multi-sector New Keynesian model with physical capital, intermediate inputs, and sector-specific government consumption spending. The economy consists of households, firms, and a government. The representative household consumes, saves in nominal bonds, provides labor to intermediate-good producers, and accumulates capital, which is then rented to firms. Intermediate-good producing firms are uniformly distributed across S sectors, which differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. The government consists of a monetary authority, which sets the nominal interest rate

following a Taylor rule, and a fiscal authority, which finances an exogenous stream of government spending by levying a lump-sum tax on the household.

Although the model incorporates input-output linkages and numerous dimensions of heterogeneity, it represents a natural extension of a the standard New Keynesian model, which it nests as a limiting case.

2.1 Households

The economy is populated by an infinitely-lived representative household that has preferences over consumption, C_t , and labor, N_t , so that its expected lifetime utility is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right], \quad (1)$$

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.

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 goods 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 lump-sum tax, T_t , to the government. The household purchases a bundle of consumption goods at price P_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

$$P_t C_t + P_{I,t} I_t + B_{t+1} + P_t T_t = W_t N_t + R_{K,t} K_t + B_t R_{t-1} + \sum_{s=1}^S D_{s,t}. \quad (2)$$

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

$$K_{t+1} = (1 - \delta) K_t + I_t \left[1 - \frac{\Omega}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right], \quad (3)$$

where δ is the depreciation rate and Ω captures the severity 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 (1) subject to the budget constraint (2), the accumulation equation (3), and a no-Ponzi

game condition.

We assume that labor and capital provided by the household to the firms cannot perfectly move across sectors. Eisfeldt and Rampini (2006), Lee and Wolpin (2006), and Lanteri (2018) document that both labor and capital adjust very sluggishly in response to shocks, and are reallocated imperfectly across sectors in the short- and medium-run. To capture this feature of the data, 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

$$N_t = \left[\sum_{s=1}^S \omega_{N,s}^{\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right]^{\frac{\nu_N}{1+\nu_N}}, \quad (4)$$

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, which captures the degree of labor mobility. When $\nu_N \rightarrow \infty$, labor is perfectly mobile and nominal wages are equalized across sectors. Instead, as long as $\nu_N < \infty$, labor is imperfectly mobile and wages can differ across sectors.³ The nominal wage rate is defined as a function of the nominal sectoral wages, $W_{s,t}$, as follows

$$W_t = \left[\sum_{s=1}^S \omega_{N,s} W_{s,t}^{1+\nu_N} \right]^{\frac{1}{1+\nu_N}}. \quad (5)$$

In equilibrium, labor is allocated across sectors such that the following first-order conditions hold

$$N_{s,t} = \omega_{N,s} \left(\frac{W_{s,t}}{W_t} \right)^{\nu_N} N_t, \quad s = 1, \dots, S. \quad (6)$$

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

$$K_t = \left[\sum_{s=1}^S \omega_{K,s}^{\frac{1}{\nu_K}} K_{s,t}^{\frac{1+\nu_K}{\nu_K}} \right]^{\frac{\nu_K}{1+\nu_K}}, \quad (7)$$

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

³Imperfect labor mobility allows our model to be consistent with the large wage differentials across sectors that have been documented in the literature (e.g., Krueger and Summers, 1988; Gibbons and Katz, 1992; Neumuller, 2015). Katayama and Kim (2018) show that modeling imperfect labor mobility as in Equation (4) provides a better account of the comovement of output and hours worked than alternative explanations based on the wealth effects associated with labor supply.

rate of capital is defined as

$$R_{K,t} = \left[\sum_{s=1}^S \omega_{K,s} R_{K,s,t}^{1+\nu_K} \right]^{\frac{1}{1+\nu_K}}, \quad (8)$$

where $R_{K,s,t}$ is the nominal rental rate of capital in sector s . In equilibrium, capital is allocated across sectors such that the following first-order conditions hold

$$K_{s,t} = \omega_{K,s} \left(\frac{R_{K,s,t}}{R_{K,t}} \right)^{\nu_K} K_t, \quad s = 1, \dots, S. \quad (9)$$

2.2 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 differentiated 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 retailers who assemble them into consumption and investment bundles sold to households, and intermediate-input bundles sold to producers.

2.2.1 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

$$Z_{s,t}^j = \left(N_{s,t}^j \alpha_{N,s} K_{s,t}^{1-\alpha_{N,s}} \right)^{1-\alpha_{H,s}} H_{s,t}^j \alpha_{H,s}, \quad (10)$$

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, $\alpha_{H,s}$ is the share of intermediate inputs in gross output, and $\alpha_{N,s}$ is the *value-added-based* labor intensity, so that $\alpha_{N,s}(1 - \alpha_{H,s})$ is the *gross-output-based* labor intensity. In equilibrium, labor-market clearing implies that $N_{s,t} = \int_0^1 N_{s,t}^j dj$, so that the amount of labor provided by the household to each sector equals the total amount of labor demanded by the producers. Analogously, we have $K_{s,t} = \int_0^1 K_{s,t}^j dj$ and $H_{s,t} = \int_0^1 H_{s,t}^j dj$.

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

$$D_{s,t}^j(P_{s,t}^j) = P_{s,t}^j Z_{s,t}^j - W_{s,t} N_{s,t}^j - R_{K,s,t} K_{s,t}^j - P_{H,s,t} H_{s,t}^j. \quad (11)$$

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. The optimal reset price, $P_{s,t}^{*,j}$, maximizes the expected discounted stream of real dividends:

$$\max_{P_{s,t}^j} \mathbb{E}_t \left[\sum_{z=t}^{\infty} \beta^{z-t} \phi_s^{z-t} \frac{C_z^{-\sigma} D_{s,z}^j(P_{s,t}^j)}{C_t^{-\sigma} P_z} \right]. \quad (12)$$

2.2.2 Wholesalers

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

$$Z_{s,t} = \left[\int_0^1 Z_{s,t}^j \frac{\epsilon-1}{\epsilon} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \quad (13)$$

where $Z_{s,t}^j$ 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. The price of the final good s is then given by

$$P_{s,t} = \left[\int_0^1 P_{s,t}^j \frac{1-\epsilon}{\epsilon} dj \right]^{\frac{1}{1-\epsilon}}, \quad (14)$$

and the problem of the representative wholesaler in sector s reads as

$$\begin{aligned} \max_{Z_{s,t}^j} & P_{s,t} Z_{s,t} - \int_0^1 P_{s,t}^j Z_{s,t}^j dj \\ \text{s.t.} & \quad Z_{s,t} = \left[\int_0^1 Z_{s,t}^j \frac{\epsilon-1}{\epsilon} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \end{aligned}$$

which implies the following first-order conditions:

$$Z_{s,t}^j = \left(\frac{P_{s,t}^j}{P_{s,t}} \right)^{-\epsilon} Z_{s,t}, \quad j \in [0, 1], \quad s = 1, \dots, S. \quad (15)$$

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:

$$Z_{s,t} = C_{s,t} + I_{s,t} + \sum_{x=1}^S H_{x,s,t} + G_{s,t}, \quad (16)$$

where $G_{s,t}$ denotes government purchases from sector s .

2.2.3 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 Cobb-Douglas technology:

$$C_t = \prod_{s=1}^S \frac{C_{s,t}^{\nu_{C,s}}}{\nu_{C,s}^{\nu_{C,s}}}, \quad (17)$$

where $C_{s,t}$ denotes the retailer's purchase of consumption goods from the wholesaler of sector s , and $\nu_{C,s}$ denotes the share of good s in the consumption bundle, such that $\sum_{s=1}^S \nu_{C,s} = 1$. The consumption bundle is sold to households at the equilibrium price P_t , given by

$$P_t = \prod_{s=1}^S P_{s,t}^{\nu_{C,s}}. \quad (18)$$

The consumption-good retailer therefore solves the following problem:

$$\begin{aligned} \max_{C_{s,t}} \quad & P_t C_t - \sum_{s=1}^S P_{s,t} C_{s,t} \\ \text{s.t.} \quad & C_t = \prod_{s=1}^S \frac{C_{s,t}^{\nu_{C,s}}}{\nu_{C,s}^{\nu_{C,s}}}, \end{aligned}$$

which yields the following first-order conditions:

$$C_{s,t} = \nu_{C,s} \frac{P_t C_t}{P_{s,t}}, \quad s = 1, \dots, S. \quad (19)$$

2.2.4 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

Cobb-Douglas technology

$$I_t = \prod_{s=1}^S \frac{I_{s,t}^{\nu_{I,s}}}{\nu_{I,s}^{\nu_{I,s}}}, \quad (20)$$

where $I_{s,t}$ denotes the retailer's purchases of investment goods from the wholesaler of sector s , and $\nu_{I,s}$ denotes the share of good s in the investment bundle, such that $\sum_{s=1}^S \nu_{I,s} = 1$. The investment bundle is sold to households at the equilibrium price $P_{I,t}$, given by

$$P_{I,t} = \prod_{s=1}^S P_{s,t}^{\nu_{I,s}}, \quad (21)$$

and the first-order conditions associated with the retailer's optimization problem are given by

$$I_{s,t} = \nu_{I,s} \frac{P_{I,t} I_t}{P_{s,t}}, \quad s = 1, \dots, S. \quad (22)$$

2.2.5 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 Cobb-Douglas technology

$$H_{s,t} = \prod_{x=1}^S \frac{H_{s,x,t}^{\nu_{H,s,x}}}{\nu_{H,s,x}^{\nu_{H,s,x}}}, \quad (23)$$

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

$$P_{H,s,t} = \prod_{x=1}^S P_{x,t}^{\nu_{H,s,x}}. \quad (24)$$

The problem of this intermediate-input retailer, therefore, is

$$\begin{aligned} & \max_{H_{s,x,t}} P_{H,s,t} H_{s,t} - \sum_{x=1}^S P_{x,t} H_{s,x,t} \\ \text{s.t.} \quad & H_{s,t} = \prod_{x=1}^S \frac{H_{s,x,t}^{\nu_{H,s,x}}}{\nu_{H,s,x}^{\nu_{H,s,x}}}, \end{aligned}$$

which implies the following first-order conditions:

$$H_{s,x,t} = \nu_{H,s,x} \frac{P_{H,s,t} H_{s,t}}{P_{x,t}}, \quad s, x = 1, \dots, S. \quad (25)$$

2.3 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

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\varphi_R} \left[(1 + \pi_t)^{\varphi_\Pi} \left(\frac{Y_t}{Y_t^{\text{flex}}} \right)^{\varphi_Y} \right]^{1-\varphi_R}, \quad (26)$$

where R denotes the steady-state nominal interest rate,⁴ φ_R is the degree of interest rate inertia, Y_t is the aggregate value added of the economy, Y_t^{flex} is the aggregate 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 the consumption-based inflation rate, $\pi_t = \frac{P_t}{P_{t-1}} - 1$, and to changes in the output gap, respectively.

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

$$\log G_{s,t} = (1 - \rho) \log G_s + \rho \log G_{s,t-1} + \epsilon_{s,t}, \quad (27)$$

where G_s defines the steady-state amount of sectoral government spending, and ρ measures the persistence of the process, which is assumed to be uniform across sectors. Sectoral government spending changes over time following the realizations of the unique source of uncertainty in the model: sectoral government spending shocks, $\epsilon_{s,t}$, which follow a normal distribution with mean zero.

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,⁵ which implies the following budget constraint for the government:

$$\sum_{s=1}^S P_{s,t} G_{s,t} = P_t T_t. \quad (28)$$

⁴Throughout the text, variables without a time subscript denote steady-state values.

⁵In Section C of the Online Appendix, we consider a version of the model in which government spending is financed with distortionary labor income taxes.

2.4 Aggregation

Let $\mathcal{Y}_{s,t}^j$ 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,

$$\mathcal{Y}_{s,t}^j = P_{s,t}^j Z_{s,t}^j - P_{H,s,t} H_{s,t}^j. \quad (29)$$

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

$$\mathcal{Y}_{s,t} \equiv \int_0^1 \mathcal{Y}_{s,t}^j dj = P_{s,t} Z_{s,t} - P_{H,s,t} H_{s,t}, \quad (30)$$

where we have used Equation (15) and the market clearing condition $H_{s,t} = \int_0^1 H_{s,t}^j dj$. Moreover, summing up nominal dividends across firms within sector s yields

$$\begin{aligned} D_{s,t} &\equiv \int_0^1 D_{s,t}^j dj = P_{s,t} Z_{s,t} - W_{s,t} N_{s,t} - R_{K,s,t} K_{s,t} - P_{H,s,t} H_{s,t} \\ &= \mathcal{Y}_{s,t} - W_{s,t} N_{s,t} - R_{K,s,t} K_{s,t}. \end{aligned} \quad (31)$$

Aggregating nominal dividends across sectors and substituting into the households' budget constraint (2), we obtain⁶

$$\sum_{s=1}^S \mathcal{Y}_{s,t} = P_t C_t + P_{I,t} I_t + \sum_{s=1}^S P_{s,t} G_{s,t}. \quad (32)$$

Equation (32) posits that the aggregate nominal value added, i.e., the sum of sectoral nominal value added, equals the sum of the nominal values of consumption, investment, and government spending. Aggregate real value added (i.e., real GDP), Y_t , is then obtained by deflating the nominal aggregate value added by the consumption-based price index, P_t :

$$Y_t \equiv \frac{\sum_{s=1}^S \mathcal{Y}_{s,t}}{P_t} = \sum_{s=1}^S Y_{s,t}, \quad (33)$$

where $Y_{s,t}$ is the sectoral real value added.

⁶To derive this equation, we have used the government budget constraint (28), the 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, $B_t = 0, \forall t$.

3 Calibration

We consider an economy consisting of $S = 58$ sectors, which roughly correspond to the 3-digit level of the NAICS code list, excluding the financial industries. Tables A1 – A3 in Section A of the Online Appendix report the entire list of sectors to which we calibrate our model. Below, we discuss our calibration strategy, and report the parameter values in Tables A4 – A7 in Section A of the Online Appendix. Throughout the analysis, we assume that one period in the model corresponds to a quarter.

We calibrate the sectoral shares $\nu_{C,s}$, $\nu_{I,s}$, and $\nu_{H,s,x}$ based on the average values reported in the Input-Output matrix of the U.S. economy from 1997 to 2015, as computed by the Bureau of Economic Analysis. The consumption shares, $\nu_{C,s}$, are measured by the contribution of each sector to personal consumption expenditures. The investment shares, $\nu_{I,s}$, are measured by the contribution of each sector to nonresidential private fixed investment in structures and in equipment. The intermediate-input shares, $\nu_{H,s,x}$, are measured by the use of intermediate inputs from sector x in the production of sector s . We also use the average contribution of each sector to general government consumption expenditure to pin down the steady-state levels of sectoral government spending, G_s . The general government consumption expenditure is defined as the sum of federal government defense spending, federal government non-defense spending, and state and local government spending.⁷ We normalize total government spending such that it sums up to 20% of aggregate value added in the steady state, as observed in the data. Importantly, the joint calibration of $\nu_{C,s}$, $\nu_{I,s}$, $\nu_{H,s,x}$, and G_s allows the model to match almost perfectly the sectoral shares in total value added.

To calibrate the factor intensities, $\alpha_{N,s}$ and $\alpha_{H,s}$, we use information from the Input-Output matrix of the U.S. economy on value added, labor compensation, and intermediate inputs. More specifically, we posit that the gross output of each sector equals the sum of the compensation of employees, the gross operating surplus, and intermediate inputs.⁸ Since we consider a constant-return-to-scale Cobb-Douglas production function, we can compute $\alpha_{H,s}$ as the sectoral shares of intermediate inputs in gross output, and $\alpha_{N,s}$ as the sectoral shares of the compensation of employees in value added.

To assign values to the sectoral Calvo probabilities, ϕ_s , we match our sectors with

⁷Since our model abstracts from public investment, we exclude this category when we measure government spending.

⁸We leave out taxes and subsidies from the computation of gross output.

the items/industries analyzed by Nakamura and Steinsson (2008) and Bouakez et al. (2011), and rely on their estimates of the sectoral durations of price spells to back out the values of ϕ_s .

The time discount factor is calibrated to $\beta = 0.995$, such that the annual steady-state nominal interest rate equals 2%, while the risk-aversion parameter is set to the standard value of $\sigma = 2$. Moreover, we choose $\eta = 0.5$, such that the Frisch elasticity equals 2, which is consistent with the estimate of the macro labor supply elasticity derived by Peterman (2016).⁹ Moreover, we set $\theta = 24.23$, such that the steady-state level of total hours, N , equals 0.33.

With respect to the elasticity of substitution of labor across sectors, we follow Horvath (2000) and set $\nu_N = 1$.¹⁰ 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 imperfect substitution of labor and capital only *around* the steady-state. In other words, labor and capital move freely across sectors in the steady state, while displaying a degree of imperfect inter-sectoral mobility in the short run. To do so, we set $\omega_{N,s} = \frac{N_s}{N}$ and $\omega_{K,s} = \frac{K_s}{K}$.

We set $\delta = 0.025$, which implies that physical capital depreciates by 10% on an annual basis. We calibrate the investment-adjustment-cost parameter such that, in the fully heterogeneous version of the model, 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 $\Omega = 17$. We calibrate the elasticity of substitution across varieties within a sector to $\epsilon = 4$, which implies a steady-state mark-up of 33%, in line with the average mark-up that De Loecker and Eeckhout (2017) estimate at the firm-level over the recent decades.

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.

To calibrate the autoregressive parameter of the sectoral processes of government spending, we follow Nakamura and Steinsson (2014) and apply the simulated method of moments to estimate the persistence of the quarterly AR(1) process using annual data on spending. This procedure yields a quarterly coefficient of $\rho = 0.90$.

⁹In Section C of the Online Appendix, we consider a version of the model with a lower Frisch elasticity (i.e., $\eta = 1$).

¹⁰Our 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). In Section C of the Online Appendix, we consider a version of the model in which there is no mobility of labor and capital across sectors (i.e., $\nu_N \rightarrow 0$ and $\nu_K \rightarrow 0$).

4 The Government Spending Multiplier in a Multi-Sector Economy

In this section, we study how and to what extent inter-sectoral linkages and sectoral heterogeneity affect the government spending multiplier. More specifically, we measure the degree to which the aggregate value-added multiplier in the multi-sector economy differs from its counterpart in a one-sector model, and evaluate the relative contribution of the different features of the multi-sector economy in accounting for this difference.

To do so, we increasingly enrich the one-sector model by successively adding different dimensions of sectoral interaction and heterogeneity. In total, we study six different economies. The first economy is the “One-Sector” model, which corresponds to a fully symmetric economy with no intermediate inputs, obtained by setting the sectoral shares to their average values and computing the value-added-based labor intensities based on aggregate variables (i.e., $\nu_{C,s} = \nu_{I,s} = 1/58$, $G_s = G$, $\phi_s = \phi$, $\alpha_{H,s} = \alpha_H = 0$, and $\alpha_{N,s} = \alpha_N$). The second model allows for the presence of intermediate inputs (i.e., $0 < \alpha_H < 1$) but imposes a fully symmetric Input-Output matrix. We refer to this case as “Symmetric Input-Output Matrix”. The third model allows for heterogeneity in the consumption shares, $\nu_{C,s}$, the investment shares, $\nu_{I,s}$, and the steady-state government spending levels, G_s . We refer to this version of the model as “Heterogeneous Shares”. The fourth model allows for heterogeneity in factor intensities, $\alpha_{N,s}$ and $\alpha_{H,s}$, and is referred to as “Heterogeneous Factor Intensities”. The fifth model allows for heterogeneity in the elements of the Input-Output matrix, $\nu_{H,s,x}$, and is referred to as “Asymmetric Input-Output Matrix”. The last model, labelled “Fully Heterogeneous”, allows for the remaining source of heterogeneity, namely, sector-specific Calvo probabilities, ϕ_s .

We maintain comparability across all these model versions by focusing on the effects of an aggregate government spending shock, that is, a shock common to all sectors. More specifically, we assume that government spending increases by the same percentage (relative to steady state) in all sectors. To account for the endogenous persistence in the effects of the shock, we compute the discounted present-value (or cumulative) spending multiplier at various horizons. The aggregate value-added multiplier at horizon \mathcal{H} is given by

$$\mathcal{M}(\mathcal{H}) = \frac{\sum_{j=0}^{\mathcal{H}} \beta^j \mathbb{E}_t (Y_{t+j} - Y)}{\sum_{j=0}^{\mathcal{H}} \beta^j \mathbb{E}_t (G_{t+j} - G)}. \quad (34)$$

In all the experiments, we compute the 1-year, 2-year, 5-year, and long-run cumulative multipliers, though the analysis will mainly focus on the long-run multiplier (i.e., the one corresponding to the case $\mathcal{H} \rightarrow \infty$). We solve all the model versions by taking a first-order approximation around the zero-inflation steady state. Table 1 reports the results.

Starting with the “One-Sector” economy, the 1-year and long-run value-added multipliers are 0.66 and 0.31, respectively. These numbers are relatively low, compared with the results reported in existing studies based on one-sector models (e.g., Galí et al., 2007 and Hall, 2009). The reason is twofold. First, we calibrate the Calvo parameters so as to match the micro evidence on the duration of prices across sectors. Accordingly, we set $\phi_s = \phi = 0.66$, which implies an average price duration of 8.7 months, significantly shorter than the one-year average duration typically assumed in the literature. Second, our framework also features physical capital, which contributes to lowering the value of the multiplier via the crowding-out effect on private investment.

Panel (a) of Table 1 also shows that moving from the one-sector model to the fully heterogeneous one raises the long-run aggregate value-added multiplier by 84%, from 0.31 to 0.57. Which features of the multi-sector economy are the most important in accounting for this amplification? Comparing the value-added multiplier across the different model economies reveals the following results, reported in Panel (b) of Table 1. First, the presence of intermediate inputs raises the long-run multiplier by 17%, from 0.31 to 0.35. Second, heterogeneity in the consumption, investment, and government spending shares, or in factor intensities, has little quantitative impact on the size of the multiplier. Finally, asymmetry of the Input-Output matrix and heterogeneity in the degree of price rigidity raise the long-run multiplier by 20% and 54%, respectively. Together, these findings imply that input-output interactions and heterogeneity in the degree of price rigidity are the dimensions that play the largest role in amplifying the effect of government spending shocks on aggregate output.¹¹

One additional observation about the results reported in Table 1 is worth emphasizing. The multi-sector model delivers a larger multiplier than the one-sector economy, regardless of the horizon over which the effects of government spending are cumulated. However, the amplification is larger the longer the horizon, amounting to 16 percent for the 1-year multiplier, 21 percent for the 2-year multiplier, 35

¹¹The results discussed above hold for the two categories of aggregate private spending, namely, consumption and investment. In Section B of the Online Appendix, we show that both the consumption and investment multipliers are significantly larger in the multi-sector economy than in the one-sector model, with sectoral heterogeneity in price rigidity and input-output interactions being chiefly responsible for this amplification.

Table 1: Aggregate Output Multiplier across the Different Models.

	One-Sector			Multi-Sector			Overall Change	
	Symmetric Input-Output Matrix	Heterogeneous Shares	Heterogeneous Factor Intensities	Asymmetric Input-Output Matrix	Fully Heterogeneous			
	Panel (a): Aggregate Output Multiplier							
1 year	0.6600	0.7050	0.6981	0.6929	0.7308	0.7635	15.7%	
2 years	0.5996	0.6459	0.6334	0.6238	0.6745	0.7276	21.3%	
5 years	0.4894	0.5385	0.5227	0.5133	0.5724	0.6593	34.7%	
Long-run	0.3066	0.3493	0.3545	0.3740	0.4267	0.5650	84.3%	
	Panel (b): Marginal Contribution							
1 year	-	43.5%	-6.7%	-5.0%	36.6%	31.6%	-	
2 years	-	36.2%	-9.8%	-7.5%	39.6%	41.5%	-	
5 years	-	28.9%	-9.3%	-5.5%	34.8%	51.1%	-	
Long-run	-	16.5%	-2.0%	7.5%	20.4%	53.5%	-	

Notes: Panel (a) reports the 1-year, 2-year, 5-year, and long-run cumulative aggregate output multipliers associated with a common government spending shock in: (i) a fully symmetric version of the model without inter-sectoral linkages (i.e., the “One-Sector” economy), (ii) a version of the model that adds a symmetric Input-Output matrix (i.e., the “Symmetric Input-Output Matrix” economy), (iii) a version of the model that adds heterogeneity in consumption and investment shares, and in the steady-state levels of sectoral government spending (i.e., the “Heterogeneous Shares” economy), (iv) a version of the model that adds heterogeneity in the factor intensities in the sectoral production function (i.e., the “Heterogeneous Production Intensities” economy), (v) a version of the model that allows for an asymmetric Input-Output matrix (i.e., the “Asymmetric Input-Output Matrix” economy), and (vi) a version of the model that adds heterogeneity in the degree of price rigidity (i.e., the “Fully Heterogeneous” economy). Panel (b) reports the marginal contribution of each model version to the overall change in the size of the multiplier between the “One-Sector” economy and the “Fully Heterogeneous” economy.

percent for the 5-year multiplier, and 84 percent for the long-run multiplier. This result implies that the bias in measuring the spending multiplier within a model that neglects sectoral heterogeneity and inter-sectoral linkages could be particularly severe at longer horizons.

4.1 Robustness

We evaluate the robustness of the results shown in Table 1 along three dimensions. First, we consider an economy with immobile labor and capital (i.e., $\nu_N \rightarrow 0$ and $\nu_K \rightarrow 0$). Second, we consider an economy in which the Frisch elasticity of labor supply is set to a lower value than that assumed in the baseline economies. More specifically, we lower this elasticity from 2 to 1 by setting $\eta = 1$. Third, we assume that additional government spending (in excess of its steady-state level) is financed through distortionary labor-income taxes instead of lump-sum taxes. The results are reported in Section C of the Online Appendix. In all cases, our conclusions continue to hold and, if anything, we find a larger amplification of the multiplier in the multi-sector economy compared with the one-sector model.

4.2 Some intuition

The results reported in Table 1 underline the prominent role of input-output interactions and sectoral heterogeneity in price rigidity in amplifying the aggregate effects of government spending shocks. To provide some intuition on the mechanisms through which these two features affect the aggregate multiplier, we rely on a simplified version of the model presented in Section 2. More specifically, we make the following assumptions: (i) no capital in the production function (i.e., $\alpha_{N,s} = 1$, for $s = 1, \dots, S$), (ii) equal gross-output-based labor intensities across sectors (i.e., $\alpha_{H,s} = \alpha_H < 1$, for $s = 1, \dots, S$), (iii) equal consumption shares (i.e., $\nu_{C,s} = \nu_C = 1/S$, for $s = 1, \dots, S$), (iv) a diagonal Input-Output matrix (i.e., $\nu_{H,s,s} = 1$, for $s = 1, \dots, S$) – which, in turn, implies that $P_{s,t} = P_{H,s,t}$, for $s = 1, \dots, S$ – and (v) equal steady-state levels of sectoral government spending (i.e., $G_s = G$, for $s = 1, \dots, S$). As a result, sectors differ only in the degree of price rigidity, ϕ_s . To simplify the algebra without loss of generality, we consider a logarithmic utility function (i.e., $\sigma = 1$), a Taylor rule that does not react to the output gap (i.e., $\varphi_Y = 0$) or allow for interest-rate smoothing (i.e., $\varphi_R = 0$), and introduce a production subsidy that neutralizes the steady-state distortion due to mark-up pricing.

We log-linearize the model by taking a first-order approximation of the equilibrium conditions around a symmetric steady state; for the remainder of this section, we measure all variables in terms of percentage deviations from their steady-state values. Define $Q_{s,t} \equiv \frac{P_{s,t}}{P_t}$ and $\pi_{s,t} = \frac{P_{s,t}}{P_{s,t-1}} - 1$ as, respectively, the relative price and the inflation rate in sector s , and let x_t denote the log-deviation of a generic variable X_t from its steady-state value, X . Under the assumption that government spending changes by the same percentage in all sectors, so that $g_{s,t} = g_t$, for $s = 1, \dots, S$, we obtain the following system, which determines c_t , $\pi_{s,t}$, and $q_{s,t}$ autonomously

$$c_t = \mathbb{E}_t c_{t+1} - (\varphi_\Pi \pi_t - \mathbb{E}_t \pi_{t+1}), \quad (35)$$

$$\pi_{s,t} = \beta \mathbb{E}_t \pi_{s,t+1} + \kappa_s (1 - \alpha_H) (\Theta q_{s,t} + \Xi c_t + \Psi g_t), \quad (36)$$

$$q_{s,t} = \pi_{s,t} - \pi_t + q_{s,t-1}, \quad (37)$$

where aggregate inflation, $\pi_t = \nu_C \sum_s \pi_{s,t}$, is a weighted average of sectoral inflation rates. The composite parameter $\kappa_s \equiv \frac{(1-\phi_s)(1-\beta\phi_s)}{\phi_s}$ is a decreasing function of the Calvo probability ϕ_s . For analytical tractability, this parameter will be used to characterize the degree of price rigidity in the remainder of this subsection. Finally, the composite parameters Θ , Ξ , and Ψ are given by

$$\begin{aligned} \Theta &\equiv \frac{\alpha_H}{1 - \alpha_H} - \frac{1 - \gamma}{\nu_N}, \\ \Xi &\equiv 1 + \eta(1 - \gamma), \\ \Psi &\equiv \eta\gamma, \end{aligned}$$

where γ is the steady-state share of total government spending in aggregate value added.¹²

Equation (35) represents the standard dynamic IS curve. Equation (36) represents the New Keynesian Phillips curve of sector s , in which the real marginal cost of production, i.e., the term $(1 - \alpha_H) (\Theta q_{s,t} + \Xi c_t + \Psi g_t)$, depends on the sector's relative price, $q_{s,t}$. Finally, Equation (37) defines the relative price of sector s .

4.2.1 The role of intermediate inputs

We first examine the implications of intermediate inputs for the size of the government spending multiplier. For this purpose, we abstract from sectoral heterogeneity in price rigidity and assume that $\kappa_s = \kappa$, for $s = 1, \dots, S$. As the model becomes perfectly symmetric in this case, $q_{s,t} = 0$ and $\pi_{s,t} = \pi_t$ for $s = 1, \dots, S$, and one

¹²The details of the derivation of Equations (35)–(37) are given in Appendix A.

can solve for the equilibrium paths of aggregate consumption and inflation using the following two-equation system:

$$c_t = \mathbb{E}_t c_{t+1} - (\varphi_\Pi \pi_t - E_t \pi_{t+1}), \quad (38)$$

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa (1 - \alpha_H) (\Xi c_t + \Psi g_t). \quad (39)$$

Since there are no state variables, under the assumption of an active monetary policy (i.e., $\varphi_\Pi > 1$) the unique rational expectations solution for consumption takes the form

$$c_t = \xi g_t. \quad (40)$$

Using the method of undetermined coefficients, one can show that the response of aggregate consumption to the government spending shock is given by

$$\xi = -\frac{(\varphi_\Pi - \rho)(1 - \alpha_H)\kappa\Psi}{(1 - \rho)(1 - \beta\rho) + (\varphi_\Pi - \rho)(1 - \alpha_H)\kappa\Xi}. \quad (41)$$

The cumulative value-added multiplier is given by

$$\mathcal{M}(\mathcal{H}) = 1 + \frac{1 - \gamma}{\gamma} \xi, \quad \text{for all } \mathcal{H}.$$

It is straightforward to show that $\mathcal{M}(\mathcal{H})$ increases in the share of intermediate inputs in gross output, α_H , which immediately implies that the aggregate value-added multiplier is larger in a model that allows for input-output linkages than in the benchmark one-sector economy. Intuitively, the fact that the gross product of each industry is both consumed and used in the production of all other goods in the economy gives rise to strategic complementarity in price setting among monopolistically competitive firms (see Basu, 1995). This feature reduces the sensitivity of real marginal cost to changes in aggregate demand. In this respect, the presence of intermediate inputs amplifies the overall degree of nominal rigidity.

4.2.2 The role of sectoral heterogeneity in price rigidity

Once symmetry in the degree of price rigidity across sectors is relaxed, even the stripped-down version of the model represented by Equations (35)–(37) does not have a closed-form solution for the multiplier. Nonetheless, useful insights into the role of heterogeneity in price rigidity in amplifying the value-added multiplier can be gained by aggregating the sectoral New Keynesian Phillips curves. To simplify the analysis, let us abstract from intermediate inputs (i.e., $\alpha_H = 0$). Taking a weighted

average of both sides of Equation (36) across sectors yields

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \bar{\kappa} (\Xi c_t + \Psi g_t) - \frac{(1-\gamma)\nu_C}{\nu_N} \sum_s \kappa_s q_{s,t}, \quad (42)$$

where $\bar{\kappa} = \nu_C \sum_s \kappa_s$. This equation nests the one obtained in a symmetric model (i.e., Equation (39) with $\kappa = \bar{\kappa}$ and $\alpha_H = 0$) as a special case in which the last term on the right-hand side of the equality, $\frac{(1-\gamma)\nu_C}{\nu_N} \sum_s \kappa_s q_{s,t}$, vanishes. When sectors exhibit different degrees of price rigidity, aggregate inflation depends negatively on an endogenous shift term that is proportional to the sum of sectoral relative prices, weighted by (the inverse of) the sectoral degrees of price rigidity. Assume, without loss of generality, that there are only two sectors, and consider a common increase in government spending. The sector with lower price rigidity experiences an increase in its relative price, while the relative price of goods produced by the other sector drops by an equal amount. However, the latter receives a larger weight in the shift term. To the extent that there is imperfect labor mobility between the two sectors (i.e., $\nu_N < \infty$), changes in relative prices imply a smaller response of aggregate inflation relative to the case of a symmetric economy with the same average degree of price rigidity. In this respect, changes in relative prices act as a further source of real rigidity that amplifies the extent of nominal rigidity and, hence, the multiplier.

5 Production Networks and the Propagation of Government Spending Shocks

Having established the role of sectoral heterogeneity and inter-sectoral linkages in amplifying the spending multiplier, we now turn to the analysis of the propagation of government spending shocks. In a multi-sector economy with heterogeneous and interconnected production sectors, the aggregate implications of a shock to a given sector depend not only on that sector's intrinsic characteristics, but also on its position in the production network. In this section, we exploit the multiple dimensions of sectoral heterogeneity that our model allows for to identify the determinants of the aggregate effects of sector-specific spending shocks. By shocking each sector in isolation, we can also trace and quantify the spillover effects that operate through the production network. All the results presented in this section are based on the "Fully Heterogeneous" model.

5.1 The aggregate effects of government spending shocks

We consider an exercise in which the economy is hit by one sector-specific shock at a time. Figure 1 reports the 1-year and long-run cumulative aggregate value-added multipliers associated with the different sector-specific shocks. The figure shows substantial heterogeneity in the size of the multiplier. The long-run multiplier ranges from 0.32 when spending occurs in Computers and Electronic Products to 0.75 when spending takes place in Data Processing, Internet Publishing, and Other Information Services. Although the 1-year multiplier displays less dispersion, the difference between the smallest (0.27 in Housing¹³) and the largest multiplier (0.89 in Other Transportation Services) is remarkable.¹⁴

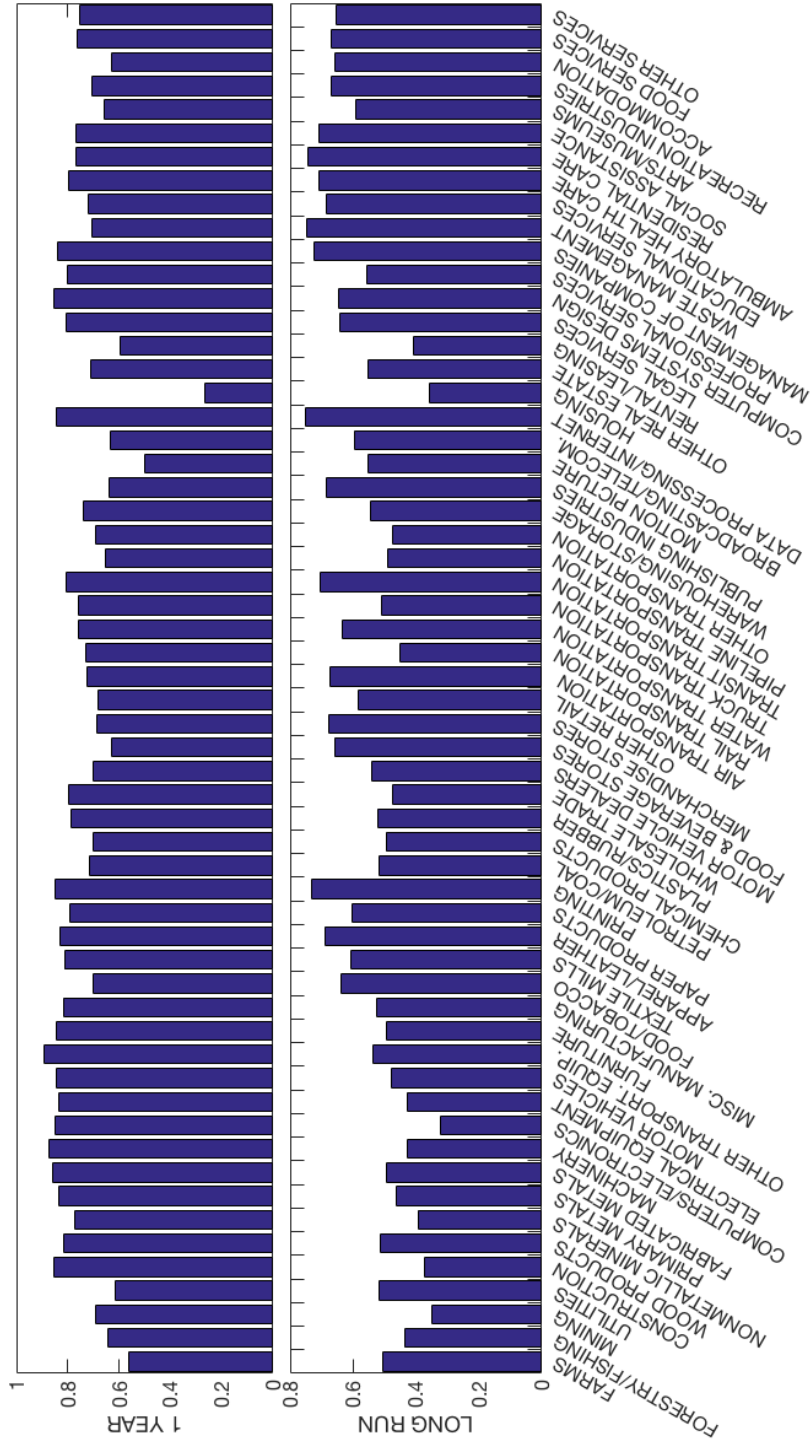
Figure 1 also shows that the difference between the 1-year and the long-run cumulative multipliers varies substantially across sectors, reflecting important sectoral heterogeneity in the propagation of sector-specific spending shocks over time. For instance, the long-run multiplier associated with government spending in Housing is larger than the 1-year multiplier (0.38 versus 0.27), whereas the opposite pattern is observed for government spending in Computers and Electronic Products (0.32 versus 0.84), thereby suggesting that the former spending category generates more persistent aggregate output effects than the latter.

Figure 2 shows the response of the aggregate real wage – measured as the ratio of the nominal wage to the consumption price index – to the different sector-specific government spending shocks. The figure reveals significant dispersion in the response of the aggregate real wage, not only in terms of magnitude, but also in terms of sign, especially at short horizons. The 1-year cumulative wage response is negative when the government spends in 30 out of the 58 sectors, whereas the long-run response is negative in 53 sectors. This result is important because the response of the real wage to a government spending shock has been invoked to discriminate between competing theories of aggregate fluctuations (e.g., Perotti, 2008 and Nekarda and Ramey, 2011). Indeed, while New Keynesian models imply that the real wage rises following an increase in public expenditure, models that abstract from nominal rigidities typically yield the opposite result. By showing that the sign of the wage response crucially depends on the sectoral composition of government spending, our findings imply that nominal rigidities *per se* do not pin down the behavior of the

¹³Housing corresponds to the activities of renting or leasing real estate to others, and managing, selling, buying, and renting real estate for others.

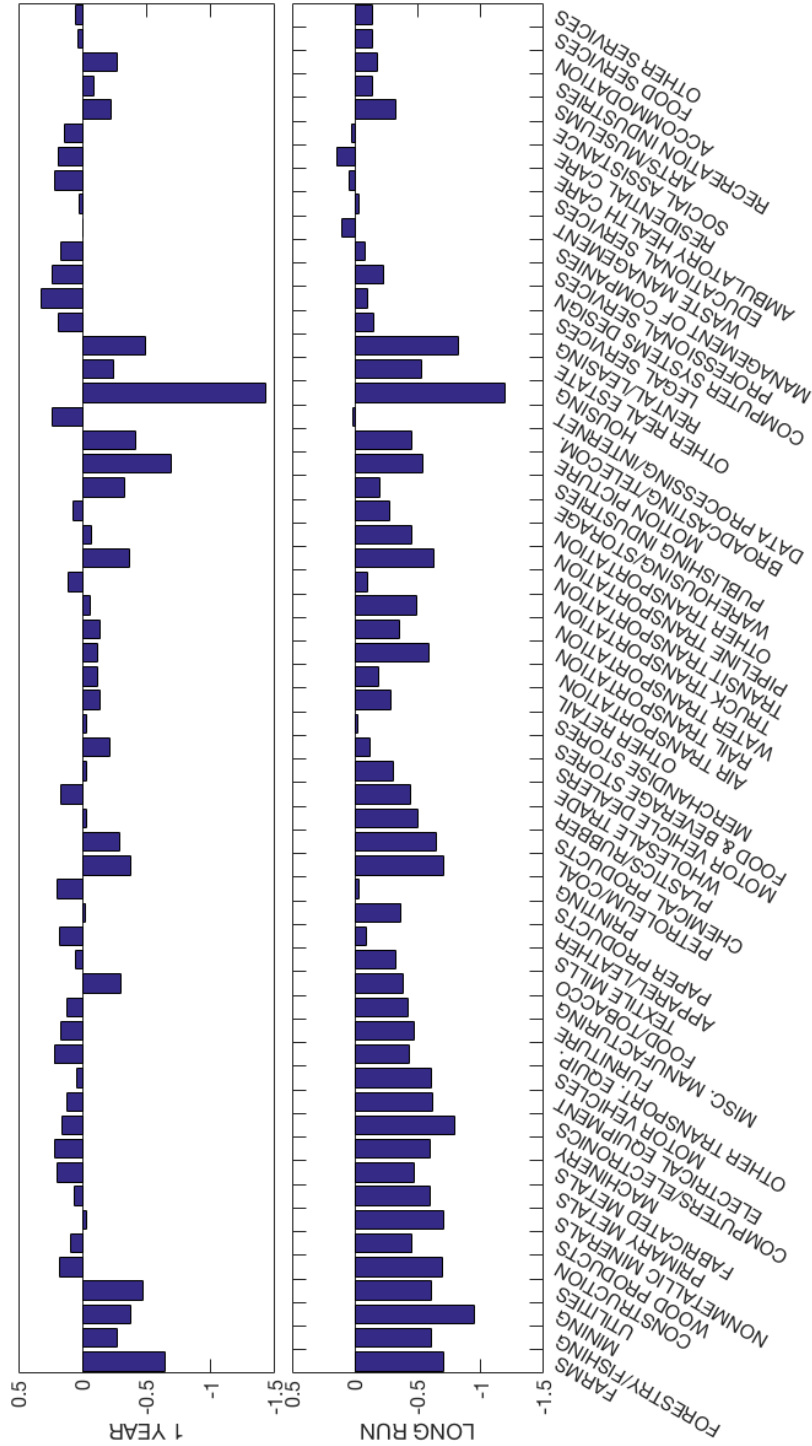
¹⁴Substantial heterogeneity also characterizes the effects of sector-specific government spending shocks on aggregate consumption, investment, employment, inflation, as well as on the nominal interest rate. These results are reported in Section D of the Online Appendix.

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



Note: The figure plots the 1-year (top panel) and long-run (bottom panel) cumulative aggregate output multipliers associated with each sectoral government spending shock. The multipliers are derived from the “Fully Heterogeneous” economy.

Figure 2: Aggregate Real Wage Response to Sectoral Government Spending Shocks.



Note: The figure plots the 1-year (top panel) and long-run (bottom panel) cumulative aggregate real wage multipliers associated with each sectoral government spending shock. The multipliers are derived from the “Fully Heterogeneous” economy.

real wage, and that, consequently, the latter should not be relied upon to reject one theory in favor of the other.

Documenting heterogeneity in the aggregate effects of sector-specific government spending shocks at the level of disaggregation considered in this paper is unprecedented. At best, some contributions employing two-sector models have focused on very broad categories of industries, such as sectors with different tradability of the final goods (e.g., Monacelli and Perotti, 2010), different labor intensities in the production function (e.g., Alonso, 2016), and different degrees of capital specialization (e.g., Ramey and Shapiro, 1998). Importantly, the amount of dispersion we report is likely to be a lower-bound estimate, as our model allows for heterogeneity on the production side, while abstracting from household heterogeneity and other features that have been found to affect the size of the spending multiplier, such as credit constraints and labor-market frictions.

5.1.1 Robustness

We check the robustness of our findings to the same perturbations considered in Section 4.1, namely, alternative values of the elasticity of substitution of labor and capital across sectors and the Frisch elasticity of labor, as well as distortionary income taxation to finance government spending. The results are reported in Section E of the Online Appendix. In all three cases, there is significant heterogeneity in the aggregate output effects of sectoral government spending shocks, especially in the economy with immobile labor and capital. In this case, the 1-year multiplier ranges between -0.23 and 1.08 , while the long-run multiplier varies between 0.14 and 1 . Hence, in this version of the model government spending can – depending on its sectoral composition – either have contractionary effects on economic activity or foster output through a multiplier above unity.

5.1.2 Accounting for heterogeneity

What drives the heterogeneity in the response of aggregate variables to sector-specific spending shocks? To answer this question, we regress the 1-year and long-run cumulative multipliers associated with the sector-specific government spending shocks on the following set of covariates: the sectoral degree of price rigidity, measured by the Calvo probability, ϕ_s , the sectoral share in the production of the consumption good, $\nu_{C,s}$, the sectoral share in the production of the investment good, $\nu_{I,s}$, the sectoral value-added-based labor intensity, $\alpha_{N,s}$, and the Katz-Bonacich eigenvector centrality measure of the sector in the Input-Output matrix of the econ-

omy.¹⁵ High values of centrality characterize the sectors located upstream in the production network of the economy. Instead, downstream sectors are characterized by low values of centrality.

Table 2 reports the results of the regressions in which the dependent variables are the aggregate output, consumption, and investment multipliers, while Table 3 reports the results for the cases in which the dependent variables are the employment, inflation, and the real wage multipliers. The results indicate that the effect of public expenditure on aggregate output is larger when the government spends in sectors that have relatively rigid prices and high value-added-based labor intensities (for given shares of intermediate inputs in gross output).

Government spending shocks originating in sectors with larger price rigidity generate a lower response of aggregate inflation, as long as labor and capital are not perfectly mobile across sectors. This endogenous inflation inertia further decreases the economy-wide markup and amplifies the outward shift in aggregate labor demand. In equilibrium, aggregate employment and production expand by more, compared with situations in which spending shocks occur in sectors characterized by relatively flexible prices.¹⁶ This argument is supported by the larger response of the aggregate real wage to shocks in sticky-price sectors, as depicted in Table 3.

The value-added-based labor intensity, on the other hand, directly maps into the slope of firms' labor demand curve, and defines the extent to which an outward shift in households' labor supply generates downward pressure on wages. A higher labor share in value added (i.e., a lower capital share in value added) implies that households react to government spending shocks by working longer hours at a relatively higher wage. Consequently, the employment multiplier in a given sector increases with its labor intensity. At the aggregate level, an increase in spending in sectors that are relatively labor intensive translates into a larger shift in aggregate labor

¹⁵We report the details of the computation of the centrality measure in Appendix B.

¹⁶The role of sectoral price rigidity can be formally shown using the simple model presented in Section 4.2. Let us abstract again from intermediate inputs, and consider only two sectors, which we label s and x , with sector s featuring relatively more rigid prices (i.e., $\kappa_s < \kappa_x$). In this case, the aggregate Phillips curve can be written as

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \bar{\kappa} \Xi c_t - \frac{\nu_C (1 - \gamma)}{\nu_N} (\kappa_s q_{s,t} + \kappa_x q_{x,t}) + \frac{\nu_C [\gamma (\kappa_s - \kappa_x) + \Psi]}{\nu_N} g_{s,t} + \frac{\nu_C [\gamma (\kappa_x - \kappa_s) + \Psi]}{\nu_N} g_{x,t}.$$

This equation shows that, to the extent that labor is not perfectly mobile across the two sectors, the marginal impact on aggregate inflation of a shock originating in sector s is smaller than that of a shock originating in sector x . This in turn means that the shock to sector s has a larger effect on aggregate output. Under perfect labor mobility, on the other hand, sectoral real marginal costs change by the same amount, implying an equal increase in labor demand in the two sectors, regardless of which sector is hit by the shock. In this case, the two spending shocks affect aggregate inflation and output identically.

Table 2: Determinants of the Aggregate Effects of Sectoral Government Spending Shocks.

	Aggregate Value-Added Multiplier		Aggregate Consumption Multiplier		Aggregate Investment Multiplier	
	1 Year	Long Run	1 Year	Long Run	1 Year	Long Run
	(1)	(2)	(3)	(4)	(5)	(6)
Price Rigidity	0.01*** (0.01)	0.01** (0.01)	0.01*** (0.01)	0.01** (0.01)	0.01*** (0.01)	0.01* (0.01)
Consumption Share	-1.96*** (0.53)	0.38 (0.44)	-1.29*** (0.36)	0.02 (0.30)	-0.66*** (0.17)	0.37 (0.32)
Investment Share	0.53 (0.41)	-1.17*** (0.22)	0.40 (0.30)	-0.60*** (0.12)	0.22 (0.27)	-0.56*** (0.10)
Value-Added-Based Labor Intensity	0.29*** (0.06)	0.22*** (0.05)	0.23*** (0.04)	0.18*** (0.03)	0.06*** (0.02)	0.03 (0.02)
Centrality	-1.79*** (0.72)	-1.23** (0.59)	-1.17** (0.60)	-0.65* (0.48)	-0.62** (0.31)	-0.61* (0.36)
R^2	0.77	0.50	0.78	0.58	0.72	0.46
N. obs.	58	58	58	58	58	58

Notes: The table reports the determinants of the response of aggregate variables to sectoral government spending shocks. Column (1) reports the results of a regression in which the dependent variable is the 1-year cumulative aggregate value-added multiplier. Column (2) reports the results of a regression in which the dependent variable is the long-run cumulative aggregate value-added multiplier. Columns (3) and (4) report analogous results for the aggregate consumption multiplier. Columns (5) and (6) report analogous results for the aggregate investment multiplier. All the regressions include the same set of independent variables, which consist of the price duration implied by the sectoral degree of price rigidity, ϕ_s , the sectoral consumption share, $\nu_{C,s}$, the sectoral investment share, $\nu_{I,s}$, the sectoral value-added-based labor intensity, $\alpha_{N,s}$, and a measure of the sector's centrality in the Input-Output matrix of the economy. Robust standard errors are reported in brackets. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively.

Table 3: Determinants of the Aggregate Effects of Sectoral Government Spending Shocks.

	Aggregate Employment Multiplier		Aggregate Inflation Multiplier		Aggregate Wage Multiplier	
	1 Year	Long Run	1 Year	Long Run	1 Year	Long Run
	(1)	(2)	(3)	(4)	(5)	(6)
Price Rigidity	0.01 (0.01)	0.01 (0.01)	-0.02*** (0.01)	-0.01*** (0.01)	0.02*** (0.01)	0.02** (0.01)
Consumption Share	1.47** (0.57)	0.94* (0.54)	3.79*** (1.06)	1.61*** (0.34)	-4.11*** (1.26)	0.37 (1.01)
Investment Share	-0.80 (0.49)	0.03 (0.41)	-1.29*** (0.37)	-0.45*** (0.15)	0.78 (0.51)	-2.13*** (0.38)
Value-Added-Based Labor Intensity	0.78*** (0.18)	0.54*** (0.18)	-0.63*** (0.12)	-0.24*** (0.04)	1.11*** (0.12)	0.93*** (0.11)
Centrality	-4.15** (1.71)	-3.54** (1.42)	-4.66** (2.16)	-1.52** (0.71)	-5.65*** (1.91)	-1.97** (1.13)
R^2	0.51	0.48	0.77	0.79	0.88	0.69
N. obs.	58	58	58	58	58	58

Notes: The table reports the determinants of the response of aggregate variables to sectoral government spending shocks. Column (1) reports the results of a regression in which the dependent variable is the 1-year cumulative aggregate employment multiplier. Column (2) reports the results of a regression in which the dependent variable is the long-run cumulative aggregate employment multiplier. Columns (3) and (4) report analogous results for the aggregate inflation multiplier. Columns (5) and (6) report analogous results for the aggregate real wage multiplier. All the regressions include the same set of independent variables, which consist of the price duration implied by the sectoral degree of price rigidity, ϕ_s , the sectoral consumption share, $\nu_{C,s}$, the sectoral investment share, $\nu_{I,s}$, the sectoral value-added-based labor intensity, $\alpha_{N,s}$, and a measure of the sector's centrality in the Input-Output matrix of the economy. Robust standard errors are reported in brackets. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively.

demand, thus resulting into higher equilibrium levels of aggregate employment and output.^{17,18} As a corollary, the aggregate real wage responds more to shocks occurring in sectors with a relatively large labor share in value added, which is confirmed by the results reported in Table 3. Importantly, this mechanism operates independently of labor and capital mobility, the degree of price rigidity, and the presence of intermediate inputs.

The 1-year cumulative effect on aggregate output tends to be negatively correlated with the sector's share in the consumption aggregator, while the long-run effect correlates negatively with the sector's share in the investment aggregator. The larger these shares, the larger the crowding-out effect of government spending on aggregate consumption and investment, and the smaller the effect on aggregate output.¹⁹ Finally, the results show that the output effect of sector-specific government spending tends to be negatively correlated with the sector's centrality. In other words, aggregate output tends to respond more when spending occurs in downstream sectors. The following sub-section is devoted to explaining this result.

5.2 The spillover effects of government spending shocks

To understand the role of the production network in shaping the aggregate effects of sectoral government spending shocks, it is useful to note that the effect on aggregate value added of a shock originating in sector s can be expressed as the sum of two components, the effect of the shock on the value added of sector s (own effect) and

¹⁷To see this point, consider a two sector-economy in which prices are fully flexible, labor is the only production input, and the two sectors, labelled s and x , are symmetric in every respect, except in their labor intensities. Assume, without loss of generality, that sector s is more labor intensive than sector x (i.e., $\alpha_{N,x} < \alpha_{N,s} < 1$). In this case, the aggregate demand schedule is given by

$$w = -(1 - \alpha_{N,x})n + \frac{\alpha_{N,s} - \alpha_{N,x}}{2}n_s.$$

An increase in spending in sector s leads to an increase in n_s and, therefore, to an outward shift in aggregate labor demand. In contrast, an increase in spending in sector x leads to a fall in n_s (since consumption falls in both sectors but government spending remains constant in sector s), implying an inward shift in aggregate labor demand.

¹⁸Galí et al. (2007) and Hall (2009) show that the spending multiplier increases with price rigidity and labor intensity in the context of a one-sector model. Higher price rigidity lowers the markup, shifting labor demand outward, while higher labor intensity flattens the labor demand curve. Our analysis, instead, shows that heterogeneity in price rigidity and labor intensity across production sectors introduces an additional shifter in the aggregate labor demand schedule.

¹⁹Heterogeneity in the consumption shares only plays a role at short horizons. Indeed, households require some time to be able to smooth out the consumption swings due to heterogeneity in the consumption shares, because of the presence of real and nominal rigidities. Instead, the relevance of the investment shares rises with the horizon at which the government spending multiplier is computed. Since we have calibrated the adjustment costs to generate a peak response of investment two years after the realization of the government spending shock, heterogeneity in the investment shares does not play a substantial role at short horizons.

its effect on the value added of all the remaining sectors (spillover effect):

$$\frac{dY_t}{dG_{s,t}} = \underbrace{\frac{dY_{s,t}}{dG_{s,t}}}_{\text{Own effect}} + \underbrace{\sum_{x=1, x \neq s}^S \frac{dY_{x,t}}{dG_{s,t}}}_{\text{Spillover effect}}.$$

Thus, everything else equal, sectoral government spending shocks will tend to have large aggregate output multipliers when they give rise to positive spillovers. Conversely, negative spillovers will tend to reduce the aggregate multiplier.

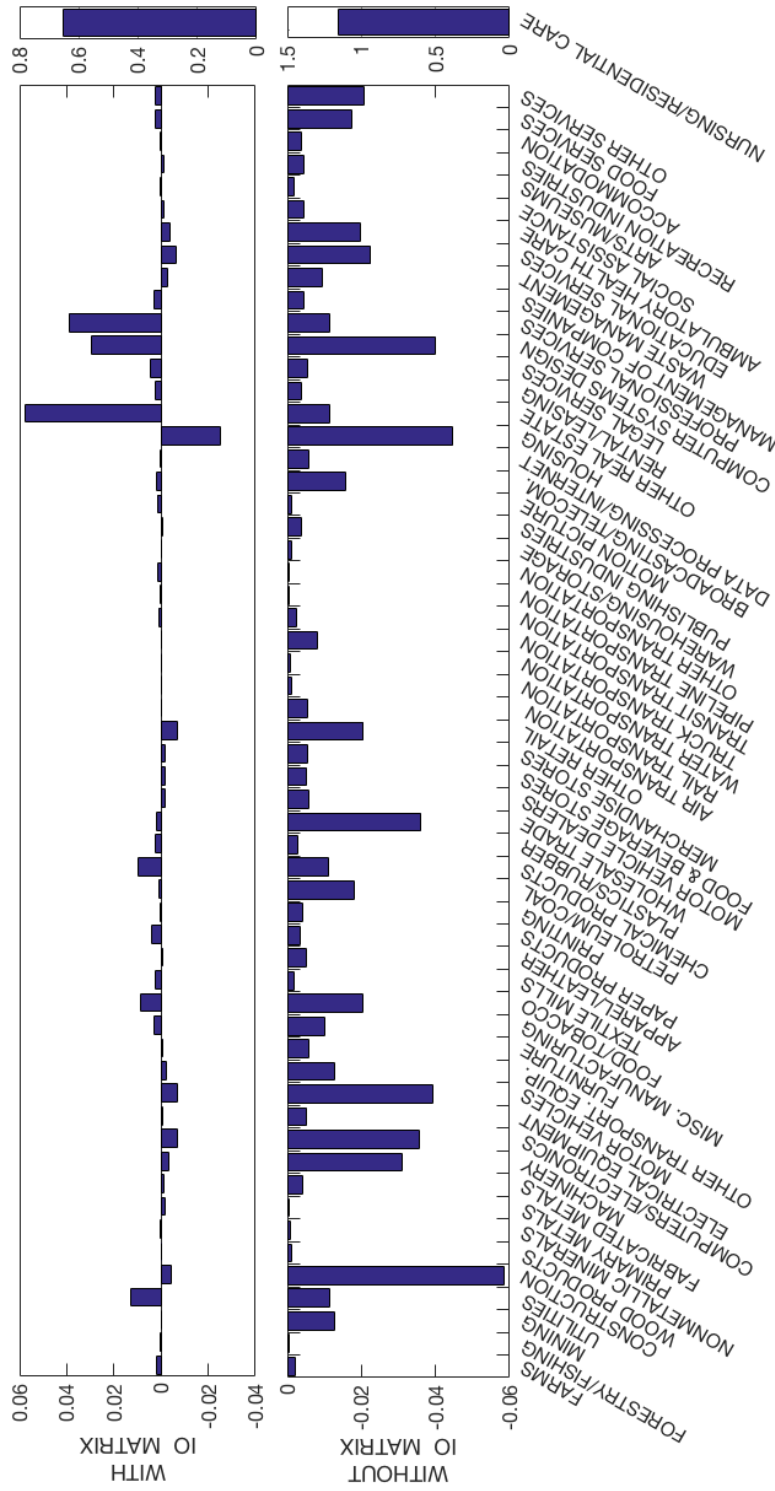
In our economy, government spending shocks generate spillovers through two interconnected channels: the production network and changes in relative prices. When the government increases its demand for the output of sector s , the latter increases its demand for intermediate inputs, leading its input-supplying industries to produce more. This channel therefore generates a positive spillover, which Acemoglu et al. (2015) refer to as the upstream propagation of government spending shocks.

At the same time, the increase in the relative price of sector s generates two competing effects on the output of the remaining industries. On the one hand, its customer industries incur an increase in the cost of their intermediate inputs, inducing them to cut production. This channel gives rise to a negative downstream spillover. On the other hand, there is an expenditure switching effect whereby households' demand is diverted from sector s to its competitors, whose relative prices have fallen. This channel produces a positive spillover that propagates both downstream and upstream.

Importantly, the downstream spillover of public spending stemming from input-output linkages is absent in the model of Acemoglu et al. (2015), as the combination of flexible prices and constant-return-to-scale Cobb-Douglas technologies and preferences prevents any change in relative prices in response to demand shocks. Instead, in our setting the relative price channel is operative owing to sectoral heterogeneity in price rigidity and imperfect factor mobility.

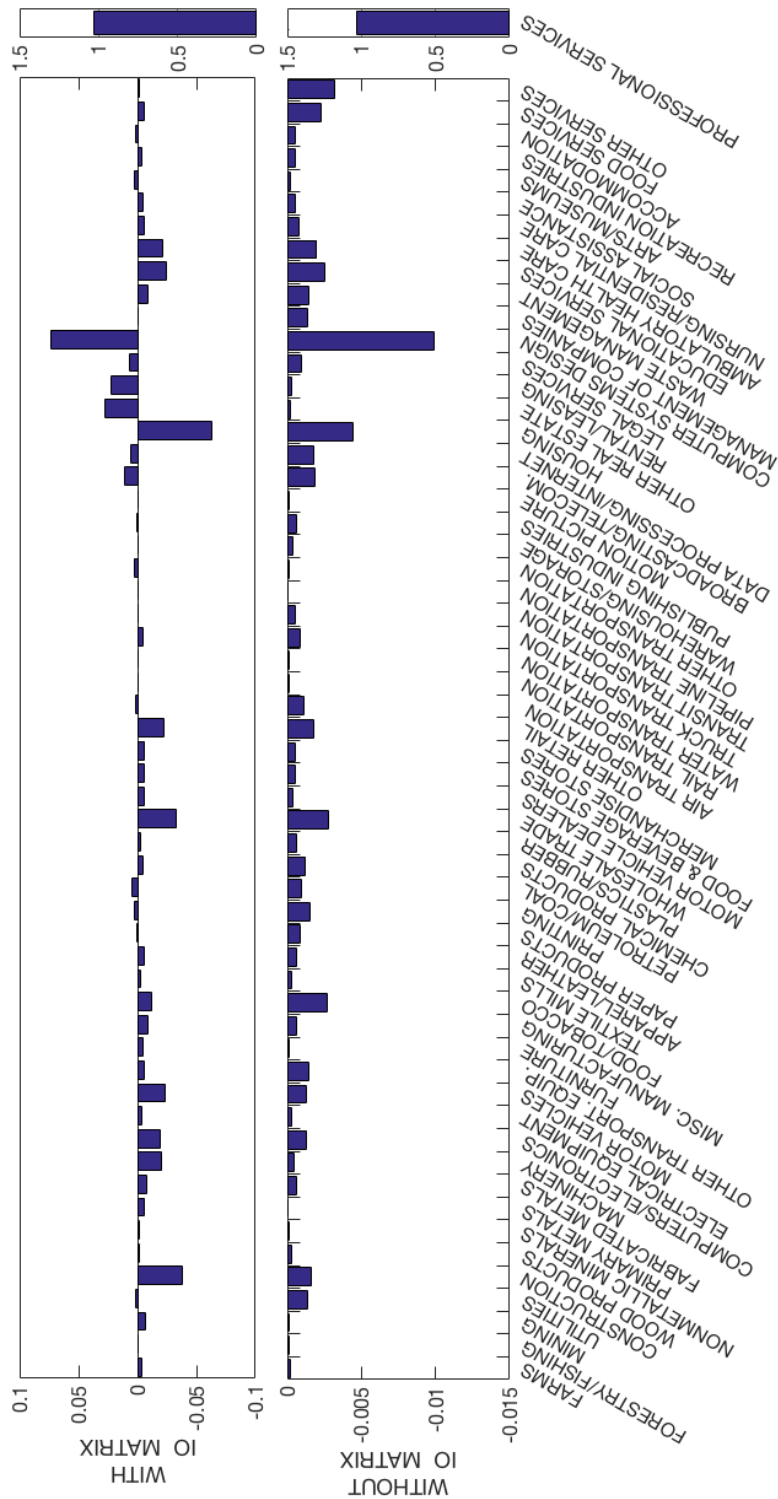
These arguments suggest that government spending shocks in downstream sectors are more likely to give rise to positive spillovers, whereas shocks to upstream sectors are more likely to generate negative spillovers. To illustrate this point, we focus on the most downstream and most upstream sectors of the economy, namely Nursing and Residential Care Services, and Professional Services, respectively. Panel (a) of Figure 3 shows the response of all the sectoral value added to an increase in government spending in Nursing and Residential Care Services, while Panel (a) of Figure 4 shows the sectoral value-added responses when the shock occurs in Pro-

Figure 3: Sectoral Value-Added Responses to a Government Spending Shock in Nursing and Residential Care.



Notes: The top graph plots the sectoral value-added multipliers associated with a government spending shock in Nursing and Residential Care in the "Fully Heterogeneous" economy. The bottom graph plots the sectoral value-added multipliers in a counterfactual model without an Input-Output matrix. In each graph, the right graph shows the response of the value added in Nursing and Residential Care to its own spending shock.

Figure 4: Sectoral Value-Added Responses to a Government Spending Shock in Professional Services.



Notes: The top graph plots the sectoral value-added multipliers associated with a government spending shock in Professional Services in the “Fully Heterogeneous” economy. The bottom graph plots the sectoral value-added multipliers in a counterfactual model without an Input-Output matrix. In each graph, the right panel shows the response of the value added in Professional Services to its own spending shock.

fessional Services. Panel (b) of each figure depicts the responses obtained from a counterfactual version of the model in which the sectors are fully heterogeneous but do not buy/sell materials inputs from/to each other (i.e., a fully heterogeneous model without Input-Output matrix).

Panel (a) of Figure 3 shows that the spending shock originating in Nursing and Residential Care Services raises output significantly in a few sectors, while leaving the value added of most sectors essentially unchanged. The sectors that expand are the largest providers of intermediate inputs to Nursing and Residential Care Services, namely Other Real Estate (which includes Real State Property Managers and the Offices of Real State Agents, Brokers, and Appraisers), Computer Systems Design Services, and the Management of Companies. Table 4 shows that 0.114 of the 0.768 dollar change in aggregate value added is due to the positive spillover of the spending shock in Nursing and Residential Care Services. On the other hand, an increase in government spending in Professional Services triggers a negative output response in a large number of sectors. The reduction in the aggregate value-added multiplier resulting from this negative spillover amounts to -0.232 dollars.

Table 4: Spillovers of Government Spending in Downstream and Upstream Sectors.

Panel a. Shock in Most Downstream Sector		
	With Input-Output Matrix	Without Input-Output Matrix
Own Effect	0.654	1.158
Spillover Effect	0.114	-0.643
Total	0.768	0.515
Panel b. Shock in Most Upstream Sector		
	With Input-Output Matrix	Without Input-Output Matrix
Own Effect	1.033	1.036
Spillover Effect	-0.232	-0.064
Total	0.802	0.972

Note. The spillover effect is computed as the sum of the responses of the sectoral value added of all sectors other than sector s to a government spending shock in sector s .

When we abstract from sectoral interactions, spending shocks in both Nursing

and Residential Care Services and Professional Services bring about a simultaneous decline in the value added of all the remaining sectors. Consistently with our discussion of the transmission of spending shocks, this counterfactual exercise reveals that neglecting input-output linkages leads to underestimating the degree of positive spillover (in fact, even implying a negative spillover) when the shock occurs in the most upstream sector, and to underestimating the extent of negative spillover when the shock originates in the most upstream sector.

These observations rationalize the fact that the aggregate effects of sector-specific shocks tend to be large when spending occurs in sectors that are relatively more downstream in the production process. The increase in the demand for intermediate inputs emanating from these sectors triggers a cascade effect on a larger number of industries, leading to a large response of aggregate output. At the same time, because these sectors have relatively few customer industries, the negative spillover they generate is very limited.

In light of this discussion, sectoral output (and employment) in the upstream sectors should be the most responsive to government spending shocks, especially those originating in downstream sectors. To verify this conjecture, we compute the mean response of sectoral value added to all the sector-specific shocks and regress it on the same set of controls of Table 2. As before, we focus on the 1-year and long-run cumulative responses. We report the results of this exercise in Table 5. The average output response tends to be larger in sectors that have relatively rigid prices and high value-added-based labor intensities. Importantly, the coefficient attached to the measure of centrality is positive and strongly statistically significant, indicating that sector-specific spending shocks tend to have relatively large effects on the output of upstream sectors. This result reflects the upstream propagation pattern resulting from the positive spillovers of government spending shocks to input-supplying industries.

Table 5: Determinants of Sectoral Value-Added Responses to Sectoral Gov. Spending Shocks.

	Average Sectoral Value-Added Multiplier	
	1 Year	Long Run
	(1)	(2)
Price Rigidity	0.01*** (0.00)	0.01** (0.00)
Consumption Share	-0.03*** (0.01)	0.01 (0.01)
Investment Share	0.01 (0.01)	-0.02*** (0.01)
Value-Added-Based Labor Intensity	0.01*** (0.00)	0.01*** (0.00)
Centrality	0.03*** (0.01)	0.02** (0.01)
R^2	0.77	0.50
N. obs.	58	58

Notes: The table reports the determinants of the average response of sectoral value added to sectoral government spending shocks. Column (1) reports the results of a regression in which the dependent variable is the average 1-year cumulative value-added multiplier across sectors. Column (2) reports the results of a regression in which the dependent variable is the average long-run cumulative sectoral value-added multiplier. All the regressions include the same set of independent variables, which consist of the price duration implied by the sectoral degree of price rigidity, ϕ_s , the sectoral consumption share, $\nu_{C,s}$, the sectoral investment share, $\nu_{I,s}$, the sectoral value-added-based labor intensity, $\alpha_{N,s}$, and a measure of the sector's centrality in the Input-Output matrix of the economy. Robust standard errors are reported in brackets. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively.

6 Concluding Remarks

This paper has studied the macroeconomic effects of government spending through the lens of a highly disaggregated multi-sector model calibrated to the U.S. economy. Our results show that the aggregate value-added multiplier is substantially larger than that obtained from the benchmark one-sector model typically considered in the literature, and that the bulk of this amplification is due to input-output interactions and sectoral heterogeneity in price rigidity. Moreover, we document substantial heterogeneity in the aggregate effects of sector-specific government spending shocks, which tend to be larger in sectors with relatively rigid prices and high value-added-based labor intensities, as well as in downstream sectors, reflecting the cascade effect stemming from positive spillovers of government spending to input-supplying industries. Together, these results suggest that taking seriously sectoral heterogeneity and production networks improves our understanding of the aggregate effects of government spending shocks and their transmission, which can be crucial when implementing spending-based stimulus or consolidation plans.

While this paper proposes a novel perspective to think about the implications of government spending, our analysis has remained positive in nature. The marked heterogeneity in the aggregate effects of sectoral public spending, and the spillover effects brought about by the input-output network, however, suggest 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.

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A Simple Model

This appendix shows the derivation of the simplified model discussed in Section 4.2. We make the following assumptions: (i) no capital in the production function (i.e., $\alpha_{N,s} = 1$, for $s = 1, \dots, S$), (ii) equal labor intensities in gross output across sectors (i.e., $\alpha_{H,s} = \alpha_H < 1$, for $s = 1, \dots, S$), (iii) equal consumption shares (i.e., $\nu_{C,s} = \nu_C = 1/S$, for $s = 1, \dots, S$), (iv) a diagonal Input-Output matrix (i.e., $\nu_{H,s,s} = 1$, for $s = 1, \dots, S$) – which, in turn, implies that $P_{s,t} = P_{H,s,t}$, for $s = 1, \dots, S$ – and (v) equal steady-state levels of sectoral government spending (i.e., $G_s = G$, for $s = 1, \dots, S$). As a result, sectors differ only in the degree of price rigidity, ϕ_s . To simplify the algebra without loss of generality, we consider a logarithmic utility function (i.e., $\sigma = 1$), a Taylor rule that does not react to the output gap (i.e., $\varphi_Y = 0$) or allow for interest-rate smoothing (i.e., $\varphi_R = 0$), and introduce a production subsidy that neutralizes the steady-state distortion due to mark-up pricing.

Log-linearizing the first-order condition for bonds yields

$$c_t = \mathbb{E}_t c_{t+1} - (r_t - \mathbb{E}_t \pi_{t+1}). \quad (\text{A.1})$$

Using the log-linearized Taylor rule (Equation 26) to substitute for r_t yields Equation (35) in the main text.

To derive Equation (36), we start combining the (log-linearized) first-order condition for the optimal price and the definition of the sectoral price index to obtain the following sectoral New Keynesian Phillips Curve:

$$\pi_{s,t} = \beta \mathbb{E}_t \pi_{s,t+1} + \kappa_s mc_{s,t}, \quad (\text{A.2})$$

where $mc_{s,t}$ denotes the real marginal cost of production in sector s (expressed as a deviation from its steady-state value). The latter can be expressed as a linear combination of the sector's real wage and relative price, $q_{s,t}$:

$$mc_{s,t} = (1 - \alpha_H)(w_{s,t} - p_t) + \alpha_H q_{s,t}. \quad (\text{A.3})$$

Log-linearizing the sectoral resource constraint yields

$$z_{s,t} = \frac{C_s}{Z_s} c_{s,t} + \frac{G_s}{Z_s} g_{s,t} + \frac{H_s}{Z_s} h_{s,t}. \quad (\text{A.4})$$

Using the linearized production function to substitute for $h_{s,t}$, we obtain

$$z_{s,t} = \frac{C_s}{Z_s} c_{s,t} + \frac{G_s}{Z_s} g_{s,t} + \frac{H_s}{Z_s} \left(\frac{1}{\alpha_H} z_{s,t} - \frac{1 - \alpha_H}{\alpha_H} n_{s,t} \right). \quad (\text{A.5})$$

By virtue of the production subsidy, the steady-state distortion due to mark-up pricing is neutralized, so that $H_s/Z_s = \alpha_H$. In the steady state, sectoral government spending is assumed to be a fraction $\gamma \in [0, 1]$ of value added, $Y_{s,t}$, so that $G_s/Z_s = \gamma(1 - \alpha_H)$ and $C_s/Z_s = (1 - \gamma)(1 - \alpha_H)$. Thus, Equation (A.5) becomes

$$n_{s,t} = (1 - \gamma)c_{s,t} + \gamma g_{s,t}. \quad (\text{A.6})$$

Imposing $g_{s,t} = g_t$, and substituting the linearized labor-supply function for sector s (i.e., $n_{s,t} = \nu_N(w_{s,t} - w_t) + n_t$), the labor supply equation (i.e., $\eta n_t + c_t = w_t - p_t$), and the demand for good s (i.e., $c_{s,t} = c_t - q_{s,t}$) into Equation (A.3), we obtain

$$m c_{s,t} = (1 - \alpha_H) (\Theta q_{s,t} + \Xi c_t + \Psi g_t), \quad (\text{A.7})$$

where

$$\begin{aligned} \Theta &\equiv \frac{\alpha_H}{1 - \alpha_H} - \frac{1 - \gamma}{\nu_N}, \\ \Xi &\equiv 1 + \eta(1 - \gamma), \\ \Psi &\equiv \gamma\eta. \end{aligned}$$

Inserting (A.7) into (A.2) yields Equation (35) in the main text.

Finally, Equation (37) in the main text follows immediately from the definition of the sectoral price: $Q_{s,t} \equiv \frac{P_{s,t}}{P_t}$.

B Centrality Measure

To determine the position of each sector in the Input-Output matrix of the economy, we follow Carvalho (2014) and use the eigenvector centrality measure introduced by Katz (1953) and Bonacich (1972). A sector is central if most of its output is sold as intermediate inputs to other sectors, and these sectors tend to be themselves providers of intermediate inputs to all the other sectors of the economy. Hence, high values in the degree of centrality characterize the sectors which are upstream in the production network of the economy. Instead, low values of centrality determine downstream sectors, which are the industries whose output is sold directly to final consumers and demand intermediate inputs from the other sectors, and these sectors tend themselves to demand intermediate inputs from all the other sectors of the economy.

The vector of centralities \mathbf{c} is computed as:

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

where $\alpha_H = 0.4648$ is the share of intermediate inputs in the gross output of the “One-Sector” economy, $S = 58$ is the number of production sectors, I is a diagonal matrix, $W = \{\nu_{H,s,x}\}_{s,x=1}^S$ characterizes the Input-Output matrix of economy, and $\mathbf{1}$ is a vector of ones.