

The Government Spending Multiplier in a Multi-Sector Economy*

Hafedh Bouakez
HEC Montréal

Omar Rachedi
Banco de España

Emiliano Santoro
University of Copenhagen

First Draft: August 2, 2018

Current Draft: June 4, 2020

Abstract

We study the effects of aggregate government spending shocks in a New Keynesian economy with multiple interconnected production sectors that differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. The model implies an aggregate value-added multiplier that is 75 percent (and 0.32 dollars) larger than that obtained in the average one-sector economy. This amplification is mainly driven by input-output linkages and sectoral heterogeneity in price rigidity. Aggregate government spending shocks also lead to heterogeneous responses of sectoral value added, with larger effects among upstream industries. We present novel empirical evidence supporting this prediction.

Key Words: Government Spending Multiplier, Input-Output Matrix, Price Rigidity, Sectoral Heterogeneity.

JEL Classification Codes: E62, H32.

*Addresses: hafedh.bouakez@hec.ca, omar.rachedi@bde.es, and emiliano.santoro@econ.ku.dk. We thank Henrique S. Basso, Florin Bilbiie, Oleksiy Kryvtsov, Jesper Linde, Ramon Marimon, Isabelle Mejean, Luca Metelli, Michael Reiter, Michael Weber, Roland Winkler, and presentation participants at the Lancaster University, Banco de España, Latvijas Banka, the Midwest Macro Meetings in Nashville, the Macro Banking and Finance Workshop in Alghero, the Conference of the ESCB Research Cluster 2 in Paris, the Joint French Macro Workshop in Paris, the SNDE Conference in Dallas, the Conference on Theories and Methods in Macroeconomics in Nuremberg, the Africa Meeting of the Econometric Society in Rabat, the Workshop on Recent Developments in Macroeconomic Modelling in Barcelona, the Macro Workshop in Pamplona, the Dynare Conference in Lausanne, and the SAEe Meetings in Alicante for useful comments. The views expressed in this paper are those of the authors and do not necessarily represent the views of the Banco de España or the Eurosystem.

1 Introduction

Despite the formidable resurgence of interest in the macroeconomic effects of government spending that has been witnessed since the Great Recession, the extant literature has been mostly relying on one-sector models (e.g., Hall, 2009; Christiano et al., 2011; Woodford, 2011; Leeper et al., 2017), which – by construction – abstract from two prominent features that characterize actual economies, namely, sectoral heterogeneity and inter-sectoral linkages. To the extent that these features affect the propagation of government purchases and their aggregate implications, the assumptions of symmetry and absence of production networks embedded in the one-sector framework can be a significant source of bias when evaluating the government spending multiplier. Moreover, these counterfactual assumptions conceal the dispersion in the sectoral responses to changes in total government spending.

This paper builds a multi-sector sticky-price model to study the effects of aggregate government spending shocks, which correspond to a common increase in government purchases from all sectors. We pursue two objectives: The first is to determine how and to what extent sectoral heterogeneity and input-output interactions alter the aggregate effects of a change in government spending relative to the average one-sector economy. The second is to unveil the degree of heterogeneity in sectoral output responses to the shock, and investigate the factors that account for it, with a focus on the role of the production network.

To capture the vast heterogeneity across industries observed in the data, our model allows sectors to differ in their price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. The economy consists of 57 sectors, which roughly correspond to the three-digit level of the North American Industry Classification System (NAICS) 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. Despite its complexity, our model represents a natural extension of the standard New Keynesian economy, which is nested as a limiting case.

Our results indicate that the present-value aggregate value-added multiplier associated with an aggregate government spending shock financed by lump-sum taxes is 75 percent larger in the baseline multi-sector economy (0.74) than in the average one-sector economy (0.42). This amplification holds for the two components of private spending – consumption and investment – and in a variety of alternative specifications of the baseline economy, including distortionary labor-income taxes and nominal wage stickiness.

Counterfactual experiments reveal that the amplification of the spending multiplier is mainly due to input-output interactions and sectoral heterogeneity in price rigidity. 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 that amplify the extent of nominal rigidity. The resulting flattening of the economy-wide Phillips curve dampens the response of aggregate inflation and magnifies the response of aggregate output to the spending shock. Consistent with this intuition, a multi-sector economy implies a very limited amplification of multipliers if prices are flexible.

In the second part of the paper, we study the sectoral implications of an aggregate government spending shock. We start by documenting significant heterogeneity in the response of sectoral value added to the shock, with the service industries being the most responsive. In fact, the value-added multiplier of a single service industry such as professional services is similar in magnitude to that of the manufacturing sector as a whole. Together, the service-producing sectors have a multiplier that is more than three times larger than that of all the manufacturing industries combined.

The dispersion in the sectoral value added multipliers is mainly driven by the sectors' positions in the production network, while being unrelated to other sectoral characteristics. More specifically, the model implies a strong positive correlation between the value-added multiplier of an industry and its centrality, where the latter measures an industry's upstreamness in the production chain. Intuitively, when the government demands more goods from all the industries, sectors located upstream raise their production to meet not only the higher demand from the government, but also the higher demand for intermediate goods from customer industries. The value added of upstream sectors therefore rises more than that of downstream sectors, *ceteris paribus*.

As an empirical validation of our multi-sector model, we test in a panel of U.S. industries the positive relationship between a sector's degree of upstreamness and the response of its value added to an aggregate government spending shock. We confirm that the value-added multiplier of a given sector increases with its centrality. Interestingly, the magnitude of this relationship is remarkably similar to the one implied by the baseline model, whereas it is severely underestimated by a counterfactual economy that abstracts from price stickiness. The latter observation reasserts the importance of the interaction of price stickiness and production networks in explaining the effects of spending shocks, and – more generally – lends

credence to the quantitative model used in this paper.

The first work on the effects of government purchases within a multi-sector model is Ramey and Shapiro (1998), which builds a two-sector flexible-price economy – abstracting from input-output linkages – to show that costly capital reallocation can produce realistic aggregate effects of government spending. Our paper considers a richer framework to evaluate the role of sectoral heterogeneity and input-output interactions in amplifying the government spending multiplier, at a granular level of disaggregation.¹ A second novel contribution of this study is to uncover the importance of the production network in accounting for the sectoral effects of aggregate spending shocks. From this perspective, our paper relates to the literature that emphasizes the implications of sectoral heterogeneity for the degree of monetary non-neutrality (e.g., Carvalho, 2006; Nakamura and Steinsson, 2010; Bouakez et al., 2014), and to the work on the relevance of production networks for aggregate fluctuations (e.g., Horvath, 1998, 2000; Bouakez et al., 2009, 2011; Acemoglu et al., 2012, 2015; Pasten et al., 2020; Carvalho and Tahbaz-Salehi, 2019; Galesi and Rachedi, 2019; Petrella et al., 2019).

While this paper focuses on the aggregate and sectoral effects of aggregate spending shocks, in a companion paper (Bouakez et al., 2020) we consider a complementary approach by studying the aggregate implications of sectoral government spending shocks. More specifically, we dissect the channels through which spending originating in a given sector spills over across industries, and map its effects on aggregate value added to the characteristics of that sector and its position in the production network.

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., 2019). 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 documents the heterogeneity in the response of sectoral value added to aggregate government spending shocks, and studies the determinants of this dispersion, with a particular focus on the role of production networks. Section 6 concludes.

¹Cox et al. (2020) corroborate our findings about the amplification of the aggregate spending multiplier in the context of a two-sector model that abstracts from input-output linkages.

2 Model

We build a multi-sector New Keynesian model with physical capital, intermediate inputs, and government consumption spending. The economy consists of households, a government, and firms uniformly distributed across S sectors. We now sketch the most relevant features of the model, and refer the reader to Appendix A for further details.

2.1 Households

An infinitely-lived representative household has preferences over aggregate consumption, C_t , aggregate government spending, G_t , and aggregate labor, N_t , so that its expected lifetime utility is

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

where

$$\tilde{C}_t = \left[\zeta^{\frac{1}{\mu}} C_t^{\frac{\mu-1}{\mu}} + (1-\zeta)^{\frac{1}{\mu}} G_t^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}.$$

In expression (1), β denotes the subjective time discount factor, σ is the degree of risk aversion, θ is a preference shifter that affects the disutility of labor, and η is the inverse of the Frisch elasticity of labor supply. As in Bouakez and Rebei (2007), we allow preferences to be non-separable in consumption and government services, with ζ denoting the weight of private consumption in the effective consumption aggregator, \tilde{C}_t , and μ the elasticity of substitution between private consumption and government spending.

The household trades one-period nominal bonds, B_t , and owns the stock of physical capital, K_t . Every period, it purchases consumption goods at price $P_{C,t}$ and investment goods, I_t , at price $P_{I,t}$. The accumulation of physical capital is subject to convex adjustment costs whose magnitude is governed by the parameter Ω . The household receives total labor income, $W_t N_t$, where W_t is the nominal aggregate wage; total capital income, $R_{K,t} K_t$, where $R_{K,t}$ is the nominal aggregate gross return on capital; and the gross return on nominal bonds, $R_{t-1} B_t$, where R_{t-1} is the gross nominal risk-free rate. Finally, the household pays a nominal lump-sum tax, T_t , and earns firms' nominal profits, D_t . Its budget constraint is therefore given by

$$P_{C,t} C_t + P_{I,t} I_t + B_{t+1} + T_t = W_t N_t + R_{K,t} K_t + B_t R_{t-1} + D_t. \quad (2)$$

As in Huffman and Wynne (1999), Horvath (2000), and Bouakez et al. (2009), we posit that the total amount of labor provided by the household is a CES function of the labor supplied to each sector, that is

$$N_t = \left[\sum_{s=1}^S \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right]^{\frac{\nu_N}{1+\nu_N}}, \quad (3)$$

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. Analogously, aggregate capital, K_t , bundles sectoral capital flows, $K_{s,t}$, with an elasticity of substitution ν_K . When $\nu_N, \nu_K \rightarrow \infty$, labor and capital are perfectly mobile and both nominal wages and nominal returns on capital are equalized across sectors. Instead, when $\nu_N, \nu_K < \infty$, labor and capital are imperfectly mobile and both wages and returns on capital can differ across sectors. Therefore, finite values of ν_N and ν_K enable us to capture in a parsimonious way the sluggish reallocation of labor and capital across sectors in response to shocks, as documented in the empirical literature (e.g., Eifeldt and Rampini, 2006; Lee and Wolpin, 2006; Lanteri, 2018).

2.2 Firms

In each sector, there is a continuum of producers that 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 wholesaler. The goods produced by the S representative wholesalers are then purchased by retailers, who assemble them into consumption and investment bundles sold to the households, a government-consumption bundle sold to the government, and intermediate-input bundles sold to the producers.

2.2.1 Producers and Wholesalers

In sector s , a continuum of monopolistically competitive producers, indexed by $j \in [0, 1]$, produce differentiated varieties using the Cobb-Douglas technology

$$Z_{s,t}^j = \left(N_{s,t}^j \alpha_{N,s} K_{s,t}^{j 1-\alpha_{N,s}} \right)^{1-\alpha_{H,s}} H_{s,t}^{j \alpha_{H,s}}, \quad (4)$$

where $Z_{s,t}^j$ is the gross output of the variety of producer j , while $N_{s,t}^j$, $K_{s,t}^j$, and $H_{s,t}^j$, respectively, denote labor, capital, and the bundle of intermediate inputs used by this producer. The factor intensities $\alpha_{N,s}$ and $\alpha_{H,s}$, respectively, correspond to the share of labor in value added and the share of intermediate inputs in gross output.

We allow these intensities to be sector-specific. Producers rent labor, capital, and intermediate inputs at the equilibrium prices $W_{s,t}$, $R_{K,s,t}$, and $P_{H,s,t}$. They face price-setting frictions that give rise to nominal price stickiness. More specifically, producers reset their prices according to a Calvo-type mechanism, with ϕ_s being the sector-specific probability of not changing prices.

Producers in each sector sell their varieties to a perfectly competitive wholesaler, which bundles them into a single final good $Z_{s,t}$ by means of a CES production technology. The elasticity of substitution across varieties is ϵ . In a Calvo-pricing model, this parameter vanishes in the log-linearization of the model around the steady-state. Thus, the assumption of a symmetric elasticity of substitution across sectors is inconsequential for our results.

2.2.2 Retailers

Perfectly competitive consumption-good retailers purchase goods $C_{s,t}$ from the wholesalers of each sector and assemble them into a bundle C_t sold to households at price $P_{C,t}$. The representative consumption-good retailer uses the CES technology:

$$C_t = \left[\sum_{s=1}^S \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C-1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C-1}}, \quad (5)$$

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 $\sum_{s=1}^S \omega_{C,s} = 1$.

An analogous investment-good bundle, I_t , is assembled by the investment-good retailers, and is sold to households at price $P_{I,t}$. The sectoral weights in this bundle are denoted by $\omega_{I,s}$, while the elasticity of substitution is denoted by ν_I .

In each sector s there is an intermediate-input retailer that aggregates sectoral intermediate inputs $H_{s,x,t}$, with ν_H being the elasticity of substitution of inputs across sectors, and $\omega_{H,s,x}$ denoting the weight of good produced by sector x in the bundle of intermediate inputs of sector s . The final intermediate input $H_{s,x}$ is sold to the producers of sector s at price $P_{H,s,t}$.

Finally, there exist perfectly competitive retailers that aggregate goods $G_{s,t}$ using a technology described in the following section. Summing up the demand from the different retailers for the good produced by sector s yields the following sectoral resource constraint:

$$Z_{s,t} = C_{s,t} + I_{s,t} + G_{s,t} + \sum_{x=1}^S H_{x,s,t}. \quad (6)$$

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 a standard Taylor rule that reacts to the aggregate output gap and to aggregate inflation, computed using the GDP deflator. The fiscal authority purchases goods G_t , whose total amount is determined by the auto-regressive process

$$\log G_t = (1 - \rho) \log G + \rho \log G_{t-1} + u_t, \quad (7)$$

where G defines the steady-state amount of government spending,² and ρ measures the persistence of the process. The only source of uncertainty in the model is given by the aggregate government spending shock, u_t , which follows a normal distribution with mean zero.

Given the realization of the aggregate spending shock, the fiscal authority buys the goods G_t at price $P_{G,t}$ from the government-consumption-good retailers. The government finances these purchases by levying lump-sum taxes on the household,³ which implies the following government budget constraint:

$$P_{G,t}G_t = T_t. \quad (8)$$

To produce the final bundle G_t , the government-consumption-good retailers purchase the goods $G_{s,t}$ from the wholesalers of each sector, and assemble them with the Cobb-Douglas technology:

$$G_t = \prod_{s=1}^S G_{s,t}^{\omega_{G,s}}, \quad (9)$$

where $\omega_{G,s}$ denotes the weight of good s in the government-consumption bundle, such that $\sum_{s=1}^S \omega_{G,s} = 1$.

Together, Equation (7) and the demand functions associated with Equation (9) imply that an aggregate spending shock raising the value of total government spending by 1 percent leads to an equal percentage increase in the value of government purchases from each sector. As a result, aggregate government spending exhibits the same sectoral composition at and outside the steady state.⁴ In this way, we can com-

²Throughout the text, variables without a time subscript denote steady-state values.

³The robustness checks carried out in Section 4.3 consider a version of the model in which government spending is financed with distortionary labor-income taxes.

⁴In other words, a dollar change in total government purchases is allocated across sectors in accordance with their steady-state sectoral shares in total spending.

pute the multiplier associated with an ‘average’ government spending shock; that is, a shock that reflects the historical sectoral composition of public expenditure, rather than the composition of some specific fiscal package.⁵

Focusing on *composition-preserving* spending shocks allows for a meaningful comparison with the one-sector model, which – by construction – abstracts from variation in the sectoral composition of government purchases. At the same time, our approach permits a closer mapping between the aggregate spending multipliers implied by the model and those estimated based on time-series data (e.g., Blanchard and Perotti, 2002; Ramey, 2011; Ramey and Zubairy, 2018). Existing empirical studies typically exploit the exogenous time-variation in aggregate government spending, and estimate the response of aggregate output by averaging out over the time-series dimension. In Section 5.2, we use a similar strategy to empirically estimate the average response of sectoral output to a change in aggregate government purchases.

3 Calibration

We consider an economy with $S = 57$ sectors, which correspond to the three-digit level of the NAICS codes, after excluding the financial and real estate services. The complete list of sectors to which we calibrate the model is listed in Appendix B. A period in the model corresponds to a quarter.

We fix the elasticity of substitution of consumption to the value of $\nu_C = 2$, in line with the estimates of Hobbijn and Nechio (2019) based on data at the same level of disaggregation considered in this paper.⁶ Analogously, we set the elasticity of substitution of investment to $\nu_I = 2$. We set the elasticity of substitution of intermediate inputs to $\nu_H = 0.1$, which generates a strong degree of complementarity of inputs across industries, in line with the empirical evidence of Barrot and Sauvagnat (2016), Atalay (2017), and Boehm et al. (2019).

We choose the sectoral weights $\omega_{C,s}$, $\omega_{I,s}$, $\omega_{H,s,x}$, and $\omega_{G,s}$ based on the contribution of each sector to aggregate consumption, aggregate investment, the use of intermediate inputs supplied by all other industries, and aggregate government

⁵In Bouakez et al. (2020), instead, we study the implications of changes in the sectoral composition of public purchases for the transmission of spending shocks and their effects on aggregate variables.

⁶The literature on structural transformation, which focuses on the reallocation of economic activity across sectors in the long run, tends to set this elasticity to lower values, usually below 1. Our calibration is consistent with the literature that uses multi-sector models to study aggregate dynamics at business-cycle frequencies, such as Carvalho (2006), Bouakez et al. (2009), Carvalho et al. (2020), and Pasten et al. (2020).

consumption, respectively.⁷ To this end, we rely on the entries of the Input-Output matrix of the U.S. Bureau of Economic Analysis, averaged over the period 1997–2015.⁸ We normalize the nominal amount of government spending $P_{G,t}G_t$ to be 20 percent of aggregate value added in the steady state, and set the autoregressive parameter of the process determining government spending to $\rho = 0.90$.

To calibrate the factor intensities, $\alpha_{N,s}$ and $\alpha_{H,s}$, we again rely on the information provided by the Input-Output matrix on gross output, value added, labor compensation, and intermediate inputs. Our assumption of a constant-return-to-scale Cobb-Douglas production function for gross output allows us to interpret $\alpha_{H,s}$ as the sectoral share of intermediate inputs in gross output. Analogously, we can interpret $\alpha_{N,s}$ as the sectoral share of the compensation of employees in value added.⁹ 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 convert their estimates of the sectoral durations of price spells into probabilities.

We set the elasticity of substitution of labor across sectors to $\nu_N = 1$, in line with Horvath (2000), and assign a similar value to ν_K . The weights of sectoral labor and capital, $\omega_{N,s}$ and $\omega_{K,s}$, are set such that the model features imperfect substitution of both factors of production only *around* the steady state, while imposing full mobility *at* the steady state. To do so, we set $\omega_{N,s} = \frac{N_s}{N}$ and $\omega_{K,s} = \frac{K_s}{K}$.

As for the parameters that affect households' utility function, we set both the time discount factor and the risk-aversion parameter to the standard values of $\beta = 0.995$ and $\sigma = 2$, respectively. We set $\eta = 1.25$ so that the Frisch elasticity is 0.8, in line with the estimate of Chetty et al. (2013). Then, we impose that the steady-state level of total hours, N , equals 0.33. To this end, we set $\theta = 41.01$. In line with the estimates of Bouakez and Rebei (2007) and Sims and Wolff (2018), we fix the elasticity of substitution between private and public consumption to $\mu = 0.3$.¹⁰ The relative weight of consumption is set $\zeta = 0.7$, which corresponds to the ratio of consumption expenditures to the sum of consumption and government expenditures.

We set the depreciation rate of physical capital to the standard quarterly value

⁷The calibration of the sectoral weights, $\omega_{C,s}$, $\omega_{I,s}$, and $\omega_{H,s,x}$, is conditional on the values of the elasticities ν_C , ν_I , and ν_H .

⁸Aggregate consumption equals personal consumption expenditures, aggregate investment is the sum of nonresidential private fixed investment in structures and in equipment, and aggregate government spending is the sum of the purchases of goods and services by the federal government, as well as state and local governments.

⁹The sectoral shares in the production function are based on a measure of sectoral gross output that excludes taxes, subsidies, and markups.

¹⁰Our calibration choice implies that consumption and government spending are Edgeworth complements in utility. This is consistent with the empirical evidence reported by Fève et al. (2013) and Leeper et al. (2017).

of $\delta = 0.025$, and calibrate the adjustment-cost parameter, Ω , such that the model predicts that the response of aggregate investment to a government spending shock reaches a trough after 8 quarters, in accordance with the empirical evidence reported by Blanchard and Perotti (2002). Accordingly, we set $\Omega = 25$. The elasticity of substitution across varieties within sectors is calibrated to $\epsilon = 4$, as the implied 33 percent steady-state mark-up is in line with firm-level estimates.

Finally, we calibrate the Taylor rule parameters following the estimates of Clarida et al. (2000), so that the degree of interest-rate inertia is $\varphi_R = 0.8$, and the inflation and output-gap feedback parameters equal $\varphi_\Pi = 1.5$ and $\varphi_Y = 0.2$, respectively.

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, defined as the dollar change in total value added that results from a dollar increase in government spending. We do so by comparing the multiplier obtained from our multi-sector model with those implied by a series counterfactual nested economies. We also study the robustness of our results to alternative modelling assumptions, and provide some intuition based on a stripped-down version of the model.

4.1 Quantifying the multiplier

We start by measuring the degree to which the aggregate value-added multiplier in the multi-sector economy differs from its counterpart in a one-sector model. To do so, we compare the predictions of the baseline multi-sector economy with those of the average one-sector economy, which corresponds to a standard one-sector model without intermediate inputs, where the value-added-based labor and capital intensities are computed based on aggregate variables, and the Calvo parameter, ϕ , equals the average of the sectoral values, ϕ_s .¹¹ The purpose of this comparison is to reveal to what extent approximating the economy with a single aggregate sector – which implies discarding all sources of heterogeneity and linkages across industries – can bias the measurement of the output effects of government spending shocks.

¹¹The multi-sector model nests the one-sector economy when all sectoral shares of consumption, investment, and government spending, as well as the factor intensities and the degrees of price rigidity are set symmetrically across sectors.

We evaluate the effects of changes in government spending on aggregate value added using the present-value spending multiplier, which is given by

$$\mathcal{M} = \frac{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t (Y_{t+j} - Y)}{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t (Q_{G,t} G_{t+j} - Q_G G)}, \quad (10)$$

where $Q_{G,t} = \frac{P_{G,t}}{P_t}$ is the relative price of government spending relative to the numeraire, the GDP deflator.¹² The multiplier, therefore, reports the dollar change in aggregate output associated with a temporary shock that raises aggregate government purchases by one dollar. The consumption and investment multipliers are computed analogously. Table 1 reports the results.

Table 1: Aggregate Spending Multipliers - Multi-Sector vs. One Sector

	Average One-Sector Economy	Multi-Sector Economy	$\Delta \%$	$\Delta \$$
Spending Multiplier	(1)	(2)	(3)	(4)
Value Added	0.4247	0.7444	+75.3%	0.3197
Consumption	-0.0854	0.0453	+153.0%	0.1307
Investment	-0.4899	-0.3009	+38.6%	0.1890

Note: the table reports the present-value multipliers of aggregate value added, aggregate consumption, and aggregate investment for the baseline “Multi-Sector Economy” in Column (1) and the “Average One-Sector Economy” in Column (2). The latter corresponds to a standard one-sector model without intermediate inputs, where the value-added-based labor and capital intensities are computed based on aggregate variables, and the degree of price rigidity is the average value over the sectoral price rigidity parameters. Column (3) reports the difference in percentage points between the multipliers of the “Multi-Sector Economy” and those of the “Average One-Sector Economy”, whereas Column (4) reports the difference in absolute values.

In the one-sector economy the value-added multiplier is 0.42. This number is 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 dura-

¹²We solve all the model versions studied in the paper by taking a first-order approximation of the equilibrium conditions around the zero-inflation steady state. Then, we back out the variables in levels to compute the multiplier.

tion of prices across sectors. Accordingly, we set $\phi = 0.68$, which implies an average price duration of around nine months, significantly shorter than the one-year average duration typically assumed in the literature. Second, our framework features physical capital, which contributes to lowering the value of the multiplier via the crowding-out effect on private investment.

The results also indicate that the multi-sector model delivers a larger multiplier than the one-sector economy. Notably, moving from the one-sector model to the multi-sector one raises the aggregate value-added multiplier by 75 percent, that is, from 0.42 to 0.74. Hence, the multi-sector economy implies that a dollar increase in government spending leads to an additional \$0.32 increase in aggregate value added relative to the one-sector framework.

Panels B and C report analogous statistics for the aggregate consumption and aggregate investment multipliers, respectively. The results reveal that the consumption multiplier features a larger amplification in relative terms than that of the investment multiplier (153 versus 39 percent). Nonetheless, in absolute terms, the increase in the consumption multiplier represents only about 40 percent of the additional increase in aggregate value added (\$0.13) obtained in the multi-sector economy, relative to the one-sector model; the remaining 60 percent (\$0.19) being attributed to the increase in the investment multiplier.¹³

4.2 Sources of amplification

Which features of the multi-sector economy are the most important in accounting for the amplification of the value-added multiplier? To answer this question, we take the baseline model as a starting point and exclude – one at a time – various defining features of the multi-sector economy, producing four counterfactual economies. More specifically, the first economy abstracts from intermediate inputs in production (i.e., $\alpha_{H,s} = 0$); the second abstracts from heterogeneity in price rigidity across sectors (i.e., $\phi_s = \phi, \forall s$); the third abstracts from heterogeneity both in consumption and investment shares (i.e., $\omega_{C,s} = \omega_{I,s} = 1/57, \forall s$); the fourth imposes homogeneity in factor intensities (i.e., $\alpha_{N,s} = \alpha_N$ and $\alpha_{H,s} = \alpha_H, \forall s$).

Panel A of Table 2 reports the value-added multiplier across the different model economies, while Panel B shows the contribution of the excluded feature to the multiplier implied by the baseline model. The results reveal that inter-sectoral linkages

¹³Letting firms produce only through labor and intermediate inputs – thus switching off the crowding-out effect of the spending shock on private investment – leads to a \$1.06 increase in aggregate value added relative to the prediction of the corresponding one-sector framework, with a multiplier that goes from 0.70 to 1.76.

Table 2: Sources of Amplification of the Aggregate Value-Added Multiplier.

Multi-Sector Economy	Counterfactual Multi-Sector Economies			
	Excluding Input-Output Matrix	Excluding Heterogeneity in Price Rigidity	Excluding Heterogeneity in Consumption & Investment Shares	Excluding Heterogeneity in Factor Intensities
(1)	(2)	(3)	(4)	(5)
Panel A: Aggregate Value-Added Multiplier				
0.7444	0.2372	0.5691	0.6890	0.7962
Panel B: Marginal Contribution of the Excluded Feature				
-	68.1%	23.6%	7.4%	7.0%

Note: Panel A reports the present-value cumulative aggregate output multipliers associated with a government spending shock in the baseline model (i.e., the “Multi-Sector Economy” in Column 1) vis-à-vis the four alternative versions of the model (i.e., the “Counterfactual Multi-Sector Economies”). Panel B reports the difference in the multiplier (in percentage terms) between the value obtained in the baseline economy and that implied by each of the counterfactual economies.

and the difference in the degree of price rigidity across industries are the two ingredients that contribute the most to amplifying the response of aggregate value added. In particular, excluding inter-sectoral linkages reduces the spending multiplier by 68 percent, from 0.74 to 0.24, whereas abstracting from heterogeneity in price rigidity reduces the spending multiplier by 24 percent, down to 0.57. Instead, heterogeneity in either the consumption and investment shares or in factor intensities has a negligible impact on the size of the multiplier.

4.3 Robustness

We evaluate the robustness of our result regarding the amplification of the aggregate value-added multiplier along four dimensions. First, we abstract from the complementarity between private and public consumption, and consider an economy in which households' instantaneous utility function is $\frac{C_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta}$.¹⁴ Second, 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, which yields the government budget constraint to read $P_{G,t}G_t = T + \tau_t W_t N_t$, where τ_t denotes the distortionary labor-income tax rate at time t . Third, we consider a model with sticky wages à la Erceg et al. (2000), in which differentiated labor-service varieties are supplied monopolistically by households to unions. The unions can then optimally set wages in a staggered fashion à la Calvo, where the probability of not changing wages is identical across sectors, in line with the empirical evidence reported by Barattieri et al. (2014).¹⁵ Finally, we consider an economy in which nominal prices are fully flexible, by assuming $\phi_s = 0$ in all sectors.

Panels B–E of Table 3 report the value-added multipliers of both the one-sector and multi-sector model for each of the four alternative economies described above. For ease of comparison, Panel A reproduces the results of the baseline model. For each of the alternative multi-sector economies, we observe a larger multiplier than in the corresponding one-sector economy. Quantitatively, however, the extent of amplification varies substantially across the alternative economies, peaking at 133 percent in the economy that relies on distortionary labor-income taxes to finance government spending.

Importantly, in the flexible-price economy there is a very small difference in the

¹⁴Abstracting from government spending in utility or assuming that it enters utility in a separable manner is irrelevant for the spending multiplier.

¹⁵We set the elasticity of substitution across labor varieties to $\epsilon_w = 4$, such that it coincides with the value of the elasticity of substitution across goods varieties, ϵ , and fix the wage Calvo probability to 0.68, such that it equals the average degree of price rigidity across sectors.

Table 3: Aggregate Value-Added Multiplier - Robustness Checks.

Average One-Sector Economy	Multi-Sector Economy	Δ %	Δ \$
(1)	(2)	(3)	(4)
Panel A: Baseline Model			
0.4247	0.7444	+75.3%	0.3197
Panel B: No Complementarity between C_t and G_t			
0.2204	0.3850	+74.7%	0.1646
Panel C: Distortionary Labor-Income Taxation			
-0.2465	0.0804	+132.6%	0.3339
Panel D: Sticky Wages			
0.5367	0.7661	+42.7%	0.2294
Panel E: Flexible Prices			
0.3363	0.4057	+20.6%	0.0694

Note: This table compares the present-value aggregate value-added multipliers of the baseline economy (Panel A), with those implied by a version of the model without complementarity between consumption and government spending (Panel B), a version of the model in which additional government spending is financed with distortionary labor-income taxes (Panel C), a version of the model with sticky wages (Panel D), and a version of the model with flexible prices (Panel E). Column (1) reports the multipliers implied by one-sector models in each of these economies, Column (2) reports the multipliers implied by the multi-sector model, Columns (3) and (4) report the amplification of the multiplier in the multi-sector model vis-à-vis the one-sector model in percentage terms and in absolute values, respectively.

level of multipliers between the one-sector and the multi-sector model. This result hints to the fact that input-output linkages are quantitatively relevant in amplifying the effects of government spending, as long as prices are sticky. The next section provides analytical insights that help clarify this point.

4.4 Some intuition

The results reported in Table 2 underline the prominent role of input-output interactions and sectoral heterogeneity in price rigidity in amplifying the aggregate output effects of government spending shocks. To provide some intuition for 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 government spending in the utility function (i.e., $\zeta = 1$);
- (ii) a logarithmic utility (i.e., $\sigma = 1$);
- (iii) no capital in production and symmetric sectoral production technologies displaying constant returns to scale (i.e., $\alpha_{N,s} = 1$ and $\alpha_{H,s} = \alpha_H, \forall s$);
- (iv) a unit elasticity of substitution of consumption and intermediate inputs across sectors (i.e., $\nu_C = \nu_H = 1$);
- (v) equal consumption shares across sectors (i.e., $\omega_{C,s} = 1/S, \forall s$);
- (vi) equal split of government spending across sectors (i.e., $\omega_{G,s} = 1/S, \forall s$);
- (vii) a diagonal Input-Output matrix (i.e., $\omega_{H,s,s} = 1, \forall s$);
- (viii) a Taylor rule that neither reacts to the output gap (i.e., $\varphi_Y = 0$) nor allows for interest-rate smoothing (i.e., $\varphi_R = 0$);
- (ix) the steady-state distortion due to mark-up pricing is neutralized via a constant production subsidy financed via lump-sum taxes.

Together, these assumptions imply that $P_{C,t} = P_{G,t} = P_t$, and $P_{s,t} = P_{H,s,t}, \forall s$.¹⁶ Moreover, this simplified economy features only one dimension of heterogeneity across sectors, that is, the variation in the degree of price rigidity ϕ_s .

Define $Q_{s,t} = \frac{P_{s,t}}{P_{C,t}}$ 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 v_t denote the log-deviation of a generic variable V_t from its steady-state value, V . Log-linearizing the equilibrium conditions around

¹⁶Appendix C describes the system of non-linear equations resulting from assumptions (i) – (ix).

a symmetric steady state, we obtain the following system of $1 + 2 \times S$ equations, which determines c_t , $\pi_{s,t}$, and $q_{s,t}$ autonomously:

$$c_t = \mathbb{E}_t c_{t+1} - (\varphi_{\Pi} \pi_t - \mathbb{E}_t \pi_{t+1}), \quad (11)$$

$$\pi_{s,t} = \beta \mathbb{E}_t \pi_{s,t+1} + \kappa_s (1 - \alpha_H) (\Theta q_{s,t} + \Xi c_t + \Psi g_t), \quad (12)$$

$$q_{s,t} = \pi_{s,t} - \pi_t + q_{s,t-1}, \quad (13)$$

where $\pi_t = \frac{1}{S} \sum_s \pi_{s,t}$ defines aggregate inflation. The composite parameter $\kappa_s = \frac{(1-\phi_s)(1-\beta\phi_s)}{\phi_s}$ is a decreasing function of the Calvo probability ϕ_s . Hence, heterogeneity in the Calvo parameter ϕ_s maps into heterogeneity in the composite parameter κ_s . For analytical tractability, we use the parameter κ_s to characterize the degree of price rigidity in the remainder of this section. Finally, the composite parameters Θ , Ξ , and Ψ are given by

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

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

Equation (11) represents the standard dynamic IS curve. Equation (12) represents the New Keynesian Phillips curve of sector s , in which the forcing variable (i.e., the sectoral real marginal cost of production) depends on the sector's relative price, $q_{s,t}$, aggregate consumption, c_t , and the spending shock, g_t . Finally, Equation (13) defines the relative price of sector s .

4.4.1 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 $\kappa_s = \kappa$, $\forall s$. As the model becomes perfectly symmetric in this case, $q_{s,t} = 0$ and $\pi_{s,t} = \pi_t$, $\forall s$, and one can solve for the equilibrium paths of aggregate consumption and inflation using the following two-equation system:

$$c_t = \mathbb{E}_t c_{t+1} - (\varphi_{\Pi} \pi_t - E_t \pi_{t+1}), \quad (14)$$

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa (1 - \alpha_H) (\Xi c_t + \Psi g_t). \quad (15)$$

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

$$c_t = \xi g_t. \quad (16)$$

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

$$\xi = -\frac{(\varphi_{\Pi} - \rho)(1 - \alpha_H)\kappa\Psi}{(1 - \rho)(1 - \beta\rho) + (\varphi_{\Pi} - \rho)(1 - \alpha_H)\kappa\Xi}. \quad (17)$$

Consequently, the value-added multiplier is given by

$$\mathcal{M} = 1 + \frac{1 - \gamma}{\gamma}\xi.$$

Equation (17) has two important implications. First, for a finite κ , the response of aggregate consumption to government spending is increasing in the share of intermediate inputs in gross output, that is, $\frac{\partial \xi}{\partial \alpha_H} > 0$. This implies that, as long as prices are rigid, the aggregate value-added multiplier is larger in a model that allows for input-output linkages than in the benchmark one-sector economy. Second, the cross partial derivative of the response of consumption to government spending with respect to the share of intermediate inputs and the inverse of the degree of price rigidity is negative, that is, $\frac{\partial^2 \xi}{\partial \alpha_H \partial \kappa} < 0$. This means that price stickiness acts as a catalyst that strengthens the role of inter-sectoral linkages in amplifying the consumption response, and thus the value-added multiplier.

Intuitively, the fact that the gross product in each industry is both consumed and used in the production of all the other goods in the same industry 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 acts as a source of real rigidity that amplifies the overall degree of nominal rigidity. The dampening of the response of aggregate inflation translates into a larger response of aggregate output. In turn, this discussion explains the very modest amplification of the spending multiplier obtained in the flexible-price economy, as shown in Panel E of Table 3.

4.4.2 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 (11)–(13) does not have a tractable 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 (12) across sectors yields

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \bar{\kappa} (\Xi c_t + \Psi g_t) - \frac{(1 - \gamma + \nu_N)}{S \nu_N} \sum_s \kappa_s q_{s,t}, \quad (18)$$

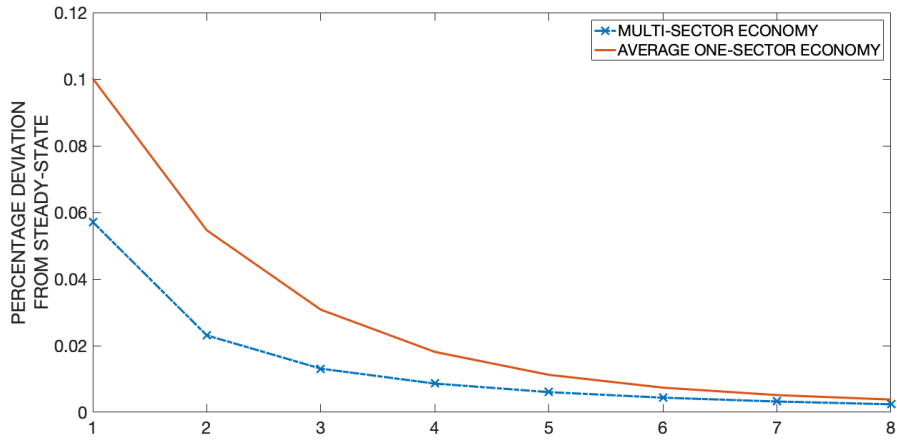
where $\bar{\kappa} = \frac{1}{S} \sum_s \kappa_s$. This equation nests the one obtained in a model with symmetric price rigidity (i.e., Equation (15) with $\kappa = \bar{\kappa}$) as a special case in which the last term on the right-hand side of the equality vanishes.

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. Thus, 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.

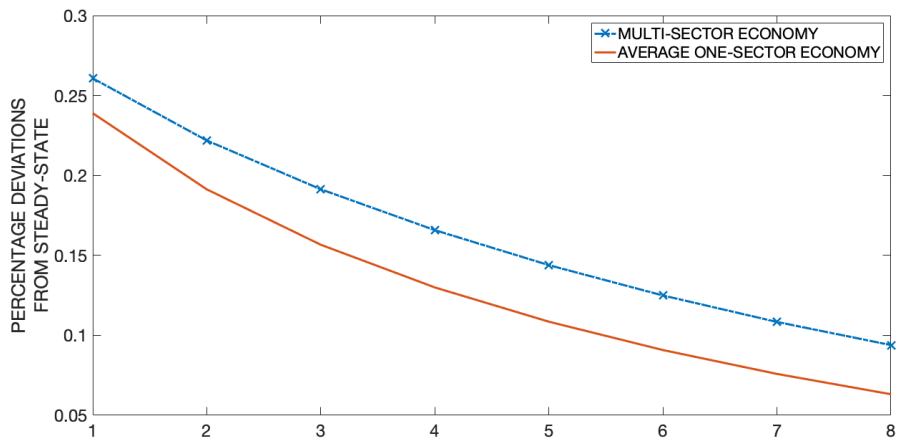
To substantiate our intuition regarding the role of intermediate inputs and heterogeneity in price stickiness as sources of real rigidity, Figure 1 reports the response of aggregate inflation (Panel a) and the response of aggregate value added in (Panel b) to a 1 percent increase in the value of government spending, both in the baseline multi-sector model and in the average one-sector economy. In accordance with our analytical results, the baseline model yields a more muted response of aggregate inflation to a government spending shock, which is accompanied by a larger response of aggregate value added.

Figure 1: The Response of Aggregate Inflation and Value Added to a Government Spending Shock.

(a) Aggregate Inflation



(b) Aggregate Value Added



Note: Panel (a) reports the response of aggregate inflation in the first 8 quarters following a 1 percent increase in the value of government spending in the “Average One-Sector Economy” (continuous red line) and in the baseline “Multi-Sector Economy” (crossed blue line). Panel (b) reports the analogous responses for aggregate value added.

5 Sectoral Implications: Winners and Losers

What distinguishes our framework from standard macroeconomic models used to study fiscal policy is that we can leverage the structure of our economy to derive the sectoral implications of government spending. Measuring the sectoral responses to an aggregate spending shock helps identify which industries are winning and which are losing in terms of value added or employment following an increase in government purchases from *all sectors*. Furthermore, we can exploit the richness of our model to isolate the features that are most relevant in accounting for the observed heterogeneity in the sectoral responses. We show below that the factor that best explains a sector’s response to an aggregate government spending shock is its position in the production network, and provide novel empirical evidence supporting this prediction.

5.1 Sectoral value-added multipliers

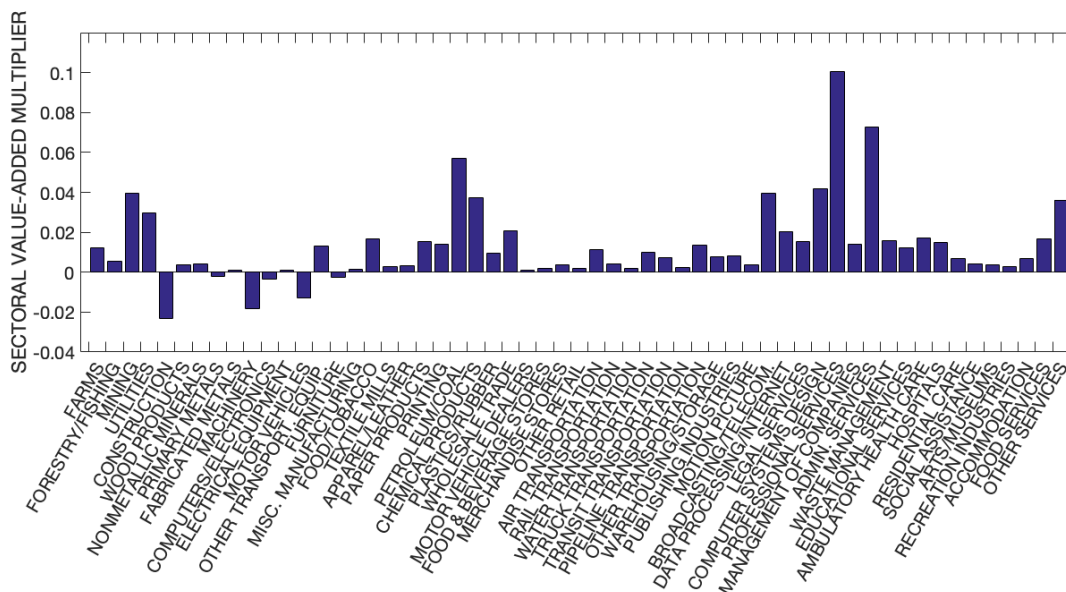
Figure 2 reports the present-value value-added multiplier for each of the 57 sectors of the model.¹⁷ Note that, by construction, the sectoral multipliers sum up to 0.74 – representing the aggregate value-added multiplier. The figure shows substantial heterogeneity in the sectoral value-added effects of a government spending shock: industries such as professional services and administrative services are associated with a multiplier of 0.10 and 0.07, respectively, whereas industries such as construction and machinery manufacturing have negative multipliers of around -0.02. By and large, the output effects of government spending are tilted towards the service industries, whose overall value-added multiplier is more than three times larger than that of the manufacturing sector.¹⁸

To appreciate the quantitative implications of this heterogeneity in the sectoral value-added multipliers, let us consider a shock that raises government spending from 20 percent up to 21 percent of aggregate value added. According to the size of U.S. GDP as of the end of 2019, this stimulus package would increase government spending by \$215 billion. In our model, a government spending shock of this size would lead aggregate value added to surge by $\$215 \times 0.7444 = \160 billion. This number implies that, on average, the value added of each of the 57 industries we consider would increase by \$3 billion. However, the results depicted in Figure

¹⁷Appendix D reports a similar plot for sectoral employment.

¹⁸The sectoral value-added multiplier in services relative to that in manufacturing is disproportionately larger than the size of the service sector relative to the manufacturing sector. In 2015, the value added of the service-producing industries was 78 percent larger than that of manufacturing industries.

Figure 2: The Response of Sectoral Value Added.



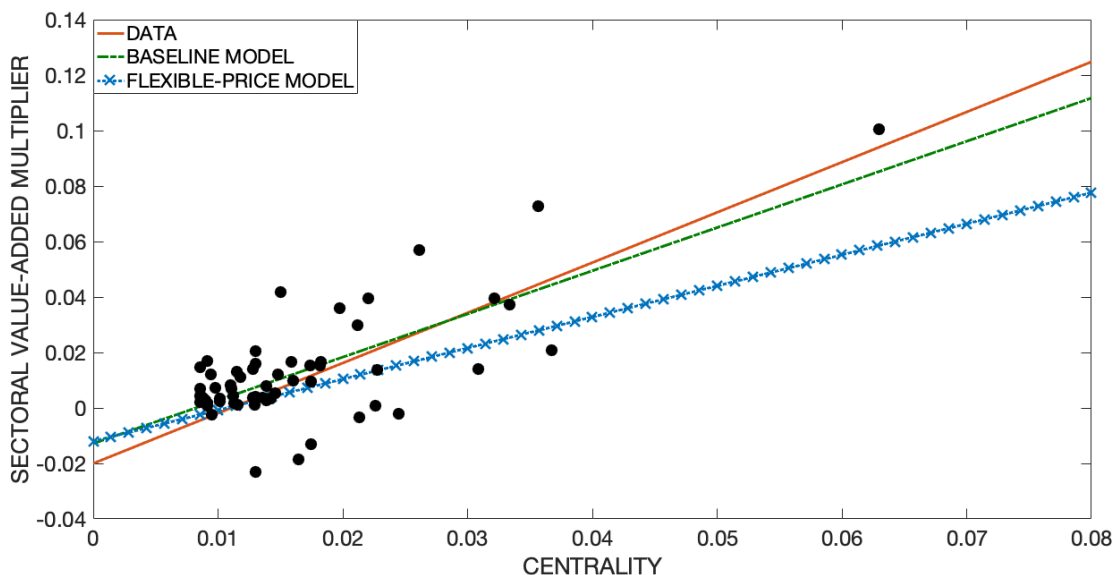
Note: The graph reports the value-added government spending multiplier for each of the 57 sectors of the model.

2 indicate that the value added of a single industry such as professional services would increase by \$22 billion, therefore accounting for almost 15 percent of the rise in aggregate output triggered by the stimulus package. This amount roughly corresponds to the increase in the value added of the entire manufacturing sector (which in our model is split in 19 industries).

The heterogeneity in the responses of sectoral value added to a change in government spending is mainly due to the industries' positions in the production network. To see this, Figure 3 shows a scatter plot of the sectoral value added multiplier and the Katz-Bonacich measure of centrality. A high value of centrality means that a sector is positioned upstream in the production network, and is therefore a relevant provider of intermediate inputs to all other industries. Instead, a low value of centrality is associated with downstream sectors, which demand intermediate inputs from other industries to produce output that is used mainly for final demand. The figure shows that there is a strong correlation of about 0.7 between the sectoral multiplier and centrality, suggesting that sectors that are located upstream in the production chain tend to experience a relatively large increase in their value added in response to an aggregate government spending shock.¹⁹ In contrast, Figures D.2–D.5 in Appendix D show that sectoral multipliers barely correlate with the other

¹⁹In fact, the relatively larger response of services can be rationalized by the fact that the top-3 upstream industries in the economy are professional services, administrative services, and wholesale trade.

Figure 3: The Response of Sectoral Value Added and Centrality.



Note: The graph reports a scatter that links the value-added multiplier of each sector (measured on the y-axis) to its centrality in the Input-Output matrix (measured in the x-axis) in the model, together with the estimated regression line in dashed green. The crossed blue line represents the regression line implied by a counterfactual version of the model with flexible prices. The solid red line represents the regression line estimated from the data.

dimensions of heterogeneity across sectors in the model.

Intuitively, when the government demands more goods from all sectors, both downstream and upstream sectors increase their production. This requires all industries to increase their usage of intermediate inputs, but relatively more upstream industries experience higher pressure to expand production, so as to meet higher demand both for final products (from the government) and for intermediate inputs (from customer industries).²⁰

Finally, Figure 3 also depicts the regression line between the sectoral value added multiplier and centrality obtained from a counterfactual economy with fully flexible prices. While the relationship is still positive, the slope of the regression line is significantly smaller than that based on the baseline model, pointing to a weaker correlation. This observation provides yet another argument for the relevance of the interaction between the production network and price stickiness. An economy that features an Input-Output matrix but abstracts from rigid prices not only un-

²⁰The high correlation between sectoral multipliers and centrality is not merely driven by the fact that in the data government spending tends to be concentrated in upstream industries. Indeed, the correlation is still high and equals 0.5 in a version of the model in which government spending is homogeneously distributed across industries.

derestimates the aggregate effects of government spending shocks, it also yields a misleading portrait of their sectoral implications.

5.2 Testing the theoretical prediction

As a validation of our multi-sector model, we test empirically the theoretical prediction of a positive relationship between the sectoral multiplier and centrality. To do so, we need to identify exogenous shocks to aggregate government spending. The empirical literature has produced two leading identification strategies: *(i)* the VAR-based approach proposed by Blanchard and Perotti (2002) and *(ii)* the narrative approach advocated by Ramey and Shapiro (1998) and Ramey (2011). Blanchard and Perotti (2002) identify government spending shocks in a structural VAR framework as the orthogonalized innovations to total public expenditure. This purely statistical scheme implies that government spending is predetermined with respect to economic activity within the quarter. Ramey (2011), however, argues that changes in government spending are subject to legislation and implementation lags that make them predictable by economic agents. In this case, the VAR-based shocks are likely to miss the timing of the announced spending policies. She extends Ramey and Shapiro (1998)'s work by using narrative evidence to construct a defense news variable, which measures changes in the expected present value of U.S. defense spending. Ramey and Zubairy (2018) combine the two approaches by using both the Blanchard and Perotti (2002)'s shocks and Ramey (2011)'s news measure as instruments to derive a series of U.S. government spending shocks. The constructed series is used to compute the aggregate spending multiplier based on the local projection method of Jordà (2005).

Our methodology builds on Ramey and Zubairy (2018), which we adapt in two ways to test our theoretical prediction. First, we focus on the sectoral output response to an aggregate government spending shock, rather than on that of aggregate output. Second, we allow the response of output in a given sector to depend on its position in the network. For this purpose, we construct a panel of sectoral real value added, aggregate real government purchases of goods and services, and real tax proceeds at an annual frequency from 1963 to 2015. Given the stability of the production network structure (e.g., Acemoglu et al., 2012), we compute a cross-sectional measure of sector centrality based on the average entries of the Input-Output Table over the same sample period. To maintain comparability with the theoretical results, we consider sectors at the level of disaggregation of the model. However, going back to 1963 allows us to recover information only on 53 of the 57 industries

to which we calibrate the model.²¹

We then estimate the following regression

$$\sum_{t=0}^T \frac{Y_{s,t}}{Y_t^*} = \beta_1 \sum_{t=0}^T \frac{G_t}{Y_t^*} + \beta_2 \sum_{t=0}^T \frac{G_t}{Y_t^*} \times \text{Centrality}_s + \text{Controls}_t + \epsilon_t, \quad (19)$$

where $Y_{s,t}$ is real value added in sector s , G_t is real aggregate government purchases of goods and services, Y_t^* is the series potential output derived by Ramey and Zubairy (2018) as a polynomial trend of real aggregate value added, and Controls_t include lagged values of both sectoral value added and aggregate government spending, as well as real tax proceeds, linear and quadratic time trends, and time fixed effects.²² Importantly, to test our theoretical prediction, we interact aggregate government spending with sectors' centrality. In this way, the estimate of β_2 informs to what extent the response of sectoral value added to an aggregate government spending shock depends on the industry's position in the production network.

As in Ramey and Zubairy (2018), the estimation is carried out by (i) introducing sectoral value added and government purchases in levels and scaling them by potential aggregate output, (ii) cumulating all variables over time, and (iii) instrumenting government spending with both the Blanchard and Perotti (2002) shock and the Ramey (2011) news variable. We also consider as instruments the interaction of the Blanchard and Perotti (2002) shock and the Ramey (2011) news variable with the Katz-Bonacich measure of centrality.²³

Table 4 reports the results of the panel regression, in which we set $T = 10$ years. We consider settings that sequentially saturate the regression with controls, time trends, and time fixed effects. Column (1) reports the estimates of a plain regression of sectoral value added on government spending, its interaction with sector centrality, and the lagged value of both sectoral value added and government spending. Column (2) introduces real taxes as an additional control, Column (3) introduces a linear and a quadratic time trend, whereas Column (4) introduces a time fixed effect. The time fixed effect absorbs both the effect of government spending, as well as those of the tax and trend controls. The results indicate that

²¹For instance, there is no detailed disaggregated information on the industries composing the retail trade sector up to 1997. All variables are taken from the Bureau of Economic Analysis.

²²Ramey and Zubairy (2018) discuss how the use of the variables in levels – and scaled by potential variable – is a necessary condition for the correct estimation of the government spending multiplier.

²³Ramey and Zubairy (2018) show that the combination of the Blanchard and Perotti (2002) shock and the Ramey (2011) news variable represent a strong instrument for government spending. This is also evident in our setting: the F-statistics of the first-stage regressions are substantially larger than the 5 percent confidence-level thresholds. This observation remains true even when we consider the more conservative thresholds proposed by Olea and Pflueger (2013), which are robust to serially correlated errors.

Table 4: Estimation Results.

Dependent Variable: $\sum_{t=0}^{10} \frac{Y_{s,t}}{Y_t^*}$				
$\sum_{t=0}^{10} \frac{G_t}{Y_t^*}$	-0.0182 (0.0176)	-0.0220 (0.0182)	-0.0219 (0.0181)	-
$\sum_{t=0}^{10} \frac{G_t}{Y_t^*} \times \text{Centrality}_s$	1.7344** (0.7393)	1.7337** (0.7396)	1.8117*** (0.4850)	1.8109*** (0.4898)
Lagged Values $\sum_{t=0}^{10} \frac{Y_{s,t}}{Y_t^*}$	YES	YES	YES	YES
Lagged Values $\sum_{t=0}^{10} \frac{G_t}{Y_t^*}$	YES	YES	YES	NO
Tax Control	NO	YES	YES	NO
Time Trends	NO	NO	YES	NO
Time Fixed Effects	NO	NO	NO	YES
N. Observations	2226	2226	2226	2226

Note: The table reports the estimates of a panel regression where the dependent variable, $\sum_{t=0}^{10} \frac{Y_{s,t}}{Y_t^*}$, is the 10-year cumulative change in sectoral value added (scaled by aggregate real potential output), and the two main independent variables, $\sum_{t=0}^{10} \frac{G_t}{Y_t^*}$ and $\sum_{t=0}^{10} \frac{G_t}{Y_t^*} \times \text{Centrality}_s$, are the 10-year cumulative change in aggregate real government purchases of goods and services and its interaction with sector centrality in the Input-Output matrix of the economy, respectively. The panel ranges from 1963 to 2015, at an annual frequency. In all cases, government spending is instrumented with the Blanchard and Perotti (2002) shock and the Ramey (2011) news variable, and their interaction with sector centrality. Column (1) also controls for the lagged values of sectoral value added and aggregate government spending, Column (2) introduces real taxes as a control, Column (3) introduces a linear and a quadratic time trend, and Column (4) introduces time fixed effects. Standard errors clustered at the sector level are reported in brackets. *** and ** indicate statistical significance at the 1% and 5%, respectively.

the real value added multiplier of a given industry increases with its centrality, as the estimate of the parameter associated with the interaction between government spending and sector centrality is highly statistically significant and rather stable across specifications, ranging between 1.7 and 1.8 . To our knowledge, this evidence of a positive relationship between the sectoral value-added multiplier and centrality is new.

To gauge the economic significance of the estimates shown in Table 4, we report in Figure 3 the estimated regression line between the sectoral multiplier and centrality, both in the data and in the model. The figure shows that the model-based regression line is remarkably similar to that implied by the data, both in terms of slope and intercept. The relevance of this result is threefold. First, it indicates that input-output linkages are not only the main driver of the amplification in the aggregate output effects of government spending in a multi-sector model relative to the one-sector framework, but they also account for the dispersion in the response of value added across sectors. Second, it confirms the importance of price stickiness as a key ingredient that shapes the role of inter-sectoral linkages in the transmission of government spending. Finally, it lends credence to the quantitative multi-sector model developed in this paper, showing that it can be an appropriate laboratory for studying the aggregate and sectoral effects of government spending shocks.

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.

We also find that the output effects of aggregate government spending shocks are heterogeneously distributed across industries, and are tilted towards the service-producing sectors. This heterogeneity is primarily driven by the industries' positions in the production network, with the response of sectoral value added being larger in upstream industries. Importantly, this prediction is strongly supported by the data, and the model-based correlation between the sectoral value-added multiplier and centrality is remarkably close to that estimated empirically.

These findings suggest that taking seriously sectoral heterogeneity and production networks improves our understanding of the effects of government spending

shocks and their transmission, which can be crucial when measuring the overall output effects of spending-based stimulus or consolidation plans.

Finally, while this paper has focused on public consumption purchases, a natural extension of our work would be to develop a multi-sector framework that allows to study the effects of public investment. Public investment has the specificity that it can alter the productive capacity of the economy, but is unlikely to affect all sectors uniformly. Some industries are indeed more heavily dependent on public infrastructure than others, which may lead to interesting sectoral and aggregate implications of public investment shocks. We leave this extension 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.
- Atalay, E.** 2017. How Important Are Sectoral Shocks? *American Economic Journal: Macroeconomics*, 9, 254-280.
- Barattieri, A., S. Basu, and P. Gottschalk.** 2014. Some Evidence on the Importance of Sticky Wages. *American Economic Journal: Macroeconomics*, 6, 70-101.
- Barrot, J., and J. Sauvagnat.** 2016. Input Specificity and the Propagation of Shocks in Production Networks, *Quarterly Journal of Economics*, 131, 1543-1592.
- Basu, S.** 1995. Intermediate Goods and Business Cycles: Implications for Productivity and Welfare. *American Economic Review*, 85, 512-531.
- 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.** 2011. Durable Goods, Inter-Sectoral Linkages and Monetary Policy. *Journal of Economic Dynamics and Control*, 35, 730-745.
- Bouakez, H., E. Cardia, and F. Ruge-Murcia.** 2014. Sectoral Price Rigidity and Aggregate Dynamics. *European Economic Review*, 65, 1-22.
- Bouakez, H. and N. Rebei.** 2007. Why Does Private Consumption Rise After a Government Spending Shock? *Canadian Journal of Economics*, 40, 954-979.
- Bouakez, H., O. Rachedi, and E. Santoro.** 2020. The Sectoral Origins of the Spending Multiplier. *Mimeo*.
- Brinca, P., H. Holter, P. Krusell, and L. Malafry.** 2016. Fiscal Multipliers in the 21st Century. *Journal of Monetary Economics*, 77, 53-69.
- Carvalho, C.** 2006. Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks. *B.E. Journal of Macroeconomics*, 2, 1-56.

- Carvalho, C., J.W. Lee, and W.Y. Park.** 2020. Sectoral Price Facts in a Sticky-Price Model. *American Economic Journal: Macroeconomics*, forthcoming.
- Carvalho, V., and A. Tahbaz-Salehi.** 2019. Production Networks: A Primer. *Annual Review of Economics*, 11, 635-663.
- 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. In: *NBER Macroeconomics Annual 2012*, 27, 1-56.
- 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. *Quarterly Journal of Economics*, 115, 147-180.
- Cox, L., G. Muller, E. Pasten, R. Schoenle, and M. Weber.** 2020. Big G. *Mimeo.*
- Eisfeldt, A., and A. Rampini.** 2006. Capital Reallocation and Liquidity. *Journal of Monetary Economics*, 53, 369-399.
- Erceg, C., D. Henderson, and A. Levin.** 2000. Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics*, 46, 281-313.
- Fève, P., J. Matheron, and J.-G. Sahuc.** 2013. A Pitfall with Estimated DSGE-Based Government Spending Multipliers. *American Economic Journal: Macroeconomics*, 5, 141-178.
- Galesi, A., and O. Rachedi.** 2019. Services Deepening and the Transmission of Monetary Policy. *Journal of the European Economic Association*, 17, 1261-1293.
- Galí, J., D. Lopez-Salido, and J. Valles.** 2007. Understanding the Effects of Government Spending on Consumption. *Journal of the European Economic Association*, 5, 227-270.
- Hagedorn, M., I. Manovski, and K. Mitman.** 2019. The Fiscal Multiplier. *Mimeo.*
- Hall, R.** 2009. By How Much Does GDP Rise If the Government Buys More Output? *Brookings Papers on Economic Activity*, 2, 183-231.
- 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. Cyclical 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.
- Jordà, O.** 2005. Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review*, 95, 161-182.
- 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., N. Traum, and T. Walker.** 2017. Clearing Up the Fiscal Multiplier Morass. *American Economic Review*, 107, 2409-2454.
- 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
- Olea, J., and C. Pflueger.** 2013. A Robust Test for Weak Instruments. *Journal of Business and Economic Statistics*, 31, 358-369.
- Pasten, E., R. Schoenle, and M. Weber.** 2020. The Propagation of Monetary Policy Shocks in a Heterogeneous Production Economy. *Journal of Monetary Economics*, forthcoming.
- Petrella, I., R. Rossi, and E. Santoro.** 2019. Monetary Policy with Sectoral Trade-offs. *Scandinavian Journal of Economics*, 121, 55-88.
- Ramey, V.** 2011. Identifying Government Spending Shocks: It's All in the Timing. *Quarterly Journal of Economics*, 126, 1-50.
- 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.
- Ramey, V., and S. Zubairy.** 2018. Government Spending Multipliers in Good Times and in Bad: Evidence from US Historical Data. *Journal of Political Economy*, 126, 850-901.
- Sims, E., and J. Wolff.** 2018. Output and Welfare Effects of Government Spending Shocks over the Business Cycle. *International Economic Review*, 59, 1403-1435.
- Woodford, M.** 2011. Simple Analytics of the Government Expenditure Multiplier. *American Economic Journal: Macroeconomics*, 3, 1-35.

A More on the Model

A.1 Households

The infinitely-lived representative household has preferences over aggregate consumption, C_t , aggregate government spending, G_t , and aggregate labor, N_t , so that its expected lifetime utility is

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

where β denotes the subjective time discount factor, σ is the degree of risk aversion, θ is a preference shifter that determines the disutility of labor, and η is the inverse of the Frisch elasticity of labor supply. The preferences are non-separable in consumption and government services: the parameter ζ denotes the relative relevance of aggregate consumption, whereas μ is the elasticity of substitution between aggregate consumption and aggregate government services.

The household trades one-period nominal bonds, B_t , and owns the stock of physical capital, K_t . Every period it purchases consumption goods at price $P_{C,t}$ and investment goods, I_t , at price $P_{I,t}$. Investment is subject to convex adjustment costs defined by the parameter Ω , such that the law of motion of physical capital is

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

where δ is the depreciation rate. Every period, the household receives total labor income, $W_t N_t$, where W_t is the nominal aggregate wage; total capital income, $R_{K,t} K_t$, where $R_{K,t}$ is the nominal aggregate return on capital; and total bond income, $R_{t-1} B_t$, where R_{t-1} is the nominal risk-free rate. Finally, the household pays a nominal lump-sum tax, T_t , and earns firms' nominal profits, D_t . Its budget constraint is therefore given by

$$P_{C,t} C_t + P_{I,t} I_t + B_{t+1} + T_t = W_t N_t + R_{K,t} K_t + B_t R_{t-1} + D_t. \quad (\text{A.3})$$

The household chooses C_t , N_t , I_t , K_{t+1} , and B_{t+1} to maximize life-time utility (A.1) subject to the budget constraint (A.3), the law of motion of capital (A.2), and a no-Ponzi game condition.

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

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

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. This aggregator implies that also the nominal aggregate wage is a function of sectoral wages, $W_{s,t}$, that is

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

In equilibrium, the optimal allocation of labor across sectors follow the first-order condition

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

Analogously, aggregate capital, K_t , bundles sectoral capital flows, $K_{s,t}$, with an elasticity of substitution ν_K , that is

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

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 nominal aggregate return on capital equals

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

which implies the following first-order conditions on the allocation of capital across sectors

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

A.2 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

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

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, respectively. Factor intensities, $\alpha_{N,s}$ and $\alpha_{H,s}$, are sector-specific. In equilibrium, labor-market clearing implies that the labor supplied by the households to each sector equals the sum of labor hired by each producer within each sector, that is, $N_{s,t} = \int_0^1 N_{s,t}^j dj$. Similarly, $K_{s,t} = \int_0^1 K_{s,t}^j dj$, and $H_{s,t} = \int_0^1 H_{s,t}^j dj$.

Each producer sets its price subject to Calvo-type frictions: producers can reset prices only with a constant probability $1 - \phi_s$, which varies across sectors. Then, the optimal reset price, $P_{s,t}^{*,j}$, maximizes the expected discounted stream of real dividends:

$$\max_{P_{s,t}^j} \mathbb{E}_t \left[\sum_{z=t}^{\infty} \beta^{z-t} \phi_s^{z-t} \frac{C_z^{-\sigma} D_{s,z}^j (P_{s,t}^j)}{C_t^{-\sigma} P_z} \right], \quad (\text{A.11})$$

where nominal dividends, $D_{s,t}^j$, are defined as the nominal value of the produced variety minus the nominal productions costs,

$$D_{s,t}^j (P_{s,t}^j) = P_{s,t}^j Z_{s,t}^j - W_{s,t} N_{s,t}^j - R_{K,s,t} K_{s,t}^j - P_{H,s,t} H_{s,t}^j. \quad (\text{A.12})$$

Aggregate nominal profits equal the sum of profits across varieties and across sectors, that is, $D_t = \sum_{s=1}^S \int_0^1 D_{s,t}^j dj$.

A.3 Wholesalers

Producers' different varieties are then aggregated into a single sectoral final good by perfectly competitive wholesalers, which bundle varieties through the following CES production technology:

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

where $Z_{s,t}^j$ is the output of sector s , and ϵ is the elasticity of substitution across varieties within sectors. This technology implies that the price of the sectoral good of sector s is

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

Thus, the representative wholesaler in sector s purchases each single variety $Z_{s,t}^j$ by solving the problem

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

which implies the optimal demand of each variety j as

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

Finally, the wholesaler sells the final sector good to consumption, investment, government and intermediate input retailers, such that

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

A.4 Consumption-good retailers

The final consumption good is assembled by perfectly competitive consumption-good retailers according to the following CES technology:

$$C_t = \left[\sum_{s=1}^S \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C-1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C-1}}, \quad (\text{A.17})$$

where $C_{s,t}$ is the purchase of consumption goods from sector s , $\omega_{C,s}$ denotes the contribution of good s in total consumption, such that $\sum_{s=1}^S \omega_{C,s} = 1$, and ν_C is the elasticity of substitution of consumption across sectors. This aggregator implies that the price of the consumption bundle is $P_{C,t}$, which equals

$$P_{C,t} = \left[\sum_{s=1}^S \omega_{C,s} P_{s,t}^{1-\nu_C} \right]^{\frac{1}{1-\nu_C}}. \quad (\text{A.18})$$

The optimal amount of consumption goods to be purchased from the wholesalers of each sectors is

$$C_{s,t} = \omega_{C,s} \left(\frac{P_{s,t}}{P_{C,t}} \right)^{-\nu_C} C_t, \quad s = 1, \dots, S, \quad (\text{A.19})$$

which is derived as the first-order condition of the problem of the consumption-good retailer:

$$\begin{aligned} \max_{C_{s,t}} & P_{C,t} C_t - \sum_{s=1}^S P_{s,t} C_{s,t} \\ \text{s.t.} & C_t = \left[\sum_{s=1}^S \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C-1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C-1}}. \end{aligned}$$

A.5 Investment-good retailers

The final investment good is assembled by perfectly competitive investment-good retailers according to the following CES technology:

$$I_t = \left[\sum_{s=1}^S \omega_{I,s}^{\frac{1}{\nu_I}} I_{s,t}^{\frac{\nu_I-1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I-1}}, \quad (\text{A.20})$$

where $I_{s,t}$ is the purchase of investment goods from sector s , $\omega_{I,s}$ denotes the contribution of good s in total investment, such that $\sum_{s=1}^S \omega_{I,s} = 1$, and ν_I is the elasticity of substitution of investment across sectors. This aggregator implies that the price of the investment bundle is $P_{I,t}$, which equals

$$P_{I,t} = \left[\sum_{s=1}^S \omega_{I,s} P_{s,t}^{1-\nu_I} \right]^{\frac{1}{1-\nu_I}}. \quad (\text{A.21})$$

The optimal amount of investment goods to be purchased from the wholesalers of each sectors is

$$I_{s,t} = \omega_{I,s} \left(\frac{P_{s,t}}{P_{I,t}} \right)^{-\nu_I} I_t, \quad s = 1, \dots, S, \quad (\text{A.22})$$

which is derived as the first-order condition of the problem of the investment-good retailer:

$$\begin{aligned} \max_{I_{s,t}} & P_{I,t} I_t - \sum_{s=1}^S P_{s,t} I_{s,t} \\ \text{s.t.} & I_t = \left[\sum_{s=1}^S \omega_{I,s}^{\frac{1}{\nu_I}} I_{s,t}^{\frac{\nu_I-1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I-1}}. \end{aligned}$$

A.6 Government-consumption-good retailers

The final government-consumption good is assembled by perfectly competitive government-consumption-good retailers according to the following Cobb-Douglas technology:

$$G_t = \prod_{s=1}^S G_{s,t}^{\omega_{G,s}}, \quad (\text{A.23})$$

where $G_{s,t}$ is the purchase of government-consumption goods from sector s , and $\omega_{G,s}$ denotes the contribution of good s in total government spending, such that $\sum_{s=1}^S \omega_{G,s} = 1$. This aggregator implies that the price of the government bundle is $P_{G,t}$, which equals

$$P_{G,t} = \prod_{s=1}^S \frac{P_{s,t}^{\omega_{G,s}}}{\omega_{G,s}}. \quad (\text{A.24})$$

The optimal amount of government-consumption goods to be purchased from the wholesalers of each sectors is

$$G_{s,t} = \omega_{G,s} \frac{P_{G,t} G_t}{P_{s,t}}, \quad s = 1, \dots, S, \quad (\text{A.25})$$

which is derived as the first-order condition of the problem of the government-consumption-good retailer:

$$\begin{aligned} \max_{G_{s,t}} \quad & P_{G,t} G_t - \sum_{s=1}^S P_{s,t} G_{s,t} \\ \text{s.t.} \quad & G_t = \prod_{s=1}^S G_{s,t}^{\omega_{G,s}}. \end{aligned}$$

A.7 Intermediate-input retailers

The final intermediate inputs used by producers of sector s are assembled by perfectly competitive intermediate-inputs retailers according to the following CES technology:

$$H_{s,t} = \left[\sum_{x=1}^S \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H-1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H-1}}, \quad (\text{A.26})$$

where $H_{s,x,t}$ is the purchase of intermediate goods from sector x , $\omega_{H,s,x}$ denotes the contribution of good x in the intermediate inputs used by sector s , such that $\sum_{x=1}^S \omega_{H,s,x} = 1$, and ν_H is the elasticity of substitution of intermediate inputs across sectors. This aggregator implies that the price of the intermediate-input bundle is

$P_{H,s,t}$, which equals

$$P_{H,s,t} = \left[\sum_{x=1}^S \omega_{H,s,x} P_{x,t}^{1-\nu_H} \right]^{\frac{1}{1-\nu_H}}. \quad (\text{A.27})$$

The optimal amount of goods to be purchased from the wholesalers of each sector x for the production of intermediate inputs used by sector s is

$$H_{s,x,t} = \omega_{H,s,x} \left(\frac{P_{x,t}}{P_{H,s,t}} \right)^{-\nu_H} H_{s,t}, \quad x = 1, \dots, S, \quad s = 1, \dots, S, \quad (\text{A.28})$$

which is derived as the first-order condition of the problem of the intermediate-input retailer of sector s :

$$\begin{aligned} \max_{H_{s,x,t}} & P_{H,s,t} H_{s,t} - \sum_{x=1}^S P_{x,t} H_{s,x,t} \\ \text{s.t.} & \quad H_{s,t} = \left[\sum_{x=1}^S \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H-1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H-1}}. \end{aligned}$$

A.8 Government

The government consists of a fiscal authority and a monetary authority. The fiscal authority purchases government goods, G_t , at price $P_{G,t}$ from the government-consumption-good retailers. Government spending is determined by the process

$$\log G_t = (1 - \rho) \log G + \rho \log G_{t-1} + \epsilon_t, \quad (\text{A.29})$$

where G defines the steady-state amount of government spending, and ρ measures the persistence of the process. The only source of uncertainty in the model is given by the aggregate government spending shock ϵ_t , which follows a normal distribution with mean zero. Government purchases are financed through lump-sum taxes paid by the household, which implies the following budget constraint for the government:

$$P_{G,t} G_t = T_t. \quad (\text{A.30})$$

The monetary authority sets the nominal interest rate according to the Taylor rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\varphi_R} \left[\left(\frac{Y_t}{Y_t^{\text{flex}}} \right)^{\varphi_Y} (1 + \pi_t)^{\varphi_\Pi} \right]^{1-\varphi_R}, \quad (\text{A.31})$$

where R is the steady-state nominal interest rate, φ_R captures the amount of interest rate inertia, Y_t is the real aggregate value added, Y_t^{flex} is the real aggregate value

added of a counterfactual flexible-price economy, φ_Y and φ_Π denote the degree to which the nominal interest rate responds to changes in the output gap, $\frac{Y_t}{Y_t^{\text{flex}}}$, and aggregate inflation, π_t , which is defined over the GDP deflator P_t , such as $\pi_t = \frac{P_t}{P_{t-1}} - 1$.

A.9 Aggregation

We denote the nominal value added of producer j in sector s as $\mathcal{Y}_{s,t}^j$, which is defined as the nominal value of gross output net of the nominal value of intermediate inputs,

$$\mathcal{Y}_{s,t}^j = P_{s,t}^j Z_{s,t}^j - P_{H,s,t} H_{s,t}^j. \quad (\text{A.32})$$

The nominal value added of sector s sums the nominal value added of all producers, that is

$$\mathcal{Y}_{s,t} = \int_0^1 \mathcal{Y}_{s,t}^j dj = P_{s,t} Z_{s,t} - P_{H,s,t} H_{s,t}. \quad (\text{A.33})$$

Summing nominal dividends across producers within sectors and then across sectors, to then substitute dividends into households' budget constraint, yields the definition of nominal aggregate value added \mathcal{Y}_t ,

$$\mathcal{Y}_t = \sum_{s=1}^S \mathcal{Y}_{s,t} = P_{C,t} C_t + P_{I,t} I_t + P_{G,t} G_t. \quad (\text{A.34})$$

We define the real aggregate value added as the ratio between nominal aggregate value added and the GDP deflator,

$$Y_t = \frac{\mathcal{Y}_t}{P_t}. \quad (\text{A.35})$$

Finally, we define analogously the real sectoral value added, $Y_{s,t}$, which is given by

$$Y_{s,t} = \frac{\mathcal{Y}_{s,t}}{P_t}, \quad s = 1, \dots, S. \quad (\text{A.36})$$

B More on the Calibration of the Model

This section presents further information on the calibration of the model. Tables B.1 – B.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. Notice that we have excluded all the financial sectors. Table B.4 shows the values of the parameters that are common to all sectors. We also report the target or the source that disciplines our calibration choice. The tables 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.

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

Parameter	Target/Source
$\beta = .995$	2 percent steady-state annual interest rate R
$\sigma = 2$	Standard value
$\theta = 41.01$	0.33 Steady-state total hours N
$\eta = 1.25$	Frisch elasticity = 0.8
$\mu = 0.3$	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 percent annual depreciation rate
$\Omega = 20$	8 quarters peak response of investment
$\nu_C = 2$	Hobijn and Nechio (2019)
$\nu_I = 2$	$\nu_C = \nu_I$
$\nu_H = 0.1$	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 percent steady-state markup
$\varphi_R = 0.8$	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

C More on the Analytical Results

This appendix shows the derivation of the simplified models employed in Section 4.4. After assuming (i)-(ix), the following set of equations summarizes the key aggregators, preferences, technological and budget constraints:

$$U(C_t, N_t) = \ln C_t - \theta \frac{N_t^{1+\eta}}{1+\eta}, \quad (\text{C.37})$$

$$P_{C,t}C_t + B_{t+1} + T_t = W_tN_t + B_tR_{t-1} + D_t, \quad (\text{C.38})$$

$$C_t = \prod_{s=1}^S C_{s,t}^{\omega_{C,s}}, \quad (\text{C.39})$$

$$P_{C,t} = \prod_{s=1}^S \frac{P_{s,t}^{\omega_{C,s}}}{\omega_{C,s}}, \quad (\text{C.40})$$

$$G_t = \prod_{s=1}^S G_{s,t}^{\omega_{G,s}}, \quad (\text{C.41})$$

$$P_{G,t} = \prod_{s=1}^S \frac{P_{s,t}^{\omega_{G,s}}}{\omega_{G,s}}, \quad (\text{C.42})$$

$$H_{s,t} = \prod_{x=1}^S H_{s,x,t}^{\omega_{H,s,x}}, \quad (\text{C.43})$$

$$P_{H,s,t} = \prod_{x=1}^S \frac{P_{x,t}^{\omega_{H,s,x}}}{\omega_{H,s,x}}, \quad (\text{C.44})$$

$$N_t = \left[\sum_{s=1}^S \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right]^{\frac{\nu_N}{1+\nu_N}}, \quad (\text{C.45})$$

$$W_t = \left[\sum_{s=1}^S \omega_{N,s} W_{s,t}^{1+\nu_N} \right]^{\frac{1}{1+\nu_N}}, \quad (\text{C.46})$$

$$Z_{s,t}^j = N_{s,t}^j 1^{-\alpha_H} H_{s,t}^{\alpha_H}, \quad (\text{C.47})$$

$$Z_{s,t} = \left[\int_0^1 Z_{s,t}^j \frac{\epsilon-1}{\epsilon} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \quad (\text{C.48})$$

$$Z_{s,t} = G_{s,t} + C_{s,t} + \sum_{x=1}^S H_{x,s,t}, \quad (\text{C.49})$$

$$T_t = P_{G,t}G_t, \quad (\text{C.50})$$

$$R_t = \left(\frac{1+\pi_t}{1+\pi} \right)^{\varphi_\Pi}, \quad (\text{C.51})$$

$$\frac{G_t}{G} = \left(\frac{G_{t-1}}{G} \right)^\rho \exp(\epsilon_t). \quad (\text{C.52})$$

In this environment, the consumption price, the price of the government spending bundle, and the numeraire of the economy (i.e., the GDP deflator) coincide, that is, $P_{C,t} = P_{G,t} = P_t = 1$. Throughout this section, we refer to the relative price of the final sectoral goods in terms of the numeraire as $Q_{s,t} = \frac{P_{s,t}}{P_{C,t}}$, the relative price of sectoral intermediate inputs as $Q_{H,s,t} = \frac{P_{H,s,t}}{P_{C,t}}$. Our set of assumptions implies that $Q_{s,t} = Q_{H,s,t}$, $\forall s$. Finally, the aggregate inflation rate can be defined as a weighted average of sectoral inflation rates, that is, $\pi_t = \prod_{s=1}^S \pi_{s,t}^{\omega_{C,s}} = \prod_{s=1}^S \pi_{s,t}^{1/S}$.

C.1 Log-linear Economy

We log-linearize the analytical framework by taking a first-order approximation of the equilibrium conditions around the steady state. This subsection deals with the derivation of the log-linear setting employed to analyze the amplification of an aggregate shock to fiscal spending. Throughout this analysis, we denote by v_t the log-deviation of a generic variable V_t from its steady-state value, V .

Log-linearizing the first-order condition for bonds yields

$$c_t = \mathbb{E}_t c_{t+1} - (r_t - \mathbb{E}_t \pi_{t+1}). \quad (\text{C.53})$$

Using the log-linearized Taylor rule in Equation (A.31) to substitute for r_t yields Equation (11) in the main text.

To derive Equation (12), 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:

$$\pi_{s,t} = \beta \mathbb{E}_t \pi_{s,t+1} + \kappa_s (mc_{s,t} - q_{s,t}), \quad (\text{C.54})$$

where $mc_{s,t}$ denotes the (log-linear) real marginal cost of production in sector s . The latter can be expressed as a linear combination of the sector's real wage (i.e., $w_{s,t} - p_t$) and relative price, $q_{s,t}$:

$$mc_{s,t} = (1 - \alpha_H) (w_{s,t} - p_t) + \alpha_H q_{s,t}. \quad (\text{C.55})$$

Log-linearizing the sectoral resource constraint yields

$$z_{s,t} = \frac{C_s}{Z_s} c_{s,t} + \frac{G_s}{Z_s} g_{s,t} + \frac{H_s}{Z_s} h_{s,t}. \quad (\text{C.56})$$

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

$$z_{s,t} = \frac{C_s}{Z_s} c_{s,t} + \frac{G_s}{Z_s} g_{s,t} + \frac{H_s}{Z_s} \left(\frac{1}{\alpha_H} z_{s,t} - \frac{1 - \alpha_H}{\alpha_H} n_{s,t} \right). \quad (\text{C.57})$$

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 sectoral 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 (C.57) becomes

$$n_{s,t} = (1 - \gamma)c_{s,t} + \gamma g_{s,t}. \quad (\text{C.58})$$

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 (C.55) and, in turn, into the New Keynesian Phillips curve, we obtain

$$\pi_{s,t} = \beta \mathbb{E}_t \pi_{s,t+1} + \kappa_s (1 - \alpha_H) (\Theta q_{s,t} + \Xi c_t + \Psi g_t), \quad (\text{C.59})$$

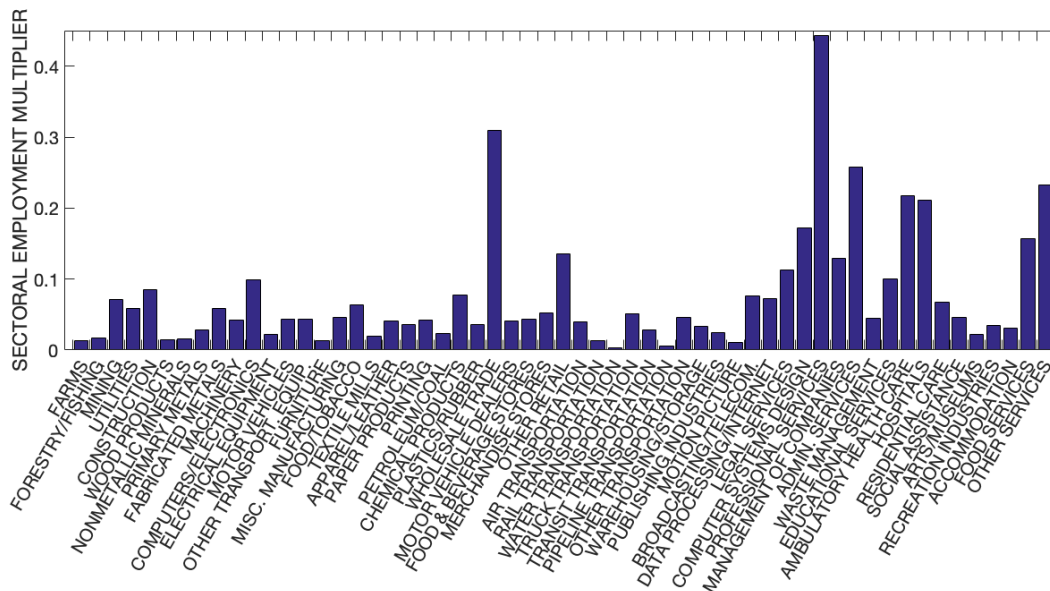
where

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

D More on Sectoral Implications

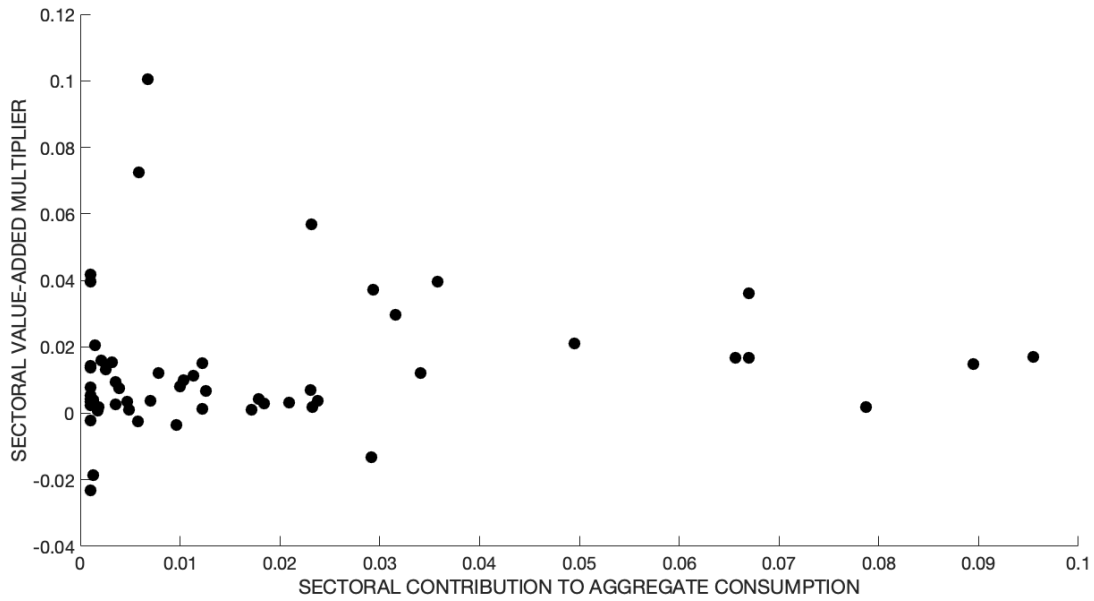
This section reports further details on the sectoral implications of a government spending shock. First, Figure D.1 reports the sectoral employment multipliers. Then, we show that the dispersion in the sectoral government spending multipliers does not correlate with heterogeneity across industries in their contribution to final consumption (i.e., variation in $\omega_{C,s}$ - see Figure D.2), contribution to final investment (i.e., variation in $\omega_{I,s}$ - see Figure D.3), heterogeneity in the value-added-based labor intensity (i.e., variation in $\alpha_{N,s}$ - see Figure D.4), and heterogeneity in the degree of price rigidity (i.e., variation in ϕ_s - see Figure D.5).

Figure D.1: The Response of Sectoral Employment



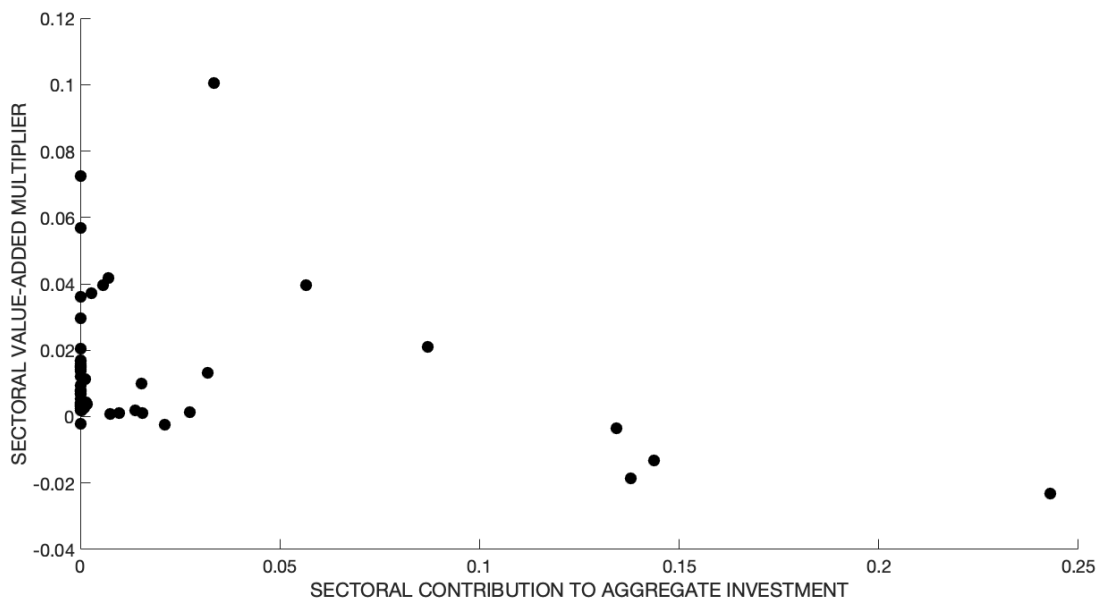
Note: The graph reports the employment government spending multiplier for each of the 57 sectors of the model.

Figure D.2: The Response of Sectoral Value Added and Sectoral Contribution to Consumption



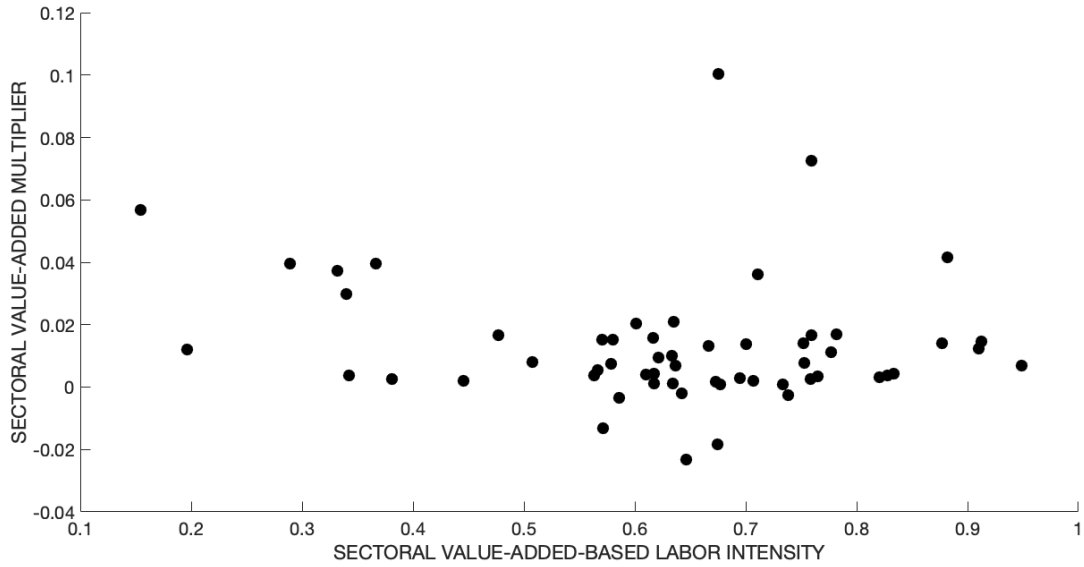
Note: The graph reports a scatter that links the sectoral value-added multiplier of each sector (measured on the y-axis) to its contribution to aggregate consumption $\omega_{C,s}$ (measured on the x-axis).

Figure D.3: The Response of Sectoral Value Added and Sectoral Contribution to Investment



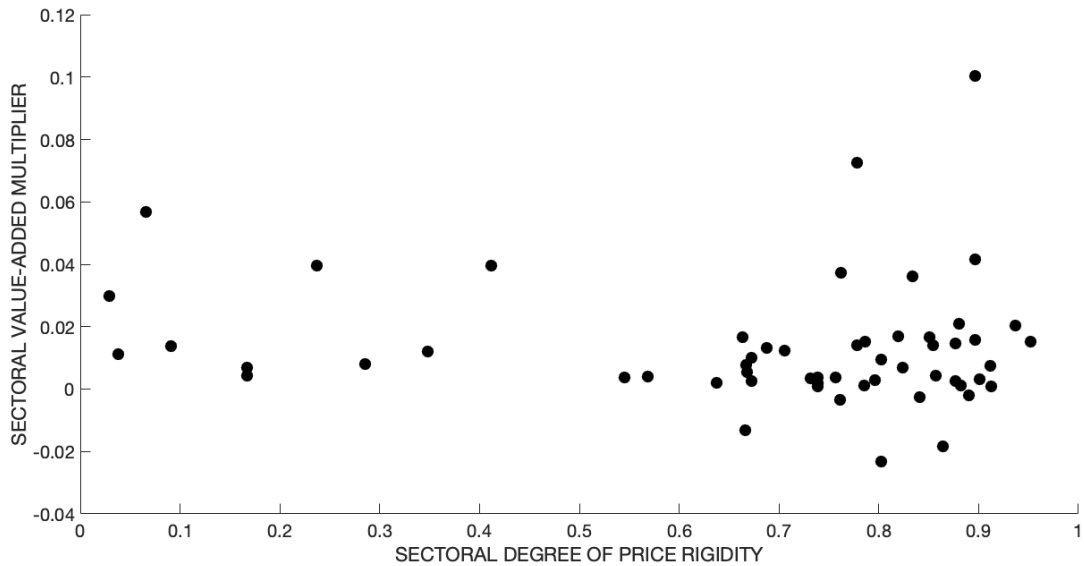
Note: The graph reports a scatter that links the sectoral value-added multiplier of each sector (measured on the y-axis) to its contribution to aggregate investment $\omega_{I,s}$ (measured on the x-axis).

Figure D.4: The Response of Sectoral Value Added and Sectoral Value-Added-Based Labor Intensity



Note: The graph reports a scatter that links the sectoral value-added multiplier of each sector (measured on the y-axis) to its value-added-based labor intensity $\alpha_{N,s}$ (measured on the x-axis).

Figure D.5: The Response of Sectoral Value Added and Sectoral Price Rigidity



Note: The graph reports a scatter that links the sectoral value-added multiplier of each sector (measured on the y-axis) to its degree of price rigidity ϕ_s (measured on the x-axis).