SECTORAL FISCAL MULTIPLIERS AND TECHNOLOGY IN OPEN ECONOMY *

Olivier CARDI†
Lancaster University Management School

Romain RESTOUT‡
Université de Lorraine BETA (CNRS UMR 7522)

Abstract

Using a panel of eighteen OECD countries over the period 1970-2015, our evidence reveals that labor growth originates from non-traded industries while real GDP growth is uniformly distributed across sectors following a government spending shock. A rationale behind these two findings lies in technology which responds endogenously to the government spending shock. While the concentration of technology improvements in traded industries increases the government spending multiplier on traded value added, technological change biased toward labor (capital) in non-traded (traded) industries increases the government spending multiplier on non-traded hours worked. Our quantitative analysis shows that a semi-small open economy model with tradables and non-tradables can reproduce the sectoral fiscal multipliers that we document empirically once we let the decision on technology improvement vary across sectors and allow firms to change the mix of labor- and capital-augmenting efficiency over time.

Keywords: Sector-biased government spending shocks; Endogenous technological change; Factor-augmenting efficiency; Open economy; Labor reallocation; CES production function; Labor income share.
JEL Classification: E25; E62; F11; F41; O33

*We are grateful to Christoph Thoenissen and Mathias Klein for their suggestions and comments. We thank participants at the Computing in Economics and Finance Conference, June 15-17 2021, and the Asian Meeting of Econometric Society in Seoul, June 25-27th 2021 for their valuable comments. Obviously, any remaining shortcomings are our own. Cardi and Restout thank the Leverhulme Trust for its research support (RPG-2019-348 project).

†Olivier Cardi. Correspondence address: Lancaster University Management School, Bailrigg, Lancaster LA1 4YX. E-mail: o.cardi@lancaster.ac.uk.

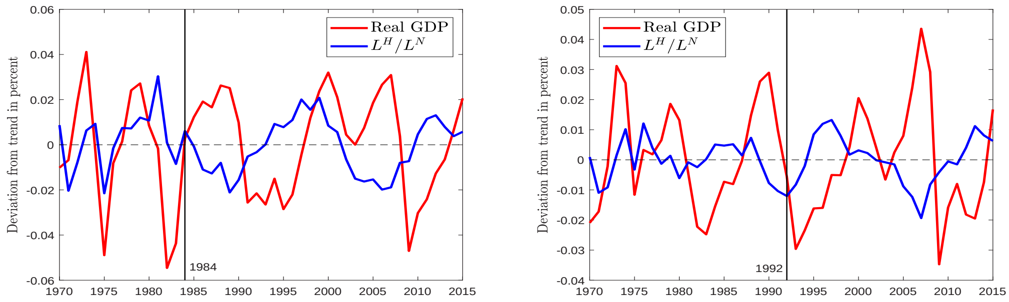
‡Romain Restout. Correspondence address: Université de Lorraine, BETA, CNRS, INRA, 54000, Nancy, France. Phone: +33 03 54 50 43 72. Fax: +33 03 54 50 43 51. E-mail: romain.restout@univ-lorraine.fr.

1 Introduction

In an environment of low interest rates, the limitations of monetary policy have sparked renewed interest in the role of government spending. In their article, Delong and Summers [2012] set out the possibility of a persistent increase in productivity following a rise in government spending. The evidence recently documented by D'Alessandro et al. [2019] and Jørgensen and Ravn [2022] on quarterly U.S. data reveals that an exogenous and temporary shock to government consumption significantly increases aggregate total factor productivity (TFP), lending credence to Delong and Summers's hypothesis. If TFP increases, the aggregate fiscal multiplier is higher than initially thought. Because the ability of firms to increase efficiency in the use of capital and labor may vary across sectors, we address the following questions: Are aggregate TFP gains further to a rise in government consumption uniformly distributed across sectors? If not, how large is the discrepancy in sectoral fiscal multipliers caused by sector differences in technology improvement? We find that shocks to government consumption significantly increase traded TFP relative to non-traded TFP, thus pushing up the government spending multiplier on traded relative to non-traded value added. While technology improvements are concentrated in the traded sector, non-traded industries bias technological change toward labor, which increases the government spending multiplier on non-traded relative to traded hours worked.

Investigating the link between technology and fiscal policy at a sectoral level is important since recent evidence suggests that during downturns, non-traded firms experience the largest drop in labor, see e.g., Mian and Sufi [2014] for the U.S. (2007-2009) and De Ferra [2018] for Italy (2011-2013). Fig. 1(a) plots the cyclical components of (logged) real GDP (displayed by the red line) and the (logged) ratio of traded to non-traded hours worked (displayed by the blue line) for (the market sector of) the United States. Over the period 1970-2015, the two series are uncorrelated, suggesting that the traded and the non-traded sectors are symmetrically affected during expansions and recessions. According to the evidence documented by Garìn et al. [2018] on U.S. data, the responses of sectors display more asymmetry along the business cycle in the post-1984 period, i.e., during the great moderation. When we split the whole period into two sub-samples, we find that the correlation between the cyclical components of real GDP and traded relative to non-traded hours worked moves from positive (at 0.43) in 1970-1984 to negative (at -0.30) in the post-1984 period. The negative correlation suggests that during recessions, non-traded industries have experienced a larger decline in hours worked than traded industries over the last thirty years.

This finding is not limited to the United States. Fig. 1(b) plots the cyclical components of real GDP and the ratio of traded to non-traded hours worked for the eighteen OECD countries in our sample. Choosing 1992 as the cutoff year for the whole sample, we find a



(a) United States (b) OECD (18 countries)

Figure 1: Real GDP and Traded relative to Non-Traded Hours Worked. Notes: Detrended (logged) real GDP and the detrended ratio of traded to non-traded hours worked are calculated as the difference between the actual series and the trend of time series. The trend is obtained by applying a Hodrick-Prescott filter with a smoothing parameter of $\lambda = 100$ (as we use annual data) to the (logged) time series. Since we seek to investigate how market sectors are relatively affected by the stage of the business cycle, we abstract from the public sector and thus removed 'Community social and personal services' (which includes public services, health and education) from real GDP and non-traded hours worked. Sample: 18 OECD countries, 1970-2015, annual data.

correlation of 0.11 over 1970-1992 and a correlation of -0.44 in the post-1992 period.[1] Data on OECD countries thus further corroborates the finding that non-traded labor is more vulnerable to downturns than traded labor (during the great moderation). The conclusion is reversed when we focus on the cyclical component of traded to non-traded value added (at constant prices).[2] We find empirically that that traded value added declines more than non-traded value added during recessions in OECD countries.[3] The fact that sectors are not symmetrically affected by recessions raises the question of the capacity of fiscal policy to mitigate such a differential response of non-tradable versus tradable industries. Our VAR evidence shows that the technology channel of fiscal policy can mitigate sector asymmetry along the business cycle by encouraging traded firms to improve their technology (which increases traded value added) and by leading non-traded firms to bias technological change toward labor (which increases non-traded hours worked).

To guide our quantitative analysis, we estimate the sectoral value added and sectoral labor effects of a shock to government consumption for eighteen OECD countries over the period running from 1970 to 2015, using Jordà's [2005] projection method. We find empirically that the aggregate fiscal multiplier is 1.2 on impact and averages 1.4 during the first six years after the shock. The rise in aggregate TFP contributes 39% of real GDP growth on average. While shocks to government consumption are strongly biased toward non-tradables, our estimates reveal that real GDP growth is uniformly distributed across sectors, i.e., in accordance with the sectoral value added share. The unresponsiveness of the value added share of non-tradables to the government spending shock is puzzling since

[1]Two-thirds of our sample is made up of European countries for which the great moderation occurs in the post-1992 period, see e.g., Benati [2008] for the U.K., González Cabanillas and Ruscher [2008] for the euro area.

[2]Our empirical findings echo evidence by Hlatshwayo and Spence [2014] on U.S. data which reveals that tradable industries are the drivers of value added growth while employment growth originates from non-traded industries.

[3]In the Online Appendix A, we document evidence for the eighteen OECD countries and the United States which shows that the cyclical component of real GDP is (strongly) positively correlated with the ratio of traded to non-traded value added.

according to the data taken from the World Input-Output Database, non-traded industries receive a share of the rise in government spending which is higher than their share in GDP. The rationale behind this finding lies in the technology channel of fiscal transmission. We find that the concentration of technology improvements in the traded sector offsets the impact of the biasedness of the government spending shock on the value added share of non-tradables which thus remains unaffected at any horizon.

The allocation of labor across sectors is quite distinct from the sectoral distribution of value added. The government spending multiplier on total hours worked averages 1.15 during the first six years after the shock. A sufficient statistic to capture the distribution of labor growth across sectors is the change in the non-tradable share of total hours worked. Our estimates show that the labor share of non-tradables increases by 0.3 percentage point of total hours worked, which leads the non-traded sector to account for 88% of the rise in total hours worked at a six year-horizon. The concentration of labor growth in the non-traded sector is the result of the combined effect of the biasedness of the demand shock toward non-tradables and the biasedness of technological change toward labor in non-traded industries. Our estimates show that non-traded firms bias (utilization-adjusted-) technological change toward labor, while traded firms bias (utilization-adjusted-) technological change toward capital, thus increasing the government spending multiplier on non-traded labor.

To account for the role of technology in determining the magnitude of government spending multipliers, we put forward a two-sector semi-small open economy model with tradables and non-tradables which contains the specific elements detailed below. Given that the non-traded sector is highly intensive in the government spending shock which provides strong incentives to shift resources toward this sector, the first set of factors determining the magnitude of sectoral fiscal multipliers are barriers to factor mobility. To allow for frictions in the movement of capital and labor between the traded sector and the non-traded sector, we assume capital adjustment costs and imperfect substitutability between sectoral hours worked. The adjustment in the terms of trade also hampers the reallocation of productive resources across sectors. More specifically, like Kehoe and Ruhl [2009], we assume that the economy is small in world capital markets so that the world interest rate is given, but large enough in the world goods market to influence the relative price of its export good so that terms of trade are endogenous. By raising the marginal revenue product of inputs, the appreciation in the terms of trade following a government spending shock stimulates the demand for labor and capital in the traded sector, which in turn mitigates the shift of productive resources toward the non-traded sector.

The second set of factors which influence the size of sectoral fiscal multipliers is related to technology. Building on Bianchi et al. [2019], we endogenize technological change at a sectoral level by allowing for endogenous utilization of existing technologies. To be consistent with the measure of technological change that we use in the empirical analysis, we also allow for endogenous capital utilization. Although higher government spending provides an incentive to improve technology, the extent of the rise in technology utilization depends on the cost of adjusting technology. While the government spending shock moves the technology frontier upward, we let the mix of labor- and capital-augmenting efficiency vary along the technology frontier, along the lines of Caselli [2016]. Because we assume that sectoral goods are produced from CES production functions, factor-biased technological change (FBTC henceforth) generates time-varying sectoral LISs. Technological change biased toward labor in the non-traded sector increases the non-traded LIS and technological change biased toward capital reduces the traded LIS.

To assess quantitatively the contribution of technology in determining the magnitude of sectoral fiscal multipliers, we start with a simplified version of our model which collapses to the semi-small open economy model developed by Kehoe and Ruhl [2009] with capital adjustment costs and imperfect mobility of labor across sectors. In this restricted version, we shut down endogenous capital and technology utilization in both sectors and assume that sectoral goods are produced from Cobb-Douglas production functions. Under these assumptions, the restricted model considerably understates the government spending multipliers on real GDP and on the total hours worked that we estimate empirically. By assuming fixed sectoral TFPs, the model also predicts a fall in traded value added and a disproportionate increase in non-traded value added, in contradiction with our evidence. Because the intensity in factors of production is constant, the model cannot generate the government spending multiplier on non-traded labor that we find in the data.

Once we let capital-utilization-adjusted-technology respond endogenously to the rise in government spending and allow firms to change the mix of labor- and capital-augmenting efficiency over time, the model can account for both the aggregate and sectoral effects that we estimate empirically. By increasing real GDP directly and also indirectly through higher wages, which provide more incentives to increase labor supply, the rise in aggregate TFP allows the model to generate government spending multipliers on real GDP (and total hours worked) in line with our evidence. Although the government spending shock is biased toward non-tradables and technology utilization rates are pro-cyclical, traded TFP increases relative to non-traded TFP because the cost of adjusting technology is lower in the traded than in the non-traded sector. The TFP differential leads the government spending multiplier on real GDP to be symmetrically distributed across sectors. Conversely, the bulk of the rise in total hours worked is concentrated in the non-traded sector which biases technological change toward labor.

One additional key contribution of our work is to explore the role of technology in driving international differences in sectoral government spending multipliers. We calibrate both the baseline model and the restricted version of the model, where technology is shut down to country-specific data, by assuming that the biasedness of the demand shock toward non-tradables is symmetric across countries. We isolate the pure contribution of technology by calculating the difference in the government spending multipliers between the former (with technology) and the latter (without technology) setup. We find that the technology channel alone increases the government spending multiplier on real GDP by 0.64 percentage point on average. This finding masks a wide cross-country dispersion however. In two-thirds of OECD countries where traded relative to non-traded TFP rises, the technology channel increases the government spending multiplier by 1.5 percentage point. In the remaining economies where traded relative to non-traded TFP declines, the technology channel lowers real GDP growth by 1 percentage point.[4] Interestingly, technological change amplifies the magnitude of the government spending multiplier on non-traded value added by 0.18 percentage point of GDP on average and this amplification is symmetric between the two groups of countries. While on average, technological change increases the government spending multiplier on traded value added by 0.46 percentage point of GDP, the fiscal multiplier for tradables varies greatly across countries, exceeding one in economies where technology improvement is concentrated in traded industries, or taking negative values otherwise.

In contrast to government spending multipliers on sectoral value added, which depend on the TFP differential, the response of hours worked is driven by FBTC. For the first group of nine OECD countries where technological change is biased toward labor in the non-traded sector, the government spending multiplier on non-traded hours worked is increased by 0.36 percentage point of total hours worked. Conversely, the government spending multiplier on traded hours worked is reduced by 0.12 percentage point because technological change is biased toward capital in the traded sector. Since the non-traded sector accounts for two-third of labor, FBTC increases the government spending multiplier on total hours worked by 0.24 percentage point for these OECD economies. Conversely, for the second group of OECD countries where technological change is biased toward capital in the non-traded sector and toward labor in the traded sector, FBTC lowers the government spending multiplier on total hours worked by 0.19 percentage point. Because non-traded production becomes more capital intensive, the government spending multiplier on non-traded hours worked is reduced by 0.27 percentage point of total hours worked.

The article is structured as follows. In section 2, we document a set of evidence which sheds some light on the role of technology in determining the size of sectoral government spending multipliers. In section 3, we develop a semi-small open economy model with tradables and non-tradables, endogenous technology choices and factor-biased technological

[4] We find that in countries where technological change is concentrated in traded industries, aggregate TFP increases while in the remaining economies, aggregate TFP declines, thus explaining why the government spending multiplier is reduced by 1 percentage point relative to a model keeping sectoral TFPs fixed.

change. In section 4, we compare the performance of the baseline model with endogenous technological change with the predictions of the same model shutting down the technology channel. Next, we calibrate the model to country-specific data to quantity the role of technology in driving international differences in government spending multipliers. The Online Appendix contains more empirical results, conducts robustness checks, details the solution method, and shows extensions of the baseline model.

Related Literature. Our paper fits into several different literature strands, as we bring several distinct threads in the existing literature together.

First, the literature investigating fiscal as well as monetary policy transmission has recently documented evidence pointing at the presence of a technology channel brought about by stabilization policies. Jordà et al. [2020] find empirically that a temporary contractionary monetary policy shock leads to a decline in TFP, thus amplifying the fall in economic activity. While the authors rationalize their evidence by assuming that the endogenous response of TFP growth depends on deviations of output from its flexible-price counterpart, Baqaee et al. [2021] show that the shifts in the allocation of resources across firms can generate a rise in aggregate TFP following an expansionary monetary policy. In contrast to these authors, in our paper, variations in TFP are the result of changes in endogenous utilization of existing technologies, along the lines of Bianchi et al. [2019]. This modelling strategy has been already introduced in a New Keynesian model by Jørgensen and Ravn [2022]. As shown by the authors, by increasing TFP and lowering prices, a shock to government consumption generates an increase in private consumption as the central bank lowers the interest rate.[5] Differently, in our paper, we attempt to answer the following question: when are sectoral government spending multipliers large? Besides the biasedness of the government spending shock toward non-traded goods, we find that the ability of sectors to improve technology and to increase the labor intensity of production are key determinants of the distribution of real GDP and labor growth across sectors, respectively.

In this regard, we also contribute to a growing literature investigating fiscal transmission at a sectoral level, both empirically and theoretically. Ramey and Shapiro [1998] find that a rise in military expenditure (which are intensive in traded goods) reallocates labor toward traded industries. Benetrix and Lane [2010] document evidence which reveals that a government spending shock disproportionately increases non-traded value added. Cardi et al. [2020] find empirically that government spending shocks are strongly biased toward non-traded goods and cause a significant reallocation of labor toward the non-traded sector, which is larger in countries where workers' costs of switching sectors are lower. As shown by Cardi et al. [2020] and Lambertini and Proebsting [2022], to account for the fiscal

[5] To generate the rise in aggregate TFP following a government spending shock, D'Alessandro et al. [2019] endogenize technological progress by assuming skill accumulation through past work experience, echoing the learning-by-doing mechanism.

transmission mechanism, the open economy model with tradables and non-tradables must allow for both a non-traded bias in government spending and imperfect mobility of labor across sectors. In contrast to both these aforementioned works, we highlight empirically the technology channel of government spending shocks and quantify its role in determining the size of sectoral government spending multipliers.

Third, our paper also relates to a growing literature which highlights the role of subcategories of aggregate government spending. Like Boehm [2020], we consider a two-sector model with imperfect mobility of labor across sectors and place the emphasis on the composition of government spending. In contrast to Boehm, who estimates the fiscal multipliers by making a distinction between government consumption and government investment shocks, we restrict our attention to government consumption and disentangle the sectoral value added and sectoral labor effects into a reallocation channel caused by the biasedness of the government spending shock toward sectoral goods and a technology channel. Like Cox et al. [2020], we find that government spending shocks are strongly biased towards a few industries and do not purely mimic consumer spending. In our model, the reallocation of productive resources toward the non-traded sector is caused by the discrepancy between the non-tradable content of government spending and the share of non-tradables in GDP. Bouakez et al. [2022] provide a decomposition of the contribution of sectors to the aggregate fiscal multiplier by evaluating the role of production networks. Their research highlights the key role of both the sectoral composition of government purchases and sectoral labor intensity in determining employment effects, like ours, but the mechanism is very different. In our paper, a government spending shock produces larger employment effects by targeting the sector that has the highest labor compensation share and biases technological change toward labor.

2 Sectoral Fiscal Multipliers and Technology: Evidence

In this section, we document evidence for eighteen OECD countries about the role of technology in determining sectoral government spending multipliers on value added and labor. Below, we denote the percentage deviation from initial steady-state (or the rate of change) with a hat.

2.1 Preliminaries

To discipline our empirical investigation, we derive some key relationships which allow us to develop intuition about how technology affects government spending multipliers at a sectoral level. Because exporting firms have more scope for productivity improvements than non-exporting firms, see e.g., Benigno et al. [2020], we make a distinction between a traded (indexed by the superscript H) vs. a non-traded sector (indexed by the superscript

N).

Sectoral decomposition of the aggregate fiscal multiplier. Real GDP denoted by Y_R is the sum of value added at constant prices, i.e., $Y_{R,t} = P^H Y_t^H + P^N Y_t^N$ where Y^j is the real value added of sector $j = H, N$ evaluated at the base year price P^j.[6] Log-linearizing in the neighborhood of the initial steady-state shows that the aggregate fiscal multiplier $\hat{Y}_{R,t}$ is the sum of sectoral fiscal multipliers:

$$\hat{Y}_{R,t} = \nu^{Y,H} \hat{Y}_t^H + \nu^{Y,N} \hat{Y}_t^N, \tag{1}$$

where we denote the value added share of sector j by $\nu^{Y,j}$ and $\hat{Y}_t^j = \frac{Y_t^j - Y^j}{Y^j}$ measures the percentage deviation of value added (at constant prices) relative to its initial steady-state. Note that $\nu^{Y,H} + \nu^{Y,N} = 1$.

Distribution of real GDP across sectors. A sufficient statistic determining the degree of asymmetry in the distribution of real GDP growth across sectors is the change in the value added share of sector $j = H, N$. More specifically, the change in the value added share of sector j at constant prices is defined as the excess (measured in ppt of GDP) of real value added growth in sector j over real GDP growth, i.e., $d\nu_t^{Y,j} = \nu^{Y,j}\left(\hat{Y}_t^j - \hat{Y}_{R,t}\right)$. Rearranging the latter equality as follows $\nu^{Y,j}\hat{Y}_t^j = \nu^{Y,j}\hat{Y}_{R,t} + d\nu_t^{Y,j}$ reveals that $d\nu_t^{Y,j}$ captures the extent of the asymmetry in the distribution of real GDP growth. When $d\nu_t^{Y,j} = 0$, we have $\nu^{Y,j}\hat{Y}_t^j = \nu^{Y,j}\hat{Y}_{R,t}$, which implies that the rise in real GDP is distributed uniformly across sectors, i.e., in accordance with their value added share. Conversely, if $d\nu_t^{Y,j} > 0$, real GDP growth is not uniformly distributed across sectors because the value added (at constant prices) of sector j increases disproportionately relative to the value added of the other sector.

Determinants of the change in the value added share of non-tradables. As shown in Online Appendix B, $d\nu_t^{Y,N}$ is determined by the reallocation of productive resources across sectors and the TFP growth differential caused by a government spending shock. Keeping technological change fixed, a rise in the value added share of non-tradables (at constant prices) can be brought about by a labor and/or a capital inflow. Incentives for reallocating production factors toward the non-traded sector come from the biasedness of the demand shock toward non-tradables. Using data from the World Input-Output Database (WIOD) [2013], [2016], we constructed time series for sectoral government consumption and find empirically that the non-traded sector receives on average 80% of government consumption (see column 4 of Table 6).[7] As shown by Cardi et al. [2020], when the intensity of the non-traded sector in the government spending shock, denoted by ω_{G^N}, is

[6] We consider an initial steady-state where prices are those at the base year so that real GDP, Y_R, collapses to nominal GDP, Y, initially. To facilitate the discussion in this subsection, we refer to $\hat{Y}_{R,t}$ as the aggregate spending multiplier and $\nu^{Y,j}\hat{Y}_t^j$ as the sectoral fiscal multiplier although this is a misnomer as both are computed (empirically and numerically) later as the ratio of the present value of cumulative change in value added to the present value of cumulative change in government consumption over a t-year horizon.

[7] Bussière et al. [2013] also find that government spending mostly includes nontradables.

higher than the share of non-tradables in GDP (which averages 64%, see column 1 of Table 6), the demand shock moves productive resources toward the non-traded sector, and thus increases $\nu_t^{Y,N}$, keeping technology constant. If government consumption induces exporting firms to increase their efficiency in the use of labor and capital, the rise in traded relative to non-traded TFP may neutralize the impact of the biasedness of the demand shock toward non-tradables on $\nu_t^{Y,N}$.

Sectoral decomposition of the government spending multiplier on labor. While changes in sectoral TFPs influence the distribution of real GDP growth across sectors, technology adjustment also shapes the responses of sectoral hours worked as a result of factor-biased technological change (FBTC henceforth). To shed some light on the impact of factor-biased technological adjustment on the responses of sectoral hours worked, we start with the sectoral decomposition of the percentage deviation of total hours worked relative to its initial steady-state:

$$\hat{L}_t = \alpha_L^H \hat{L}_t^H + \alpha_L^N \hat{L}_t^N, \tag{2}$$

where L and L^j are total and sectoral hours worked, respectively, α_L^j is the labor compensation share in sector j and $\alpha_L^H + \alpha_L^N = 1$. Note that α_L^j collapses to L^j/L when we impose perfect mobility of labor across sectors.

Determinants of the change in the labor share of non-tradables. Like the value added share, the change in the labor share of sector j indicates whether the rise in total hours worked is uniformly distributed across sectors. The change in the labor share of non-tradables is computed as $d\nu_t^{L,N} = \alpha_L^N \left(\hat{L}_t^N - \hat{L}_t\right)$, see Online Appendix C. When the government spending shock is biased toward non-tradables, as evidence suggests, labor shifts toward the non-traded sector, i.e., $d\nu_t^{L,N} > 0$, which increases the fiscal multiplier on non-traded labor measured by $\alpha_L^N \hat{L}_t^N = \alpha_L^N \hat{L}_t + d\nu_t^{L,N}$. Both barriers to mobility and factor-augmenting technology influence the magnitude of $d\nu_t^{L,N} > 0$.

Frictions in the movement of labor between sectors, caused by labor mobility costs and endogenous terms of trade, mitigate the rise in $\nu_t^{L,N}$. Labor mobility costs amount to assuming that sectoral hours worked are imperfect substitutes (from the worker point of view). Denoting the elasticity of labor supply across sectors by ϵ, the share of hours worked supplied to sector j is increasing in the wage differential, i.e., $\frac{L_t^j}{L_t} = \vartheta^j \left(\frac{W_t^j}{W_t}\right)^{\epsilon}$ where ϑ^j stands for the weight attached to labor supply in sector $j = H, N$, W_t^j and W_t are sectoral and aggregate wage rates, respectively. We assume perfectly competitive markets and constant returns to scale in production. Under these assumptions, labor is paid its marginal product. Denoting the labor income share by s_L^j, the marginal revenue product of labor, $s_{L,t}^j \frac{P_t^j Y_t^j}{L_t^j}$, must equate the wage rate W_t^j. The same logic applies at an aggregate level, i.e., $s_{L,t} \frac{Y_t}{L_t} = W_t$ where $s_{L,t}$ is the aggregate LIS and Y_t is GDP at current prices. Dividing W_t^N by W_t and making use of the labor supply schedule to eliminate the relative wage

W_t^N/W_t leads to the non-traded-goods-share of total hours worked (see Online Appendix C):

$$\frac{L_t^N}{L_t} = (1-\vartheta)^{\frac{1}{1+\epsilon}} \left(\frac{s_{L,t}^N}{s_{L,t}}\right)^{\frac{\epsilon}{1+\epsilon}} \left(\omega_t^{Y,N}\right)^{\frac{\epsilon}{1+\epsilon}}, \tag{3}$$

where $\omega_t^{Y,N}$ is the value added share of non-tradables at current prices. In a model where production functions are Cobb-Douglas, LISs remain fixed. Under this assumption, (3) says that the labor share of non-tradables, L_t^N/L_t, increases if the demand shock raises the value added share of non-tradables at current prices. For $\omega^{Y,N}$ to increase, the demand shock must be biased toward non-tradables. Because the traded sector also receives a share of the rise in government spending and experiences an increase in its relative price, by mitigating the rise in $\omega_t^{Y,N}$, the appreciation in the terms of trade acts as a barrier to mobility. In addition, labor mobility costs further hamper the rise in L_t^N/L_t for a given change in $\omega_t^{Y,N}$, and all the more so as ϵ takes lower values. If sectoral goods are produced by means of CES production functions, the technology of production can become more labor (capital) intensive if technological change is biased toward labor (capital). If non-traded firms decide to bias technological change toward labor and traded firms to bias technological change toward capital, the non-traded LIS, $s_{L,t}^N$, increases relative to the aggregate LIS, $s_{L,t}$. By tilting the demand for labor toward the non-traded sector and amplifying the shift of labor toward this sector, a rise in $s_{L,t}^N/s_{L,t}$ further increases the government spending multiplier on non-traded hours.

2.2 VAR Model and Identification

To conduct our empirical study, we compute the responses of selected variables by using a two-step estimation procedure. We first identify shocks to government consumption by considering a baseline VAR model where government spending is ordered before the other variables. In the second step, we trace out the dynamic effects of the identified shock to government consumption by using Jordà's [2005] single-equation method.

The first step amounts to adopting the standard Cholesky decomposition pioneered by Blanchard and Perotti [2002]. Denoting the vector of endogenous variables by $Z_{i,t}$, we estimate the reduced-form VAR model in panel format on annual data:

$$Z_{i,t} = \alpha_i + \alpha_t + \beta_i t + \sum_{k=1}^{2} A^{-1} B_k Z_{i,t-k} + A^{-1}\epsilon_{i,t}, \tag{4}$$

where subscripts i and t denote the country and the year, k is the number of lags; the specification includes country fixed effects, α_i, time dummies, α_t, and country-specific linear time trends; A is a matrix that describes the contemporaneous relation among the variables collected in vector $Z_{i,t}$, B_k is a matrix of lag-specific own- and cross-effects of variables on current observations, and the vector $\epsilon_{i,t}$ contains the structural disturbances which are uncorrelated with each other. In line with current practice, we include two lags in the regression model and use a panel OLS regression to estimate the coefficients $A^{-1}B_k$ and the reduced-form innovations $A^{-1}\epsilon_{i,t}$. The VAR model we estimate in the first step includes government final consumption expenditure, real GDP, total hours worked, private investment, the real consumption wage, and aggregate total factor productivity, where all variables are logged, while all quantities are expressed in real terms and scaled by the working-age population.

Like Blanchard and Perotti [2002], we base the identification scheme on the assumption that there are some delays inherent to the legislative system which prevents government spending from responding endogenously to contemporaneous output developments. Once we have identified government spending shocks, in the second step, we estimate the effects on selected variables (detailed later) by using Jordà's [2005] single-equation method. The local projection method amounts to running a series of regressions of each variable of interest on a structural identified shock for each horizon $h = 0, 1, 2, ...$:

$$x_{i,t+h} = \alpha_{i,h} + \alpha_{t,h} + \beta_{i,h}t + \psi_h(L)\, z_{i,t-1} + \gamma_h \epsilon^G_{i,t} + \eta_{i,t+h}, \tag{5}$$

where $\alpha_{i,h}$ are country fixed effects, $\alpha_{t,h}$ are time dummies, and we include country-specific linear time trends; x is the logarithm of the variable of interest, z is a vector of control variables (i.e., past values of government spending and of the variable of interest), $\psi_h(L)$ is a polynomial (of order two) in the lag operator and $\epsilon^G_{i,t}$ is the identified government spending shock.

The Blanchard-Perotti identification scheme may raise two potential concerns related to endogeneity and anticipation issues. While using annual data makes the assumption that government spending is unresponsive to current output developments due to decision and implementation lags in the legislative process less relevant, the test performed by Born and Müller [2012] reveals that the assumption that government spending is predetermined within the year cannot be rejected. As Ramey [2011] argued, Blanchard and Perotti's [2002] approach to identifying government spending shocks in VAR models may also lead to incorrect timing of the identified fiscal shocks. To address the concern that shocks constructed from the Blanchard-Perotti identification scheme could be anticipated, we adopt the approach pioneered by Auerbach and Gorodnichenko [2004] who compute government spending forecast errors as the difference between forecast series and actual series of the government consumption growth rate. We use the OECD Economic Outlook's Statistics and Projections Database which allows us to construct one-year-ahead forecasts of government consumption growth. In Online Appendix Q.2, we find that the responses of the variables of interest to forecast errors lie within the same confidence interval as the responses obtained after a shock to government consumption constructed from the Blanchard-Perotti identification scheme.

2.3 Data Construction

Before presenting evidence on fiscal transmission across sectors, we briefly discuss the dataset we use. Our sample contains annual observations and consists of a panel of 18 OECD countries. The period runs from 1970 to 2015.

Classification of industries as tradables or non-tradables. Since our primary objective is to quantify the role of the technology channel in determining the sectoral effects of a government spending shock, we describe below how we construct time series at a sectoral level. Our sample covers eleven 1-digit ISIC-rev.3 industries. Following De Gregorio et al. [1994], we define the tradability of an industry by constructing its openness to international trade given by the ratio of total trade (imports plus exports) to gross output, see Online Appendix Q.1 for more details. Data for trade and output are taken from WIOD [2013], [2016]. "Agriculture, Hunting, Forestry and Fishing", "Mining and Quarrying", "Total Manufacturing" and "Transport, Storage and Communication" exhibit high openness ratios and are thus classified as tradables. At the other end of the scale, "Electricity, Gas and Water Supply", "Construction", "Wholesale and Retail Trade" and "Community Social and Personal Services" are considered as non-tradables since the openness ratio in this group of industries is low (0.07 in average). For the three remaining industries "Hotels and Restaurants", "Financial Intermediation", "Real Estate, Renting and Business Services" the results are less clearcut since the average openness ratio comes to 0.18. In the benchmark classification, we adopt the standard classification of De Gregorio et al. [1994] by treating "Real Estate, Renting and Business Services" and "Hotels and Restaurants" as non-traded industries. Given the dramatic increase in financial openness that OECD countries have experienced since the end of the eighties, we allocate "Financial Intermediation" to the traded sector. This choice is also consistent with the classification of Jensen and Kletzer [2006] who categorize "Finance and Insurance" as tradable.[8]

In Online Appendix E, we detail the source and the construction of time series for sectoral value added at constant prices, Y_{it}^j, sectoral hours worked, L_{it}^j, the relative wage in sector j constructed as the ratio of the sectoral wage to the aggregate wage, W_{it}^j/W_{it}, the labor share of sector j, $\nu_{it}^{L,j}$, the value added share at constant prices, $\nu_{it}^{Y,j}$, the relative price of non-tradables constructed as the ratio of the non-traded value added deflator to the traded value added deflator, $P_{it} = P_t^N/\mathsf{P}_{it}^H$, and the terms of trade constructed as the ratio of the traded value added deflator of the home country i to the geometric average of the traded value added deflator of the seventeen trade partners of the corresponding country i,

[8] Because "Financial Intermediation" and "Real Estate, Renting and Business Services" are made up of sub-sectors which display a high heterogeneity in terms of tradability, and "Hotels and Restaurants" has experienced a large increase in tradability over the last fifty years, we perform a sensitivity analysis with respect to the classification for the three aforementioned sectors in Online Appendix Q.1. Treating "Financial Intermediation" as non-tradables or classifying "Hotels and Restaurants" or "Real Estate, Renting and Business Services" as tradables does not affect our main results.

the weight being equal to the share $\alpha_i^{M,k}$ of imports from the trade partner k (averaged over 1970-2015), i.e, $\text{TOT}_{it} = P_{it}^H / P_{it}^{H,\star}$ where $P_{it}^{H,\star} = \Pi_{k\neq i}\left(P_t^{H,k}\right)^{\alpha_i^{M,k}}$. The share of imports $\alpha_i^{M,k}$ of country i by trade partner k is taken from the Direction of Trade Statistics [2017].

Utilization-adjusted sectoral TFPs. Sectoral TFPs are Solow residuals calculated from constant-price (domestic currency) series of value added, Y_{it}^j, capital stock, K_{it}^j, and hours worked, L_{it}^j, i.e., $\hat{\text{TFP}}_{it}^j = \hat{Y}_{it}^j - s_{L,i}^j \hat{L}_{it}^j - \left(1 - s_{L,i}^j\right)\hat{K}_{it}^j$ where $s_{L,i}^j$ is the LIS in sector j averaged over the period 1970-2015. To obtain series for the capital stock in sector j, we first compute the overall capital stock by adopting the perpetual inventory approach, using constant-price investment series taken from the OECD's Annual National Accounts. Following Garofalo and Yamarik [2002], we split the gross capital stock into traded and non-traded industries by using sectoral valued added shares. Once we have constructed the Solow residual for the traded and the non-traded sectors, we construct a measure for technological change by adjusting the Solow residual with the capital utilization rate, denoted by $u_{it}^{K,j}$:

$$\hat{Z}_{it}^j = \hat{\text{TFP}}_{it}^j - \left(1 - s_{L,i}^j\right)\hat{u}_{it}^{K,j}, \tag{6}$$

where we follow Imbs [1999] in constructing time series for $u_{it}^{K,j}$, see Online Appendix F.

2.4 Sectoral Effects of Government Spending Shocks: VAR Evidence

We generated impulse response functions by means of local projections. The dynamic adjustment of variables to an exogenous increase in government spending by 1% of GDP is displayed by the solid blue line in Fig. 2. The shaded areas indicate 90% confidence bounds. The horizontal axis of each panel measures the time after the shock in years and the vertical axis measures deviations from trend. Responses of sectoral value added and sectoral hours worked are re-scaled by the sample average of sectoral value added to GDP and sectoral labor compensation share, respectively. As such, on impact, the responses of sectoral value added at constant prices and sectoral hours worked can be interpreted as government spending multipliers on value added and labor, as they are expressed in percentage points of GDP and total hours worked, respectively. We also compute the government spending multipliers over a six-year horizon by calculating the ratio of the present value of the cumulative change in value added/labor to the present value of the cumulative change in government consumption, setting the world interest rate to 3% in line with our estimates summarized in Table 5.[9]

Aggregate effects. The first row of Fig. 2 displays the aggregate effects of a shock to government consumption. As shown in Fig. 2(a), government consumption, G_t, follows a hump-shaped response and displays a high level of persistence. Fig. 2(b) and 2(c) reveal that a rise in G_t has a strong expansionary effect on total hours worked and real GDP.

[9]We choose a six-year horizon because the responses of aggregate variables (real GDP, total hours worked, aggregate TFP) are statistically significant over this period only.

Total hours worked increase by 0.9% on impact, while real GDP increases by 1.2%. The government spending multiplier on real GDP and total hours worked at a 6-year-horizon averages 1.4 and 1.15, respectively, both responses being statistically significant over this period. One key factor that generates a multiplier on real GDP larger than one is technology, since 39% of real GDP growth is driven by aggregate TFP growth (displayed by Fig. 2(d)) over a six-year horizon. To further check the importance of technology improvement in driving real GDP growth, we have adapted the methodology proposed by Sims and Zha [2006] in order to estimate empirically the government spending multiplier if the technology channel were shut down. As detailed in Online Appendix K, we find that the fiscal multiplier is reduced by 42% when the response of TFP to a shock to government consumption is shut down.[10]

Government spending multiplier on sectoral labor. The second row of Fig. 2 displays the dynamic adjustment of sectoral hours worked. Fig. 2(e) and 2(f) reveal that a shock to government consumption by 1% of GDP increases both traded and non-traded hours worked but only the latter is statistically significant. More specifically, the government spending multiplier on non-traded hours worked averages 1.02 ppt of total hours worked, while the government spending multiplier on traded hours worked averages 0.13 ppt of total hours worked. Therefore, the rise in non-traded hours worked contributes 88% to the increase in total hours worked. Fig. 2(g) shows the response of the labor share of non-tradables, i.e., L^N/L. On average, over the first six years, the non-traded goods-sector-share of total hours worked increases by 0.3 ppt of total hours worked, which implies that the reallocation of labor toward the non-traded sector contributes 29% to the rise in L^N. As mentioned previously, the reallocation of labor toward the non-traded sector is driven by the biasedness of the demand shock toward-non-tradables.[11] The reallocation of labor toward the non-traded sector is amplified when non-traded production becomes more labor intensive, as reflected in a non-traded LIS which builds up relative to the traded LIS, see Fig. 2(h). Our evidence shown below reveals that the rise in s_L^N/s_L^H is brought about by technological change biased toward labor.[12]

Government spending multiplier on sectoral value added and technology. The third row of Fig. 2 shows that a rise in G_t increases both traded and non-traded value added at constant prices. Both responses are statistically significant. Over the first six years, the government spending multiplier on traded value added averages 0.52 ppt of GDP while the government spending multiplier on non-traded value added averages 0.89

[10] We estimate a VAR model with three variables, government consumption, aggregate TFP and real GDP. We find a six-year-horizon-government spending multiplier on real GDP of 1.25. When we shut down technological change, the government spending multiplier averages 0.73 over the first six years.

[11] Fig. 8 relegated to the Online Appendix G shows that a shock to government consumption by 1% of GDP is associated with a rise in G^N by 0.8% of GDP on impact.

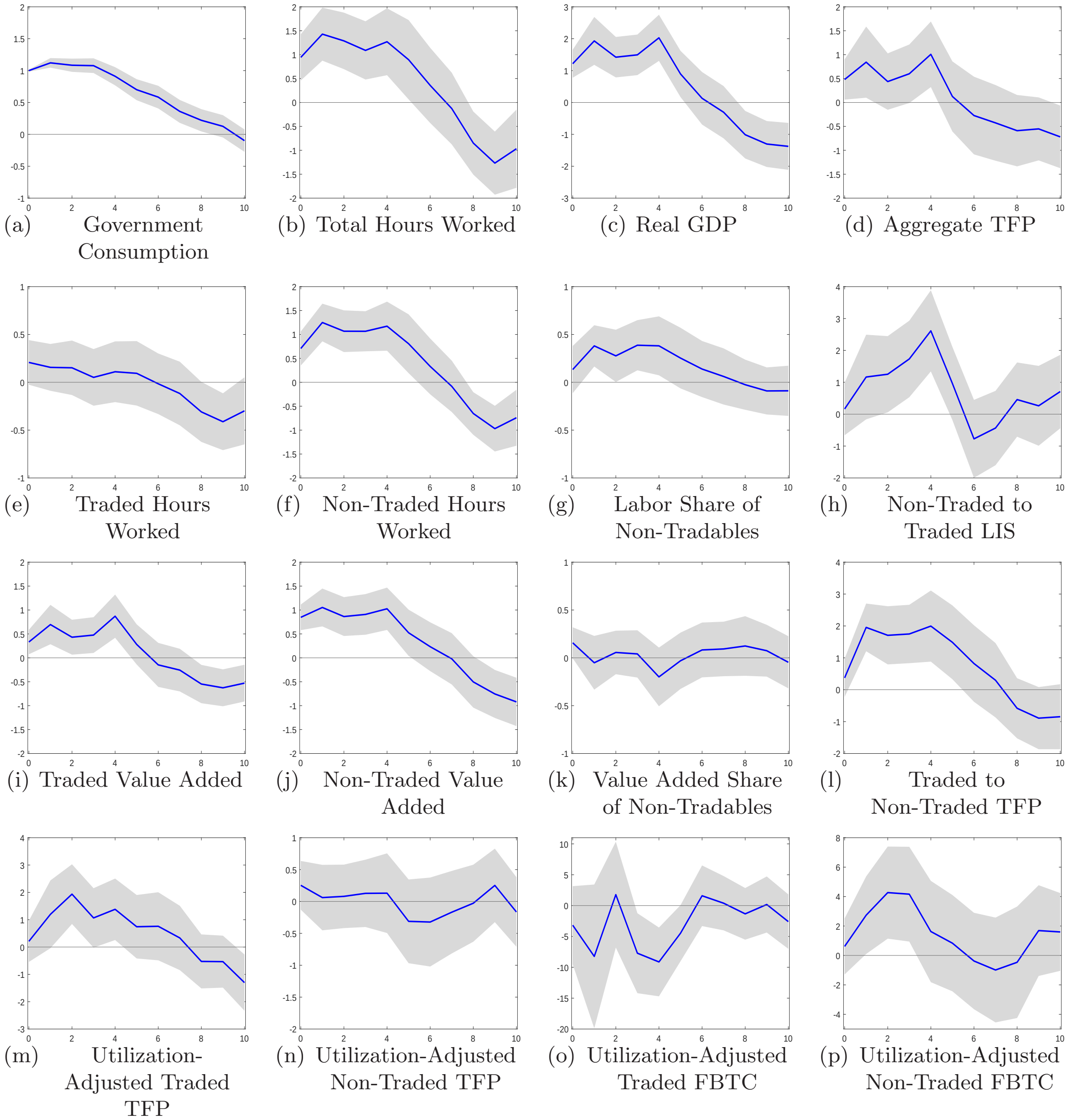
[12] We compute the LIS like Gollin [2002], i.e., labor compensation is defined as the sum of compensation of employees plus compensation of the self-employed. We find that our results are robust to alternative constructions of the LIS, see Online Appendix Q.3.

ppt. In contrast to labor, the non-traded sector contributes 64% only to real GDP growth, a value which collapses to the share of non-tradables in GDP. In accordance with this observation, Fig. 2(k) reveals that the value added share of non-tradables (at constant prices) remains unresponsive to the shock, thus confirming that the government spending multiplier on real GDP is uniformly distributed across sectors, i.e., in accordance with their value added share.[13] This result is puzzling because the government spending shock is strongly biased toward non-tradables and triggers a reallocation of productive resources toward the non-traded sector. As shown in Fig. 2(l), the solution to this puzzle lies in the technology channel. On average, over the first six years, the TFP differential between tradables and non-tradables amounts to 1.5% per year. The technology gap between sectors is large enough to neutralize the impact of the reallocation of productive resources toward the non-traded sector, thus leaving $\nu_t^{Y,N}$ unaffected.

Fiscal policy and utilization-adjusted TFP. The last row of Fig. 2 displays the dynamic adjustment of TFP and FBTC for tradables and non-tradables, which are both adjusted with capital utilization to reflect the true variations of technological change, see Basu et al. [2006]. Fig. 2(m) and 2(n) show the responses of traded and non-traded TFP once we control for varying utilization of capital at a sectoral level. See Online Appendix F, where we detail the adaptation of the approach proposed by Imbs [1999] to measure the capital utilization rate in the traded and non-traded sector by considering CES production functions. After correcting for capital utilization, Fig. 2(m) and Fig. 2(n) confirm that technology improves in the traded sector and is essentially unchanged in the non-traded sector. Because the capital utilization rate increases in the traded relative to the non-traded sector, these findings indicate that the rise in the relative TFP of tradables shown in Fig. 2(l) is driven by both a higher utilization of capital and a technology improvement in the traded sector.

Fiscal policy and utilization-adjusted FBTC. While the rise in traded relative to non-traded TFP leads real GDP growth to be uniformly distributed across sectors, the last two panels of the last row of Fig. 2 show that the differential in FBTC between non-tradables and tradables can rationalize the concentration of labor growth in the non-traded sector. To measure capital-utilization-adjusted-FBTC in the traded and non-traded sectors, we draw on Caselli and Coleman [2006] and Caselli [2016]. Denoting the elasticity of substitution between capital and labor by σ^j, capital- and labor-augmenting efficiency

[13] In contrast to Benetrix and Lane [2010] and Cardi et al. [2020], we do not find a disproportionate increase in non-traded value added, although our estimates confirm that the non-traded sector is highly intensive in the government spending shock. As shown in Online Appendix Q.5, the reason is twofold. Our dataset runs from 1970-2015 instead of ending in 2005 or 2007 and includes 18 OECD countries. Importantly, we adopt a two-step estimation method where we first identify the shock by adopting the Blanchard and Perotti [2002] approach and estimate the dynamic effects by using Jordà's [2005] projection method, which does not impose the dynamic restrictions implicitly embedded in VARs and can accommodate non-linearities in the response function. Our two-step approach also ensures that all variables respond to the same identified spending shock.



(a) Government Consumption

(b) Total Hours Worked

(c) Real GDP

(d) Aggregate TFP

(e) Traded Hours Worked

(f) Non-Traded Hours Worked

(g) Labor Share of Non-Tradables

(h) Non-Traded to Traded LIS

(i) Traded Value Added

(j) Non-Traded Value Added

(k) Value Added Share of Non-Tradables

(l) Traded to Non-Traded TFP

(m) Utilization-Adjusted Traded TFP

(n) Utilization-Adjusted Non-Traded TFP

(o) Utilization-Adjusted Traded FBTC

(p) Utilization-Adjusted Non-Traded FBTC

Figure 2: Sectoral Effects of a Shock to Government Consumption. Notes: The solid blue line shows the response of aggregate and sectoral variables to an exogenous increase in government final consumption expenditure by 1% of GDP. Shaded areas indicate the 90 percent confidence bounds. To estimate the dynamic responses to a shock to government consumption, we adopt a two-step method. In the first step, the government spending shock is identified by estimating a VAR model that includes real government final consumption expenditure, real GDP, total hours worked, the real consumption wage, and aggregate TFP. In the second step, we estimate the effects by using Jordà's [2005] single-equation method. Horizontal axes indicate years. Vertical axes measure percentage deviation from trend in GDP units (sectoral value added, sectoral value added share, labor income share), percentage deviation from trend in total hours worked units (sectoral hours worked, labor share), percentage deviation from trend (sectoral TFPs, sectoral FBTC). Sample: 18 OECD countries, 1970-2015, annual data.

by B_t^j and A_t^j, respectively, our measure of capital-utilization-adjusted-FBTC, denoted by $\text{FTBC}^j_{t,adjK}$, reads (see Online Appendix H):

$$\text{FTBC}^j_{t,adjK} = \left(\frac{B_t^j/\bar{B}^j}{A_t^j/\bar{A}^j}\right)^{\frac{1-\sigma^j}{\sigma^j}} = \frac{S_t^j}{\bar{S}^j}\left(\frac{k_t^j}{\bar{k}^j}\right)^{-\frac{1-\sigma^j}{\sigma^j}}\left(\frac{u_t^{K,j}}{\bar{u}^{K,j}}\right)^{-\frac{1-\sigma^j}{\sigma^j}}, \tag{7}$$

where a bar refers to averaged values of the corresponding variable over 1970-2015. To construct time series for $\text{FTBC}^j_{t,adjK}$, we plug estimates for the elasticity of substitution between capital and labor, σ^j, and time series for the ratio of labor to capital income share, $S_t^j = \frac{s^j_{L,t}}{1-s^j_{L,t}}$, the capital-labor ratio, k_t^j, and the capital utilization rate, $u_t^{K,j}$, in sector $j = H, N$. An increase in our measure $\text{FTBC}^j_{t,adjK}$ described by (7) means that technological change is biased toward labor. Since this measure crucially depends on σ^j, we have estimated this parameter for both sectors, see Online Appendix M.3. We find empirically that $\sigma^H = 0.64$ for the traded sector and $\sigma^N = 0.80$ for the non-traded sector for the whole sample, as summarized in columns 18 and 19 of Table 6. Evidence displayed by Fig. 2(o) and 2(p) suggests that technological change is biased toward capital in the traded sector while technological change is biased toward labor in the non-traded sector. These findings are consistent with the rise in non-traded LIS relative to the traded LIS shown in Fig. 2(h).

Because capital and labor are gross complements in production (i.e., both σ^H, σ^N are smaller than one), our evidence indicates that traded firms tend to lower B^H/A^H and non-traded firms to increase B^N/A^N. In Online Appendix J, we document evidence which rationalizes the decision to bias technological change toward one specific factor. Because the non-traded sector must pay higher wages to encourage workers to shift, non-traded firms increase labor-augmenting productivity to mitigate the rise in the labor cost. Since labor- and capital-augmenting productivity are strong complements along the technology frontier, capital productivity disproportionately increases, thus generating a rise in B^N/A^N. The other way around is true in the traded sector.

Technology channel at a disaggregated level. We are aware that the traded and non-traded sectors are made-up of several industries, and that variations in TFP in broad sectors could be the result of changes in the value added share of sub-sectors (between-effect) rather than a technology improvement within the industry (within-effect). Our dataset covers eleven industries and in Online Appendix Q.4, we conduct the same empirical analysis as in the main text, but at a disaggregated industry level. We find that all industries classified as tradables increase their TFP, which confirms that the rise in traded TFP is driven by a technology improvement within each industry. Conversely, the responses of TFP in non-traded industries are more heterogenous and clustered around the horizontal axis.

Cross-country differences in the technology channel. The evidence documented above raises two important questions: does the technology channel vary across countries and which factor causes these international differences? In Online Appendix L, we take advantage of the panel data dimension of our sample and estimate the effects of a government spending shock for one country at a time. We detect a negative cross-country relationship between the response of the value added share of non-tradables and the TFP differential between tradables and non-tradables, both computed as the present value of the cumulative change over a six-year horizon and divided by the present value of the cumulative change in government consumption. Further, we find empirically that technology improvements are driven by a cost-minimization strategy, as sector $j = H, N$ increases utilization-adjusted-TFP in countries where the unit cost for producing rises following a government spending shock. In accordance with our estimates and as detailed in the next section, we model the decision to increase the utilization of available technology as a trade-off between the rise in output generated by enhanced productivity and the cost associated with a higher utilization rate of technology within each sector $j = H, N$. Our second set of empirical findings sheds some light on international differences in FBTC. We find that a government spending shock increases (lowers) the sectoral LISs in countries where firms bias technological change toward labor (capital). Our estimates also show that the differential in FBTC between non-tradables and tradable influences the change in the labor share of non-tradables caused by a government spending shock. More specifically, we find that the rise in the non-traded-goods-share of total hours worked caused by the biasedness of the government spending shock toward non-tradables is amplified in countries where technological change is more biased toward labor in the non-traded than in the traded sector. Conversely, our estimates reveal that labor can shift toward the traded sector when traded firms strongly bias technological change toward labor. In section 4.4, we calibrate our model to country-specific data and quantify the role of the technology channel in determining international differences in government spending multipliers at both an aggregate and a sectoral level.

Isolating the technology channel. In Online Appendix K, we adapt the Sims and Zha [2006] methodology to our case to answer one key question: what would the sectoral government spending multiplier be if the technology channel were shut down? If traded relative to non-traded TFP were kept fixed, our estimates reveal that the biasedness of the government spending shock would disproportionately benefit the non-traded sector as we find that $\nu_t^{Y,N}$ increases by 0.26 ppt per year over a six-year horizon. Once we let the TFP differential respond to the government shock, the rise in $\nu_t^{Y,N}$ is lowered at 0.09 ppt because the technology channel significantly neutralizes the biasedness of the government spending shock toward non-tradables. When we turn to the labor share of non-tradables, we find empirically that labor reallocation almost doubles when we let the ratio of the non-traded to the traded LIS respond to the government spending shock. When we shut down capital-utilization-adjusted-FBTC, sectoral LISs remain unresponsive to the government spending shock. These findings corroborate the evidence that we document above following a government spending shock: technology improvement concentrated in traded industries leads real GDP growth to be uniformly distributed across sectors, and non-traded production becomes more labor intensive as non-traded firms bias technological change toward labor which leads labor growth to be concentrated in non-traded industries.

3 A Semi-Small Open Economy Model with Tradables and Non-Tradables

We consider a semi-small open economy that is populated by a constant number of identical households and firms that have perfect foresight and live forever. The country is assumed to be semi-small in the sense that it is a price-taker in international capital markets, and thus faces a given world interest rate, $r^\star$, but is large enough on world good markets to influence the price of its export goods. The open economy produces a traded good which can be exported, consumed or invested and imports consumption and investment goods. While the home-produced traded good, denoted by the superscript H, faces both a domestic and a foreign demand, a non-traded sector produces a good, denoted by the superscript N, for domestic absorption only. The foreign good is chosen as the numeraire. Time is continuous and indexed by t.

3.1 Households

At each instant the representative household consumes traded and non-traded goods denoted by $C^T(t)$ and $C^N(t)$, respectively, which are aggregated by means of a CES function:

$$C(t) = \left[\varphi^{\frac{1}{\phi}} \left(C^T(t)\right)^{\frac{\phi-1}{\phi}} + (1-\varphi)^{\frac{1}{\phi}} \left(C^N(t)\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}, \tag{8}$$

where $0 < \varphi < 1$ is the weight of the traded good in the overall consumption bundle and ϕ corresponds to the elasticity of substitution between traded goods and non-traded goods. The traded consumption index $C^T(t)$ is defined as a CES aggregator of home-produced traded goods, $C^H(t)$, and foreign-produced traded goods, $C^F(t)$:

$$C^T(t) = \left[\left(\varphi^H\right)^{\frac{1}{\rho}} \left(C^H(t)\right)^{\frac{\rho-1}{\rho}} + \left(1-\varphi^H\right)^{\frac{1}{\rho}} \left(C^F(t)\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}, \tag{9}$$

where $0 < \varphi^H < 1$ is the weight of the home-produced traded good and ρ corresponds to the elasticity of substitution between home- and foreign-produced traded goods. The consumption-based price index $P_C(t)$ is a function of traded and non-traded prices, denoted by $P^T(t)$ and $P^N(t)$, respectively:

$$P_C(t) = \left[\varphi \left(P^T(t)\right)^{1-\phi} + (1-\varphi) \left(P^N(t)\right)^{1-\phi}\right]^{\frac{1}{1-\phi}}, \tag{10}$$

where the price index for traded goods is a function of the terms of trade denoted by P^H(t):

$$P^T(t) = \left[\varphi^H \left(P^H(t)\right)^{1-\rho} + \left(1-\varphi^H\right)\right]^{\frac{1}{1-\rho}}. \tag{11}$$

As shall be useful later in the quantitative analysis, we denote the relative price of non-tradables by $P(t) = P^N(t)/P^H(t)$.

The representative household supplies labor to the traded and non-traded sectors, denoted by $L^H(t)$ and $L^N(t)$, respectively. To put frictions into the movement of labor between the traded sector and the non-traded sector, we assume that sectoral hours worked are imperfect substitutes, in lines with Horvath [2000]:

$$L(t) = \left[\vartheta^{-1/\epsilon}\left(L^H(t)\right)^{\frac{\epsilon+1}{\epsilon}} + (1-\vartheta)^{-1/\epsilon}\left(L^N(t)\right)^{\frac{\epsilon+1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon+1}}, \tag{12}$$

where $0 < \vartheta < 1$ parametrizes the weight attached to the supply of hours worked in the traded sector and ϵ is the elasticity of substitution between sectoral hours worked. The aggregate wage index $W(.)$ associated with the above defined labor index (12) is:

$$W(t) = \left[\vartheta\left(W^H(t)\right)^{\epsilon+1} + (1-\vartheta)\left(W^N(t)\right)^{\epsilon+1}\right]^{\frac{1}{\epsilon+1}}, \tag{13}$$

where $W^j(t)$ is the wage rate paid in sector $j = H, N$.

The representative agent is endowed with one unit of time, supplies a fraction $L(t)$ as labor, and consumes the remainder $1 - L(t)$ as leisure. At any instant of time, households derive utility from their consumption and experience disutility from working. Assuming that the felicity function is additively separable in consumption and labor, the representative household maximizes the following objective function:

$$U = \int_0^{\infty}\left\{\frac{1}{1-\frac{1}{\sigma_C}}C(t)^{1-\frac{1}{\sigma_C}} - \frac{1}{1+\frac{1}{\sigma_L}}L(t)^{1+\frac{1}{\sigma_L}}\right\}e^{-\beta t}\mathrm{d}t, \tag{14}$$

where $\beta > 0$ is the discount rate, $\sigma_C > 0$ the intertemporal elasticity of substitution for consumption, and $\sigma_L > 0$ the Frisch elasticity of (aggregate) labor supply.

Households supply labor $L(t)$ and capital services $K(t)$ and, in exchange, receive a wage rate $W(t)$ and a capital rental rate $R(t)$. We assume that households choose the level of capital utilization $u^{K,j}(t)$ in sector j. They also own the stock of intangible capital $\bar{Z}^j$ and decide about the level of utilization $u^{Z,j}(t)$ of existing technology in sector j. In the sequel, we normalize the stock of knowledge, $\bar{Z}^j$, to one as we abstract from endogenous choices on the stock of knowledge.[14] Because households may decide to use more intensively the stock of knowledge in sector j which increases the efficiency in the use of inputs, the counterpart is a rise in factor prices, since factors are paid their marginal product. In accordance with the Euler Theorem, we have $P^j(t)u^{Z,j}(t)Y^j(t) = \tilde{W}^j(t)L^j(t) + \tilde{R}^j(t)u^{K,j}(t)K^j(t)$ where $\tilde{W}^j(t) = u^{Z,j}(t)W^j(t)$, $\tilde{R}^j(t) = u^{Z,j}(t)R(t)$, P^j is the value added deflator and Y^j stands for technology-utilization-adjusted value added. Both the capital $u^{K,j}(t)$ and the technology

[14] Bianchi et al. [2019] assume that firms can choose both the technology utilization rate and the stock of knowledge. We assume that the stock of knowledge is constant over time since we are interested in fiscal policy effects at business cycle frequencies and find empirically that sectoral TFPs remain unaffected in the long run. More specifically, our estimates show that utilization-adjusted-sectoral TFP is restored back toward its initial steady-state level in both sectors, see Fig. 2(m) and Fig. 2(n), which is consistent with a time-varying technology utilization rate at a sectoral level.

utilization rate $u^{Z,j}(t)$ collapse to one at the steady-state. We let the function $C^{K,j}(t)$ and $C^{Z,j}(t)$ denote the adjustment costs associated with the choice of capital and technology utilization rates, which are increasing and convex functions of utilization rates $u^{K,j}(t)$ and $u^{Z,j}(t)$:

$$C^{K,j}(t) = \xi_1^j \left(u^{K,j}(t) - 1\right) + \frac{\xi_2^j}{2}\left(u^{K,j}(t) - 1\right)^2, \tag{15a}$$

$$C^{Z,j}(t) = \chi_1^j \left(u^{Z,j}(t) - 1\right) + \frac{\chi_2^j}{2}\left(u^{Z,j}(t) - 1\right)^2, \tag{15b}$$

where $\xi_2^j > 0$, $\chi_2^j > 0$ are free parameters; as $\xi_2^j \to \infty$, $\chi_2^j \to \infty$, utilization is fixed at unity. It is worth mentioning that while the technology utilization rate is assumed to be Hicks-neutral and factor-biased technological change is recovered by using a wedge analysis as detailed later, we could alternatively assume that households choose the utilization rate of factor-augmenting technology. We have considered this possibility both theoretically and numerically in Online Appendix V. The model fails to reproduce our VAR evidence however as it can account for neither the technology improvement in the traded sector nor the magnitude of technological change biased toward labor which is necessary to generate a rise in the non-traded LIS.[15]

Households can accumulate internationally traded bonds (expressed in foreign good units), $N(t)$, that yield net interest rate earnings of $r^\star N(t)$. Denoting lump-sum taxes by $T(t)$, the household's flow budget constraint states that real disposable income can be saved by accumulating traded bonds, $\dot{N}(t)$, can be consumed, $P_C(t)C(t)$, invested, $P_J(t)J(t)$, or cover utilization adjustment costs:

$$\begin{aligned}
\dot{N}(t) \quad & +P_C(t)C(t) + P_J(t)J(t) + P^H(t)C^{K,H}(t)\alpha_K(t)K(t) + P^N(t)C^{K,N}(t)\left(1-\alpha_K(t)\right)K(t) \\
+ \quad & P^H(t)C^{Z,H}(t) + P^N(t)C^{Z,N}(t) = \left[\alpha_L(t)u^{Z,H}(t) + \left(1-\alpha_L(t)\right)u^{Z,N}(t)\right]W(t)L(t) \\
+ \quad & \left[\alpha_K(t)u^{K,H}(t)u^{Z,H}(t) + \left(1-\alpha_K(t)\right)u^{K,N}(t)u^{Z,N}(t)\right]R(t)K(t) + r^\star N(t) - T(t), \quad (16)
\end{aligned}$$

where we denote the share of traded capital in the aggregate capital stock by $\alpha_K(t) = K^H(t)/K(t)$ and the labor compensation share of tradables by $\alpha_L(t) = \frac{W^H(t)L^H(t)}{W(t)L(t)}$.

The investment good is (costlessly) produced using inputs of the traded good and the non-traded good by means of a CES technology:

$$J(t) = \left[\varphi_J^{\frac{1}{\phi_J}}\left(J^T(t)\right)^{\frac{\phi_J - 1}{\phi_J}} + \left(1-\varphi_J\right)^{\frac{1}{\phi_J}}\left(J^N(t)\right)^{\frac{\phi_J - 1}{\phi_J}}\right]^{\frac{\phi_J}{\phi_J - 1}}, \tag{17}$$

where $0 < \varphi_J < 1$ is the weight of the investment traded input and ϕ_J corresponds to the elasticity of substitution between investment traded goods and investment non-traded

[15]While factor-biased technology utilization rates are pro-cyclical like Hicks-neutral technology utilization rates, they are also positively correlated with the factor income share. By reducing the return on labor-augmenting productivity, the fall in the traded LIS overturns the positive impact triggered by higher government spending consumption, thus leading to a fall in utilization-adjusted traded TFP. In addition, the model fails to account for the rise in the non-traded LIS because the change in the ratio of the capital- to the labor-augmenting technology utilization rate $\frac{u^{B,j}(t)}{u^{A,j}(t)}$ is only driven by the change in the capital-labor ratio which is too small to produce the rise in s_L^N that we estimate empirically.

goods. The index $J^T(t)$ is defined as a CES aggregator of home-produced traded inputs, $J^H(t)$, and foreign-produced traded inputs, $J^F(t)$:

$$J^T(t) = \left[\left(\iota^H\right)^{\frac{1}{\rho_J}} \left(J^H(t)\right)^{\frac{\rho_J-1}{\rho_J}} + \left(1-\iota^H\right)^{\frac{1}{\rho_J}} \left(J^F(t)\right)^{\frac{\rho_J-1}{\rho_J}}\right]^{\frac{\rho_J}{\rho_J-1}}, \tag{18}$$

where $0 < \iota^H < 1$ is the weight of the home-produced traded input and ρ_J corresponds to the elasticity of substitution between home- and foreign-produced traded inputs. The investment-based price index $P_J(t)$ is a function of traded and non-traded prices:

$$P_J(t) = \left[\iota \left(P_J^T(t)\right)^{1-\phi_J} + (1-\iota)\left(P^N(t)\right)^{1-\phi_J}\right]^{\frac{1}{1-\phi_J}}, \tag{19}$$

where the price index for traded investment goods reads:

$$P_J^T(t) = \left[\iota^H \left(P^H(t)\right)^{1-\rho_J} + \left(1-\iota^H\right)\right]^{\frac{1}{1-\rho_J}}. \tag{20}$$

Installation of new investment goods involves convex costs, assumed to be quadratic. Thus, total investment $J(t)$ differs from effectively installed new capital:

$$J(t) = I(t) + \frac{\kappa}{2}\left(\frac{I(t)}{K(t)} - \delta_K\right)^2 K(t), \tag{21}$$

where the parameter $\kappa > 0$ governs the magnitude of adjustment costs to capital accumulation. Denoting the fixed capital depreciation rate by $0 \leq \delta_K < 1$, aggregate investment, $I(t)$, gives rise to capital accumulation according to the dynamic equation:

$$\dot{K}(t) = I(t) - \delta_K K(t). \tag{22}$$

Households choose consumption, worked hours, capital and technology utilization rates, investment in physical capital by maximizing lifetime utility (14) subject to (16) and (22) together with (21). Denoting by λ and Q' the co-state variables associated with (16) and (22), the first-order conditions characterizing the representative household's optimal plans are:

$$(C(t))^{-\frac{1}{\sigma_C}} = P_C(t)\lambda(t), \tag{23a}$$

$$\gamma\,(L(t))^{\frac{1}{\sigma_L}} = \lambda(t)\tilde{W}(t), \tag{23b}$$

$$Q(t) = P_J(t)\left[1 + \kappa\left(\frac{I(t)}{K(t)} - \delta_K\right)\right], \tag{23c}$$

$$\dot{\lambda}(t) = \lambda\left(\beta - r^\star\right), \tag{23d}$$

$$\begin{aligned}\dot{Q}(t) = \left(r^\star + \delta_K\right)Q(t) - \Big\{ &\left[\alpha_K(t)u^{K,H}(t)u^{Z,H}(t) + \left(1-\alpha_K(t)\right)u^{K,N}(t)u^{Z,N}(t)\right]R(t) \\ &- P^H(t)C^{K,H}(t)\alpha_K(t) - P^N(t)C^{K,N}(t)\left(1-\alpha_K(t)\right) - P_J(t)\frac{\partial J(t)}{\partial K(t)}\Big\},\end{aligned} \tag{23e}$$

$$R(t)u^{Z,H}(t) = P^H(t)\left[\xi_1^H + \xi_2^H\left(u^{K,H}(t)-1\right)\right], \tag{23f}$$

$$R(t)u^{Z,N}(t) = P^N(t)\left[\xi_1^N + \xi_2^N\left(u^{K,N}(t)-1\right)\right], \tag{23g}$$

$$R(t)u^{K,H}(t)K^H(t) + W^H(t)L^H(t) = P^H(t)\left[\chi_1^H + \chi_2^H\left(u^{Z,H}(t)-1\right)\right], \tag{23h}$$

$$R(t)u^{K,N}(t)K^N(t) + W^N(t)L^N(t) = P^N(t)\left[\chi_1^N + \chi_2^N\left(u^{Z,N}(t)-1\right)\right], \tag{23i}$$

and the transversality conditions $\lim_{t\to\infty} \bar{\lambda} N(t) e^{-\beta t} = 0$ and $\lim_{t\to\infty} Q(t) K(t) e^{-\beta t} = 0$; to derive the labor supply decision (23b), we use the fact that $\left[\alpha_L(t) u^{Z,H}(t) + (1-\alpha_L(t))\, u^{Z,N}(t)\right] W(t) L(t) = \tilde{W}^H(t) L^H(t) + \tilde{W}^N(t) L^N(t)$ where we add a tilde when factor prices include technology utilization. To derive (23c) and (23e), we used the fact that $Q(t) = Q'(t)/\lambda(t)$. In an open economy model with a representative agent having perfect foresight, a constant rate of time preference and perfect access to world capital markets, we impose $\beta = r^\star$ in order to generate an interior solution. Setting $\beta = r^\star$ into (23d) implies that the shadow value of wealth is constant over time, i.e., $\lambda(t) = \lambda$. When new information about the fiscal shock arrives, λ jumps (to fulfill the intertemporal solvency condition determined later) and remains constant afterwards.

Solving (23c) for investment, i.e., $\frac{I(t)}{K(t)} = \frac{1}{\kappa}\left(\frac{Q(t)}{P_J(t)} - 1\right) + \delta_K$, leads to a positive relationship between investment and Tobin's q, which is defined as the shadow value to the firm of installed capital, $Q(t)$, divided by its replacement cost, $P_J(t)$. For the sake of clarity, we drop the time argument below provided this causes no confusion.

Applying Shephard's lemma (or the envelope theorem) yields the following demand for the home- and the foreign-produced traded good for consumption and investment:

$$C^H = \varphi \left(\frac{P^T}{P_C}\right)^{-\phi} \varphi^H \left(\frac{P^H}{P^T}\right)^{-\rho} C, \qquad C^F = \varphi \left(\frac{P^T}{P_C}\right)^{-\phi} \left(1-\varphi^H\right) \left(\frac{1}{P^T}\right)^{-\rho} C, \quad \text{(24a)}$$

$$J^H = \iota \left(\frac{P_J^T}{P_J}\right)^{-\phi_J} \iota^H \left(\frac{P^H}{P_J^T}\right)^{-\rho_J} J, \qquad J^F = \iota \left(\frac{P_J^T}{P_J}\right)^{-\phi_J} \left(1-\iota^H\right) \left(\frac{1}{P_J^T}\right)^{-\rho_J} J, \quad \text{(24b)}$$

and the demand for non-traded consumption and investment goods, respectively:

$$C^N = (1-\varphi)\left(P^N/P_C\right)^{-\phi} C, \qquad J^N = (1-\iota)\left(P^N/P_J\right)^{-\phi_J} J. \quad \text{(25)}$$

Given the aggregate wage index (13) and $\tilde{W}^j(t) = u^{Z,j}(t) W^j(t)$, the allocation of aggregate labor supply to the traded and the non-traded sector reads:

$$L^H = \vartheta \left(\tilde{W}^H/\tilde{W}\right)^{\epsilon} L, \qquad L^N = (1-\vartheta)\left(\tilde{W}^N/\tilde{W}\right)^{\epsilon} L, \quad \text{(26)}$$

where ϵ determines the percentage change in the share of hours worked in sector j, L^j/L, following a rise in the relative wage, $\tilde{W}^j/\tilde{W}$, by 1%. As the elasticity of labor supply across sectors, ϵ, takes higher values, workers experience lower mobility costs and thus more labor shifts from one sector to another.

3.2 Firms

We denote by $\tilde{Y}^j(t)$ the value added of sector j inclusive of technology utilization, i.e., $\tilde{Y}^j(t) = u^Z(t) Y^j(t)$. Both the traded and non-traded sectors use physical capital (inclusive of capital utilization), denoted by $\tilde{K}^j(t) = u^{K,j}(t) K^j(t)$, and labor, L^j, according to a constant returns-to-scale technology described by a CES production function:

$$\tilde{Y}^j(t) = \left[\gamma^j \left(\tilde{A}^j(t) L^j(t)\right)^{\frac{\sigma^j-1}{\sigma^j}} + \left(1-\gamma^j\right)\left(\tilde{B}^j(t)\tilde{K}^j(t)\right)^{\frac{\sigma^j-1}{\sigma^j}}\right]^{\frac{\sigma^j}{\sigma^j-1}}, \quad \text{(27)}$$

where $0 < \gamma^j < 1$ and $0 < 1 - \gamma^j < 1$ are the weight of labor and capital in the production technology, respectively, σ^j is the elasticity of substitution between capital and labor in sector $j = H, N$. We allow for labor- and capital-augmenting efficiency denoted by $\tilde{A}^j(t)$ and $\tilde{B}^j(t)$. We assume that factor-augmenting productivity has a symmetric time-varying component which collapses to $u^{Z,j}(t)$, such that $\tilde{A}^j(t) = u^{Z,j}(t)A^j(t)$ and $\tilde{B}^j(t) = u^{Z,j}(t)B^j(t)$. For given Hicks-neutral technology improvement, the mix of labor and capital-augmenting efficiency can change at each point of time along the technology frontier described later.

Firms lease the capital from households and hire workers. They face two cost components: a capital rental cost equal to $R(t)$, and a labor cost equal to the wage rate $W^j(t)$. Both sectors are assumed to be perfectly competitive and thus choose capital services and labor by taking prices as given. While capital can move freely between the two sectors, costly labor mobility implies a wage differential across sectors:[16]

$$P^j(t)\gamma^j \left(A^j(t)\right)^{\frac{\sigma^j-1}{\sigma^j}} \left(y^j(t)\right)^{\frac{1}{\sigma^j}} = W^j(t), \tag{28a}$$

$$P^j(t)\left(1-\gamma^j\right)\left(B^j(t)\right)^{\frac{\sigma^j-1}{\sigma^j}} \left(u^{K,j}(t)k^j(t)\right)^{-\frac{1}{\sigma^j}} \left(y^j(t)\right)^{\frac{1}{\sigma^j}} = R(t), \tag{28b}$$

where we denote by $k^j(t) \equiv K^j(t)/L^j(t)$ the capital-labor ratio for sector $j = H, N$, and $y^j(t) \equiv Y^j(t)/L^j(t)$ refers to value added per hours worked.

Demand for inputs can be rewritten in terms of their respective cost in value added; for labor, we have $s_L^j(t) = \gamma^j \left(A^j(t)/y^j(t)\right)^{\frac{\sigma^j-1}{\sigma^j}}$. Applying the same logic for capital and denoting the ratio of labor to capital income share by $S^j(t) \equiv \frac{s_L^j(t)}{1-s_L^j(t)}$, we have:

$$S^j(t) \equiv \frac{s_L^j(t)}{1-s_L^j(t)} = \frac{\gamma^j}{1-\gamma^j}\left(\frac{B^j(t)u^{K,j}(t)K^j(t)}{A^j(t)L^j(t)}\right)^{\frac{1-\sigma^j}{\sigma^j}}. \tag{29}$$

When technological change is assumed to be Hicks-neutral, productivity increases uniformly across inputs, i.e., $\hat{A}^j(t) = \hat{B}^j(t)$. Hence a change in $B^j(t)/A^j(t)$ on the RHS of eq. (29) has no impact on sectoral LISs, which are only affected through changes in $u^{K,j}(t)k^j(t)$. Therefore, if sector j decides to use less capital, its LIS $s_L^j(t)$ declines because capital and labor are gross complements in production, i.e., $\sigma^j < 1$, as evidence suggests (see e.g., Klump et al. [2007], Herrendorf et al. [2015], Oberfield and Raval [2014], Chirinko and Mallick [2017]). By contrast, when technological change is factor-biased, an increase in capital relative to labor efficiency (i.e., a rise in $B^j(t)/A^j(t)$) impinges on the sectoral LIS directly and indirectly through changes in capital use $\tilde{k}^j(t) = u^{K,j}(t)k^j(t)$. The measure of capital-utilization-adjusted-FBTC in sector j is: $\text{FBTC}^j_{adjK}(t) = \left(B^j(t)/A^j(t)\right)^{\frac{1-\sigma^j}{\sigma^j}}$. Utilization-adjusted technological change is biased toward labor when $\text{FBTC}^j_{adjK}(t)$ increases.

Finally, aggregating over the two sectors gives us the resource constraint for capital:

$$K^H(t) + K^N(t) = K(t). \tag{30}$$

[16] Since the profit function is a linear function of the technology utilization rate, i.e., $\tilde{\Pi}^j(t) = u^{Z,j}(t)\Pi^j(t)$, $u^{Z,j}(t)$ does not show up in the first-order conditions shown in (28).

3.3 Technology Frontier

While households choose capital and technology utilization rates, firms within each sector $j = H, N$ decide about the split of capital-utilization-adjusted-TFP, denoted by $Z^j(t) = u^{Z,j}(t)\bar{Z}^j$ where $\bar{Z}^j$ is normalized to one, between labor- and capital-augmenting efficiency $\tilde{A}^j(t)$ and $\tilde{B}^j(t)$. Following Caselli and Coleman [2006] and Caselli [2016], we assume that firms choose a mix of $\tilde{A}^j(t)$ and $\tilde{B}^j(t)$ along a technology frontier (which is assumed to take a CES form):

$$\left[\gamma_Z^j \left(\tilde{A}^j(t)\right)^{\frac{\sigma_Z^j-1}{\sigma_Z^j}} + \left(1-\gamma_Z^j\right)\left(\tilde{B}^j(t)\right)^{\frac{\sigma_Z^j-1}{\sigma_Z^j}}\right]^{\frac{\sigma_Z^j}{\sigma_Z^j-1}} \leq Z^j(t), \tag{31}$$

where $Z^j(t) > 0$ is the height of the technology frontier, $0 < \gamma_Z^j < 1$ is the weight of labor efficiency in utilization-adjusted-TFP and $\sigma_Z^j > 0$ corresponds to the elasticity of substitution between labor- and capital-augmenting productivity. Firms choose labor and capital efficiency, $\tilde{A}^j$ and $\tilde{B}^j$, along the technology frontier described by eq. (31) that minimizes the unit cost function. The unit cost minimization requires that (see Online Appendix J):

$$\frac{\gamma_Z^j}{1-\gamma_Z^j}\left(\frac{\tilde{A}^j(t)}{\tilde{B}^j(t)}\right)^{\frac{\sigma_Z^j-1}{\sigma_Z^j}} = \frac{s_L^j(t)}{1-s_L^j(t)} \equiv S^j(t). \tag{32}$$

Solving (32) for the LIS in sector j leads to $s_L^j = \gamma_Z^j \left(\tilde{A}^j/Z^j\right)^{\frac{\sigma_Z^j-1}{\sigma_Z^j}}$. Inserting this equality into the log-linearized version of the technology frontier (31) shows that technological change in sector j is a factor-income-share-weighted sum of changes in factor-augmenting efficiency:

$$\hat{Z}^j(t) = s_L^j \hat{\tilde{A}}^j(t) + \left(1-s_L^j\right)\hat{\tilde{B}}^j(t). \tag{33}$$

While the technological frontier imposes a structure on the mapping between the utilization-adjusted-TFP and factor-augmenting efficiency, as described by (33), it has the advantage of ensuring a consistency between the theoretical and the empirical approach where we used the utilization-adjusted-Solow residual to measure technological change. More specifically, we assume that technology improvement is Hicks-neutral within each sector j, i.e., $Z^j(t) = u^{Z,j}(t)$, while the stock of knowledge is made up of a mix of labor- and capital-augmenting productivity which can be modified at each point in time, thus leading technological change to be factor-biased.

3.4 Government

The final agent in the economy is the government. Government spending includes expenditure on non-traded goods, G^N, home- and foreign-produced traded goods, G^H and G^F, respectively. The government finances public spending, G, by raising lump-sum taxes, T. As a result, Ricardian equivalence obtains and the time path of taxes is irrelevant for the real allocation. We may thus assume without loss of generality that government budget is balanced at each instant:

$$G(t) \equiv P^N(t)G^N(t) + P^H(t)G^H(t) + G^F(t) = T(t). \tag{34}$$

In Online Appendix U, we allow for distortionary labor and consumption taxation and consider a rise in government spending which is debt-financed. Quantitative results displayed in Online Appendix U.7 show that results are similar to those obtained when assuming a balanced-budget government spending shock.

3.5 Model Closure and Equilibrium

To fully describe the equilibrium, we impose goods market clearing conditions for non-traded and home-produced traded goods:

$$Y^N(t) = C^N(t) + J^N(t) + G^N(t) + C^{K,N}(t)K^N(t) + C^{Z,N}(t), \tag{35a}$$

$$Y^H(t) = C^H(t) + J^H(t) + G^H(t) + X^H(t) + C^{K,H}(t)K^H(t) + C^{Z,H}(t), \tag{35b}$$

where X^H stands for exports of home-produced goods; exports are assumed to be a decreasing function of terms of trade, P^H:[17]

$$X^H(t) = \varphi_X \left(P^H(t)\right)^{-\phi_X}, \tag{36}$$

where $\varphi_X > 0$ is a scaling parameter, and ϕ_X is the elasticity of exports w.r.t. P^H.

Setting the dynamics of government consumption and FBTC. We drop the time index below to denote steady-state values. In order to account for the dynamic adjustment of $G(t)$ (see Fig. 2(a)), we assume that the deviation of government spending relative to its initial value, i.e., $dG(t) = G(t) - G$, as a percentage of initial GDP is governed by the law of motion:

$$dG(t)/Y = e^{-\xi t} - (1-g)\, e^{-\chi t}, \tag{37}$$

where $g > 0$ parametrizes the magnitude of the exogenous fiscal shock, $\xi > 0$ and $\chi > 0$ are (positive) parameters which are set in order to capture the hump-shaped endogenous response of $G(t)$. We assume that the rise in government consumption is split into non-traded, ω_{G^N}, home-produced traded goods, $\omega_{G^H} = \frac{P^H G^H}{G}$, and foreign-produced traded goods, ω_{G^F}. Formally, we have $dG(t)/Y = \sum_{g=F,H,N} \omega_{G^g} dG(t)/Y$. In line with the evidence we document in Appendix G, ω_{G^N} refers to the non-tradable content of government consumption, as well as the intensity of the government spending shock in non-traded goods.

To recover the dynamics of factor-augmenting productivity, we adopt a wedge analysis. As detailed in subsection 4.2, we estimate the shifts of $A^j(t)$ and $B^j(t)$ along the technology

[17] Domestic exports are the sum of foreign demand for the domestically produced tradable consumption goods and investment inputs denoted by $C^{F,\star}$ and $J^{F,\star}$, and we assume that the rest of the world have similar preferences with potentially different elasticities (i..e, $\phi^\star \neq \phi$ and $\phi_J^\star \neq \phi_J$) between foreign and domestic tradable goods. Since we abstract from trend labor-augmenting technological change, foreign prices remain fixed so that domestic exports are decreasing in the terms of trade, $P^H(t)$.

frontier (31), which are consistent with the demand for labor relative to the demand for capital described by (29). To achieve a perfect match with the data, we specify the law of motion for labor- and capital-augmenting efficiency expressed as a percentage deviation relative to the initial steady-state:

$$\hat{A}^j(t) = e^{-\xi_A^j t} - \left(1 - a^j\right) e^{-\chi_A^j t}, \tag{38a}$$

$$\hat{B}^j(t) = e^{-\xi_B^j t} - \left(1 - b^j\right) e^{-\chi_B^j t}, \tag{38b}$$

and choose a^j (b^j) to reproduce the impact response of labor- (capital-) augmenting technological change while $\xi_A^j > 0$ ($\xi_B^j > 0$) and $\chi_A^j > 0$ ($\chi_B^j > 0$) are chosen to reproduce the shape of factor-augmenting productivity together with their cumulative change following a shock to government consumption that we infer from (29) and (33).

Solving the model for a shock to government consumption. The adjustment of the open economy toward the steady state is described by a dynamic system which comprises two equations that are functions of $K(t)$, $Q(t)$, $G(t)$, $A^j(t)$, $B^j(t)$:

$$\dot{K}(t) = \Upsilon\left(K(t), Q(t), G(t), A^H(t), B^H(t), A^N(t), B^N(t)\right), \tag{39a}$$

$$\dot{Q}(t) = \Sigma\left(K(t), Q(t), G(t), A^H(t), B^H(t), A^N(t), B^N(t)\right). \tag{39b}$$

The first dynamic equation corresponds to the non-traded goods market clearing condition (35a) and the second dynamic equation corresponds to (23e), which equalizes the rates of return on domestic equities and foreign bonds, $r^\star$, once we have substituted appropriate first-order conditions. Linearizing the dynamic equations (39a)-(39b) in the neighborhood of the steady-state, inserting the law of motion of government consumption (37) and factor-augmenting efficiency (38a)-(38b) leads to a system of first-order linear differential equations which can be solved by applying standard methods (see solution method by Buiter [1984] for continuous time models):

$$K(t) - K = X_1(t) + X_2(t), \quad Q(t) - Q = \omega_2^1 X_1(t) + \omega_2^2 X_2(t), \tag{40}$$

where we denote the negative eigenvalue by ν_1, the positive eigenvalue by ν_2, and ω_2^i is the element of the eigenvector associated with the eigenvalue ν_i (with $i = 1, 2$) and $X_1(t)$ and $X_2(t)$ are solutions which characterize the trajectory of $K(t)$ and $Q(t)$. See Online Appendix T which details the solution method.

Using the properties of constant returns to scale in production, identities $P_C(t)C(t) = \sum_g P^g(t)C^g(t)$ and $P_J(t)J(t) = \sum_g P^g(t)J^g(t)$ (with $g = F, H, N$) along with market clearing conditions (35), the current account equation (16) can be rewritten as a function of the trade balance:

$$\dot{N}(t) = r^\star N(t) + P^H(t)X^H(t) - M^F(t), \tag{41}$$

where $M^F(t) = C^F(t) + G^F(t) + J^F(t)$ stands for imports of foreign-produced consumption and investment goods. Eq. (41) can be written as a function of state and control variables, i.e., $\dot{N}(t) \equiv r^{\star}N(t) + \Xi\left(K(t), Q(t), G(t), A^H(t), B^H(t), A^N(t), B^N(t)\right)$. Linearizing around the steady state, substituting the solutions for $K(t)$ and $Q(t)$ given by (40), solving and invoking the transversality condition leads to the intertemporal solvency condition:

$$(N_0 - N) + \frac{\omega_N^1}{\nu_1 - r^{\star}} + \frac{\omega_N^{2,G}}{\xi + r^{\star}} + \sum_{X^j} \frac{\omega_N^{2,X^j}}{\xi_X^j + r^{\star}} = 0, \tag{42}$$

where N_0 is the initial stock of traded bonds, $X^j = A^j, B^j$ with $j = H, N$; ω_N^1, $\omega_N^{2,G}$, ω_N^{2,X^j}, are terms which are functions of parameters, eigenvalues and eigenvectors. The assumption $\beta = r^{\star}$ requires the joint determination of the transition and the steady-state since the constancy of the marginal utility of wealth implies that the intertemporal solvency condition (42) depends on eigenvalues' and eigenvectors' elements, see e.g., Turnovsky [1997].[18]

4 Quantitative Analysis

In this section, we take the model to the data. For this purpose we solve the model numerically. Therefore, first we discuss parameter values before turning to the effects of an exogenous temporary increase in government consumption.

4.1 Calibration

Calibration strategy. At the steady-state, utilization rates for technology, $u^{Z,j}$, and capital, $u^{K,j}$, collapse to one so that $\tilde{Y}^j = Y^j$ and $\tilde{K}^j = K^j$. We consider an initial steady-state with Hicks-neutral technological change and normalize $A^j = B^j = Z^j$ to 1. To ensure that the initial steady-state with CES production functions is invariant when σ^j is changed, we normalize CES production functions by choosing the initial steady-state in a model with Cobb-Douglas production functions as the normalization point. To calibrate the reference model that we use to normalize the CES economy, we have estimated a set of ratios and parameters for the eighteen OECD economies in our dataset. Our reference period for the calibration corresponds to the period 1970-2015. Table 6 summarizes our estimates of the ratios and estimated parameters for all countries in our sample.

We first calibrate the model to a representative OECD country to assess the model's performance when we allow for time-varying technological change and contrast the model's predictions when we shut down technological change. Later, we move a step further and calibrate the model to country-specific data to quantify the contribution of technological change to international differences in sectoral government spending multipliers. To capture the key properties of a typical OECD economy, we take unweighted average values of ratios, which are shown in the last line of Table 6. Among the 32 parameters that the model contains, 22 have empirical counterparts while the remaining 10 parameters, i.e., φ, ι, φ^H, ι^H, ϑ, δ_K, ξ_1^H, ξ_1^N, χ_1^H, χ_1^N together with initial conditions (N_0, K_0), must be

[18]Eq. (42) determines the steady-state change in the net foreign asset position following a temporary fiscal expansion, as the assumption $\beta = r^{\star}$ implies that temporary policies have permanent effects.

endogenously calibrated to match ratios $1-\alpha_C$, $1-\alpha_J$, α^H, α_J^H, $\frac{L^N}{L}$, ω_J, R/P^H, R/P^N, Y^H, Y^N, $\upsilon_{NX} = \frac{NX}{P^H Y^H}$ with $NX = P^H X^H - C^F - I^F - G^F$, as summarized in Table 7, relegated to Online Appendix M.1. We choose the model period to be one year and set the world interest rate, $r^\star$, which is equal to the subjective time discount rate, β, to 3%, in line with the average of our estimates, shown in the last line of Table 5.

Preferences. The degree of labor mobility captured by ϵ is set to 0.83, in line with the average of our estimates, shown in the last line of column 17 of Table 6. Estimated values of ϵ range from a low of about 0.1 for Ireland and Norway to a high of 2.3 for South Korea and 2.4 for the United States. See Online Appendix M.2, which details our empirical strategy and shows our panel data estimations of ϵ.

Building on our panel data estimates, the elasticity of substitution ϕ between traded and non-traded goods is set to 0.77 in the baseline calibration, since this value corresponds to the average of estimates shown in the last line of column 16 of Table 6. This value is close to the estimated elasticity by Mendoza [1995], who reports an estimate of 0.74. See Online Appendix M.2, which details our empirical strategy and shows our panel data estimations of ϕ. The weight of consumption in non-tradables $1-\varphi$ is set to target a non-tradable content in total consumption expenditure (i.e., $1-\alpha_C$) of 56%, in line with the average of our estimates (see the last line of column 2 of Table 6). Following Backus et al. [1994], we set the elasticity of substitution, ρ, in consumption between home- and foreign-produced traded goods (inputs) to 1.5. The weight of consumption in home-produced traded goods φ^H is set to target a home content of consumption expenditure in tradables (i.e. α^H) of 66%, in line with the average of our estimates shown in the last line of column 8 of Table 6.

We choose a value of one for the elasticity of intertemporal substitution for consumption, σ_C, which is a typical choice in the business cycle literature. We set the Frisch elasticity of labor supply to 1 which is halfway between the large values of σ_L reported by Peterman [2016] and low values reported by Fiorito and Zanella [2012]. The weight of labor supply to the non-traded sector, $1-\vartheta$, is set to target a share of non-tradables in total hours worked of 62% (see the last line of column 5 of Table 6).

Production and investment. We now describe the calibration of production-side parameters. We assume that physical capital depreciates at a rate $\delta_K = 7.8\%$ to target an investment-to-GDP ratio of 24% (see column 14 of Table 6). In line with mean values shown in columns 11 and 12 of Table 6, the shares of labor income in traded and non-traded value added, s_L^H and s_L^N, are set to 0.63 and 0.69, respectively, which leads to an aggregate LIS of 66% (see the last line of column 13 of Table 6). We set the elasticity of substitution, ϕ_J, between J^T and J^N to 1, in line with the empirical findings documented by Bems [2008] for OECD countries. Further, the weight of non-traded investment $(1-\varphi_I)$ is set to target a non-tradable content of investment expenditure of 69% (see the last line of column 3 of Table 6). Like for consumption goods, following Backus et al. [1994], we set the elasticity of substitution, ρ_J, in investment between home- and foreign-produced traded inputs to 1.5. The weight of home-produced traded investment ι^H is set to target a home content of investment expenditure in tradables (i.e. α_J^H) of 43% (see column 9 of Table 6). We choose the value of parameter κ so that the elasticity of I/K with respect to Tobin's q, i.e., Q/P_J, is equal to the value implied by estimates in Eberly, Rebelo, and Vincent [2008]. The resulting value of κ is equal to 17.

Demand components. As shown in columns 4 and 10 of Table 6, the non-tradable, ω_{G^N}, and the home-produced tradable content, ω_{G^H}, of government spending averages 80% and 18%, respectively. The import content of government spending is lower at $\omega_{G^F} =$ 2%. We set government consumption on non-traded goods and home-produced traded goods, i.e., G^N and G^H, so as to target both the non-tradable and home-tradable share of government spending, together with government spending as a share of GDP of 19% (see column 15 of Table 6).

We choose initial conditions so that trade is initially balanced. Since net exports are nil, the investment-to-GDP ratio, ω_J, and government spending as a share of GDP, ω_G, imply a consumption-to-GDP ratio of $\omega_C = 57\%$. It is worth mentioning that the tradable content of GDP is endogenously determined by the market clearing condition for traded goods, i.e., $P^H Y^H / Y = \omega_C \alpha_C + \omega_J \alpha_J + \omega_{G^T} \omega_G = 36\%$ where $\omega_{G^T} = \omega_{G^H} + \omega_{G^F}$. Building on structural estimates of the price elasticities of aggregate exports documented by Imbs and Mejean [2015], we set the export price elasticity, ϕ_X, to 1.7 in the baseline calibration (see the last line of the last column of Table 6). Because trade is balanced, export as a share of GDP, $\omega_X = P^H X^H / Y$, is endogenously determined by the import content of consumption, $1 - \alpha^H$, government spending, ω_{G^F}, and investment expenditure, $1 - \alpha_J^H$, along with ω_C, ω_G, and ω_J.

CES production functions. Since the model with Cobb-Douglas production functions is the normalization point, when we calibrate the model with CES production functions, φ, ι, φ^H, ι^H, ϑ, δ_K, N_0, K_0, Z^j, γ^j are endogenously set to target $1 - \bar{\alpha}_C$, $1 - \bar{\alpha}_J$, $\bar{\alpha}^H$, $\bar{\alpha}_J^H$, $\bar{L}^N / \bar{L}$, $\bar{\omega}_J$, $\bar{\upsilon}_{NX}$, $\bar{K}$, $\bar{y}^j$, $\bar{s}_L^j$, respectively, where a bar indicates that the ratio is obtained from the Cobb-Douglas economy. Drawing on Antràs [2004], we estimate the elasticity of substitution between capital and labor for tradables and non-tradables and set σ^H and σ^N, to 0.64 and 0.80 (see the last line of columns 18 and 19 of Table 6).

4.2 Government Spending Shock and Technology: Calibration

Endogenous response of government consumption to exogenous fiscal shock. In order to capture the endogenous response of government spending to an exogenous fiscal shock, we assume that the dynamic adjustment of government consumption is governed by eq. (37). In the quantitative analysis, we set $g = 0.01$ so that government consumption increases by 1% of initial GDP. To calibrate ξ and χ which parametrize the shape of the dynamic adjustment of government consumption along with its persistence, we proceed as follows. Because $G(t)$ peaks after one year, we have $\dot{G}(1)/Y = -\left[\xi e^{-\xi} - \chi\left(1-g\right)e^{-\chi}\right] = 0$. In addition, the cumulative response of government consumption over a six-year horizon is $\int_0^5 \left[dG(\tau)/Y\right] e^{-r^{\star}\tau} d\tau = g'$ with $g' = 5.5$ percentage point of GDP. We choose $\xi = 0.430$ and $\chi = 0.439$. Left-multiplying eq. (37) by ω_{G^g} (with $g = F, H, N$) gives the dynamic adjustment of sectoral government consumption to an exogenous fiscal shock:

$$\omega_{G^g}\left(dG(t)/Y\right) = \omega_{G^g}\left[e^{-\xi t} - \left(1-g\right)e^{-\chi t}\right], \tag{43}$$

where ω_{G^g} is the fraction of government consumption in good g. To determine (43), we assume that the parameters that govern the persistence and shape of the response of sectoral government consumption are identical across sectors, while the sectoral intensity of the government spending shock is constant over time and thus collapses to the share of government final consumption expenditure on good j.[19]

Capital and technology utilization adjustment costs. We turn to the calibration of parameters which govern the capital and technology adjustment cost functions described by (15a) and (15b), respectively. Evaluating first-order conditions (23f)-(23g) at the steady-state leads to $\xi_1^j = \frac{R}{P^j}$, and thus ξ_1^j is endogenously pinned down by the initial steady-state value of the ratio of the capital rental rate to the value added deflator, P^j. It gives us $\xi_1^H = 0.11$ and $\xi_1^N = 0.09$. Denoting $R^j(t) = R(t)u^{Z,j}(t)$ and log-linearizing (23f)-(23g) leads to:

$$\hat{u}^{K,j}(t) = \frac{\xi_1^j}{\xi_2^j}\left(\hat{R}^j(t) - \hat{P}^j(t)\right). \tag{44}$$

According to eq. (44), it is profitable to increase the capital utilization rate when the real capital cost goes up, while the parameter ξ_2^j determines the magnitude of the adjustment in $u^{K,j}(t)$. We choose a value for the parameter ξ_2^j so as to account for the empirical response of the capital utilization rate following a government spending shock, see Fig. 7 in Online Appendix F.[20] The same logic applies to pinning down the parameters governing the endogenous response of the technology utilization rate in sector j to a shock to government consumption. Evaluating first-order conditions (23h)-(23i) at the steady-state leads to $\chi_1^j = Y^j$. We obtain $\chi_1^H = 0.84$ and $\chi_1^N = 1.19$. Log-linearizing (23h)-(23i) leads to:

$$\hat{u}^{Z,j}(t) = \frac{\chi_1^j}{\chi_2^j}\hat{Y}^j(t). \tag{45}$$

[19] Assuming that the intensity of the non-traded sector in the government spending shock collapses to the non-tradable content of government consumption is in line with the evidence documented in Online Appendix G, especially in the short-run.

[20] As reported in Table 7, we choose a value for ξ_2^H of 0.27 and a value for ξ_2^N of 0.03. Alternatively, eq. (44) can be solved for $\xi_2^j = \frac{\xi_1^j}{\hat{u}^{K,j}(t)}\left(\hat{R}^j(t) - \hat{P}^j(t)\right)$. Plugging empirical IRF from local projection estimations and calculating the mean returns a value of 0.22 for ξ_2^H and 0.05 for ξ_2^N which are close to the values we choose.

According to eq. (45), the technology utilization rate is pro-cyclical; intuitively, since $Y^j(t) = \frac{W^j(t)L^j(t)+R(t)\tilde{K}^j(t)}{P^j(t)}$, it is profitable to increase the technology rate when the real cost of producing goes up. The parameter χ_2^j determines the magnitude of the response of the technology utilization rate $u^{Z,j}(t)$. We choose a value for χ_2^j in order to reproduce the empirical response of the capital-utilization-adjusted-TFP, $Z^j(t)$, see Table 7.

Factor-augmenting efficiency. To set the adjustment of factor-augmenting efficiency, $B^j(t)$ and $A^j(t)$, we first recover they dynamics in the data. Using the fact that factor-augmenting productivity has a symmetric time-varying component denoted by $u^{Z,j}(t)$ such that $\tilde{A}^j(t) = u^{Z,j}(t)A^j(t)$ and $\tilde{B}^j(t) = u^{Z,j}(t)B^j(t)$, log-linearizing the demand for labor relative to the demand for capital (29) and using the log-linearized version of the technology frontier (33), we can solve for changes in labor- and capital-augmenting productivity:

$$\hat{A}^j(t) = -\left(1 - s_L^j\right)\left[\left(\frac{\sigma^j}{1-\sigma^j}\right)\hat{S}^j(t) - \hat{k}^j(t) - \hat{u}^{K,j}(t)\right], \tag{46a}$$

$$\hat{B}^j(t) = s_L^j\left[\left(\frac{\sigma^j}{1-\sigma^j}\right)\hat{S}^j(t) - \hat{k}^j(t) - \hat{u}^{K,j}(t)\right]. \tag{46b}$$

Plugging estimated values for σ^j and empirically estimated responses for $s_L^j(t)$, $k^j(t)$, $u^{K,j}(t)$ into above equations enables us to recover the dynamics for $A^j(t)$ and $B^j(t)$ consistent with the demand for factors of production (29) and the technology frontier (33).

Once we have determined the underlying dynamic process for labor and capital efficiency by using (46a)-(46b), we have to choose values for exogenous parameters x^j (for $x = a, b$), ξ_X^j and χ_X^j (for $X = A, B$) within sector $j = H, N$, which are consistent with the continuous time paths (38). Setting $t = 0$ into (38a)-(38b) yields $a^j = \hat{A}^j(0)$, and $b^j = \hat{B}^j(0)$ and we choose a^j and b^j so as to reproduce the impact responses of factor-augmenting productivity in sector j. Next, we choose values for ξ_X^j and χ_X^j so as to reproduce the shape of the dynamic adjustment of sectoral factor-augmenting efficiency recovered by using (46) together with its cumulative change over a six-year period.

4.3 Government Spending Shock and Technology: Model Performance

In this subsection, we analyze the role of technology in shaping the size of sectoral fiscal multipliers in an open economy following an exogenous temporary increase in government consumption by 1% of GDP. In our baseline calibration, we assume that capital and technology utilization rates, $u^{K,j}(t)$ and $u^{Z,j}(t)$, respond endogenously to the government spending shock, and allow for time-varying FBTC in sector j driven by the dynamic adjustment of labor- and capital-augmenting efficiency, while sectoral goods are produced from CES production functions. To gauge the quantitative implications of technology for fiscal transmission, we contrast our results with those obtained in a restricted model with Cobb-Douglas production functions where we shut down the endogenous response of capital and technology utilization by letting ξ_2^j and χ_2^j tend towards infinity and impose $\xi_A^j = \xi_B^j = \chi_A^j = \chi_B^j = 0$ so that $u^{K,j}(t) = u^{Z,j}(t) = A^j(t) = B^j(t) = 1$.

In Table 1, we report the simulated impact (i.e., at $t = 0$) and six-year cumulative (i.e., at $t = 0, ..., 5$) effects. Cumulative effects are expressed in present discounted value terms.[21] While columns 1 and 4 show impact and (present discounted value of) cumulative responses from local projection for comparison purposes, columns 2 and 5 show results for the baseline model. We contrast the benchmark results with those shown in columns 3 and 6 for impact and cumulative effects, respectively, which are obtained in the restricted model where technology is shut down. While in Table 1, we focus on sectoral government spending multipliers, numerical results for sectoral TFPs, utilization-adjusted-TFPs, and sectoral LISs are displayed in Table 11, relegated to Online Appendix N for reasons of space.

Adjustment in government consumption. As can be seen in the first row of panel A of Table 1, the baseline (and the restricted) model generates a present discounted value of the cumulative change in government consumption of 5.46 ppt of GDP (see columns 5-6), close to our estimation of 5.51 ppt (see column 4). As shown in Fig. 4(a), the black line with squares lies within the confidence bounds, and therefore the endogenous response of government spending to an exogenous fiscal shock that we generate theoretically by specifying the law of motion (37) reproduces well the dynamic adjustment of $G(t)/Y$ estimated from the local projection shown in the blue line.

Restricted model. We first consider the scenario with Cobb-Douglas production functions, i.e., $\sigma^j = 1$, we let ξ_2^j and χ_2^j tend toward infinity, and impose $\xi_A^j = \xi_B^j = \chi_A^j = \chi_B^j = 0$. Results for the restricted model are reported in columns 3 and 6 of Table 1. Because the capital and technology utilization rates remain fixed, sectoral TFPs are unchanged (see panel D of Table 11 in Online Appendix N). Because the elasticity of value added w.r.t. inputs is fixed, the fraction of value added paid to workers, i.e., the LIS, does not change over time (see panel E of Table 11).

We start with the aggregate effects. By producing a negative wealth effect, a balanced-budget government spending shock leads agents to supply more labor, which in turn increases real GDP. As shown in panel A of Table 1, a rise in government consumption by 1% of GDP generates an increase in total hours worked by 0.63% and a rise in real GDP by 0.42% on impact, the latter value being almost three times smaller than what we estimate empirically (i.e., 1.18%, see column 1).

Panel B of Table 1 shows that hours worked increase by 0.54 ppt of total hours worked in the non-traded sector and by 0.09 ppt only in the traded sector. Formally, the rise in non-traded hours worked can be broken into two components, i.e., $\alpha_L^N \hat{L}^N(t) = \alpha_L^N \hat{L}(t) + d\nu^{L,N}(t)$. The government spending multiplier on non-traded labor is larger than that for tradables, since the non-traded sector accounts for a greater fraction of labor (as captured

[21] The percentage deviation of each macroeconomic variable $X(t)$ relative to its initial steady-state is denoted with a hat, i.e., $\hat{X}(t) = dX(t)/X$. We calculate the present discounted value of the percentage deviation relative to the initial steady-state as follows: $\int_0^t \hat{X}(\tau)e^{-r^\star \tau}d\tau$.

by α_L^N which averages 63% in the data) and because labor shifts towards the non-traded sector, as captured by $d\nu^{L,N}(t) > 0$, as a result of the biasedness of the government spending shock towards non-tradables.

As shown in the third row of panel B, the demand shock raises the labor share of non-tradables, $\nu^{L,N}(t)$, by 0.14 ppt of total hours worked on impact, close to what we estimate empirically. In this regard, it is worth mentioning that barriers to mobility included in the restricted (and baseline) setup avoid the model overestimating the reallocation of labor. If we had imposed perfect mobility of labor and exogenous terms of trade, the labor share of non-tradables would have increased by 0.77 ppt of total hours worked, while traded hours worked would have declined dramatically (by $\alpha_L^H \hat{L}^H(0) = -0.71$ ppt of total hours worked), see Online Appendix P.[22] Conversely, by increasing the demand for labor in the traded sector and hampering the reallocation of labor toward the non-traded sector, both the appreciation in the terms of trade and workers' mobility costs mitigate the rise in $\nu^{L,N}(t)$ and thus allow the model to generate an increase in L^H instead of a decline.

Contrasting the sectoral labor cumulative effects (shown in panel B) estimated empirically (column 3) with those estimated numerically (column 6) reveals that the restricted model substantially understates the government spending multiplier on non-traded labor by understating both the rise in labor supply and the cumulative change in $\nu^{L,N}(t)$ (0.71 ppt against 1.68 ppt of total hours worked).

We turn to the distribution of the rise in real GDP across sectors displayed by panel C of Table 1. The first row of panel C reveals that $\tilde{Y}^H$ falls by 0.04 ppt of GDP and non-traded value added rises by 0.46 ppt of GDP. The decline in traded value added caused by the capital outflow experienced by this sector is at odds with the evidence, as we find empirically that $\tilde{Y}^H$ rises by 0.33 ppt of GDP on impact (see column 1). The restricted model also understates the rise in $\tilde{Y}^N$ both on impact (0.46 ppt against 0.85 ppt in the data) and along the transitional path (2.41 ppt against 4.88 ppt in the data). While the restricted model underpredicts $\hat{\tilde{Y}}^N(t)$, it produces a cumulative change in $\nu^{Y,N}(t)$ by 1.07 ppt of GDP, in contradiction with our empirical findings indicating that the value added share of non-tradables is essentially unchanged (see the third row of column 4). The underestimation of the increase in $\tilde{Y}^N(t)$ is the result of the underestimation of real GDP growth (2.14% against 7.74% in the data) caused by fixed TFP.

Baseline model. The performance of the model increases when capital and technology utilization rate are allowed to respond endogenously to the government spending shock and firms bias technological change toward production factors. Quantitative results are shown in column 2 for impact effects and column 5 for (the present discounted value of the)

[22] Columns 3 and 6 of Table 14 in Online Appendix P show numerical results for a model assuming Cobb-Douglas production functions, abstracting from technological change, imposing perfect mobility of labor across sectors (i.e., we let ϵ tend toward infinity) and exogenous terms of trade (i.e., we let ρ and ρ_J tend toward infinity).

Table 1: Impact and Cumulative Effects of an Increase in Government Consumption by 1% of GDP

	LP $t = 0$	Impact Responses		LP $t = 0..5$	Cumulative Responses	
	Data	CES-TECH	CD	Data	CES-TECH	CD
	(1)	(2)	(3)	(4)	(5)	(6)
A.Aggregate Multipliers						
Gov. spending, $dG(t)$	1.00	1.00	1.00	5.51	5.46	5.46
Total hours worked, $dL(t)$	0.91	0.97	0.63	6.37	5.61	3.34
Real GDP, $dY_R(t)$	1.18	1.07	0.42	7.74	7.36	2.14
B.Sectoral Labor						
Traded labor, $dL^H(t)$	0.21	0.18	0.09	0.73	0.69	0.47
Non-traded labor, $dL^N(t)$	0.71	0.78	0.54	5.64	4.92	2.87
Labor share of non-tradables, $d\nu^{L,N}(t)$	0.13	0.16	0.14	1.68	1.26	0.71
Decomposition						
Caused by $d\omega^{Y,N}(t)$		0.14	0.14		0.31	0.71
Caused by cap. deep. differential		0.01	0.00		-0.24	0.00
Caused by **FBTC** differential		0.01	0.00		1.20	0.00
C.Sectoral Value Added						
Traded VA, $dY^H(t)$	0.33	0.20	-0.04	2.86	3.12	-0.28
Non-traded VA, $dY^N(t)$	0.85	0.88	0.46	4.88	4.24	2.41
Non-traded VA share, $d\nu^{Y,N}(t)$	0.16	0.20	0.20	-0.01	-0.41	1.07
Decomposition						
Caused by TFP differential		0.03	0.00		-0.47	0.00
Caused by labor reallocation		0.16	0.14		1.30	0.72
Caused by capital reallocation		0.01	0.06		-1.23	0.35

Notes: Impact ($t = 0$) and cumulative ($t = 0...5$) effects of an exogenous temporary increase in government consumption by 1% of GDP. Panels A,B,C show the deviation in percentage relative to the steady-state for aggregate and sectoral variables. Sectoral value added and value added share are expressed as a percentage of initial GDP, while sectoral labor and labor shares are expressed as a percentage of initial total hours worked. Columns 2 and 5, labelled 'CES-TECH', show predictions of the baseline model while columns 3 and 6, labelled 'CD', shows predictions of the restricted version of the model. In the restricted model, we impose $\sigma^j = 1$ so that production functions are Cobb-Douglas, let ξ_2^j, χ_2^j tend toward infinity so that the capital and technology utilization rate collapses to one, and set ξ_A^j, χ_A^j, ξ_B^j, χ_B^j to zero so that the labor- and capital-augmenting technological rate remain fixed. In columns 1 and 4, we report point estimates from local projections. Since there is a (slight) discrepancy between the response of aggregate real GDP (total hours worked) and the sum of the responses of traded and non-traded value added (hours worked), columns 1 and 4 report the sum of responses of Y^H and Y^N (L^H and L^N, resp.) to ensure consistency between aggregate and sectoral responses.

cumulative effects over a six-year horizon.

As can be seen in panel A of Table 1, the baseline model does a good job in reproducing the aggregate effects of a shock to government consumption. More specifically, total hours worked increase by 0.97%, close to the rise by 0.91% we estimate empirically. Like in the data, we find a government spending multiplier above one, as real GDP increases by 1.07% on impact against 1.18% in the data. Along the transitional path, the baseline model produces a cumulative change in $L(t)$ and real GDP of 5.61% and 7.36% (vs. 6.37% and 7.74% in the data), respectively, thus generating a government spending multiplier on labor and real GDP of 1.03 and 1.35 on average over the first six years close to the multipliers of 1.16 and 1.40 that we estimate empirically. Three factors amplify the rise in total hours worked and in real GDP compared with the restricted model. First, in the face of a higher real capital cost, both sectors, especially traded firms, increase the capital utilization rate, $u^{K,j}(t)$. By raising the demand for labor and the use of capital input, higher capital utilization amplifies the rise in $L(t)$ and $\tilde{Y}_R(t)$. Second, because the rise in government spending puts upward pressure on the unit cost for producing, it is optimal to increase the technology utilization rate in both sectors.[23] Whilst the rise in aggregate TFP directly increases real GDP, it also raises $\tilde{Y}_R(t)$ by increasing the wage rate, which encourages agents to supply more labor. Third, as discussed below, the rise in $L(t)$ is amplified because the production technology becomes more labor-intensive in the non-traded sector, which accounts for two-thirds of total hours worked.

Panel B of Table 1 reveals that the baseline model with endogenous technology reproduces well the adjustment in traded and non-traded hours worked, both on impact (column 2 vs. column 1) and over a six-year horizon (column 5 vs. column 4). As mentioned above, the restricted model understates the expansionary effect of a government spending shock on sectoral hours worked by shutting down the capital and technology utilization rates together with FBTC. Conversely, as shown in column 5, the baseline model can reproduce the cumulative rise in traded and non-traded hours worked which amounts to 0.69 ppt and 4.92 ppt of total hours worked. The reason is twofold. First, the model allowing for technological change can account for the increase in total hours worked, each sector receiving a share (equal to their labor compensation share, α_L^j) of $\hat{L}(t)$. Second, because non-traded firms bias technological change toward labor and traded firms bias technological change toward capital, technology further tilts the demand of labor toward non-tradables which amplifies the shift of labor toward the non-traded sector, as detailed below.

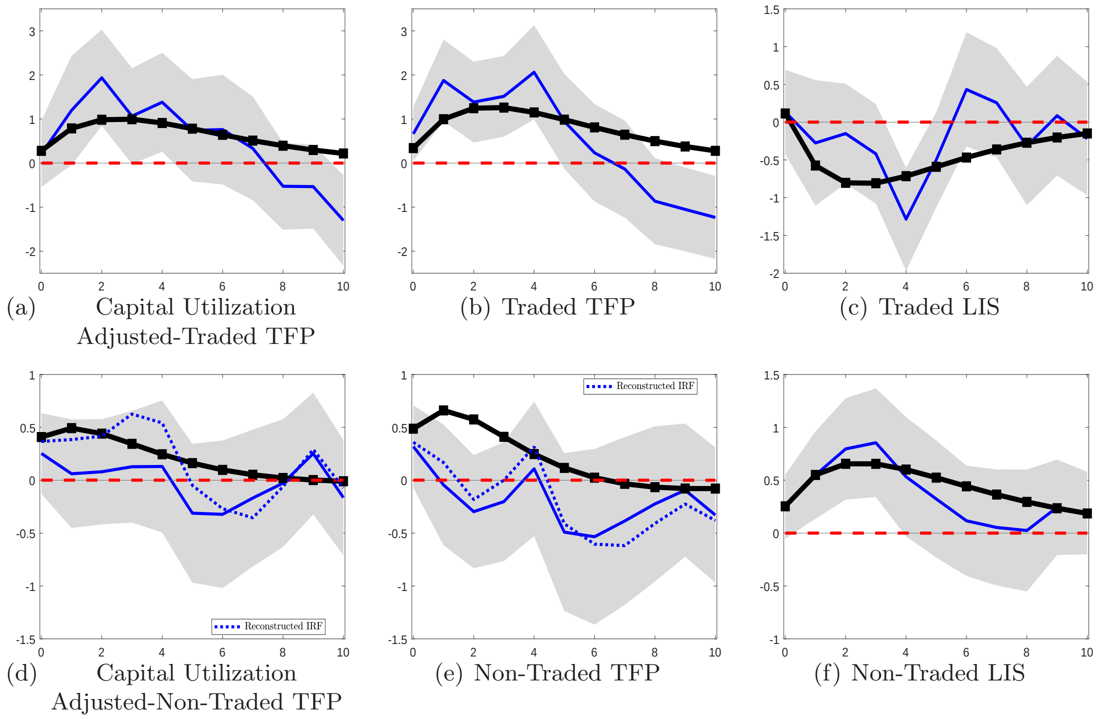
The reallocation of labor toward the non-traded sector is measured by the change in the labor share of non-tradables, $d\nu^{L,N}(t)$. When $d\nu^{L,N}(t) = 0$, the rise in total hours worked is uniformly distributed across sectors, while $d\nu^{L,N}(t) > 0$ implies that labor growth is concentrated in the non-traded sector. To get a better understanding of the factors leading

[23] Aggregate TFP increases by 0.43%, a value close to what we estimate empirically (i.e., 0.5%) on impact.

labor to shift toward the non-traded sector, the last three rows of panel B of Table 1 breaks down the change in the labor share of non-tradables into three components, see Online Appendix D which details the steps for breaking down $d\nu^{L,N}(t)$ analytically. Focusing on cumulative changes, the decomposition shown in column 6 of panel B for the restricted model reveals that the rise in $\nu^{L,N}(t)$ by 0.71 ppt of total hours worked is only driven by the biasedness of the demand shock toward non-tradables. When we turn to the decomposition of $d\nu^{L,N}(t)$ for the baseline model shown in column 5, our findings show that the bulk of $d\nu^{L,N}(t)$ is driven by the FBTC differential between non-tradables and tradables. The combined effect of technological change biased toward labor in the non-traded sector and biased toward capital in the traded sector generates on its own a cumulative reallocation of labor of 1.2 ppt of total hours worked toward the non-traded sector. The biasedness of the demand shock toward non-tradables further increases $\nu^{L,N}(t)$ by 0.31 ppt of total hours worked. Conversely, capital deepening in the traded sector increases labor demand in this sector, which lowers $\nu^{L,N}(t)$ by -0.24 ppt of total hours worked. The sum of these three effects results in a cumulative increase in the labor share of non-tradables by 1.26 ppt of total hours worked (1.68 ppt in the data). Importantly, FBTC contributes 69% on its own to the change in $\nu^{L,N}(t)$ over a six-year horizon.

We turn to the adjustment in sectoral value added at constant prices, shown in panel C of Table 1. While FBTC influences labor reallocation and the responses of sectoral hours worked, the variations in sectoral value added are mostly influenced by changes in sectoral TFPs. As can be seen in the first row of panel C, the restricted model abstracting from endogenous technological change predicts a fall in Y^H, both on impact and over a six-year horizon, which is in sharp contradiction with our estimates shown in columns 1 and 4. In contrast, by letting traded firms use installed capital and existing technology more intensively, the baseline model generates an increase in $\tilde{Y}^H(t)$ by 0.20 ppt of GDP on impact (0.33 ppt in the data) and 3.12 ppt of GDP over a six-year horizon (2.86 ppt in the data), as can be seen in columns 2 and 5. As discussed below, by allowing for sectoral differences in technology improvement, the baseline model can account for the distribution of the government spending multiplier on real GDP across sectors. More specifically, we estimate empirically a government spending multiplier of 0.52 (= 2.86/5.51) for tradables and 0.89 (= 4.88/5.51) for non-tradables on average over a six-year horizon, while the baseline model generates a multiplier of 0.57 (= 3.12/5.46) for tradables and 0.78 (= 4.24/5.46) for non-tradables, respectively.

Like labor, the change in the value added share of non-tradables, $d\nu^{Y,N}(t)$, indicates whether real GDP growth is symmetrically (i.e., $d\nu^{Y,j}(t) = 0$) or asymmetrically distributed across sectors. As shown in the third row of column 4, $d\nu^{Y,N}(t)$ remains almost unchanged and thus real GDP growth is distributed across sectors in accordance with their value added share. The last three rows of panel C of Table 1 provide a quantitative decomposition of the



(a) Capital Utilization Adjusted-Traded TFP (b) Traded TFP (c) Traded LIS

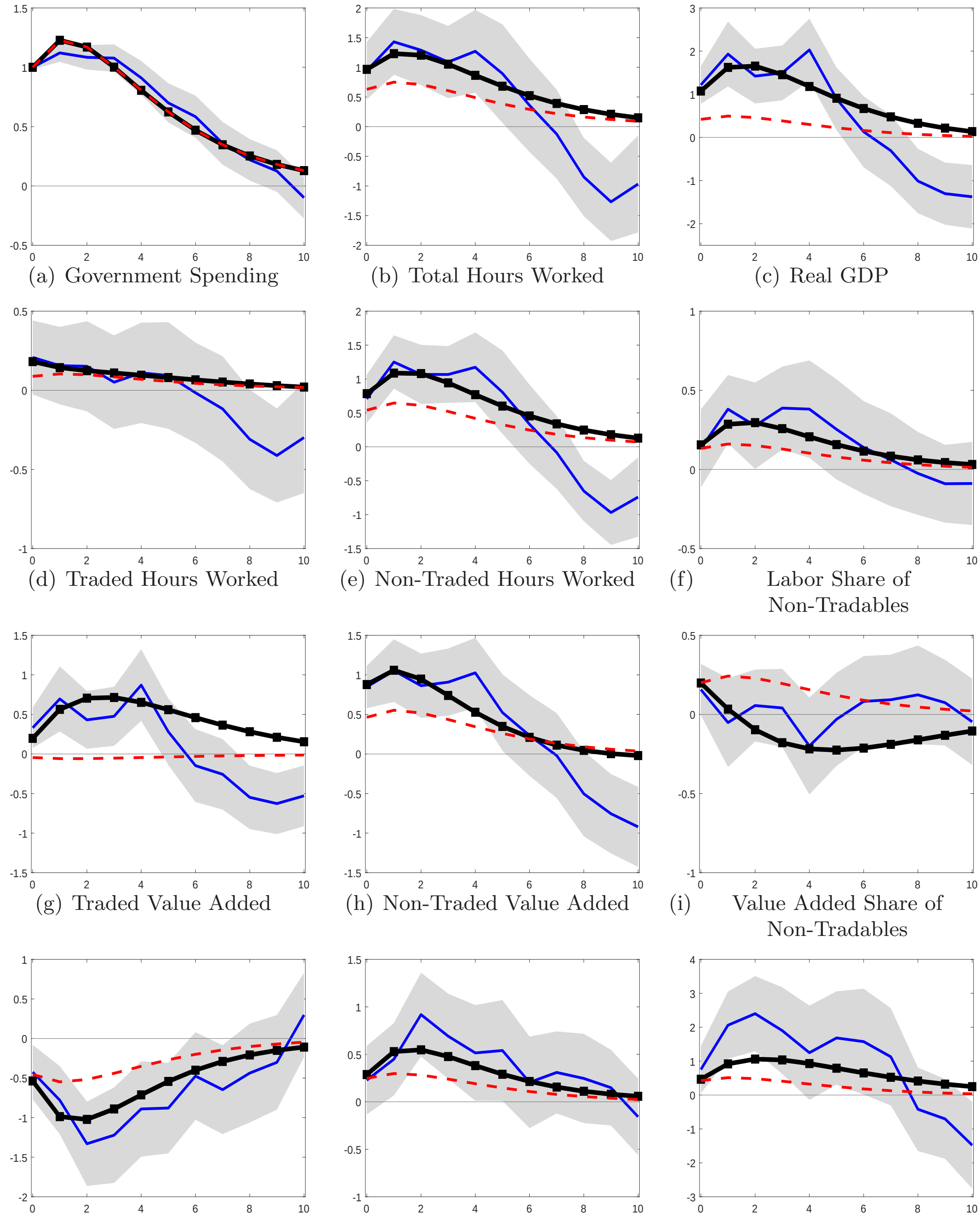
(d) Capital Utilization Adjusted-Non-Traded TFP (e) Non-Traded TFP (f) Non-Traded LIS

Figure 3: Theoretical vs. Empirical Responses Following Unanticipated Government Spending Shock: Technology Effects. Notes: Solid blue line displays point estimate from local projection with shaded areas indicating 90% confidence bounds; in the dotted blue line, we reconstruct the empirical response of $\text{TFP}^N(t)$ and $Z^N(t)$ because we found a substantial discrepancy between the empirically estimated and reconstructed responses. In the latter case, we use empirical responses of aggregate and traded TFP, which are both statistically significant, to reconstruct the dynamic responses of $\hat{\text{TFP}}^N(t)$ (by using eq. (56)), and we plug the latter together with the response of $\hat{u}^{K,N}(t)$ to recover $\hat{Z}^N(t)$. The thick solid black line with squares displays model predictions in the baseline scenario with capital and technology utilization together with FBTC, while the dashed red line shows predictions of a model with Cobb-Douglas production functions and abstracting from capital and technology utilization.

cumulative change in the value added share of non-tradables, see Online Appendix D for a formal derivation. As can be seen in column 6, when technological change is shut down, both labor and capital shift toward the non-traded sector, increasing $\nu^{Y,N}(t)$ by 1.07 ppt of GDP, in contradiction with our evidence. In contrast, in the baseline scenario displayed by column 5, the labor inflow amplified by technological change biased toward labor in the non-traded sector is almost fully offset by the capital outflow caused by technological change biased toward capital in the traded sector. Because TFP increases are concentrated in the traded sector, $\nu^{Y,N}(t)$ slightly declines by 0.41 ppt, which in turn prevents traded value added from decreasing, in line with our evidence.

Dynamics: Empirical vs. theoretical responses. While in Table 1, we restrict our attention to impact and cumulative responses, in Fig. 3 and Fig. 4, we contrast theoretical (displayed by solid black lines with squares) with empirical (displayed by solid blue lines) dynamic responses. Empirical responses display the point estimate obtained from local projections, with the shaded area indicating the 90% confidence bounds. We also contrast theoretical responses from the baseline model with the predictions of the restricted model, where we shut down the response of technology as shown in the dashed red lines.

We start with the adjustment of technology displayed by Fig. 3. Unsurprisingly, the restricted model shown in dashed red lines cannot account for technology change. Conversely,



(a) Government Spending
(b) Total Hours Worked
(c) Real GDP
(d) Traded Hours Worked
(e) Non-Traded Hours Worked
(f) Labor Share of Non-Tradables
(g) Traded Value Added
(h) Non-Traded Value Added
(i) Value Added Share of Non-Tradables
(j) Relative Wage of Tradables
(k) Relative Wage of Non-Tradables
(l) Non-Traded to Traded Prices

Figure 4: Theoretical vs. Empirical Responses Following Unanticipated Government Spending Shock: Labor and Output Effects. Notes: Solid blue line displays point estimate from local projections with shaded areas indicating 90% confidence bounds; the thick solid black line with squares displays model predictions in the baseline scenario with capital and technology utilization together with FBTC, while the dashed red line shows predictions of a model with Cobb-Douglas production functions and abstracting from capital and technology utilization.

by allowing for endogenous technology utilization and time-varying FBTC, the baseline model can reproduce the adjustment of technology to the government spending shock. Because higher government consumption increases demand for traded and non-traded goods, both sectors find it profitable to raise their efficiency in the use of inputs to meet higher demand for sectoral goods. While the demand shock is biased toward non-traded goods, Fig. 3(a) and Fig. 3(d) show that technology improvements along the transitional path (i.e., $\hat{Z}^j(t) > 0$) are much more pronounced in the traded than in the non-traded sector because the former sector experiences a lower adjustment cost of technology. Since the demand for capital rises in both sectors, which puts upward pressure on the real capital rental rates, it is profitable to use the stock of capital more intensively (i.e., $u^{K,j}(t)$ rises) which results in higher sectoral TFPs (since $\hat{\text{TFP}}^j(t) = \hat{Z}^j(t) + \left(1 - s_L^j\right) \hat{u}^{K,j}(t) > 0$), as displayed by Fig. 3(b) and Fig. 3(e). Besides technology improvements, firms change the mix of labor- and capital-augmenting efficiency. Because traded firms bias technological change toward capital, the traded LIS falls below trend, as shown in Fig. 3(c). Conversely, non-traded firms bias technological change toward labor which increases the non-traded LIS, as displayed by Fig. 3(f).

As shown in Fig. 4, both the shift in the technology frontier and the change in the mix of labor- and capital-augmenting efficiency along the technology frontier increase the ability of the two-sector open economy model to account for the VAR evidence. Following a rise in government consumption, as shown in Fig. 4(a), the baseline model is able to capture the dynamics of total hours worked and real GDP once we allow for an endogenous response of sectoral TFP, as can be seen in Fig. 4(b) and Fig. 4(c). Intuitively, technology improvements and a higher labor intensity of production result in a higher wage rate which encourages agents to supply more labor. The combined effect of the rise in aggregate TFP and higher labor supply amplifies the increase in real GDP.

As is clear from the second row of Fig. 4, the model can account for the dynamics of traded and non-traded hours worked (see Fig. 4(d) and 4(e)) once we allow non-traded firms to bias technological change toward labor and let traded technology become more capital-intensive, as shown in the black lines with squares. As displayed by Fig. 4(f), the ability of the baseline model to reproduce the distribution of the rise in total hours worked between sectors lies in its ability to account for the rise in the labor share of non-tradables because non-traded (traded) firms use labor (capital) more intensively, which amplifies the reallocation of hours worked toward this sector.

The third row of Fig. 4 shows the distribution of the rise in real GDP across sectors. As displayed by the dashed red lines in Fig. 4(i), because the restricted model overstates the shift of productive resources toward the non-traded sector and generates an increase in the value added share of non-tradables, it produces a decline in $\tilde{Y}^H(t)$ in contradiction with our evidence, see Fig. 4(g). Conversely, by letting both capital and technology utilization rates increase endogenously, the baseline model is able to generate the hump-shaped dynamics of traded value added. While the baseline model somewhat overstates the decline in $\nu^{Y,N}(t)$, Fig. 4(h) shows that it can reproduce the dynamics of $\tilde{Y}^N(t)$.

In section 2, we have focused our attention on the fiscal multipliers by stressing the role of technology. To gain a better understanding of fiscal transmission, in the fourth row of Fig. 4, we assess the ability of our model to account for the behavior of relative wages $\tilde{W}^j(t)/\tilde{W}(t)$ and the relative price of non-tradables. As shown in Fig. 4(j) and Fig. 4(k), non-traded firms pay higher wages relative to traded firms to encourage workers to shift hours worked toward the non-traded sector. Because technological change is biased toward capital in the traded sector and biased toward labor in the non-traded sector, the adjustment in relative wages is more pronounced in the baseline model, in line with the evidence. As can be seen in Fig. 4(l), because the demand shock is biased toward non-tradables, the relative price of non-tradables appreciates. The appreciation in $P^N(t)/P^H(t)$ is more pronounced in the baseline model because the TFP differential mitigates the increase in non-traded relative to traded value added.

Distortionary labor and consumption taxation. Overall, the baseline model's predictions displayed by the solid black line with squares in Fig. 3 and Fig. 4 reveal that the model with time-varying technological change can account for the VAR evidence, especially until $t = 6$; however, it cannot account for the persistent decline in value added and in hours worked below trend after $t = 7$. Since the endogenous response of government consumption does not display any reversal, we conjecture that distortionary taxation significantly increases from $t = 6$. Estimates from local projections in Online Appendix U.7 corroborate our assumption, as we find that the labor tax rate increases gradually over time while consumption taxation falls over the first six years and increases afterwards. In Online Appendix U, we relax the assumption of lump-sum taxes and allow for labor and consumption taxation. We find that in the first six years, the performance of the model is essentially identical to that of the baseline model, while allowing for distortionary taxation allows the model to account for the persistent decline in hours worked and value added below trend after $t = 7$, in line with our evidence.

4.4 Government Spending Shock and Technology: Cross-Country Differences

We now move a step further and calibrate our model to country-specific data. Our objective is to assess the impact of international differences in the adjustment of technology following a fiscal shock on sectoral fiscal multipliers. To isolate the pure role of technological change, we control for international differences in the biasedness of the demand shock toward non-tradables by assuming that the intensity of the non-traded sector in the government spending shock, ω_{G^N}, is symmetric across countries.

Calibration to country-specific data. To conduct our cross-country analysis, we calibrate our model to match the key ratios of the 18 OECD economies in our sample, as summarized in Table 6, while ϵ, ϕ, σ^j, ϕ_X are set in accordance with the estimates shown in the last five columns of the table. We also set $\beta = r^\star$ in line with our estimates for each OECD country shown in the first column of Table 5. As for a representative OECD economy, we consider the initial steady-state with Cobb-Douglas production functions as the normalization point and calibrate the reference model to the data, see Online Appendix O.1. All parameters and ratios vary across countries except for σ_L, σ_C, ρ, ϕ_J, ρ_J, κ, which take the same values as those summarized in Table 7. We also let the government spending shock, sectoral technology improvement and sectoral FBTC vary across countries, in line with our estimates. The high uncertainty surrounding the estimates of responses of sectoral capital utilization rates at a country level led us to abstract from capital utilization in the cross-country exercise. Once the model is calibrated, we numerically estimate the effects of an exogenous temporary increase in government consumption by 1% of GDP for one country at a time.

Columns 1-3 of Table 2 show numerical results when we simulate the baseline model with CES production functions and technological change. Panel A shows results for value added, while panel B shows results for hours worked. Each figure (in the first row of panel A and B) is calculated as an unweighted average of eighteen-OECD-countries. For each country, we compute the ratio of the present discounted value of the cumulative change in the corresponding quantity divided by the present discounted value of the cumulative change in government consumption, both calculated over a six-year period. Therefore, each figure gives the average annual rise in value added or hours worked following a rise in government spending by 1% of GDP in the first six years after the shock. Table 12 and Table 13 in Online Appendix O.2 show the government spending multiplier on value added and labor over a six-year horizon per country.

Column 4 of Table 2 shows the TFP differential between tradables and non-tradables in panel A, and the FBTC differential between non-tradables and tradables (where $\text{FBTC}^j(t)$ is scaled by the capital income share $1 - s_L^j$) in panel B. Each figure in columns 5-7 of Table 2 shows the excess of the government spending multiplier driven by technological change. The excess (or reduction) is computed as the difference between the government spending multiplier in the baseline model and the government spending multiplier in the restricted model with no technological change.

Cross-country differences in government spending multiplier on non-traded value added. How do international differences in the response of technology to a government spending shock modify the government spending multiplier on sectoral value added?

For the sake of convenience, we repeat the decomposition of the government spending multiplier on non-traded value added, which is a function of real GDP growth, $\hat{Y}_R(t)$, and the change in the value added share of non-tradadables, $d\nu^{Y,N}(t)$, i.e., $\nu^{Y,N}\hat{Y}^N(t) = \nu^{Y,N}\hat{Y}_R(t) + d\nu^{Y,N}(t)$. Column 1 of panel A of Table 2 shows that the government spending multiplier on real GDP averages about one over the first six years. As shown in column 2 of Table 2, the government spending multiplier on non-traded value added is equal to 0.6 ppt of GDP while the value added share of non-tradables declines very slightly, by 0.05 ppt of GDP, as can be seen in column 3. The rationale behind the insignificant change in $\nu^{Y,N}(t)$ lies in the TFP differential between tradables and non-tradables of 0.12%, as shown in column 4, which offsets the positive impact of the biasedness of the government spending shock toward non-tradables on $d\nu^{Y,N}(t)$.

Column 5 of Table 2 shows the excess of the government spending multiplier on real GDP caused by technological change. On average, technological change increases the aggregate government spending multiplier by 0.64 ppt of GDP. Fig. 5(a) plots the excess (or the reduction) of the government spending multiplier driven by technological change over a six-year horizon against the excess of traded over non-traded TFP. One-third of OECD countries which are positioned in the south-west of the figure experience a decline in traded relative to non-traded TFP (averaging 0.92%, see column 4 of Table 2). For these economies, technological change lowers the government spending multiplier by -1 ppt of GDP (see the second row of panel A in column 5) because these economies experience a decline in aggregate TFP. Conversely, countries positioned in the north-east of Fig. 5(a) experience a positive TFP differential which averages 0.64%, and these economies also have a government spending multiplier which is 1.5 ppt of GDP larger (see the last row of column 5). This is because when technological change is concentrated in traded industries, aggregate TFP rises, while when technological change is concentrated in non-traded industries, aggregate TFP declines as a result of the dramatic fall in traded TFP.

Interestingly, column 6 of Table 2 reveals that the excess of the government spending multiplier on non-traded value added does not vary much, whether the technology improvement is concentrated in traded or non-traded industries. According to our estimates, countries where technology improvement is concentrated in the non-traded sector experience a reduction in real GDP growth due to a decline in aggregate TFP (see column 5). However, because these countries experience a significant increase in $\nu^{Y,N}(t)$, as shown in the north-west part of Fig. 5(c), technological change increases the non-traded government spending multiplier by 0.15 ppt of GDP. The corollary is that technology drives down the multiplier for traded value added, by 1.20 ppt of GDP. Conversely, in countries where $\text{TFP}^H(t)/\text{TFP}^N(t)$ increases, as shown in the south-east of Fig. 5(c), the fall in $\nu^{Y,N}(t)$ by -0.73 ppt of GDP is offset by the positive impact of higher real GDP growth, so that the government spending multiplier on non-traded value added remains almost unchanged.

Table 2: Numerically Computed Values of Government Spending Multiplier on Non-Tradables

A-Value Added	Baseline Model			Excess Baseline Model over Restricted model			
	$\hat{Y}_R(t)$	$\nu^{Y,N}\hat{Y}^N(t)$	$d\nu^{Y,N}(t)$	TFP diff	$\hat{Y}_R(t)$	$\nu^{Y,N}\hat{Y}^N(t)$	$d\nu^{Y,N}(t)$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Mean	1.03	0.60	-0.05	0.12	0.64	0.18	-0.22
TFP diff < 0				-0.92	-1.01	0.15	0.79
TFP diff > 0				0.64	1.47	0.19	-0.73
B-Hours	Baseline Model			Excess Baseline Model over Restricted model			
	$\hat{L}(t)$	$\alpha^{L,N}\hat{L}^N(t)$	$d\nu^{L,N}(t)$	FBTC diff	$\hat{L}(t)$	$\alpha^{L,N}\hat{L}^N(t)$	$d\nu^{L,N}(t)$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Mean	0.68	0.55	0.10	0.08	0.02	0.05	0.03
FBTC diff < 0				-0.54	-0.19	-0.27	-0.13
FBTC diff > 0				0.69	0.24	0.36	0.19

Notes: Columns 1-4 show numerical results when we simulate the baseline model with CES production functions and technological change. Columns 1-2 show the government spending multiplier on real GDP and non-traded value added (panel A), on total hours worked and non-traded hours worked (panel B). Column 3 shows the change in the value added (panel A) and labor share (panel B) of non-tradables. Column 4 shows the response of the TFP differential between tradables and non-tradables (panel A) and the FBTC differential between non-tradables and tradables (panel B) to a shock to government consumption. We scale the TFP differential between tradables and non-tradables and the FBTC differential between non-tradables and tradables, so that the figure gives their contribution in ppt of real GDP and in ppt of total hours worked, respectively. We scale the TFP differential by $\left(1-\nu^{Y,H}\right)\nu^{Y,H}$ while the adjusted FBTC differential reads $\alpha_L^H\alpha_L^N\left[\left(1-s_L^N\right)\hat{\text{FBTC}}^N(t)-\left(1-s_L^H\right)\hat{\text{FBTC}}^H(t)\right]$. We numerically compute the responses of real GDP/hours worked, non-traded value added/hours worked, value added/labor share of non-tradables to a 1% temporary increase in government consumption and calculate the government spending multiplier as the ratio of the present discounted value of the cumulative change in the corresponding quantity to the present discounted value of the cumulative change in government consumption over a six-year horizon. To ensure consistency, the TFP/FBTC differential is expressed as present discounted cumulative change divided by the present discounted cumulative change in government consumption. Columns 5-6 show the excess of the government spending multiplier in the baseline model over a model with Cobb-Douglas production functions abstracting from technological change (panel A) or shutting down only FBTC (panel B). Column 7 shows the excess of the change in the value added (panel A) and labor share (panel B) of non-tradables in the baseline model over the restricted model.

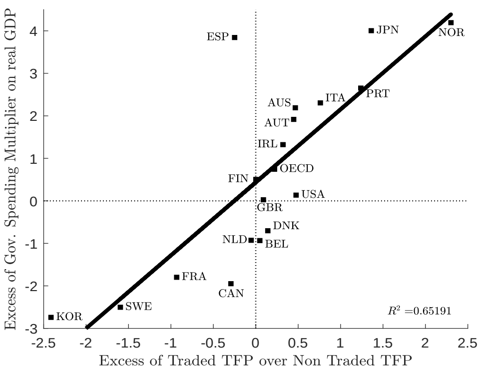
Conversely, the multiplier on traded value added is increased by 1.28 ppt of GDP through the technology channel.

Cross-country differences in government spending multipliers on non-traded hours worked. We now explore the role of international differences in technology in driving cross-country differences in the government spending multiplier on non-traded hours worked, which can be broken down into two components: $\alpha_L^N\hat{L}^N(t)=\alpha_L^N\hat{L}(t)+d\nu^{L,N}(t)$ where α_L^N is the labor compensation share of non-tradables. When $d\nu^{L,N}(t)>0$, non-traded hours worked increase disproportionately relative to traded hours worked, as labor shifts toward the non-traded sector.

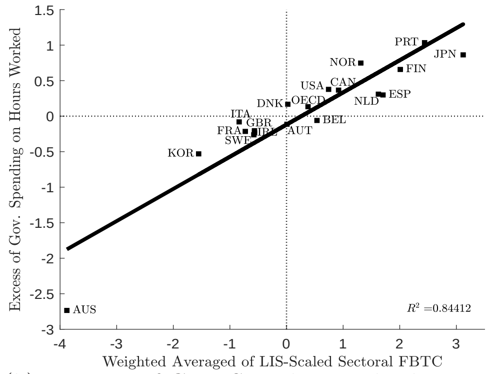
As can be seen in column 1 of panel B of Table 2, the government spending multiplier on total hours worked averages 0.68 over a six-year horizon. Column 2 reveals that non-traded hours worked increase by 0.55 ppt of total hours worked, which account for more than 80% of the rise in $L(t)$. The bulk of labor growth is concentrated in the non-traded sector, because this sector accounts for almost two-third of total hours worked and also benefits from a shift of labor as captured by a rise in $\nu^{L,N}(t)$ by 0.10 ppt of total hours worked (see column 3). The reallocation of hours worked toward the non-traded sector is driven by the biasedness of the demand shock toward non-tradables, together with the biasedness of technological change toward labor in the non-traded sector.

Real GDP

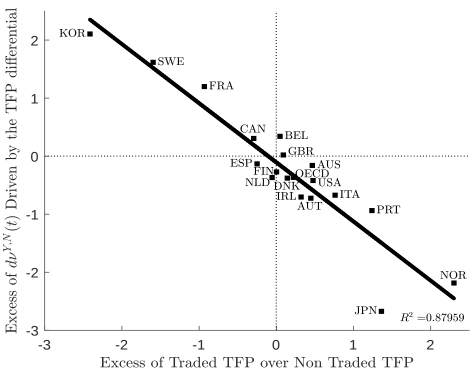
Hours Worked



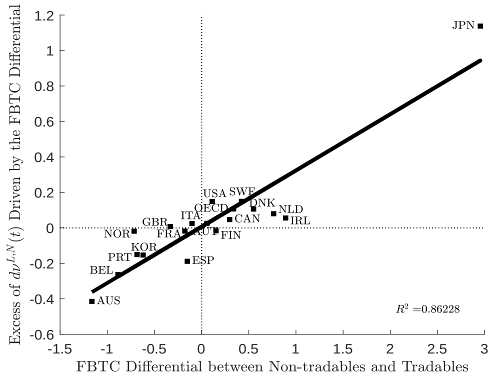
(a) Excess of Gov. Spending Multiplier on Real GDP vs. Relative TFP



(b) Excess of Gov. Spending Multiplier on Hours Worked vs. Weighted Sum of FBTC



(c) Excess of Value Added Share of Non-Tradables against TFP Differential



(d) Excess of Labor Share of Non-Tradables against Utilization Adjusted-FBTC Differential

Figure 5: Government Spending Multiplier and Technology: Cross-Country Analysis. Notes: Fig. 5(a) plots the excess of the government spending multiplier on real GDP (vertical axis) in the baseline model over a model with Cobb-Douglas production functions shutting down technological change against the (scaled) excess of traded over non-traded TFP (horizontal axis), i.e., $\nu^{Y,H}\left(1-\nu^{Y,H}\right)\left(\hat{\text{TFP}}^{H}(t)-\hat{\text{TFP}}^{N}(t)\right)$. Fig. 5(b) plots the excess of the government spending multiplier on total hours worked in the baseline model over a model with Cobb-Douglas production functions with time-varying sectoral TFPs while shutting down sectoral FBTC against the weighted sum of sectoral FBTC adjusted with the capital income share, i.e., $\sum_{j=H,N}\alpha_L^j\left(1-s_L^j\right)\hat{\text{FBTC}}^j(t)$. Fig. 5(c) plots the excess of the change in the value added share of non-tradables, $d\nu^{Y,N}(t)$, in the baseline model over a model shutting down technological change (vertical axis), against the (scaled) excess of traded TFP relative to non-traded TFP (horizontal axis), i.e., $\nu^{Y,H}\left(1-\nu^{Y,H}\right)\left(\hat{\text{TFP}}^{H}(t)-\hat{\text{TFP}}^{N}(t)\right)$. Fig. 5(d) plots the excess of the change in the labor share of non-tradables, $d\nu^{L,N}(t)$, in the baseline model over a model imposing Hicks-neutral technological change (vertical axis) against the differential in the utilization-adjusted FBTC scaled by the capital income share between non-tradables and tradables (horizontal axis), i.e., $\alpha_L^N\left(1-s_L^N\right)\hat{\text{FBTC}}^N(t)-\alpha_L^H\left(1-s_L^H\right)\hat{\text{FBTC}}^H(t)$.

Column 4 displays the adjusted differential in FBTC (scaled by the capital income share) between non-tradables and tradables. Column 5 shows that the excess of the rise in total hours worked in a model which allows for FBTC compared with a model which imposes Hicks-neutral technological change is negligible, as it averages 0.02 ppt of total hours worked. As can be seen in column 6, FBTC amplifies the rise in non-traded hours worked by 0.05 ppt of total hours worked, mostly due to the reallocation of labor toward the non-traded sector, which amounts to 0.03 ppt of total hours worked. These low figures mask a wide cross-country dispersion, however. In Fig. 5(b), we plot the excess of total hours worked caused by FBTC (on the vertical axis) against the weighted sum of FBTC in the traded and the non-traded sector (on the horizontal axis), i.e., $\sum_{j=H,N} \alpha_L^j \left(1 - s_L^j\right) \hat{\text{FBTC}}^j(t)$.[24] The scatter-plot shows that there exists a strong and positive cross-country relationship between the weighted sum of sectoral FBTC and the rise in total hours worked following a government spending shock. More specifically, in (the seven OECD) countries where technological change is biased toward capital, i.e., $\sum_{j=H,N} \alpha_L^j \left(1 - s_L^j\right) \hat{\text{FBTC}}^j(t) < 0$, the rise in total hours worked is 0.6 ppt lower than the increase in $L(t)$ in a model abstracting from FBTC. Conversely, in countries positioned in the north-east part of Fig. 5(b), where technological change is biased toward labor, the rise in total hours worked is amplified by 0.4 ppt on average.

As can be seen in the last two rows of column 4 of panel B of Table 2, the FBTC differential between non-tradables and tradables varies widely across countries.[25] Fig. 5(d) plots the excess of the change (over a six-year horizon) in the labor share of non-tradables caused by FBTC (vertical axis) against the adjusted differential in FBTC between non-tradables and tradables (horizontal axis). An inspection of Fig. 5(d) reveals that technological change is more biased toward labor in the non-traded than in the traded sector in half of the countries, which shifts labor toward the non-traded sector. The combined effect of $d\nu^{L,N}(t) = 0.19$ ppt of total hours worked (see column 7 of panel B of Table 2) and higher labor growth (see column 5 of panel B) further increases the government spending multiplier on non-traded hours worked, by 0.36 ppt of total hours worked (see column 6 of panel B).

Conversely, in the remaining nine OECD countries positioned in the south-west of Fig. 5(d), a shock to government consumption leads non-traded firms to bias technological change toward capital, which shifts labor toward the traded sector. Because $\nu^{L,N}(t)$ is reduced by 0.13 ppt of total hours worked (compared with a model shutting down FBTC), as shown in column 7 of panel B, and since these countries also experience lower labor

[24] It is worth mentioning that the weighted sum of FBTC in the traded and the non-traded sector is strongly correlated with the FBTC differential between non-tradables and tradables.

[25] While in Fig. 5(b), we consider aggregate FBTC, i.e., $\sum_{j=H,N} \alpha_L^j \left(1 - s_L^j\right) \hat{\text{FBTC}}^j(t)$, to measure its impact on the rise in total hours worked, in Fig. 5(d), we consider the FBTC differential, as we are interested in determining its impact on the difference in the government spending multiplier as captured by $d\nu^{L,N}(t)$.

growth (the rise in $L(t)$ is lowered by 0.19%), FBTC reduces the government spending multiplier on non-traded hours worked by 0.27 ppt, as can be seen in column 6 of panel B of Table 2.

5 Conclusion

This paper contributes to the literature investigating the effects of a government spending shock both empirically and theoretically. From an empirical point of view, we use a panel of eighteen OECD countries over the period 1970-2015 and document evidence pointing to the key role of technological change in determining the size of sectoral fiscal multipliers. First, we find empirically that the government spending multiplier is higher than one over a six-year horizon, and that 39% of the rise in real GDP is driven by the endogenous increase in aggregate TFP. Second, we find that real GDP growth is distributed uniformly across sectors at any horizon because technology improvement is concentrated in traded industries, which neutralizes the impact of the biasedness of the spending shock toward non-tradables on the value added share of non-tradables. Third, 88% of the rise in total hours worked is concentrated in the non-traded sector. Our empirical findings reveal that the disproportionate increase in non-traded hours worked is driven by FBTC, as non-traded firms bias technological change toward labor and traded firms bias technological change toward capital. Fourth, our hypothesis of FBTC concurs with the redistributive effects that we document empirically, as our estimates reveal that the non-traded LIS increases while the traded LIS declines.

To rationalize our evidence, we develop a semi-small open economy with tradables and non-tradables, along the lines of Kehoe and Ruhl [2009], where we allow for labor mobility costs and endogenous terms of trade to account for the frictions on factor movements between the traded and non-traded sectors. We extend the model along two dimensions. First, to account for real GDP growth and its distribution across sectors, drawing on Bianchi et al. [2019], we assume that each sector can choose to use the capital stock and existing technology more intensively. Second, we also allow for FBTC at a sectoral level. Adapting the methodology of Caselli and Coleman [2006] to our model with capital and labor, we allow firms to change the mix of labor- and capital-augmenting technological change at each point in time.

To quantify the role of technology in determining the size of government spending multipliers and their distribution across sectors, we contrast the predictions of the baseline model with those of a restricted model where technological change is shut down and sectoral goods are produced from Cobb-Douglas production functions. Our quantitative analysis shows that a model abstracting from technological change cannot generate the rise in real GDP and in total hours worked that we estimate empirically, generates a disproportionate increase in non-traded relative to traded value added in contradiction with our evidence, understates the rise in non-traded hours worked, and cannot account for the dynamics of sectoral LISs. Conversely, the model can account for the evidence once we let the decision on technology improvement vary across sectors and allow firms to change the factor intensity of production over time.

We also take advantage of the panel data dimension of our sample to quantify the role of technology in driving international differences in government spending multipliers. We calibrate the semi-small open economy to country-specific data and isolate the pure effect of technology by assuming that the intensity of the non-traded sector in the government spending shock is symmetric across countries. We compute the aggregate and sectoral government spending multipliers over a six-year horizon in the baseline and the restricted model where technological change is shut down which allows us to calculate the excess of or the reduction in value added growth through the technology channel. While traded relative to non-traded TFP increases in two-thirds of the OECD economies in response to a government spending shock, non-traded relative to traded TFP rises in one-third of the countries. Technological change amplifies real GDP growth which disproportionately benefits the traded sector in the first group of countries, while the decline in aggregate TFP reduces real GDP growth in the second group of countries where non-traded value added increases disproportionately. Importantly, because government spending is strongly biased toward non-tradables, the increase in the government spending multiplier on non-traded value added driven by technological change remains moderate and stable in both groups of countries. In contrast, the multiplier on traded value added displays a wide dispersion, exceeding one in the first group and moving into negative values in the second group.

Turning to labor, we compute the aggregate and sectoral government spending multipliers on hours worked over a six-year horizon in the baseline (with FBTC) and the restricted model where technological change is assumed to be Hicks-neutral which allows us to calculate the excess of or the reduction in labor growth caused by FBTC. We find that a government spending shock leads firms to bias technological toward labor in two-thirds of OECD countries, which increases labor growth by 0.4 ppt. Conversely, in the remaining countries where technological change is biased toward capital, the rise in total hours worked is reduced by 0.6 ppt. FBTC also varies between sectors, which affects the distribution of labor growth between the traded and non-traded sector. In half of the countries, technological change is more biased toward labor in the non-traded than in the traded sector, which increases the government spending multiplier on non-traded hours worked by 0.36 ppt of total hours worked. Conversely, in the remaining half of OECD countries, technological change is more biased toward capital in the non-traded than in the traded sector which lowers the government spending multiplier on non-traded hours worked by 0.27 ppt of total hours worked. In both cases, half of the excess of or reduction in the multiplier on non-traded hours worked is caused by the reallocation of labor toward or away from the non-traded sector.

References

Antràs, Pol (2004) Is the U.S. Aggregate Production Function Cobb-Douglas? New Estimates of the Elasticity of Substitution. *The B.E. Journal of Macroeconomics*, vol. 4(1), pages 1-36.

Auerbach, Alan J. and Yuriy Gorodnichenko (2012) Measuring the Output Responses to Ffiscal Policy. *American Economic Journal: Economic Policy* 4, pp. 1-27.

Backus, David K, Patrick J, Kehoe, Finn E. Kydland (1994) Dynamics of the Trade Balance and the Terms of Trade: The J-Curve? *American Economic Review*, 84(1), pp. 84-103.

Baqaee, David, Emmanuel Farhi and Kunal Sangani (2021) The Supply-Side Effects of Monetary Policy. NBER Working Papers 28345.

Basu, Susanto, Miles S. Kimball, John G. Fernald (2006) Are Technology Improvements Contractionary? *American Economic Review*, 96(5), pages 1418-1448.

Bems, Rudolfs (2008) Aggregate Investment Expenditures on Tradable and Nontradable Goods. *Review of Economic Dynamics*, 4, pp. 852-883.

Benati, Luca (2008) The "Great Moderation" in the United Kingdom. *Journal of Money, Credit and Banking*, 40(1), pp. 121-147.

Benetrix, Agustin and Philip R. Lane (2010) Fiscal Shocks and the Sectoral Composition of Output. *Open Economies Review*, 21(3), pp. 335-350.

Benigno, Gianluca, Luca Fornaro, and Martin Wolf (2020) The Global Financial Resource Curse. *Staff Reports* 915, Federal Reserve Bank of New York.

Bianchi, Francesco, Howard Kung, and Gonzalo Morales (2019) Growth, Slowdowns, and Recoveries. *Journal of Monetary Economics*, 101, pp; 47-63.

Blanchard, Olivier J., and Roberto Perotti (2002) An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. *Quarterly Journal of Economcis* 177, pp. 1329-1368.

Boehm, Christoph E. (2020) Government Consumption and Investment: Does the Composition of Purchases Affect the Multiplier? *Journal of Monetary Economics*, 115(C), pages 80-93.

Born, Benjamin, and Gernot Müller (2012) Government Spending Shocks in Quarterly and Annual Time Series. *Journal of Money, Credit, and Banking* 44(2), pp. 507-517.

Bouakez, Hafedh, Omar Rachedi, and Emiliano Santoro (2022) The Government Spending Multiplier in a Multi-Sector Economy. *American Economic Journal: Macroeconomics, forthcoming.*

Buiter, Willem H. (1984) Saddlepoint Problems in Continuous Time Rational Expectations Models: A General Method and some Macroeconomic Examples. *Econometrica*, 52, pp. 665-80.

Bussière, Matthieu, Giovanni Callegari, Fabio Ghironi, Giulia Sestieri, and Norihiko Yamano (2013) Estimating Trade Elasticities: Demand Composition and the Trade Collapse of 2008-2009. *American Economic Journal: Macroeconomics*, 5(3), pp. 118-151.

Cardi, Olivier, Romain Restout, and Peter Claeys (2020) Imperfect Mobility of Labor across Sectors and Fiscal Transmission in Open Economy. *Journal of Economic Dynamics and Control*, forthcoming.

Caselli, Francesco (2016) Technology Differences over Time and Space. Princeton University Press.

Caselli, Francesco, and Wilbur John Coleman II (2006) The World Technology Frontier. *American Economic Review*, 96(3), pp. 499-522.

Chirinko, Robert S., and Debdulal Mallick (2017) The Substitution Elasticity, Factor Shares, and the Low-Frequency Panel Model. *American Economic Journal: Macroeconomics*, 9(4), pp 225-253.

Cox, Lydia, Gernot Müller, Ernesto Pastén, Raphael Schoenle, and Michael Weber (2020) Big G. *NBER Working Papers 27034.*

D'Alessandro, Antonello, Giulio Fella and Leonardo Melosi (2019) Fiscal Stimulus With Learning-By-Doing. *International Economic Review*, 60(3), pp. 1413-1432.

De Ferra, Sergio (2018) Sovereign Debt Crises, Fiscal Austerity and Corporate Default. Mimeo.

Delong, Brad, and Lawrence H. Summers (2012) Fiscal Policy in a Depressed Economy *Brookings Papers on Economic Activity*, Spring, pp. 233-274.

Eberly, Janice Sergio Rebelo, and Nicolas Vincent (2008) Investment and Value: A Neoclassical Benchmark. *NBER Working Papers* 13866.

European Union KLEMS, 2017. Growth and productivity accounts.

Fernández de Córdoba, Gonzalo and Timothy J. Kehoe (2000) Capital Flows and Real Exchange Rate Fluctuations Following Spain's Entry into the European Community. *Journal of International Economics*, 51(1), 49-78.

Fiorito, Ricardo and Giulio Zanella (2012) The Anatomy of the Aggregate Labor Supply Elasticity *Review of Economic Dynamics*, 15(2), pp. 171-187.

Garofalo, Gasper A., and Steven Yamarik (2002) Regional Convergence: Evidence From A New State-By-State Capital Stock Series. *Review of Economics and Statistics*, 84(2), pp. 316-323.

Gollin, D. (2002) Getting Income Shares Right. *Journal of Political Economy*, 110, 458-474.

González Cabanillas, Laura, and Eric Ruscher (2016) The Great Moderation in the Euro Area: What Role have Macroeconomic Policies played? *European Economy Discussion Papers*, n°331.

Hlatshwayo, Sandile, and Michael Spence (2014) Demand and Defective Growth Patterns: The Role of the Tradable and Non-tradable Sectors in an Open Economy. *American Economic Review*, 104(5), pp. 272-277.

Herrendorf, Berthold, Christopher Herrington, and Ákos Valentinyi (2015) Sectoral Technology and Structural Transformation. *American Economic Journal: Macroeconomics*, 7(4), pp. 104-133.

Horvath, Michael (2000) Sectoral Shocks and Aggregate Fluctuations. *Journal of Monetary Economics*, 45, pp. 69-106.

Imbs, Jean (1999) Technology, Growth and the Business Cycle. *Journal of Monetary Economics*, 44(1), pages 65-80.

Imbs, Jean, and Isabelle Mejean (2015) Elasticity Optimism. *American Economic Journal: Macroeconomics*, 7(3), pages 43-83.

Jensen, Bradford J., and Lori G. Kletzer, (2006) Offshoring White-Collar Work, in Susan M. Collins and Lael Brainard, eds., *Brookings Trade Forum* 2005, Offshoring White-Collar Work. Brookings Institution: Washington, DC, pp. 75-134.

Jordà, Òscar (2005) Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review*, 95(1), pp. 161-182.

Jordà, Òscar, Sanjay R. Singh, and Alan M. Taylor (2020) The Long-Run Effects of Monetary Policy. NBER Working Papers 26666.

Jørgensen, Peter Lihn, and Søren Hove Ravn (2022) The Inflation Response to Government Spending Shocks: A Fiscal Price Puzzle? *European Economic Review*, forthcoming.

Kehoe, Timothy J. and Kim J., Ruhl (2009) Sudden Stops, Sectoral Reallocations, and the Real Exchange Rate. *Journal of Development Economics*, 89(2), pages 235-249.

Klump, Rainer, Peter McAdam and Alpo Willman (2007) Factor Substitution and Factor-Augmenting Technical Progress in the United States: A Normalized Supply-Side System Approach. *Review of Economics and Statistics*, 89(1), pp. 183-92.

Lambertini, Luisa and Christian Proebsting (2022) Fiscal Policy, Relative Prices and Net Exports in a Currency Union. *American Economic Journal: Macroeconomics, forthcoming.*

Mendoza, Enrique, G. (1995) The Terms of Trade, Real Exchange Rate and Economic Fluctuations. *International Economic Review*, 36, pp. 101-137.

Mian, Atif, and Amir Sufi (2014) Whar Explains the 2007-2009 Drop in Employment. *Econometrica*, 82(6), pp. 2197-2223.

Oberfield, Ezra, and Devesh Raval (2014) Micro Data and Macro Technology. NBER Working Papers 20452.

Organization for Economic Cooperation and Development (2017), *Structural Analysis Database*, OECD, Paris.

Organization for Economic Cooperation and Development (2017), *Annual National Accounts*, OECD, Paris.

Peterman, William B. (2016) "Reconciling Micro And Macro Estimates Of The Frisch Labor Supply Elasticity. *Economic Inquiry*, 54(1), pp. 100-120.

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

Ramey, Valerie A., and Matthew D. Shapiro (1998) Costly Capital Reallocation and the Effects of Government Spending. *Carnegie-Rochester Conference Series on Public Policy*, 48, pp. 145-194.

Sims, Chritopher, and Tao Zha (2006) Does Monetary Policy Generate Recessions? *Macroeconomic Dynamics*, 10(2), 231-272.

Stockman Alan C. and Linda L. Tesar (1995) Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements. *American Economic Review* 85(1), pp. 168-185.

Turnosvsky, Stephen J. (1997) International Macroeconomic Dynamics. MIT press.

WIOD: Construction and Applications (2013). World Input-Output Database.

WIOD: Construction and Applications (2016). World Input-Output Database.