D2.2: Final report on Multi-sector extension of baseline model. Revised

Deliverable D2.2: Final report on Multi-sector extension of baseline model. Revised.

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Project Information Summary

Table 1: Project Information Summary

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Deliverable Documentation Sheet

Table 2: Deliverable Documentation Sheet

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Quality Control Assessment Sheet

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Contents

Executive Summary

In this second work package, we extend the baseline model to allow for the presence of multiple sectors in the economy. Each sector produces its own output, develops and adopts new technologies. Sectors may differ in a number of dimensions: their share in GDP, the parameters in the R&D production function, their rate of technology adoption, and policies that may be targeted to specific sectors (e.g., output subsidies). In that context, it is clear that bringing in sectoral heterogeneity in a model such as FRAME is important for evaluating the effectiveness of various policies.

The goal of this report is to describe a multi-sector extension of the baseline model that does precisely that. Our model has multiple sectors, with sector-specific innovation and technology adoption. In addition, the model considers a subset of the economy-wide policies we included in the baseline model (WP1) plus some new policies that are sector-specific.

After developing the model we solve for the steady state and use estimates from WP6 as well as from publicly available data sources yo calibrate the key model parameters in an environment where there are two sectors (manufacturing and services) in the context of the German economy.

We use the calibrated model to study the effect of sector-specific output subsidies as well as aggregate R&D and adoption subsidies on standard macro variables such as output, consumption, and hours worked, sectoral variables such as the sectoral composition of output and the evolution of technology in each sector.

The key findings from our simulation exercises are:

(i) Subsidies to one sector have asymmetric effects over the other sectors. However, there are positive spillovers.

(ii) Sectoral subsidies have persistent and permanent effects on sectoral and total output. The nature of this long-run effects depends on the specific assumptions made on the degree of wage rigidity. When wages are fully flexible the long-run effects are entirely driven by the impact of the subsidy on capital accumulation. When there are wage rigidities, in addition the shock has a long-run affect on the stock of adopted technologies.

(iii) Subsidies to adoption have symmetric effects. Their final effects depend on the elasticities of the technology to investment. This policy have positive impact in the short-run but negative in the long-run.

(iv) Subsidies to R&D investment have symmetric effects. Their final effects depend on the elasticities of the technology to investment too. This policy have negative impact in the short-run but positive in the long-run. Therefore, there is a trade-off when subsidizing adoption or R&D.

(v) Finally, we conclude from our policy simulations, that a subsidy to profits might be the best way to stimulate the economy both in the short- and the long-run. With the effects depending on the share in the economy of the sector subsidized.

1 Introduction

In this second work package, we extend the simplified baseline model (i.e., without price and wage rigidities) to allow for the presence of multiple sectors in the economy. Each sector produces its own output, develops and adopts new technologies. Sectors may differ in a number of dimensions: their share in GDP, the parameters in the R&D production function, their rate of technology adoption, and policies that may be targeted to specific sectors (e.g., output subsidies). In that context, it is clear that bringing in sectoral heterogeneity in a model such as FRAME is important for evaluating the effectiveness of various policies.

There is a long tradition in the induced innovation literature going back to Kennedy (1964) that has emphasized the importance of factor abundance for the direction of technical change. A modern, and more rigorous, formulation of this literature is developed by Acemoglu (2002).

In Frame we are interested in exploring the effects of policies and business cycle shocks on technological change and the economy as a whole. Therefore, we need to go beyond the traditional models of directed technical change to include (i) features that make the models response to business cycle shocks realistic (such as adjustment costs to investment and habit formation),[1] (ii) a realistic characterization of the process by which new technologies are incorporated into production (i.e., slow diffusion) and (iii) a rich array of policies that governments can use to impact the direction of technological change and to stabilize business cycle fluctuations.

The goal of this report is to describe a multi-sector extension of the simplified baseline model that does precisely that. Our model has multiple sectors, with sector-specific innovation and technology adoption. In addition, the model considers a subset of the economy-wide policies we included in the baseline model (WP1) plus some new policies that are sector-specific.

After developing the model we solve for the steady state and use estimates from WP6 as well as from publicly available data sources yo calibrate the key model parameters in an environment where there are two sectors (manufacturing and services) in the context of the German economy.

We use the calibrated model to study the effect of sector-specific output subsidies as well as aggregate R&D and adoption subsidies on standard macro variables such as output, consumption, and hours worked, sectoral variables such as the sectoral composition of output and the evolution of technology in each sector.

We conclude by discussing extensions of our model and by relating it with models of structural transformations and by connecting the predictions of our analysis to the drivers of the direction of technical change in the literature.

We organize this report as follows. Section 2 discusses the model focusing on the new features. In section 3, we discuss the steady state. In section 4 we present the calibration.

[1] As discussed before, the model we use does not have price and wage rigidities. Opting for this real version of the baseline model is in our view a good compromise between having a realistic model and keeping things as simple as possible to better understand the mechanisms at work. We thank the evaluators for making this suggestion.

In Section 5, we conduct a number of policy experiments. In section 6, we discuss relevant extensions. Section 7 concludes.

2 Model

Our starting point is the simplified baseline FRAME model presented in WP1. Recall that in this model, the economy is real and there are no frictions in labor markets. We modify the production of intermediate goods composite Y_{mt}, and the innovation and diffusion problems. We organize the exposition of the model by presenting first the production side, the endogenous technology features, and conclude with a discussion of the steady state.

2.1 Production

As in the baseline model there are two types of firms: (i) final goods producers and (ii) intermediate goods producers. There are a continuum, measure unity, of monopolistically competitive final goods producers. Each final goods firm i produces a differentiated output Y_t^i. A final good composite is then the following CES aggregate of the differentiated final goods:

$$Y_t = \left(\int_0^1 (Y_t^i)^{\frac{1}{\mu}} di \right)^{\mu} \tag{1}$$

where $\mu > 1$ is given exogenously.

Each final good firm i uses Y_{mt}^i units of intermediate goods composite as input to produce output, according to the following simple linear technology

$$Y_t^i = Y_{mt}^i \tag{2}$$

As discussed in WP1, we introduce price rigidities by modelling the price setting process of differentiated output firms. This feature is still present in the model but we do not discuss it in the report since it is unchanged from WP1. Given the total number of final goods firms is unity, given the production function for each final goods producer (2), we showed in WP1 that

$$Y_t = Y_{mt} = \int_0^1 Y_{mt}^i di. \tag{3}$$

The first key deviation of the multi-sector model is that the composite Y_{mt} is produced by combining the output of F sectors, Y_{fmt}, for $f = 1, ..., F$. In particular,

$$Y_{mt} = \int_0^1 Y_{mt}^i di = \frac{\prod_{f=1}^F Y_{fmt}^{\alpha_f}}{\prod_{f=1}^F \alpha_f^{\alpha_f}} \tag{4}$$

Equation (4) states that the intermediate good composite Y_{mt} is produced as a Cobb-Douglas composite of the sectoral outputs $\{Y_{fmt}\}_{f=1}^F$. α_f is sector f' share in the economy. The term in the denominator is just a normalization. Formally, cost minimization implies that

$$P_{fmt} Y_{fmt} = \alpha_f P_{mt} Y_{mt}, \tag{5}$$

where P_{fmt} is the price of sector f intermediate good composite, and P_{mt} the price of the economy-wide intermediate composite.

Using the symmetric equilibrium condition for the final output companies, we can rewrite this condition as

$$P_{fmt}Y_{fmt} = \alpha_f MC_t Y_t \tag{6}$$

where $MC_t = P_{mt}Y_{mt}/Y$ is the marginal cost of production faced by final goods producers, and is equal to $1/\mu$, where μ is the markup charged by final output firms. Condition (6) states that the share in GDP of sector f is α_f.[2]

The output from sector f, Y_{fmt}, is produce in a way akin to equation (3) in WP1. Let A_{ft} be the measure of technologies used in production in sector f. Each technology is associated to an intermediate good that is produced monopolistically by a producer that has acquired his rights and succeeded in adopting it. Let the output associated with the j^{th} intermediate good in sector f be Y^j_{fmt}. Then the intermediate goods composite for sector f is the following CES aggregate of individual intermediate goods:

$$Y_{fmt} = \left(\int_0^{A_{ft}} (Y^j_{fmt})^{\frac{1}{\vartheta}} dj \right)^{\vartheta} \tag{7}$$

with $\vartheta > 1$.

Let K^j_{ft} be the stock of capital firm j employs, U^j_{ft} be how intensely this capital is used, and L^j_{ft} the stock of labor employed. Then firm j uses capital services $U^j_{ft}K^j_{ft}$ and unskilled labor L^j_{ft} as inputs to produce output Y^j_{fmt} according to the following Cobb-Douglas technology:

$$Y^j_{fmt} = \theta_t \left(U^j_{ft} K^j_{ft} \right)^{\alpha} (L^j_{ft})^{1-\alpha} \tag{8}$$

where θ_t is an exogenous random disturbance. As we will make clear shortly, θ_t is the exogenous component of total factor productivity. Finally, we suppose that intermediate goods firms set prices each period. That is, intermediate goods prices are perfectly flexible, in contrast to final good prices.

We consider the possibility of sector-specific output subsidies, τ_{ft}. Given that the optimal pricing rule of intermediate good producers is a constant markup ϑ times the marginal cost of production, the price of sector's f intermediate good composite can be expressed as

$$P_{fmt} = (1 - \tau_{ft}) \vartheta MC_{fmt} \tag{9}$$

where MC_{fmt} is the marginal cost of production for the intermediate composite Y_{fmt}.

In the symmetric equilibrium, the first order conditions for intermediate goods producers imply the following demand for productive factors:

$$\alpha \frac{MC_{fmt}Y_{fmt}}{K_{fmt}} = D_t + \delta \left(U_{fmt} \right) Q_t \tag{10}$$

$$\alpha \frac{MC_{fmt}Y_{fmt}}{U_{fmt}} = \delta' \left(U_{fmt} \right) K_{fmt} Q_t \tag{11}$$

$$(1-\alpha) \frac{MC_{fmt}Y_{fmt}}{L_{fmt}} = w_t \tag{12}$$

[2] In section x we discuss extensions that relax this implication of constant sectoral shares.

Substituting in for (9) and (6) we obtain

$$\alpha \frac{\alpha_f Y_t}{K_{fmt}} = \mu\vartheta\left(1-\tau_{ft}\right)\left[D_t + \delta\left(U_{fmt}\right)Q_t\right] \quad (13)$$

$$\alpha \frac{\alpha_f Y_t}{U_{fmt}} = \mu\vartheta\left(1-\tau_{ft}\right)\left[\delta'\left(U_{fmt}\right)K_{fmt}Q_t\right] \quad (14)$$

$$(1-\alpha)\frac{\alpha_f Y_t}{L_{fmt}} = \mu\vartheta\left(1-\tau_{ft}\right)w_t \quad (15)$$

Equations (13) - (15) imply that for any two sectors, f and f',

$$\frac{L_{fmt}}{L_{f'mt}} = \frac{K_{fmt}}{K_{f'mt}} = \frac{\alpha_f}{\alpha_{f'}}\frac{\left(1-\tau_{f'm}\right)}{\left(1-\tau_{fm}\right)} \quad (16)$$

and

$$U_{fmt} = U_{f'mt}.$$

Market clearing in unskilled labor and capital implies that

$$\sum_{f=1}^{F} L_{fmt} = L_t \quad (17)$$

$$\sum_{f=1}^{F} K_{fmt} = K_t \quad (18)$$

Let's define $\hat{\alpha}_{ft}$ as

$$\hat{\alpha}_{ft} = \frac{\alpha_f}{1-\tau_{ft}}\left[\sum_{f'=1}^{F}\frac{\alpha_{f'}}{1-\tau_{f't}}\right]^{-1} \quad (19)$$

Note that in the special case where the sectoral subsidy is the same across sectors, $\hat{\alpha}_{ft} = \alpha_{ft}$.

Then, we can express the allocation of capital and unskilled labor across sectors as follows:

$$K_{ft} = \hat{\alpha}_{ft}K_t \quad (20)$$

$$L_{ft} = \hat{\alpha}_{ft}L_t \quad (21)$$

$$U_{ft} = U_t \quad (22)$$

Substituting these equilibrium allocations into conditions (13) - (15), we can rewrite aggregate factor demands as

$$\alpha\left[\sum_{f'=1}^{F}\frac{\alpha_{f'}}{1-\tau_{f't}}\right]\frac{Y_t}{K_t} = \mu\vartheta\left[D_t + \delta\left(U_{fmt}\right)Q_t\right] \quad (23)$$

$$\alpha\left[\sum_{f'=1}^{F}\frac{\alpha_{f'}}{1-\tau_{f't}}\right]\frac{Y_t}{U_t} = \mu\vartheta\left[\delta'\left(U_{fmt}\right)K_{fmt}Q_t\right] \quad (24)$$

$$(1-\alpha)\left[\sum_{f'=1}^{F}\frac{\alpha_{f'}}{1-\tau_{f't}}\right]\frac{Y_t}{L_t} = \mu\vartheta w_t \quad (25)$$

Using the sectoral production function (8) and equations (20)-(22), we can express sectoral output as

$$Y_{fmt} = \theta_t A_{ft}^{\vartheta-1} \hat{\alpha}_{ft} \left(U_t K_t\right)^{\alpha} L_t^{1-\alpha} \tag{26}$$

Recall that to a first order, $Y_t = Y_{mt}$, therefore the intermediate good composite and aggregate output can be expressed as

$$Y_t = Y_{mt} = \theta_t \frac{\prod_{f=1}^{F} \hat{\alpha}_f^{\alpha_f} A_{ft}^{\alpha_f(\vartheta-1)}}{\prod_{f=1}^{F} \alpha_f^{\alpha_f}} \left(U_t K_t\right)^{\alpha} L_t^{1-\alpha} \tag{27}$$

To shed light on the consequences of including multiple sectors in the production side of the economy, it is helpful to compare this expression with the equivalent expression for aggregate output from WP1:

$$Y_t = \left[A_t^{\vartheta-1}\theta_t\right] \cdot (U_t K_t)^{\alpha} (L_t)^{1-\alpha} \tag{28}$$

Comparing expressions (27) and (28) we can notice two key differences. The first is that the endogenous component of TFP now is a geometric weighted average of the sectoral measures of technologies adopted, A_{ft}, where the weights are given by the sectoral share in aggregate output α_f. The second difference is that, the presence of subsidies to sectoral output, in general, will impact aggregate output. In the special case where output subsidies are the same across sectors then expression (27) simplifies to

$$Y_t = \theta_t \frac{\prod_{f=1}^{F} \alpha_f^{\alpha_f} A_{ft}^{\alpha_f(\vartheta-1)}}{\prod_{f=1}^{F} \alpha_f^{\alpha_f}} \left(U_t K_t\right)^{\alpha} L_t^{1-\alpha} \tag{29}$$

We next describe the mechanisms through which new intermediate goods are created and adopted.

2.2 R&D and Adoption

As in the baseline FRAME model, the processes for creating and adopting new technologies are based on Comin and Gertler (2006). The key difference with the baseline model is that now we allow for the stock of technologies and the stock of adopted technologies to be sector-specific. Let Z_{ft} denote the stock of technologies in sector f, while A_{ft} is the stock of adopted technologies (intermediate goods) in sector f. In turn, the difference $Z_{ft} - A_{ft}$ is the stock of unadopted technologies. R&D expenditures increase Z_{ft} while adoption expenditure increase A_{ft}. We distinguish between creation and adoption because we wish to allow for realistic lags in the adoption of new technologies. We first characterize the R&D and adoption processes and then discuss the optimal investments in R&D and adoption.

2.2.1 R&D: Creation of Z_{ft}

The micro-foundation for the innovation process is the same as in the baseline model. The key difference is that now technologies are targeted to a specific sector f. Let L_{sfrt}^{p} be skilled labor employed in R&D by innovator p to develop technologies in sector f and let φ_{ft} be the number of new technologies at time $t+1$ that each unit of skilled labor at t can create in sector f. We assume φ_{ft} is given by

$$\varphi_{ft} = \chi_{ft} Z_{ft} L_{sfrt}^{\rho_{zf}-1} L_{pufrt}^{\gamma_z} \tag{30}$$

where χ_{ft} is an exogenous disturbance to the R&D technology L_{pufrt} is the number of public R&D labor devoted to sector f, and L_{sfrt} is the total amount of skilled labor working on R&D in sector f, which an individual innovator takes as given. There are a few significant differences between φ_{ft} and the equivalent formulation in WP1. The productivity of R&D labor is sector specific for various reasons. First, the R&D productivity shock might be sector specific. Second, the knowledge spillovers represented by the term Z_{ft} are sector specific. Third, the factor that captures congestion externality is the measure of (private) R&D workers in the sector. Third, the elasticity of φ_{ft} with respect to L_{sfrt} (ρ_{zf}) is also sector specific. Finally, the government may target a particular sector in deploying the public R&D input and as a result L_{pufrt} is also sector specific. When simulating the model, we take advantage of these dimensions of sectoral heterogeneity, but as it is clear from expression (30), the model has ample room to introduce sectoral variation in technology and in policies.

Aggregating across individual researchers, we obtain the following law of motion for the stock of technologies in sector f :

$$Z_{ft+1} = \varphi_{ft} L_{sfrt} + \phi Z_{ft} \tag{31}$$

which substituting in φ_{ft} simplifies to

$$\frac{Z_{ft+1}}{Z_{ft}} = \chi_{ft} L_{sfrt}^{\rho_{zf}} L_{pufrt}^{\gamma_z} + \phi \tag{32}$$

2.2.2 Adoption: Transformation of Z_{ft} into A_{ft}

We next describe how newly created intermediate goods are adopted, i.e. the process of converting Z_{ft} to A_{ft}. Here we capture the fact that technology adoption takes time on average, but the adoption rate can vary pro-cyclically, consistent with evidence in Comin (2009). In addition, we would like to characterize the diffusion process in a way that minimizes the complications from aggregation. In particular, we would like to avoid having to keep track, for every available technology, of the fraction of firms that have and have not adopted it.

Accordingly, we proceed as follows. We suppose there are a competitive group of "adopters" who convert unadopted technologies into ones that can be used in production. They buy the rights to the technology from the innovator at the competitive price which is the value of an unadopted technology and that we define below. They then convert the technology into use by employing skilled labor as input. This process takes time on average, and the conversion rate may vary endogenously.

Let's define by λ_{ft} as the probability of adoption in sector f. For simplicity, we abstract from the possibility of direct government involvement in facilitating adoption as we considered in WP1. Therefore, the adoption rate depends on the amount of skilled labor employed by private companies for adopting a particular technology in sector f and that we denote by L_{sfat}. Formally,

$$\lambda_{ft} = \bar{\lambda}_{0f} * (Z_{ft} L_{sfat})^{\rho_\lambda} \tag{33}$$

with $\rho_\lambda \in (0,1)$ and $\bar{\lambda}_{0f} > 0$, with the latter now being sector specific. Note also that the knowledge spillover Z_{ft} that ensures a constant adoption rate in the balanced growth path is sector specific. As in WP1, the average adoption lag is $1/\lambda_{ft}$ and we will use evidence on adoption lags across sectors to calibrate $\bar{\lambda}_{0f}$.

Given that λ_{ft} does not depend on adopter-specific characteristics, we can sum across the adopters in a sector to obtain the following relation for the evolution of adopted technologies

$$A_{ft+1} = \lambda_{ft}\phi[Z_{ft} - A_{ft}] + \phi A_{ft} \tag{34}$$

where $Z_{ft} - A_{ft}$ is the stock of unadopted technologies in sector f.

2.2.3 Market values and optimal R&D and adoption

To determine the amount of skilled labor hired in equilibrium to conduct R&D and adoption activities in each sector, we need to compute the market value of adopted and unadopted technologies in each sectors. These depend on the profits earned by a monopolist that can sell an adopted intermediate good. Let's define by π_{fmt} the profits earned by a monopolist that commercializes an adopted intermediate good in sector f.

$$\pi_{fmt} = \frac{(\vartheta - 1)\,\alpha_f Y_t}{\mu\vartheta\,(1 - \tau_{ft})\,A_{ft}} \tag{35}$$

The value of an adopted technology in sector f can be expressed using the following Bellman equation:

$$v_{ft} = \pi_{fmt} + E_t\left[\phi\Lambda_{t,t+1} v_{ft+1}\right] \tag{36}$$

where $\Lambda_{t,t+1}$ is the stochastic discount factor between t and $t{+}1$. The value of an unadopted technology is

$$j_{ft} = \max_{Lsfat} -w_t^s L_{sfat} + E_t\left[\phi\Lambda_{t,t+1}\left\{\lambda_{ft} v_{ft+1} + (1-\lambda_{ft}) j_{ft+1}\right\}\right] \tag{37}$$

where λ_{ft} is defined by expression (33).

Given these market values for an adopted and unadopted technologies, the optimal R&D and adoption conditions are as follows:

$$E_t\{\Lambda_{t,t+1} j_{ft+1} \phi \chi_{ft} Z_{ft} L_{sfrt}^{\rho_{zf}-1} L_{purt}^{\gamma_z}\} = (1-\tau_{rt}^s) w_{st} \tag{38}$$

$$\rho_\lambda \frac{\lambda_{ft}}{L_{sfat}} \cdot \phi E_t\{\Lambda_{t,t+1}[v_{ft+1} - j_{ft+1}]\} = (1-\tau_{at}^s) w_{st} \tag{39}$$

2.3 Fiscal policy

Monetary policy is identical to the FRAME baseline model. We take two approaches when including government, lump-sum or distortionary taxes. If we assume that government activities G_t, L_{pufrt}, are financed with lump sum taxes T_t, government's budget constraint is

$$G_t + w_{st} \sum_{f=1}^{F} L_{pufrt} + w_{st} \sum_{f=1}^{F} (\tau_{rt}^s L_{sfrt} + \tau_{at}^s L_{sfat}) + Y_t \sum_{f=1}^{F} \tau_{ft} \alpha_f = T_t \tag{40}$$

while with distortionary taxes it writes

$$G_t + w_{st} \sum_{f=1}^{F} L_{pufrt} + w_{st} \sum_{f=1}^{F} (\tau_{rt}^s L_{sfrt} + \tau_{at}^s L_{sfat}) + Y_t \sum_{f=1}^{F} \tau_{ft} \alpha_f = \tau_t^l (w_t L_t + w_{st} L_{st}) \tag{41}$$

Further, the (log) deviation of G_t, L_{pufrt}, τ_{rt}^s, τ_{at}^s and τ_{ft} from the deterministic trend of the economy follows AR(1) processes. Formally, for each $\mathcal{X}_t \in \{G_t, L_{pufrt}, L_{pufat}, \tau_{rt}^s, \tau_{at}^s, \tau_{ft}\}$, we have

$$\log(\mathcal{X}_t/(1+\gamma_y)^t) = (1-\rho_{\mathcal{X}})\bar{\mathcal{X}} + \rho_{\mathcal{X}} \log(\mathcal{X}_{t-1}/(1+\gamma_y)^{t-1}) + \epsilon_t^{\mathcal{X}} \tag{42}$$

2.4 Resource constraints and equilibrium

The resource constraint is given by

$$Y_t = C_t + p_{kt} \left[1 + f\left(\frac{I_{t+\tau}}{(1+\gamma_y) I_{t+\tau-1}} \right) \right] I_t + G_t \tag{43}$$

Capital evolves according to

$$K_{t+1} = I_t + (1 - \delta(U_t)) K_t \tag{44}$$

The market for skilled labor must clear:

$$L_{st} = \sum_{f=1}^{F} [(Z_{ft} - A_{ft}) * L_{sfat} + L_{sfrt} + L_{pufrt}] \tag{45}$$

Finally, the market for risk-free bonds must clear, which implies that in equilibrium, risk-free bonds are in zero net supply

$$B_t = 0$$

This completes the description of the model.

3 Steady state

In the steady state of the multi-sector economy, Z_{ft} and A_{ft} grow at a rate $g_{zf} > 0$, $\lambda_{ft} = \lambda_f > 0$. The endogenous component of TFP grows at rate $g_A = \prod_{f=1}^{F} (1 + g_{zf})^{\alpha_f(\vartheta - 1)} - 1$, which is approximately equal to $(\vartheta-1)\sum_{f=1}^{F}\alpha_f * g_{zf}$. We can express g_A as $(\vartheta-1)*g_{\bar{z}}$, where $g_{\bar{z}}$ is the average growth of technology across sectors. Output, and the market value of all technologies in any given sector grow at rate $g_y=\frac{g_A}{1-\alpha}$. Defining

In our model, the rate between the growth rate of real output in sector f to the growth rate of GDP is proportional to $g_A/\left(\vartheta-1\right)$. That is,

$$\frac{g_{y_{fm}}}{g_y}=\frac{g_{zf}}{\sum_{f=1}^{F}\alpha_f g_{zf}}. \tag{46}$$

Next we discuss how to compute these steady state variables.

Let define the following ratios for the steady state of the economy:

$$Z\_A_f = Z_{ft}/A_{ft} \tag{47}$$
$$\pi\_y_f = \pi_{fmt}*A_{ft}/Y_t \tag{48}$$
$$v\_y_f = v_{ft}*A_{ft}/Y_t \tag{49}$$
$$j\_y_f = j_{ft}*Z_{ft}/Y_t \tag{50}$$

It follows from equation (34) that

$$Z\_A_f-1=\frac{g_{zf}+(1-\phi)}{\lambda_f\phi} \tag{51}$$

It follows from equation (36) that

$$v\_y_f=\frac{\pi\_y_f}{1-\frac{\phi}{R}\frac{1+g_y}{1+g_{zf}}} \tag{52}$$

Let

$$Ad\_pr_f=(1-\tau_{at})L_{sfat}w_t^sZ_{ft}/Y_t \tag{53}$$

be a proxy for the share of private adoption costs in sector f in GDP, and

$$RD\_y_f=\left(1-\tau_{st}\right)L_{sfrt}w_t^s/Y_t \tag{54}$$

be the ratio of private R&D investment in sector f in GDP.

The optimal adoption condition implies that

$$\rho_\lambda j\_y_f\left[1-\frac{\phi}{R}\frac{1+g_y}{1+g_{zf}}\right]=(1-\rho_\lambda)*Ad\_pr_f \tag{55}$$

Combining this with the Bellman equation for unadopted technologies, it follows that

$$j\_y_f\left[1-\frac{\left(1-\lambda_f\right)\phi}{R}\frac{1+g_y}{1+g_{zf}}\right]+Ad\_pr_f=\frac{\phi}{R}\frac{\lambda_f Z\_A_f(1+g_y)}{1+g_{zf}}*v\_y_f \tag{56}$$

which simplifies to

$$j\_y_f=\frac{\frac{\phi}{R}\frac{\lambda_f Z\_A_f(1+g_y)}{1+g_{zf}}*v\_y_f}{1-\frac{(1-\lambda_f)\phi}{R}\frac{1+g_y}{1+g_{zf}}+\frac{\rho_\lambda}{1-\rho_\lambda}\left(1-\frac{\phi}{R}\frac{1+g_y}{1+g_{zf}}\right)} \tag{57}$$

The free entry condition implies that

$$\frac{\left(g_{zf}+(1-\phi)\right)}{R}\frac{1+g_y}{1+g_{zf}}j\_y_f=RD\_y_f \tag{58}$$

4 Calibration

For concreteness, we take Germany as benchmark for the calibration. The strategy we follow to calibrate the model consists in two parts. First, we borrow the aggregate parameters from the calibration of the baseline model in WP1. Second, we gather information from micro-sources to calibrate the key sectoral ratios/parameters including, (i) the sectoral share in output, (ii) the growth rate of value added, (iii) the R&D share, (iv) the adoption rate, and (v) the curvature of the sectoral R&D production function. Next we discuss this second process in detail.

(i) Sectoral share: We use data from COMPUSTAT to compute the share in value added of services and manufacturing. We focus on these two sectors because the R&D data we use to calibrate the model does not cover agriculture. Agriculture represents a small share of the economy (less than 1% in Germany). The average shares for the period 2008-2015 are 0.74 for services and 0.26 for manufacturing.

(ii) Relative growth in manufacturing: We use data from KLEMS to compute the average growth rate of the manufacturing sector and of the economy as a whole for the period 1995-2015. The ratio of the two is 1.25. With that information, we can compute the sectoral growth rates of technology. Recall that

$$g_y = \frac{\vartheta - 1}{1 - \alpha} g_{\bar{z}} \tag{59}$$

For for $\alpha = 1/3$, and $\vartheta = 1.35$, this implies that

$$g_{\bar{z}} = 1.9 * g_y \tag{60}$$

Since $g_y = .0047$, $g_{\bar{z}} = 0.009$.

But we know that $g_{zm} = 1.25 * g_{\bar{z}} = 0.0112$. Using the definition of $g_{\bar{z}}$ and the information in (i) on the relative shares of manufacturing and services in GDP, it follows that $g_{zs} = .0083$.

(iii) R&D share: We compute the R&D share from the Mannheim Innovation Panel (MIP, 1993-2014). This dataset covers a representative sample of German companies in manufacturing and services. Using the population weights we calculate the ratio of sectoral private R&D spending to sectoral sales. The sample averages are 2.9% for manufacturing and 0.9% for services. Aggregate private R&D in Germany represents 2.81% of GDP. Assuming a constant share of intermediate goods to gross output in manufacturing and services, these figures imply that sales are twice as large as value added. Therefore, the share of private R&D in manufacturing in GDP is 1.54%, while in services it is 1.31%.

(iv) Adoption rate: Calibrating adoption rates is not trivial since we observe the diffusion process predominantly for major technologies whose development and adoption, presumably is more involved, than smaller technologies. We use information on adoption lags estimated by Comin and Ferrer (2013) which cover a few technologies from both services and manufacturing sectors as well as some that are relevant to both sectors (e.g., computers and the internet). We follow Anzoategui et al. (2016) and use an average adoption lag of 5 years for manufacturing technologies and 6.25 years for services.[3] This

[3]The former is teh same Anzoategui et al. (2016) use for the US as a whole. So the average adoption lag we calibrate for Germany is slightly above the equivalent number in the US.

implies that λ_f is equal to 0.05 for manufacturing and 0.04 for services.

(v) Curvature of the R&D production function: The final structural parameter that we allow to vary by sector is the curvature in the R&D production function (ρ_{zf}). In work package 6, we have merged the MIP firm-level information on R&D with DMPA (German Patent and Trademark Office) data to build a panel dataset that covers R&D and patents granted at the company level. We have then estimated the key parameters of the R&D production function in manufacturing and services. We find that ρ_{zf} is equal to 0.71 in manufacturing and 0.65 in services.[4]

The final step of the calibration consists on combining this information with expressions (52), (57) and (58) to have an expression that relates the observed sectoral R&D shares in GDP to the sectoral subsidies (τ_f). Solving for them we find that $\tau_m = .105$ and $\tau_s = .138$.

It is important to note that these subsidies to production have the same effect as price markups. So an alternative to introducing the sector-specific subsidies is to calibrate the intermediate goods markups in each sector to match the observed private R&D intensities. If we followed this alternative approach, we would conclude that the intermediate goods (gross) markup in manufacturing that is consistent with the observed R&D intensity in manufacturing is 1.41, while for services, the gross markup that is isomorphic to the output subsidy is 1.43.

5 Policy Simulations

In this section we describe and conduct our policy experiments. We first study the response of the economy to an asymmetric subsidy shock. We show the effect of increasing subsidies to one sector and maintaining other subsidies fixed. Then, we study the effects of subsidies to adoption and R&D.

5.1 Production subsidies

Figure (1) depicts the effect of a sectoral production subsidy to manufacturing. This shock has a direct effect on profits with effects on the two margins of sectors: production and innovation.

When government subsidizes production in a sector it is encouraging factor demand (in this case, capital and labor). This pushes up unskilled wages and returns to capital that stimulate labor and capital supply. These are the direct effects. Indirectly, the other sector also reacts because it sees a reaction in markets for inputs, and because income variation affects the marginal utility of consumption. For concreteness, we start with the subsidy to manufacturing. In the short term manufacturing demands more capital and labor. In the simplified version of the model without wage rigidities, wages and interest rates adjust. In particular, skilled and unskilled wages increase, and consumers respond to the higher income by raising consumption. Additionally, the increase in consumption

[4] This parameter is not relevant to calibrate the steady state of the economy but it impacts the transitional dynamics of the model.

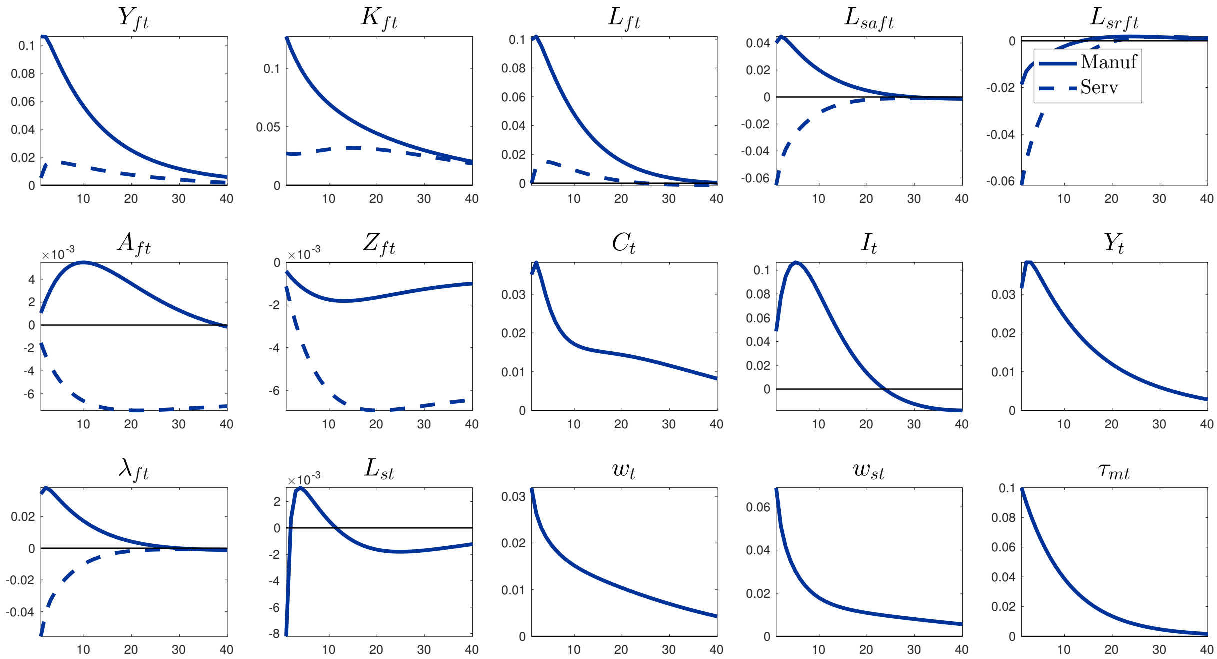

Figure 1: IRF's to a sectoral production subsidy shock, Manufactures τ_{mt}.

lowers the marginal utility of income. This effect lowers the supply curve for both types of workers. Overall, the effect of the subsidy on hours worked (in the flexible wage setting) is ambiguous because it shifts upwards the labor demand but inwards the labor supply. In the Figure it is clear that the increase in labor demand increases the unskilled hours worked but reduces the skilled hours worked. This is the case because the marginal product of unskilled labor increases by more than the marginal product of skilled labor. This again follows from the fact that the output subsidy affects directly the (after subsidy) marginal product of unskilled workers, while the effect on the marginal product of skilled workers is indirect and only operates through the change in the value of adopted and unadopted technologies.

It is worthwhile noting that this asymmetry on the effect of the subsidy on the hours worked for both types of workers hinges on the flexible wage assumption. In Appendix B, we present the impulse response functions for the model with wage rigidity. In this case, wages do not adjust after the increase in the manufacturing subsidy. As a result, consumers' income does not increase much and therefore, consumption increases by less and the marginal utility of income declines less. So, by introducing wage rigidities, labor supply contracts less and the expansion of labor demand dominates raising both hours worked by skilled and unskilled workers.

This is only part of the story because at the same time the subsidy encourages production it is impacting investment in technology adoption as innovation depends on present and expected profits. As expected, while profits rise, manufacturing investment in adoption increases. This pushes demand for skilled labor up, raising the wage for skilled labor. Note that, as mentioned above, the overall supply of skilled labor declines upon impact. This is the case because, while the hours devoted to manufacturing adoption increases,

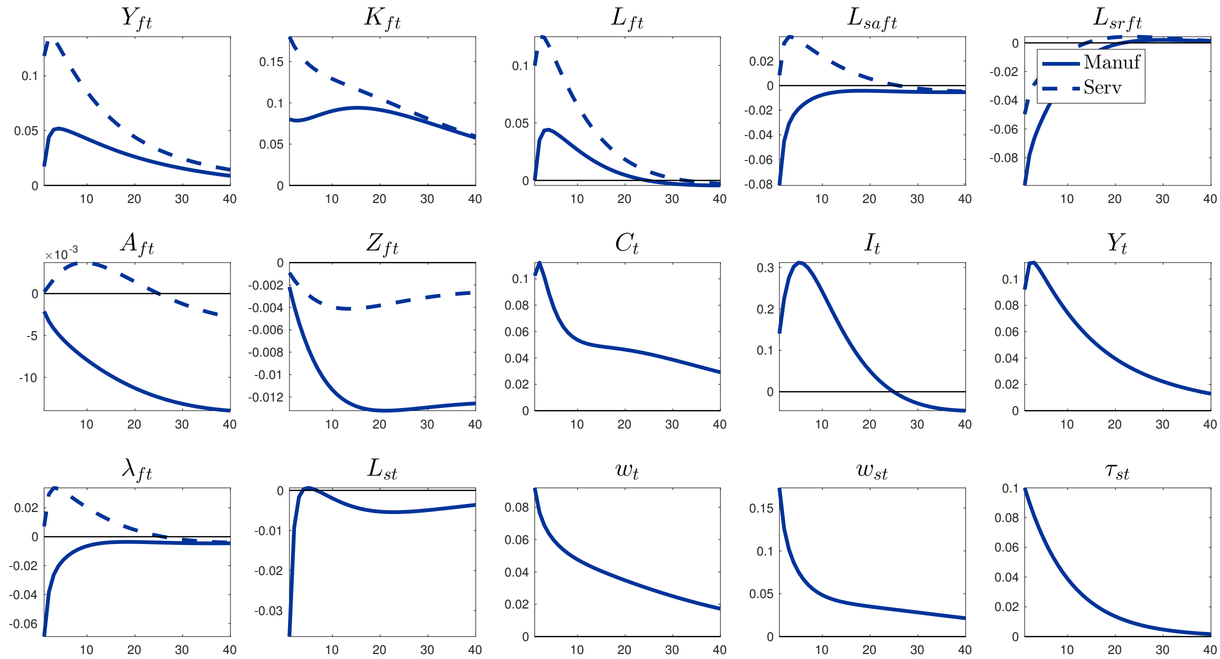

Figure 2: IRF's to a sectoral production subsidy shock, Services τ_{st}.

the skilled hours devotes to services adoption and to R&D decline. This causes again an asymmetric response of A_t in manufacturing and services, where the former increases while the latter declines. Furthermore Z_t declines gradually in both sectors, causing the stock of adopted technologies to eventually decline in both sectors.

This feature of the response is also markedly different in the simplified model and in the model with wage rigidities. Figure (5) in the appendix shows that, as the wage for skilled workers does not adjust initially, in response to a manufacturing subsidy, adoption increases both in manufacturing and services and R&D increases in manufacturing.

Finally, the effect of the manufacturing subsidy on the economy is long lasting. In the simplified model, the source of the persistently higher output is the effect of the shock on the capital stock. In the model with wage rigidities, the long run impact on output is greater because in addition to the effect on capital, the sectoral output subsidy also has a persistent positive effect on the stock of adopted technologies in manufacturing.

The results for a subsidy to services has, in this economy, similar effects, as figure (2) shows. The main take away from our analysis of the sectoral output subsidy is that, while they trigger expansionary responses of sectoral output and this feature is robust to the assumptions made on the wage setting mechanism, the impact that the sectoral subsidies have on the evolution of technology depends heavily on the degree of wage rigidity. In the case where wages are flexible, sectoral subsidies have contractionary effects on technology in the medium term, while in the presence of wage rigidities sectoral output subsidies have permanent expansionary effects on the stock of adopted technologies in the subsidized sector and transitory positive effects on the technology in the non-subsidized sector.

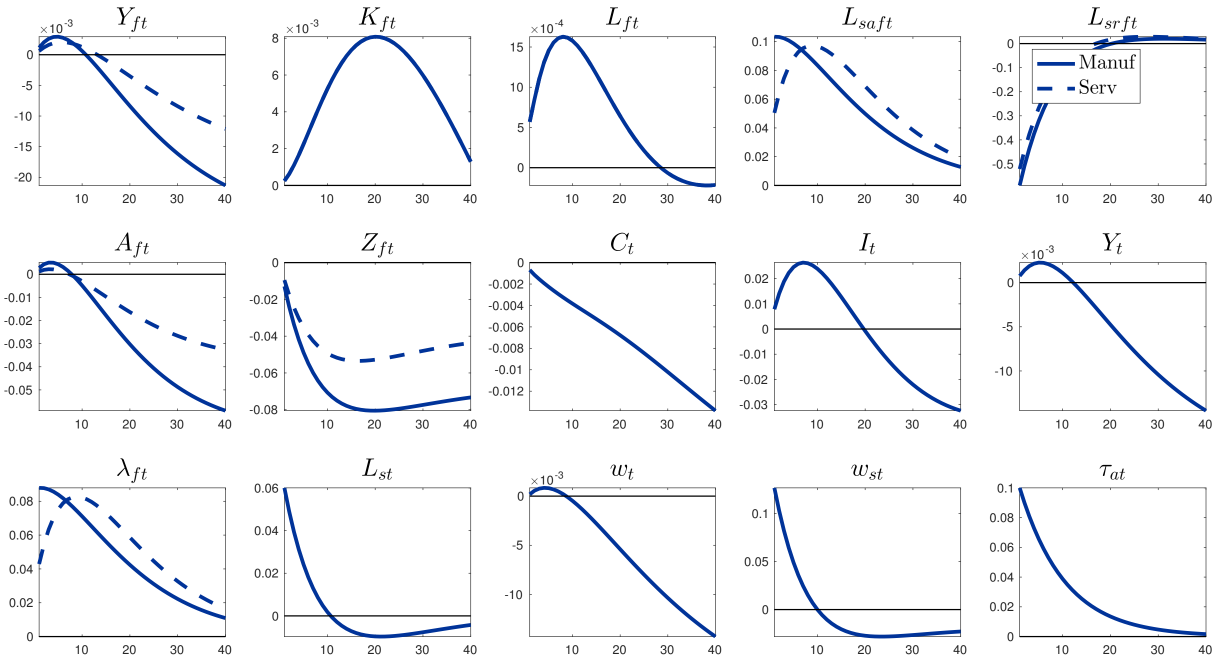

Figure 3: IRF's to an adoption subsidies shock τ_{at}.

5.2 Subsidies to technology adoption and R&D

In this section we study the effects of subsidies to adoption, τ_{at} and R&D, τ_{rt}. The main difference of this exercise respect to the previous one is that we are only affecting innovation activities, unlike the production subsidy that affects both margins directly. The subsidies now are symmetric across sectors.

Figure (3) shows the effect of adoption subsidies. The first to note is that this policy has a similar effect to the sectorial subsidy. The main difference is in the response on investment in R&D, that falls. This happens because although there is an increase in the supply of skilled labor, it is not enough to provide all the labor required to adoption investment. This generates a shift from R&D labor to adoption. The main implication of this movement is that the stock of technologies fall largely. Therefore, in the short-run the impact on the economy is expansionary but in the long-run it is contractionary. The shape of the medium term response is similar to figures (1) and (2) but converging to a contraction in the long run.

Is also interesting to note the differences in the response of wages. Unskilled wages have a hump-shaped positive response while skilled wages jump up in the short run but converges to negative figures in the long-run. This is because they are driven by different factors. Skilled wages are driven by technology and unskilled by a mix between capital and technology. As capital rises an order of magnitude more than the drop in technology, skilled wages maintain positive for a longer time.

Finally, figure (4) shows a symmetric subsidy to R&D. As expected, and in similar way to WP1, we find that a subsidy to R&D stimulates the economy greatly, but at a cost of ten periods of mild recession. This, because the extra demand of skilled labor don't pushes the overall supply for skilled labor, so investment in adoption has to fall in the short-run,

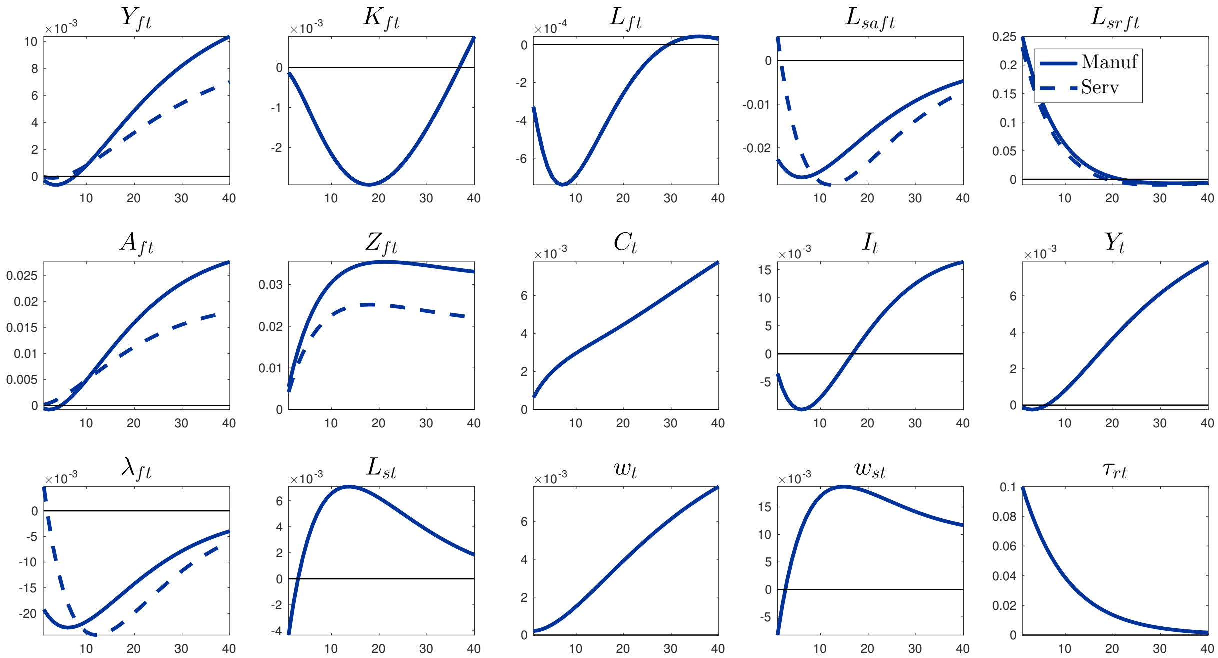

Figure 4: IRF's to an R&D subsidies shock τ_{rt}.

so embodied technologies fall as well. However, the stock of technologies increase steadily and permanently. This, plus the recovery of adoption investment (due also to the return of R&D investment to steady state) makes the embodiment of technologies more likely (λ_t goes up). Therefore, the economy experiences a boom in adoption and in consequence, production rises permanently. As the technological process in services is less efficient ($\rho_{zs} < \rho_{zm}$), services sees a smaller boom.

We can extract two big conclusions out of these two exercises. First, that a subsidy to profits seems to be a better policy to stimulate the economy, both in the short- and the long-run. This is because it affects the two margins of technology, adoption and R&D which demand skilled labor both. For a subsidy of any of the technological activities instead, this doesn't happen, because only one margin has to be fulfilled and the other reacts to the development of the economy. Second, that follows from the previous reason, is that as both things happen there are spillover on the economy. Both sectors are stimulated, because of the higher availability of inputs in the economy; hence, all sectors experience a boom that is persistent and permanent. However, the aggregate effect depends on the share of the sector. The larger is the share, the larger is the impact of a subsidy to that sector, as we can see from the difference of the long-run response of subsidies to profits in manufactures and services.

To conclude this section, it is worth to notice that when we consider a subsidy to production (or profits), the trade-off between the long and short-run that appears when subsidizing innovation activities is not present anymore.

6 Discussion of extensions and sectoral trends

In this section, we take a step back and discuss some of the modeling strategies as well as alternatives and their implications for structural change and the direction of innovation. In particular, we discuss three broad issues: (i) the modification of the sectoral production function to allow for sectoral heterogeneity in the intensity of productive factors; (ii) the drivers of structural change; and (iii) the drivers of sectoral variation in innovation activity.

6.1 Sectoral heterogeneity in skilled labor

In the model the factor intensity is constant across sectors. This simplifying assumption facilitates the task of obtaining an aggregate representation of production. However, it may limit the model in determining the drivers of the direction of innovation (i.e. the sectoral composition of R&D). Next, we briefly discuss this topic by considering an extension of the sectoral production function (8) where skilled labor also enters in the production of final output and where factor shares differ across sectors. In particular, intermediate goods are produced according to

$$Y_{fmt} = \theta_t A_{ft}^{\vartheta-1} \left(U_{ft} K_{ft}\right)^{\alpha_f} L_{fst}^{\alpha_f^s} L_{ft}^{1-\alpha_f-\alpha_f^s} \tag{61}$$

where the skilled labor share in sector f is α_f^s.

Beyond the implications that this modification has for the aggregate production function, we want to emphasize how policies that induce changes in the supply of skilled labor (e.g. an education subsidy such as those considered in WP3) affect the profitability of intermediate goods in skilled intensive sectors. In particular, a policy that leads to an exogenous increase in the supply of skilled labor will, ceteris paribus, lead to a reduction in skilled wages, lowering the marginal cost of production specially in sectors that are intensive in skilled labor. The reduction of the marginal cost in skilled intensive sector leads to an increase in the profits earned by intermediate goods producers in those sectors. Hence, policies that affect skilled labor supply in a context where skill-intensity varies across sectors is equivalent to sector-specific output subsidies.

As we have seen above, sector-specific output subsidies lead to an increase in R&D and adoption activity especially in the sector that experience the increase in output subsidies. Hence, we should expect that exogenous increases in the supply of skilled labor will lead to an increase in innovation activity in sectors that are intensive in skilled labor. This result has been highlighted by the induced/directed technical change literature (e.g., Acemoglu (2002)), and we provide some supportive evidence below.

6.2 Structural transformations

In the model we have developed in this work package, the sectoral shares in GDP are constant. This feature of the model is important because it permits it to have a balanced growth path. The existence of a balanced growth path is necessary for the method we use to compute the model transitional dynamics. Namely, to log-linearize the dynamic system that defines the equilibrium of the economy around the steady state. Therefore, for technical reasons, we must construct the model in a way that it contains a balanced growth path.

The constancy of the sectoral shares is not a bad approximation of the data over the short and medium term but it is counterfactual over protracted periods of time. It is well known that economies undergo large scale sectoral reallocations of employment and capital as they develop, in a process commonly known as structural change (Kuznets (1973); Maddison, 1980; Herrendorf et al. (2014); Vries et al. (2014)). These reallocations lead to a gradual fall in the relative size of the agricultural sector and a corresponding rise in manufacturing. As income continues to grow, services eventually emerge as the largest sector in the economy.

Leading theories of structural change attempt to understand these sweeping transformations through mechanisms involving either supply or demand. Supply-side theories focus on differences across sectors in the rates of technological growth and capital intensities, which create trends in the composition of consumption through price (substitution) effects (Baumol (1967); Ngai and Pissarides (2007); Acemoglu and Guerrieri (2008)). Demand-side theories, in contrast, emphasize the role of heterogeneity in income elasticities of demand across sectors (nonhomotheticity in preferences) in driving the observed reallocations accompanying income growth (Kongsamut et al. (2001), Comin et al. (2015), CLM henceforth).

To understand the connection between income and price effects and structural transformation consider the following expression for the (log) share of nominal value added in services relative to manufacturing $\left(\frac{VA_s}{VA_m}\right)$ from CLM.

$$log\left(\frac{VA_s}{VA_m}\right) = \beta + (1-\sigma) * \log\left(\frac{p_s}{p_m}\right) + (\epsilon_s - \epsilon_m) * \log\left(C_t\right) \tag{62}$$

In this expression, β is a constant, σ is the elasticity of substitution across sectors, $\frac{p_s}{p_m}$ is the relative price of services vs. manufacturing, ϵ_i is the slope of the Engel curve in sector i, and C_t is an index of real consumption. It is clear from (62) that changes in share of services may be driven by changes in relative prices and by changes in aggregate consumption/income. In particular, if the elasticity of substitution, σ, is smaller than 1, increases in the relative price of services will lead to increases in the relative share of services. Similarly if the income elasticity of services is greater than in manufacturing (i.e. $\epsilon_s > \epsilon_m$), the relative share of services increases as the economy and aggregate consumption grow. CLM show that both of these mechanisms are at work in explaining structural transformations but that income effects are much more relevant than price effects.

Inspecting expression (62), it is quite straightforward to see why the FRAME model cannot account for structural transformations. First, the sectoral aggregator in our model is Cobb-Douglas, and therefore the elasticity of substitution across sectors is equal to 1. Therefore, price effects so not affect sectoral nominal shares. Second, the income elasticity of demand for all sectors is equal to 1, therefore, income effects do not alter relative sectoral shares either.

6.3 Drivers of sectoral R&D

In addition to the transformation of the sectoral distribution of economic activity there has been a much less studied transformation of the direction of innovation. Comin et al. (2015) document this transformation which is illustrated in Tables (4) and (5) for the US, and more broadly for the US, Germany, Japan, UK and France. Broadly speaking, R&D has shifted from manufacturing to non-manufacturing sectors. Within manufacturing it has declined in industrial chemicals, motor vehicles and petroleum and it has increased in pharmaceuticals.

An interesting question in the context of the general questions posed in WP2 is what factors may have contributed to the structural transformation of innovation. Comin et al. (2015) explore two factors that we have already discussed: differences in the skill-intensity of production of sectoral output, and differences in the income elasticity of demand for sectoral outputs.

We estimate the following regression

$$\triangle R\&D_f = \alpha + \beta * \epsilon_f + \gamma * skill\_intensity_f + u_f \tag{63}$$

In this regression, the dependent variable is the change in the average share of R&D in sector f to total private R&D spending between the period 1980-84 and the period 2011-2015. This data is calculated using COMPUSTAT data for US publicly-traded companies. ϵ_f is the income elasticity of the value added produced in sector f. $skill\_intensity_f$ is the share in the wage bill of college graduates in 1998. u_f is the error term.

Table (6) presents our estimates. The key finding is that both income elasticities and skill_intensity are significant drivers of the transformation in innovation. This finding supports the key mechanisms of the models in WP1 and WP2 of FRAME which, based on the simulations, have shown how innovation activity responds to both demand-side and supply-side shocks.

7 Conclusion

In this second Work Package we have developed a multi-sector extension of the baseline model which serves to analyze the drivers of R&D and productivity growth across sectors. As in WP1, we have considered a diverse set of policies ranging from R&D and adoption subsidies to sector-specific subsidies which also capture policies that affect the supply of factors whose intensity differs across sectors (e.g., skilled labor). We have solved for the steady state of the model and calibrated the model parameters to match key facts about the German economy such as the sectoral distribution of R&D, value added and growth. Then we have used the model to simulate the effects of sector-specific subsidies as well as subsidies to R&D and adoption costs that are symmetric in manufacturing and services.

The key findings from our simulation exercises are:

(i) Subsidies to one sector have asymmetric effects over the other sectors. However, there are positive spillovers on output.

(ii) Sectoral subsidies have persistent and permanent effects on sectoral and total output. The nature of this long-run effects depends on the specific assumptions made on the degree of wage rigidity. When wages are fully flexible the long-run effects are entirely driven by the impact of the subsidy on capital accumulation. When there are wage rigidities, in addition the shock has a long-run affect on the stock of adopted technologies.

(iii) Subsidies to adoption have symmetric effects. Their final effects depend on the elasticities of the technology to investment. This policy have positive impact in the short-run but negative in the long-run.

(iv) Subsidies to R&D investment have symmetric effects. Their final effects depend on the elasticities of the technology to investment too. This policy have negative impact in the short-run but positive in the long-run. Therefore, there is a trade-off when subsidizing adoption or R&D.

(v) Finally, we conclude from our policy simulations, that a subsidy to profits might be the best way to stimulate the economy both in the short- and the long-run. With the effects depending on the share in the economy of the sector subsidized.

Our analysis can be extended in several ways. In the light of our discussion, the most natural extension is to allow for richer demand systems that allow for non-homethicities and for non-unitary elasticities of substitution across sectors. The main challenge of this extension is technical. This more general model will not have a balanced growth path. As a result, we cannot study its transitional dynamics by using standard approximation methods. The extension, however, shall provide new insights on the drivers of structural transformations and the direction of innovation at different stages of development as well as on the effect of supply-side policies on the composition of economic activity and R&D at different horizons.

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A Tables

2013			1981		
Manufacturing industries	31-33	68.39%	Manufacturing industries	20-39	96.60%
Food, Beverage and Tobacco	311, 312	2.08%	Food and Kindred products	20	2.02%
Textile, apparel, and leather products	313-16	0.24%	Textile and Apparel	22,23	0.35%
Wood products and furniture	331, 337	0.22%	Lumber wood and furniture	24,25	0.47%
Chemicals	325	20.49%	Chemicals	28	13.98%
Industrial Chemicals	3251-53	1.74%	Industrial Chemicals	281-82, 286	6.18%
Pharmaceuticals and medicines	3254	17.32%	Drugs and medicines	283	5.65%
Other chemicals	3255-59	1.43%	Other chemicals	284-85, 287-289	2.15%
Primary metals	331	0.23%	Primary Metals	33	2.00%
Fabricated metal products	332	0.73%	Fabricated Metal Products	34	1.58%
Machinery	333	4.56%	Other Machinery (except electrical)	351-56,358-59	6.06%
Comp, electro prod & electrical equip	334, 335	23,03%	Comp, electro prod & electrical equip	357, 36	29.47%
Transportation equipment	336	9.50%	Transportation equipment	37	21.44%
Motor vehicles and equipment	3361-63	5.32%	Motor vehicles and equipment	371	12.15%
Aerospace products and parts	3364	3.79%	Aircraft and missiles	372,376	9.05%
Other transportation	other 336	0.39%	Other transportation equiment	373-375, 379	0.24%
Nonmanufacturing industries	21-23, 42-81	31.61%	Nonmanufacturing industries	1-17, 40-89	3.40%
Information	51	21.15%			
Professional, scientific, & technical serv	54	5.90%			
Other nonmanufacturing	21-23, 42-49				
Other nonmanufacturing	52, 53, 55-81	4.56%			

Source: NSF Tables B-6 for 1981 and Table 29 for 2013

Table 4

	1987		2008		Increment	
	US, Jap, Ger	US, Ger, Jap, Fra, UK	US, Jap, Ger	US, Ger, Jap, Fra, UK	US, Jap, Ger	US, Ger, Jap, Fra, UK
agri	0.001	0.003	0.004	0.004	0.003	0.001
manu	0.938	0.927	0.767	0.770	-0.171	-0.157
Manu+min+constr	0.963	0.936	0.770	0.773	-0.193	-0.163
serv	0.033	0.059	0.227	0.223	0.194	0.164
food&tob	0.016	0.016	0.012	0.013	-0.004	-0.003
coke and petr	0.016	0.017	0.004	0.005	-0.012	-0.012
chem	0.136	0.143	0.182	0.189	0.046	0.046
pharma	0.051	0.056	0.137	0.143	0.086	0.087
Other Chemicals	0.085	0.087	0.045	0.046	-0.040	-0.041
Machinery and eq sh	0.052	0.050	0.056	0.055	0.004	0.005
Radio and TV	0.195	0.190	0.130	0.124	-0.065	-0.066
Medical Instruments	0.046	0.043	0.066	0.065	0.020	0.022
Motor vehicle	0.289	0.263	0.111	0.111	-0.178	-0.152
electrical machinery	0.044	0.045	0.030	0.031	-0.014	-0.014
OCAM	0.112	0.102	0.032	0.030	-0.080	-0.072

Note: Company R&D in US, Germany and Japan is allocated by main activity of the firm, while in France and UK R&D it is allocated based on the product field.

Table 5

	R&D share 2011-2015 minus share 1980-84					
	I	II	III	IV	V	VI
Income Elasticity	2.13	2.11	1.78	1.76	2.07	2.05
	(0.76)	(0.69)	(0.7)	(0.63)	(0.63)	(0.57)
Share of College educ in Wage Bill					0.17	0.17
					(0.06)	(0.055)
Minimum R&D share	> 0.001	>0.0005	>0.001	>0.0005	> 0.001	> 0.0005
Weighted	Av sec R&D	Av sec R&D	Init R&D share	Init R&D share	Init R&D share	Init R&D share
Broad sector Dummies	Yes	Yes	Yes	Yes	Yes	Yes
N	29	34	29	34	29	34
R2	0.35	0.35	0.35	0.35	0.48	0.48

(): robust standard deviations.

Table 6

B Real model simulations

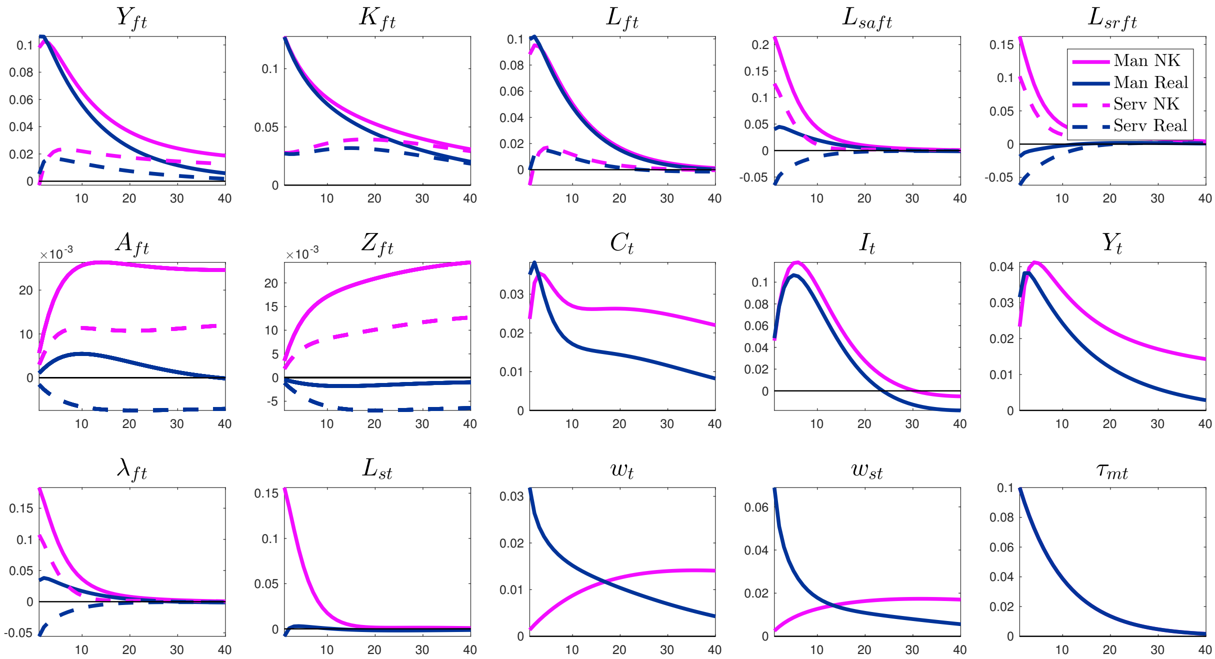

Figure 5: IRF's to a sectoral production subsidy shock, Manufactures τ_{mt}, in the Real and the New Keynesian model.

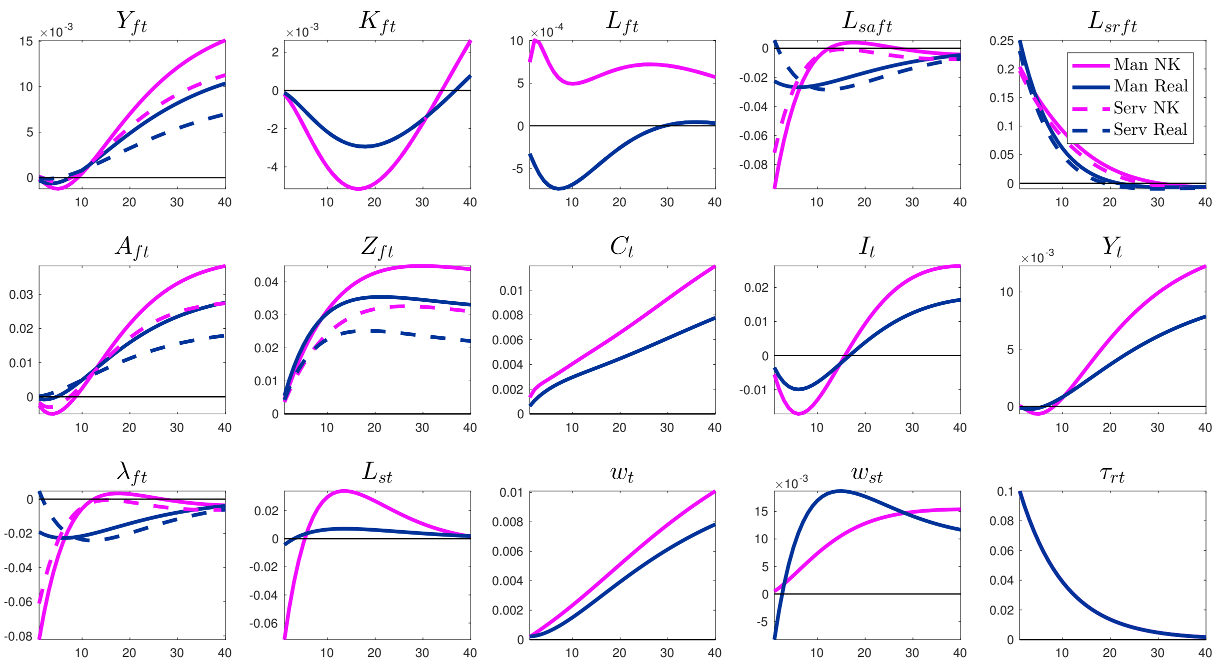

Figure 6: IRF's to an R&D subsidy shock, τ_{rt}, in the Real and the New Keynesian model.