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Labour market skills, endogenous productivity and business cycles

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Abstract

This paper analyses how labour market heterogeneity affects unemployment, productivity and business cycle dynamics that are relevant for monetary policy. The model matches remarkably well the short and long run dynamics of skilled and unskilled workers. Skill mismatch and skill-specific labour market institutions have three main effects on business cycles and growth dynamics. First, as the composition of labour market skills leads to supply segmentation, the relative scarcity of skilled workers increases the natural rate of unemployment and reduces total factor productivity with long-run effects on the growth rate of output. Second, skill heterogeneity in the labour market generates asymmetric outcomes and amplifies measures of employment, wages and consumption inequality. Finally, the model provides important insights for the Phillips and Beveridge curves. Skill-specific labour market heterogeneity leads to a flattening of the Phillips curve as wages and unemployment are affected differently across skill types. Also, the model generates sideward shifts of the Beveridge curve following business cycle shocks that are related to the degree of skill heterogeneity.

JEL classification: E24, E3, E5, O41, J64

Keywords: Monetary policy, labour market, skill heterogeneity, endogenous growth, unemployment fluctuations; Phillips curve; Beveridge curve; consumption inequality.

Non-Technical Summary

Technological changes have been skill biased during the last decades and technological revolutions have led to capital reallocation towards highly innovative jobs and firms. This, in turn, has affected labour productivity and its dispersion across firms as well as wage premia among skilled and unskilled workers. Skill-biased and routine-biased technological changes have further built up heterogeneity in labour market outcomes, including inequality across workers. This has transformed the long-term potential of modern economies as well as their business cycle dynamics, including the macroeconomic environment in which monetary policy operates.

This paper develops a model to analyse how labour market skill heterogeneity affects, among others, unemployment, productivity and wages. It derives important insights for monetary policy as it looks at the relationship between wages and unemployment - the Phillips curve – and at the relationship between job vacancies and unemployment - the Beveridge curve – over the business cycle. The model combines three main ingredients: (i) three different types of households: entrepreneurs, high-skilled and low-skilled workers, (ii) segmented labour markets for skilled and unskilled workers, with search and matching frictions in each of them and (iii) endogenous productivity through R&D investment and intangible capital accumulation. The model is calibrated for the euro area aggregate and at a quarterly frequency. Standard macroeconomic variables are derived from Eurostat National Accounts and the HICP database, while data on wages and employment rates by skills are from Eurostat EU SILC (2005 – 2018) and the Labour Force Survey (2000-2019) database. The model provides a rich characterization of the labour market and a rigorous framework to study the interaction between the economy's skill distribution, labour market institutions and business cycle dynamics.

In our model, skill-specific labour market heterogeneities lead to a flattening of the Phillips curve as wages and unemployment levels are affected differently across skill types, with unskilled workers being more likely to become unemployed while skilled ones are more likely to be re-hired at a lower wage. Hence, at the aggregate level, skill heterogeneity has an impact on the sensitivity of wages to unemployment conditions. Skill heterogeneity is also important for the Beveridge curve. While business cycle shocks generally lead to fluctuations along the Beveridge curve, the presence of skill heterogeneity in the model can generate larger side shifts. This shows that not all outward shifts of the Beveridge curve – leading to an increase in the unemployment rate – are related to labour market inefficiency and therefore it has implications for the assessment of the natural rate of unemployment.

We show that the model is able to match the dynamics of wages and employment rates after the global financial and euro area sovereign debt crisis. This is so because the introduction of labour market skills allows a strong reaction of the wage skill premium to be generated along with a gap between skilled and unskilled employment rates. In doing so, the model is able to generate meaningful developments in consumption and wage inequality across skill types.

1 Introduction

The Global Financial Crisis and the European sovereign debt crisis have led to prolonged and negative effects on output, TFP and labour productivity growth in the euro area, spurring talks of an acceleration of the secular stagnation hypothesis and bringing back the peril of economic hysteresis. For the euro area, output growth before the 2008 Global Financial Crisis (GFC) was almost three times greater than in the subsequent ten years. Similarly, labour productivity growth has been half of what the euro area economy experienced before the GFC (see Table 1). The fallouts from the crises have been particularly harsh for the weakest segments of the labour force. The euro area unemployment rate was back to pre-2008 levels as recently as 2019 (at about 7.5%), after having reached a record high level in 2012 at about 12%. The labour market adjustment has been particularly delayed for low-skilled workers and young people, who have suffered from higher and longer unemployment spells.[1]

Figure 1 shows that the evolution of employment rates and real wages in the euro area have differed significantly among skilled and unskilled workers.[2] The decline of employment rates has been much more severe for unskilled workers (-5.4pp) compared to the skilled workers (-3.0pp) over the period 2008-2013. The unemployment rate in 2013 was 13.9 percent for unskilled workers and 7.4 percent for skilled ones. On the other hand, the response of real wages has been more severe for skilled workers. Gross annual real wages declined more than 7 percent for the highly skilled, while the figure was about 3 percent for low-skilled workers. Following the GFC, the wage premium of highly educated workers has shrunk while the employment rate gap has increased with the crisis.[3] These results are corroborated by the empirical evidence on the career effects of entering in the labour market during a recession or when general business cycle conditions are not favourable as shown by Oreopoulos et al. (2012), Raaum and Roed (2006), and Von Wachter (2020). There is thus an important rationale for taking a deeper look at skill heterogeneity in the labour market as, over the business cycle, aggregate employment fluctuations are mostly driven by unskilled workers while wage dynamics are mostly

[1] Recent research shows that labour market heterogeneity is not only important per se, but also for the general equilibrium effects including the underlying process for labour productivity, long-term growth as well as wage and price formation. For example, Sahin et al. (2014) show that industry and occupation mismatch lead to lower matching efficiency and can explain about one third of the increase in the unemployment rate in the US during the GFC via lower job finding rates. Labour market heterogeneity or segmentation across workers may affect the aggregate job finding rate via composition and dispersion effects in matching efficiency as shown in the work by Barnichon and Figura (2015). Ahn and Hamilton (2018) document that worker heterogeneity in survey sampling leads to mismeasurement of the unemployment rate and its duration.

[2] High-skilled workers are college graduates. Low-skilled workers include workers with low and middle education, including workers with secondary education, high school and university drop-outs. Data on gross wages is from the EU-SILC database, and are deflated by the consumption deflator. Data on employment rates by skill are from Eurostat.

[3] See also Checchi et al. (2016).

affected by skilled workers. Furthermore, such heterogenous effects across labour market groups may also have important effects during the recovery.

The aim of this paper is to analyse how labour market segmentation and worker heterogeneity affect unemployment, productivity and business cycle dynamics. For this purpose, we set up a New Keynesian model with incomplete asset markets that combines: (i) three different types of households - entrepreneurs, high-skilled and low-skilled workers; (ii) segmented labour markets with search and matching frictions in each of them; and (iii) endogenous productivity growth through R&D investment and intangible capital accumulation. The model provides a rich characterization of the labour market and a rigorous framework to study the interaction between the economy's skill and asset distribution, labour market institutions and monetary policy.

We investigate the effects of two aspects of labour market heterogeneity: skill mismatch and skill-specific labour market institutions. The first aspect refers to the mismatch between the relative demand for skilled workers - which is strictly related to their weight in the production function - and their relative supply, which is determined by the proportion of high-skilled workers in the population. Asymmetric, skill-specific, labour market institutions are modelled by assuming that skilled workers have higher bargaining power and get more generous unemployment benefits than the unskilled. The model is calibrated to the euro area and parsimoniously considers only two shocks: a liquidity and a technology shock. Overall, we find that the model has the potential to match remarkably well both the second moments of the data and the short and long run dynamics of the labour markets for high and low-skilled workers.

We find that skill mismatch and asymmetric labour market institutions have profound effects on both business cycle and growth dynamics. We highlight three main results. First, we show that the relative scarcity of high-skilled workers produces strong effects not only on long-run measures of earning and employment inequalities, but also on the long run level of employment and on the growth rate of TFP and output, which are reduced. These effects are quantitatively large: compared to a situation with no differences between skilled and unskilled workers, the presence of skill mismatch and asymmetric institutions increases the natural unemployment rate from 5 to 10 percent, and decreases the long run growth rate of the economy from 1.6 to around 1 percent (annualized). This happens because the scarcity of high-skilled workers limits firms' profitability and does not fully enable firms to expand production and investment which is an obstacle to long-term growth. The reduction in employment and production, in fact, reduce the demand for specialized goods. This diminishes investment in R&D and leads to sizeable negative effects on TFP growth.

Second, we show that asymmetric labour market structures have large effects on measures of employment, wages and consumption inequalities. In particular, both liquidity and technology shocks trigger a strong reaction of the wage skill premium and an even stronger reaction of the employment rate ratio between skilled and unskilled workers' employment rates. These results are mainly due to the large supply of unskilled workers, which lowers the equilibrium value of an employment relationship with an unskilled worker. This in turn implies, for a given level of the bargaining power, larger employment fluctuations and less volatile wages in the low-skilled segment of the labour market (see, e.g., Hagedorn and Manovski, 2008). The model is thus able to match, at least qualitatively, the dynamics of wages and employment rates after the 2008 and 2011 crises depicted in Figure 1.

Third, we show that skill mismatch and labour market asymmetries strongly affect the economy's Phillips and Beveridge curves. The Phillips curve shifts outwards, because labour market heterogeneity increases the natural unemployment rate, and becomes flatter, because the relative abundance of unskilled workers reduces the elasticity of wages and marginal costs to employment fluctuations. Similarly, the presence of a skill mismatch shifts the Beveridge curve outwards, because it reduces the overall efficiency of the matching process and increases the average unemployment rate in the economy, and makes it flatter. Interestingly, once we allow for asymmetric labour market institutions that give more power to high-skilled workers, the average unemployment rate and measures of unemployment inequality are actually reduced, and both the Phillips and the Beveridge curves shift partially back. This happens because the increased cost of hiring high-skilled workers reduces the tightness of their labour market, while the tightness of the low-skilled market increases to more normal levels. The search and matching process becomes more fluid in both markets, slightly increasing average employment, production and growth.

Our paper relates to several strands in the literature. First, by considering heterogeneous households and incomplete markets our model relates to the burgeoning literature on macroeconomic dynamics and inequality (see e.g. Kaplan et al., 2016; Luetticke, 2017; Ravn and Sterk, 2016; Gornemann et al. 2016). More specifically, our model builds on a few articles which explore the ability of tractable models to mimic properties of richer but more complex Heterogeneous Agents New Keynesian (HANK) models. For example, Debortoli and Galí (2018) show that a simple Two-Agents New Keynesian (TANK) model with a constant share of constrained households and no heterogeneity within either type, approximates reasonably well the implications of HANK models regarding the effects of aggregate shocks on aggregate output. Cantore and Freund (2021) develop a Capitalist-Worker New Keynesian model where capitalists receive earnings from profits but do not supply labour, while workers only receive labour income and are subject to portfolio adjustment costs. They show that these assumptions allow the model to deliver realistic intertemporal marginal propensity to consume, and to avoid implausible income effects on labour supply. We extend the models by Debortoli and Galí (2018) and Cantore and Freund (2021) by allowing not only for the distinction between capitalists (who we call entrepreneurs in our paper) and workers, but also for the distinction between skilled and unskilled workers. Moreover, by allowing for segmented labour markets and asymmetric matching frictions, our framework enables us to study the effects of different types of labour market heterogeneity on aggregate fluctuations and measures of earning and consumption inequality.

Our paper also relates to the recent literature that integrates innovation and the adoption of new technologies into a real business cycle model (see e.g. Comin and Gertler, 2006; Kung and Schmidt, 2015; Guerron-Quintana and Jinnai, 2018, Anzoategui et al. (2019) among others). The introduction of a mechanism of endogenous growth allows us to explicitly study the effect of labour market heterogeneity via different skill types on aggregate productivity and TFP dynamics, and to conduct a unified treatment of business cycles and long-term dynamics following demand and supply shocks.

Finally, our model is related to the literature studying workers heterogeneity in search and matching models of the labour market (see e.g. Shimer , 2007; Bils et al. 2012; Sahin et al., 2014; Mueller 2017), and to the literature combining nominal rigidities and search and matching frictions (see e.g. Walsh, 2005; Blanchard and Galí, 2010; Gertler, Sala and Trigari, 2008; Gertler and Trigari, 2009). Our approach is closer to the models of Ravenna and Walsh (2012) and Dolado et al. (2021). Ravenna and Walsh (2012) develop a monetary model where workers with different efficiencies compete for the same position, and firms need to screen out less efficient candidates. During recessions the share of low-efficiency workers in the pool of unemployed rises, and this composition effect reduces the incentives of firms to post vacancies. For this reason, heterogeneity in workers' efficiency amplifies unemployment fluctuations and leads to slow recoveries. Our modelling of labour markets differ from Ravenna and Walsh (2012) in that we assume that the labour markets for high and low-skilled workers are segmented, and subject to asymmetric search and matching frictions. This allows us to study, in a very tractable setting, the effect of different labour market institutions on labour markets and business cycle dynamics. Dolado et al. (2021) develop a New Keynesian model with asymmetric search and matching frictions between skilled and unskilled workers and capital-skill complementarity to investigate how monetary policy affects inequality over the business cycle. They find that an unexpected monetary expansion leads to an increase in the wage premium for high-skilled workers, due to their smaller matching frictions and to the higher complementarity of skilled workers with capital. We borrow the modelling of labour markets from Dolado et al. (2021), but we differ in two main respects. First, we assume that technology is endogenous and sustained by innovation through R&D. Second, we have a different focus, as we study the effects of different types of labour market heterogeneity on both short-run business cycle dynamics and long-run growth dynamics.

The remaining sections are structured as follows. Section 2 outlines the monetary model with skill heterogeneity and frictional labour markets. Section 3 discusses the baseline calibration, and the main results are described in Section 4. We conclude in Section 5.

2 The Model

Following Dolado et al. (2021), we assume that there are three different types of households: entrepreneurs, high skilled workers and low skilled workers, with constant masses φ^k, $k \in \{E, H, L\}$ such that $\sum_k \varphi^k = 1$. Entrepreneurs own the capital stock and firms. High and low skilled workers are combined in production according to a Cobb-Douglas production function, which allows for different productivity levels of the two types of workers. Financial markets are incomplete: different households can trade with each other in a single risk-free bond market. This incompleteness prevents full insurance against shocks, and leads to fluctuations in consumption inequality. Hiring is subject to search and matching frictions and wages are set by Nash bargaining. Technological growth is endogenous and sustained by innovation through R&D.

2.1 The labour markets

The labour markets for high and low skilled workers are completely segmented. Total employment for workers of skill k evolves following a process of job matching and destruction. A fraction ρ^k of employment relationships is destroyed in every period t and a number m_t^k becomes immediately operative. The law of motion is thereby

$$N_t^k = \left(1 - \rho^k\right) N_{t-1}^k + m_t^k \tag{1}$$

where $N_t^k = \varphi^k n_t^k$.

The matching technology for skill k is

$$m_t^k = \bar{m}^k \left(S_t^k\right)^{\zeta^k} \left(v_t^k\right)^{1-\zeta^k}$$

where $S_t^k = \varphi^k s_t^k$ is the aggregate measure of *searching workers* at the beginning of period t and v_t^k is the number of posted vacancies. The labour force participation rate is normalized to 1. The proportion of searching workers in family k is

$$s_t^k = 1 - \left(1 - \rho^k\right) n_{t-1}^k$$

Labour market tightness θ_t^k, vacancy filling probabilities q_t^k and hiring probabilities f_t^k are defined as follows:

$$\begin{aligned}
\theta_t^k &= \frac{v_t^k}{S_t^k} \\
q_t^k &= \frac{m_t^k}{v_t^k} = \bar{m}\left(\theta_t^k\right)^{-\zeta} \\
f_t^k &= \frac{m_t^k}{S_t^k} = \theta_t^k q_t^k.
\end{aligned}$$

For future reference, we also define *(after-hiring) unemployment* as the fraction of searching workers that remain unemployed after hiring takes place: $U_t^k = \varphi^k u_t^k$, where $u_t^k = 1 - n_t^k$.

2.2 Household optimization

2.2.1 Entrepreneurs

Entrepreneurs do not participate in the labour market, and for simplicity it is assumed that they derive fixed utility from leisure, which is normalized to zero. They can save by investing in a non-state contingent bond, B_t^E, and in physical capital, k_t. We assume external habit in consumption, i.e. the utility depends on past aggregate consumption levels $\tilde{c}_{t-1}^E$. Entrepreneurs own the firms in the economy, and receive all profits D_t^f as dividends.

Entrepreneurs maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log\left(c_t^E - h\tilde{c}_{t-1}^E\right) + \varsigma_t^E \chi_{bt}^E \frac{B_t^E}{P_t} \right\}$$

subject to

$$c_t^E + i_t + t_t^E + \frac{B_t^E}{P_t} \leq r_{Kt} z_t k_t + \frac{R_{t-1} B_{t-1}^E}{P_t} + D_t^f$$

where c_t^E denotes consumption and t_t^E are lump sum taxes. Notice that, following Anzoategui et al. (2019), we incorporate bonds in the utility function to capture a preference for the safe asset

(Krishnamurty and Vissing-Jorgensen, 2012). The parameter $\chi_{bt}^{E} = \frac{\chi_{b}^{E}}{\Psi_t}$ governs this preference for riskfree assets, where Ψ_t is a scaling factor which ensures the existence of a balanced growth path. $\varsigma_t^E > 0$ captures a shock to liquidity demand. As shown by Fisher (2015), this shock can be thought of as a structural interpretation of the Smetz and Wouters (2007)'s risk premium shock. Moreover, Anzoategui et al. (2019) show that the shock to liquidity demand transmits to the economy like a financial shock. Therefore, the shock to ς_t^E allows us to study the implications of a financial shock without explicitely modelling financial frictions.

Physical capital follows the law of motion:

$$k_{t+1} = (1 - \delta_K(z_t))\, k_t + \left[1 - \frac{\Theta_I}{2}\left(\frac{i_t}{i_{t-1}} - g\right)^2\right] i_t$$

where z_t is the capital utilization rate and $\delta_K(z_t) = \delta z_t^{\phi_k}$ is the depreciation rate, as e.g., in Greenwood et al. (1988). The quadratic term $\frac{\Theta_I}{2}\left(\frac{i_t}{i_{t-1}} - g\right)^2$ captures convex costs in physical investment and $\Theta_I > 0$ is a scale parameter. g denotes the steady state growth rate of the economy.

Denoting by λ_t^E the multiplier associated to the budget constraint and denoting the liquidity shock in consumption units as $\varrho_t^E = \frac{\varsigma_t^E \chi_{bt}^E}{\lambda_t^E}$, the solution to the maximization problem leads to the following first order conditions:

$$\begin{aligned}
\lambda_t^E &= \frac{1}{\left(c_t^E - h\tilde{c}_{t-1}^E\right)} \\
1 &= \beta R_t \mathbb{E}_t \frac{\lambda_{t+1}^E}{\lambda_t^E} \frac{R_t}{\pi_{t+1}} + \varrho_t^E \\
1 &= Q_{Kt}\left\{\left[1 - \frac{\Theta_I}{2}\left(\frac{i_t}{i_{t-1}} - g\right)^2\right] - \Theta_I\left(\frac{i_t}{i_{t-1}} - g\right)\frac{i_t}{i_{t-1}}\right\} \\
&\quad + \mathbb{E}_t \beta \frac{\lambda_{t+1}^E}{\lambda_t^E} Q_{Kt+1}\left\{\Theta_I\left(\frac{i_{t+1}}{i_t} - g\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right\} \\
Q_{Kt} &= \mathbb{E}_t \beta \frac{\lambda_{t+1}^E}{\lambda_t^E}\left\{(1 - \delta_K(z_{t+1}))\, Q_{Kt+1} + r_{Kt+1} z_{t+1}\right\} \\
r_{Kt} &= Q_{Kt}\delta_K'(z_t)
\end{aligned}$$

where Q_{Kt} is the Tobin's Q.

2.2.2 Workers

There are two types of worker households, $k \in \{H, L\}$, which maximize lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log\left(c_t^k - h\tilde{c}_{t-1}^k\right) + \varsigma_t^k \chi_{bt}^k \frac{B_t^k}{P_t} \right\}$$

where $\chi_{bt}^k = \frac{\chi_b^k}{\Psi_t} > 0$, subject to the budget constraint:

$$c_t^k + t_t^k + \frac{B_t^k}{P_t} + \frac{\vartheta_t^p}{2}\left(\frac{B_t^k}{P_t\tilde{c}_t^k} - \bar{B}^k\right)^2 \leq w_t^k n_t^k + b_t^k u_t^k + \frac{R_{t-1}B_{t-1}^K}{P_t} + h_t^k$$

and the law of motion of employment:

$$n_t^k = \left(1 - \rho^k\right) n_{t-1}^k + f_t^k s_t^k$$

Notice that to provide stationarity to the model in the presence of incomplete financial markets, we introduce a small portfolio adjustment cost, governed by $\vartheta_t^p = \vartheta^p \tilde{c}_t^k$, which penalizes households in case their real bond holdings as a fraction of average consumption, $\frac{B_t^k}{P_t\tilde{c}_t^k}$, deviate from some benchmark level $\bar{B}^k$. The financial autarky case can be approximated for $\vartheta^p \to \infty$. We assume that all these costs are rebated to the families as a lump sum $h_t^k = \frac{\vartheta_t^p}{2}\left(\frac{B_t^k}{P_t\tilde{c}_t^k} - \bar{B}^k\right)^2$. w_t^k denote real wages, t_t^k are lump sum taxes while $b_t^k = b^k\Psi_t$ denotes unemployment benefits paid to an unemployed worker of skill k.[4]

The solution to the maximization problem of household k gives standard conditions for the Lagrange multiplier on the budget constraint and the Euler equation:

$$\lambda_t^k = \frac{1}{\left(c_t^k - h\tilde{c}_{t-1}^k\right)}$$

$$\left\{1 + \vartheta^p\left(\frac{B_t^k}{P_t\tilde{c}_t^k} - \bar{B}^k\right)\right\} = \beta R_t \mathbb{E}_t \frac{\lambda_{t+1}^k}{\lambda_t^k \pi_{t+1}} + \varrho_t^k$$

where $\varrho_t^k = \frac{\varsigma_t^k \chi_{bt}^k}{\lambda_t^k}$ is the liquidity shock in consumption units. The value of an employment relationship for the household k, $V_t^{E,k}$, is

$$V_t^{E,k} = w_t^k - b_t^k + \mathbb{E}_t \beta \frac{\lambda_{t+1}^k}{\lambda_t^k}\left(1 - \rho^k\right)\left(1 - f_{t+1}^k\right) V_{t+1}^{E,k}$$

[4] To ensure balanced growth, we assume that unemployment benefits and vacancy posting costs grow at the same rate as the economy. In fact, if unemployment benefits and vacancy posting costs were constant, they would become irrelevant over time. See, e.g., Christiano, Eichenbaum and Trabandt (2015) and (2016) for similar assumptions and a discussion.

The net value of an additional employed worker in the household is the wage w_t^k net of unemployment benefits b_t^k, plus the expected continuation value from the employment relationship.

2.3 Supply side

There are four sectors in the economy. Firms in the intermediate good sector produce the intermediate homogeneous good in competitive markets using labour and capital. This output is sold to specialized patent producers who are monopolistically competitive. Patent producers own the exclusive right to make specialized patented goods that are then sold to retailers. Retailers transform these specialized goods into differentiated final goods that are sold to households. New patents are created by innovation through R&D in the innovation sector. Price rigidities, in the form of convex adjustment costs, arise in the retail sector, while search frictions together with convex wage adjustment costs exist in the intermediate good sector.

2.3.1 Final good and Retailers

There is a measure one of monopolistic retailers indexed by i on the unit interval, each of them producing one differentiated product. These differentiated goods are then assembled to become the final composite good:

$$Y_t = \left[\int_0^1 \left(Y_t^i \right)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \tag{2}$$

where ϵ represents the elasticity of substitution between retail goods. Due to imperfect substitutability across goods, the demand function for each retailer for its product is:

$$Y_t^i = \left(\frac{P_t^i}{P_t} \right)^{-\epsilon} Y_t \tag{3}$$

where P_t^i is the price of the final good i and the aggregate price index is $P_t = \left[\int_0^1 \left(P_t^i \right)^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$. Retailers produce the final retail good using a composite of specialized goods $Y_{S,t}^j$, according to the following CES production function:

$$Y_t^i = \left[\int_0^{Z_t} \left(Y_{S,t}^j \right)^{v} dj \right]^{\frac{1}{v}} \tag{4}$$

where Z_t is the number of patents in use at date t, $Y_{S,t}^j$ is the quantity of specialized good j and $p_{S,t}^j$ is the corresponding real price. $v < 1$ governs the elasticity of substitution between patents.

We introduce nominal rigidities for retailers assuming firms face Rotemberg-style quadratic costs of adjusting prices. Retail firms maximize expected profits

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t^E}{\lambda_0^E} \left\{ \left[\frac{P_t^i}{P_t} - \Gamma_t^i \right] Y_t^i - \int_0^{Z_t} p_{S,t}^j Y_{S,t}^j dj \right\}$$

subject to price adjustment costs $\Gamma_t^i = \frac{\psi}{2} \left(\frac{P_t^i}{P_{t-1}^i} - \pi^* \right)^2$, to the Dixit–Stiglitz demand function faced by each retailer (3), and to the retailer production function (4). π^* is trend inflation. Let us denote by

$$p_{S,t} = \left\{ \int_0^{Z_t} \left(p_{S,t}^j \right)^{\frac{v}{v-1}} dj \right\}^{\frac{v-1}{v}}$$

the aggregate real price of the composite of specialized goods, $\left[\int_0^{Z_t} \left(Y_{S,t}^j \right)^v dj \right]^{\frac{1}{v}}$. The first order conditions for retail firms earn a demand function for each specialized variety

$$Y_{S,t}^j = \left(\frac{p_{S,t}^j}{p_{S,t}} \right)^{\frac{1}{v-1}} Y_t^i$$

and a Phillips curve:

$$\Gamma_t' \pi_t = \epsilon \left(p_{S,t} + \Gamma_t \right) - (\epsilon - 1) + \beta \mathbb{E}_t \left[\left(\frac{\lambda_{t+1}^E}{\lambda_t^E} \right) \frac{Y_{t+1}}{Y_t} \Gamma_{t+1}' \pi_{t+1} \right]$$

where $\pi_t = \frac{P_t^i}{P_{t-1}^i} = \frac{P_t}{P_{t-1}}$ denotes gross inflation and we used the fact that, in equilibrium, all retail firms set the same price and produce the same quantities. In equilibrium, price inflation dynamics only depend on the cost of the aggregate composite good $p_{S,t}$, which represents the marginal cost of final good retailers, and on the evolution of price adjustment costs.

2.3.2 Specialized good production

Specialized goods firms produce a differentiated variety j transforming one unit of the intermediate good X_t^j into one unit of their patented good:

$$Y_{S,t}^j = X_t^j$$

where X_t^j denotes the quantity of the intermediate homogenous goods bought by firm j. Following, e.g., Anzoategui et al. (2019) and Benigno and Fornaro (2018), we allow for the possibility that the desired mark-up $\mu^{I,C}$ is lower than the optimal unconstrained mark-up $\mu^{I,U} = \frac{1}{\nu}$ due to the threat of entry by imitators.[5] This assumption, which is common in the endogenous growth literature, allows a closer match between the mark-ups and the capital and labour shares of the model with their empirical counterparts. In equilibrium, specialized goods producers set the price as a constant mark-up over the price of intermediate goods, $p_{I,t}$:

$$p^j_{S,t} = \mu^{I,C} p_{I,t}$$

and profits depend on the demand of specialized goods and are thus procyclical:

$$\Pi^j_t = \left(\mu^{I,C} - 1\right) p_{I,t} Y^j_{S,t}$$

2.3.3 Intermediate production sector

Each firm in the intermediate production sector produces according to the following technology[6]:

$$X_t = A_t \left(N_t\right)^{1-\alpha} \left(K_t\right)^{\alpha} \tag{5}$$

where K_t denotes aggregate effective physical capital:

$$K_t = \varphi^E z_t k_t$$

while N_t denotes the aggregate effective labour input, which is a Cobb-Douglas aggregator of the labour input of high skill and low skill workers:

$$N_t = \left(N^H_t\right)^{\mu} \left(N^L_t\right)^{1-\mu}$$

where the parameter μ captures the skill intensity of production.

The intermediate good is sold to specialized goods producers at the relative price $p_{I,t}$. In order to find a worker, firms must actively search for workers in the unemployment pool. The idea is formalized

[5] This limit pricing can be justified, for instance, by assuming the presence in each industry of a single leader able to produce good j of quality 1, and a fringe of competitors which are able to produce a version of good j of quality $1/\chi^f$. In this case, the leader will find it optimal to set a price that is sufficiently below the monopoly price so as to make it just barely unprofitable for the fringe of competitors to produce. Given this market structure, the leader captures the whole market for good j by charging the price

$$p^j_{S,t} = \mu^{I,C} mc$$

where the markup up $\mu^{I,C} = \min(\chi^f, \frac{1}{\nu})$. See also, e.g, Benigno and Fornaro (2018) for a discussion and the appendix to Chapter 7 of Barro and Sala-i Martin (2004) for a derivation.

[6] A version of the current model using a task-based production function to account for the role of automation in the economy has been presented in Anderton et al. (2020), in which the production function allows for different degrees of complementarity and substitutability among capital and the two types of labour input. We then study how automation shocks affect labour market outcomes, including wages and prices.

by assuming that firms post vacancies. The cost of posting a vacancy is $\kappa_t = \kappa\Psi_t$.

The representative firm maximizes expected profits:

$$\mathbb{E}_t\left\{\sum_{j=0}^{\infty}\beta_{t,t+j}\left[\begin{array}{c} p_{I,t+j}X_{t+j}-\left(w^H_{t+j}+c^{W,H}_{t+j}\right)N^H_{t+j}-\left(w^L_{t+j}+c^{W,L}_{t+j}\right)N^L_{t+j} \\ \kappa^H_{t+j}v^H_{t+j}-\kappa^L_{t+j}v^L_{t+j}-r_{Kt+j}K_{t+j}\end{array}\right]\right\}$$

Subject to the sequence of law of motions of high and low skilled labour:

$$N^H_t = \left(1-\rho^H\right)N^H_{t-1}+q^H_t v^H_t$$
$$N^L_t = \left(1-\rho^L\right)N^L_{t-1}+q^L_t v^L_t$$

Wages are determined in a bargaining scheme taking into account the wage adjustment costs. $\beta_{t,t+j} = \beta\frac{\lambda^E_{t+j}}{\lambda^E_t}$ is the discount factor of the entrepreneurs, reflecting the ownership of firms. $c^{W,k}_t = \frac{\phi^w\Psi_t}{2}\left(\frac{W^k_t}{W^k_{t-1}}-g^W\right)^2$ is a quadratic adjustment cost function of the nominal wage W^k_t. g^W is the long run trend growth of nominal wages.

Let us denote by J^k_t the marginal value of a worker of skill k to the firm. Maximization leads to the following first order conditions:

$$r_{Kt} = p_{I,t}\alpha\frac{X_t}{K_t} \tag{6}$$

$$\frac{\kappa^H_t}{q^H_t} = J^H_t \tag{7}$$

$$\frac{\kappa^L_t}{q^L_t} = J^L_t \tag{8}$$

$$J^H_t = p_{I,t}\frac{\partial X_t}{\partial N^H_t}-\left(w^H_t+c^{W,H}_t\right)+\mathbb{E}_t\left[\beta_{t,t+1}\left(1-\rho^H\right)J^H_{t+1}\right] \tag{9}$$

$$J^L_t = p_{I,t}\frac{\partial X_t}{\partial N^L_t}-\left(w^L_t+c^{W,L}_t\right)+\mathbb{E}_t\left[\beta_{t,t+1}\left(1-\rho^L\right)J^L_{t+1}\right] \tag{10}$$

where $\frac{\partial X_t}{\partial N^H_t}$ and $\frac{\partial X_t}{\partial N^L_t}$ are respectively the marginal product of high and low skill workers. Notice that the values for the firm of an employment relationship with a worker of skill k, J^k_t, are strictly related to the corresponding marginal productivities, $\frac{\partial X_t}{\partial N^k_t}$. These, in turn, are closely related to the skill intensity of production and to the relative supply of high and low skilled workers:

$$\frac{\partial X_t}{\partial N^H_t} = \mu\left(1-\alpha\right)\frac{X_t}{N^H_t} = \mu\left(1-\alpha\right)\frac{X_t}{\varphi^H n^H_t}$$
$$\frac{\partial X_t}{\partial N^L_t} = \left(1-\mu\right)\left(1-\alpha\right)\frac{X_t}{N^L_t} = \left(1-\mu\right)\left(1-\alpha\right)\frac{X_t}{\varphi^L n^L_t}$$

Skill composition and marginal costs

To get more intuition on the determinants of marginal production costs, let us define marginal labour costs in sector k, mlc_t^k, as the sum of real wages and marginal hiring costs $mhc_t^k = \frac{\kappa_t^k}{q_t^k} + c_t^{W,k} - \mathbb{E}_t\left[\beta_{t,t+1}\left(1-\rho^k\right)\frac{\kappa_{t+1}^k}{q_{t+1}^k}\right]$:

$$mlc_t^k = w_t^k + mhc_t^k \tag{11}$$

Using this definition, one can rewrite the job creation conditions with respect to high and low skilled workers as:

$$p_{I,t}\frac{\partial X_t}{\partial N_t^H} = mlc_t^H$$
$$p_{I,t}\frac{\partial X_t}{\partial N_t^L} = mlc_t^L$$

Maximization requires firms to equalize the marginal return of an employment relationship with the corresponding marginal labour costs, which include wages and marginal hiring costs. Rearranging, one can derive the following expression equating the price of intermediate goods to the corresponding marginal costs of production:

$$p_{I,t} = \frac{1}{A_t}\left(\frac{mlc_t^L}{(1-\mu)(1-\alpha)}\right)^{(1-\mu)(1-\alpha)}\left(\frac{mlc_t^H}{\mu(1-\alpha)}\right)^{\mu(1-\alpha)}\left(\frac{r_{Kt}}{\alpha}\right)^{\alpha} \tag{12}$$

Equation (12) shows that the marginal production costs in the economy are strongly influenced by the evolution of marginal labour costs for the skilled and unskilled workers. These, in turn, depend on the evolution of real wages and marginal hiring costs, which are affected by the relative supply of skilled workers and labour market institutions like unemployment benefits, bargaining power, and job finding and job filling rates.

2.3.4 Wage determination

Wages are negotiated separately on the high and low skilled labour markets by Nash bargaining:

$$\arg\max_{W_t^k}\left[\left(J_t^k\right)^{1-\eta^k}\left(V_t^{E,k}\right)^{\eta^k}\right]$$

where η^k is the bargaining power of workers of skill k. Bargaining over the nominal wage yields an optimal sharing rule similar to the standard Nash bargaining solution:

$$\varpi_t^k J_t^k = \left(1 - \varpi_t^k\right) V_t^{E,k}$$

where ϖ_t^k is the effective bargaining power of workers:

$$\varpi_t^k = \frac{\eta^k}{\eta^k + (1 - \eta^k)\left(1 + \tau_{t,t+1}^k\right)}$$

and $\tau_{t,t+1}^k$ captures the marginal costs of wage adjustments:

$$\tau_{t,t+1}^k = \frac{\partial c_t^{W,k}}{\partial W_t^k} P_t + \mathbb{E}_t \beta_{t,t+1} \left(\left(1 - \rho^k\right) \frac{\partial c_{t+1}^{W,k}}{\partial W_t^k} P_t \right)$$

When wage adjustment costs are zero, $\omega_t^k = \eta^k$ and we obtain the constant sharing rule, $\eta^k J_t^k = \left(1 - \eta^k\right) V_t^{E,k}$. With positive adjustment costs, the effective bargaining power ϖ_t^k becomes state dependent. Specifically, since $\partial c_t^{W,k} / \partial W_t^k > 0$, the effective bargaining power of workers declines during periods of rising wages, while it increases during periods of declining wages, dampening in both cases the fluctuations of nominal wages.

Substituting the definitions of J_t^k and $V_t^{E,k}$ into the optimal sharing rule one gets the following condition for the bargained real wages:

$$w_t^k = b_t^k + \frac{\varpi_t^k}{\left(1 - \varpi_t^k\right)} \frac{\kappa_t^k}{q_t^k} - \beta \left(1 - \rho^k\right) \mathbb{E}_t \frac{\lambda_{t+1}^k}{\lambda_t^k} \left(1 - f_{t+1}^k\right) \frac{\varpi_{t+1}^k}{\left(1 - \varpi_{t+1}^k\right)} \frac{\kappa_{t+1}^k}{q_{t+1}^k}$$

which highlight the strong dependence of wages on the conditions of the labour markets through, e.g., the unemployment benefits b_t^k, the job finding rates f_t^k and the job filling probabilities q_t^k.

2.3.5 Innovation

New patents are created by innovation through R&D in the innovation sector. Innovating firms use the final good as input and sell the patent to patent producers. Since we assume perfect competition, the price of a new patent equals its value to the patent producers, V_t^j, which is in turn given by the present value of current and future monopoly profits:

$$V_t^j = \Pi_t^j + (1 - \delta_Z) \mathbb{E}_t \beta_{t,t+1} V_{t+1}^j$$

where δ_Z is the patent obsolescence rate.

Following Kung and Schmidt (2015), we assume that the number of new patents evolves according to:

$$Z_{t+1} = \vartheta_t S_t^{RD} + (1 - \delta_Z) Z_t$$

where S_t^{RD} is the R&D expenditure and ϑ_t represents the productivity of the R&D sector, which is taken as given by innovating firms. Its functional form is:

$$\vartheta_t = \chi Z_t \left[(\Psi_t)^{\tau} \left(S_t^{RD} \right)^{(1-\tau)} \right]^{-1}$$

where $\chi > 0$ is a constant, $\tau \in [0, 1]$ is the elasticity of new patents with respect to R&D and Ψ_t is a scaling factor that ensures balanced growth. This specification of the product innovation efficiency combines a knowledge spillover á la Romer (1990), where new discoveries facilitate new innovative ideas, $\partial\vartheta/\partial Z > 0$, with a congestion externality effect capturing decreasing returns to R&D investment, $\partial\vartheta/\partial S^{RD} < 0$.[7]

The payoffs to innovation are the discounted future profits of a patented good, i.e. $\mathbb{E}_t \beta_{t,t+1} V_{t+1}$. Because the R&D sector is competitive, free entry implies (in the symmetric equilibrium):

$$\frac{1}{\vartheta_t} = \mathbb{E}_t \beta_{t,t+1} V_{t+1}$$

This condition is crucial in the model, because it determines the amount of R&D investment and therefore the equilibrium growth rate in the economy.

2.4 Market clearing

Aggregate market clearing conditions are found by aggregating across all retailers i and specialized firms j. For instance, the market clearing condition for intermediate goods X_t is

$$X_t = \int_0^{Z_t} X_t^j dj = Z_t X_t^j$$

where we have assumed symmetry across firms. Similar conditions hold for aggregate profits of specialized firms and value of patents.

Final output is used for consumption, investment in physical capital, R&D investment and job

[7] See Comin and Gertler (2006) and Kung and Schmidt (2015) for a discussion.

posting costs:

$$Y_t\left(1-\Gamma_t\right)-c_t^{W,H}N_t^H-c_t^{W,L}N_t^L=C_t+I_t+S_t^{RD}+\kappa_t^H v_t^H+\kappa_t^L v_t^L$$

where we used the fact that $C_t=\sum_k \varphi^k c_t^k$ and $I_t=\varphi^E i_t$.

Households can trade bonds with each others and not with foreign agents and the government. It follows:

$$\sum_k \varphi^k \frac{B_t^k}{P_t}=0$$

The government runs a balanced budget in every period:

$$T_t=b_t^H U_t^H+b_t^F U_t^F$$

The distribution of lump sum taxes is assumed to be equal across households' types, i.e. $t_t^k=T_t$ for all k.

2.5 Monetary policy

We assume the central bank sets the short term nominal interest rate by reacting to price inflation and to output growth. More specifically, the central bank adopts an augmented Taylor type rule for the nominal interest rate:

$$R_t=\left(R_{t-1}\right)^{\omega_r}\left[R\left(\frac{\pi_t}{\pi^*}\right)^{\omega_\pi}\left(\frac{Y_t/Y_{t-1}}{g}\right)^{\omega_{\Delta y}}\right]^{1-\omega_r}$$

Consistently with empirical evidence, we assume that monetary policy displays a certain degree ω_r of interest rate smoothing. The parameters ω_π and $\omega_{\Delta y}$ are the response coefficients to inflation and output growth.

2.6 Model implied Total Factor Productivity (TFP)

After aggregation and using equilibrium conditions, the production function becomes:

$$Y_t=Z_t^{\left(\frac{1}{v}-1\right)}A_t N_t^{1-\alpha}K_t^{\alpha} \tag{13}$$

where $N_t = (N_{Ht})^{\mu} (N_{Lt})^{1-\mu}$. Let us denote aggregate *measured* employment as:

$$N_t^m = \int_0^1 n_{i,t} di = \varphi^H n_t^H + \varphi^L n_t^L = N_{Ht} + N_{Lt}$$

It follows that we can rewrite the production function as:

$$Y_t = Z_t^{\left(\frac{1}{v}-1\right)} A_t (SC_t)^{1-\alpha} (N_t^m)^{1-\alpha} \left(\varphi^E z_t k_t\right)^{\alpha}$$

where SC_t is a term that capture skill composition and is computed as:

$$SC_t = \frac{N_t}{N_t^m} = \frac{\left(N_t^H\right)^{\mu} \left(N_t^L\right)^{1-\mu}}{N_t^H + N_t^L}$$

One can distinguish two measures of TFP. Aggregate, non-adjusted, TFP is measured as:

$$TFP_t = Z_t^{\left(\frac{1}{v}-1\right)} A_t (SC_t)^{1-\alpha} (z_t)^{\alpha}$$

while utilization-adjusted TFP is determined as

$$TFP_t^{util} = Z_t^{\left(\frac{1}{v}-1\right)} A_t (SC_t)^{1-\alpha}$$

Therefore, even when corrected for the utilization of capital, TFP_t^{util} varies with three terms: the exogenous technological component A_t, the endogenous stock of intangible capital Z_t and the skill composition term SC_t.

As evidenced by equation (13), output in the long run is growing endogenously with the stock of intangible capital. To ensure balanced growth, we assume that the scaling factor is

$$\Psi_t = Z_t^{\Upsilon}$$

where $\Upsilon = \frac{\left(\frac{1}{v}-1\right)}{(1-\alpha)}$.

3 Calibration

The model is calibrated at the quarterly frequency. The values of the parameters are chosen to capture the main structural features of the euro area and are close to the standard values used in the literature. In the baseline calibration we assume that the two labour markets are perfectly identical.

We then progressively introduce asymmetries in the composition of the workforce and in labour market institutions. The wage and investment adjustment costs, and the volatility of the exogenous technology shocks are set so that our preferred version of the model, the one with asymmetries in the composition of the workforce and in labour market institutions, matches selected moments of the euro data.

Households. In the baseline calibration, we assume 45 percent of the population is high-skilled, 45 percent is low-skilled and 10 percent are entrepreneurs. The discount factor β is set to 0.99. The elasticity of substitution of retail goods is $\epsilon = 11$, as in Christoffel et al. (2009) and Fahr and Smets (2010). The portfolio adjustment costs are set to a very low level, $\vartheta^p = 0.01$, just to ensure the stationarity of the system. The parameter determining habit in consumption, h, is set to 0.6, as estimated by Smets and Wouters (2003).

Labour markets. In a first step, we assume that the labour markets of skilled and unskilled workers are perfectly symmetric. In the model, the skill mismatch between the demand and supply of high skilled workers reduces job findings rates and increases unemployment rates. Since we want to explain the relatively high european unemployment rates with skill mismatch, we assume that in the absence of skill mismatch the european labour markets would be relatively fluid, with the job-finding rates $f^k = 0.55$ and the steady state unemployment rates equal to $ur^k = 5$ percent. The implied value for the job separation rate is $\rho^k = 0.0643$. As we show later, this calibration strategy allows us to get an average unemployment rate of around 10 percent and job finding rate of around 0.39 in the more realistic case of asymmetries between the high and the low skill labour markets.

The calibration of remaining labour market parameters is standard. The quarterly job filling rates are set to $q^k = 0.8$. The elasticities of job matches with respect to vacancies are set to $\zeta^k = 0.5$, consistently with the estimations of Petrongolo and Pissarides (2001). The workers' bargaining weights are set to $\eta^k = 0.5$, as e.g. in Blanchard and Galí (2010). Job posting costs are chosen such that the value of unemployment benefits, b^k, is 75 percent of steady state wages, in the middle of the range of the parameters used in the literature. The matching efficiency parameters $\bar{m}^k$ are determined through steady state relationships.

Price adjustment costs. The degree of price rigidities is set to $\phi^p = 116.50$. This is consistent with a Calvo parameter of 0.75 which represents a mean price duration of about 4 quarters. The degree of wage rigidity, ϕ^W, is set to match the observed relative volatility of nominal wage inflation. We get $\phi^W = 19.5$.

Production. We assume that there is no technological skill-bias in the production function, i.e.

$\mu = 0.5$, which implies that the two types of workers are equally productive. The capital elasticity α is set to 0.3 while we set the quarterly capital depreciation rate to $\delta_K = 0.02$, corresponding to an annual capital depreciation rate of 8 percent. Following Anzoategui et al. (2019), the parameter $v = 0.74$ is set to produce an elasticity of substitution of 3.85 between specialized goods, while the markup of specialized goods is set to $\mu^{I,C} = 1.18$, in the middle of the range of the estimates in the literature. The elasticity of capital depreciation to changes in utilization is parametrized so that under the baseline calibration the steady state value of the utilization rate $z = 1$. We get $\phi_k = 1.71$, a value close to the ones used, e.g., in Greenwood et al. (1988) and Neiss and Pappa (2005). The investment adjustment cost is set to $\Theta_I = 0.6$, in order to match the relative standard deviation of investment to gdp. The steady state value of technology, A, is chosen so that the gross output in the steady state of the detrended system is normalized to be one.

R&D sector. The elasticity of new patents to R&D is set to $\tau = 0.85$, close to the values used by Comin and Gertler (2006) and Kung and Schmidt (2015). Following Guerron-Quintana and Jinnai (2019), we set the patent obsolescence rate to $\delta_Z = 0.03$. The scale parameter χ is chosen to get an average annual growth rate of 1.60 percent.

Monetary policy. We assume that the central bank reacts to inflation with an elasticity $\omega_\pi = 1.5$ and a persistence in interest rates $\omega_r = 0.85$. The response coefficient on the output growth is set to $\omega_{\Delta y} = 0.5/4$. The gross inflation target is set to $\pi^* = 1.005$, which corresponds to an annual inflation rate of 2 percent.

Shock processes. For simplicity, we consider only two shocks: a liquidity shock, and an exogenous technology shock. Regarding the technology shock, we set its persistence parameter to the standard value $\rho_A = 0.95$, while its volatility is set to $\sigma_A = 0.505$ percent in order to match the average volatility of gdp per capita. To calibrate the liquidity shock, we follow Abbritti and Weber (2019) and use recent measures of credit spreads in the Euro area calculated by Gilchrist and Mojon (2018). Specifically, we fit an AR(1) process to the credit spread series of non financial corporations with respect to the Bund. The data covers France, Germany, Italy, Spain and the euro area as a whole during the sample period 1999q1-2015q4. Based on this evidence, we calibrate the persistence and volatility of the liquidity shocks to $\rho_\varsigma = 0.85$ and $\sigma_\varsigma = 0.1$. For simplicity, we assume that liquidity shocks hit identically all the households in the economy, and that in the steady state the liquidity premium is zero. The scale parameters on bonds in the utility functions, χ_b^k, are determined residually through steady state relationships.

4 Results

The model provides a rich laboratory to study the interactions between labour market skill heterogeneity, labour market institutions, growth and business cycle dynamics. In this section we present some results which show the functioning of the model, the importance of labour market heterogeneity for business cycle dynamics and labour market inequality, and the effects of different institutions on short and long run TFP dynamics.

4.1 Steady state analysis

In the model, TFP is an endogenous variable and the steady state growth rates of output, consumption, wages etc. are a function of the deep parameters of the model. This allows us to get an (admittedly simplified) idea of the effect of different labour market structures not only on unemployment rates and wages, but also on the long run growth rates of technological knowledge and output.

We start by studying the effects of varying labour market parameters on the steady state of the economy (Table 2). The exercise is performed by fixing all the deep parameters of the model to their values of the baseline calibration, and allowing all the endogenous variables to adjust to changes in the policy parameters of interest. Specifically, we consider three different calibrations of the model:

1. The *baseline calibration*, described in detail in Section 3, assumes that the labour markets for skilled and unskilled workers are perfectly symmetric. This serves as a natural reference point to understand the effects of different parameters on the long run equilibrium of the model.

2. In the *"Asymmetric Labour Markets 1"* calibration (*Asym. LM 1* in the table) we assume that the two labour markets differ only in the relative supply of high versus low skilled workers. Specifically, we assume that only 30 percent of the workers are high-skilled while 60 percent are low-skilled. These numbers are roughly in line with the average proportion of college graduates in Europe (see e.g. Crivellato, 2014). Since we continue to assume that there is no technological skill-bias in the production function, i.e. $\mu = 0.5$, this calibration implies a mismatch in the labour market between the relative supply of high skilled workers, $\varphi^H/\varphi^L = 0.5$, and the relative demand of high skilled workers, which is strictly related to the technological skill-bias $\mu/(1-\mu) = 1$.

3. In the *"Asymmetric Labour Markets 2"* calibration (*Asym. LM 2* in the table) we assume three differences between the labour markets for high and low skilled workers: (1) a lower

supply of high skilled workers, as in the previous calibration ($\varphi^H/\varphi^L = 0.5$); (2) unskilled workers have lower bargaining power than skilled workers $\left(\eta^L = 0.1 < \eta^H = 0.5\right)$; (3) when unemployed, high skilled workers receive higher unemployment benefits than low skilled workers ($b^H = 0.69 > b^L = 0.46$).[8] These assumptions, for which there is ample empirical and anecdotal evidence, allow us to get a prima facie understanding of the effect of different labour market institutions on short and long run dynamics.

Table 2 shows the effects of these calibrations on the steady state of the model. While in the baseline calibration there is no difference between the high and low skilled markets, the introduction of relative scarcity of high skilled workers produces strong earning and employment inequalities. In fact, under the *Asym. LM 1* calibration the wage of high skilled workers is more than 60 percent higher than the one of low skilled workers, while unemployment rates are around 1 percent in the high skill segment and 17 percent in the low skill segment. The aggregate unemployment rate increases from 5 percent of the baseline calibration to more than 12 percent. The relative scarcity of skilled workers produces strong effects also on the long run level of employment and output, which are reduced, and on the growth rate of the economy, which is also reduced. This happens because the higher number of unskilled workers together with the higher tightness of the labour market for skilled workers induces firms to over-spend on less productive workers, whose marginal productivity decreases. The reductions in employment and production, in turn, reduce the demand for specialized goods. This diminishes investments in R&D and leads to a sizeable negative effect on growth.

Once we allow for additional differences in the bargaining power and in the outside options of high skilled workers (calibration *Asym. LM 2* in the table), we find that the wage inequality is amplified, with the wage of high skilled workers getting more than 80 percent higher than the wage of low skilled workers. However, both the unemployment inequality and the aggregate unemployment rate of the economy are actually reduced. Unemployment rates are around 5 percent in the high skill segment and 13 percent in the low skill segment, getting closer to the Euro area data. The aggregate unemployment rate is reduced from 12 to 10 percent. The increased cost of high skilled workers reduces the tightness of the market for the high skilled, while the tightness of the low skilled market increases to more normal levels. The search and matching process becomes more fluid for both types of workers, slightly increasing average employment, production and growth. In this way, labour market institutions that give more power to high skilled workers actually compensate for the

[8] Notice that even if the absolute value of unemployment benefits is larger for high-skilled workers, the benefit replacement ratio, i.e. the ratio between unemployment benefits and wages, $brr^k = b^k/w^k$, is still higher for low skilled workers, because the steady state value of wages is much higher for skilled workers than for unskilled workers.

relative scarcity of the high skilled, and reduce the overall inefficiency of the matching process of the labour market.

The combined effect of skill mismatch and asymmetric labour market institutions allows the steady state of the model to get close to the data. In fact, as shown in Table 3, the model under calibration *Asym. LM 2* does a good job in matching not only the long run level of output growth and unemployment rates, but also the employment rate premium and (to a lesser extent) the wage skill premium that characterize european labour markets.

4.2 Labour market structures and business cycle dynamics

To understand the effects of different market structures on short and long run dynamics, in this section we show how the impulse responses of the model change with the calibration of the labour markets.

Figure 2 shows the effects of a large liquidity shock on selected aggregate variables of the economy under the three calibrations discussed in Section 4.1. The shock corresponds to an increase of the risk premium by 50 basis points, i.e. 2 percent if annualized. This is in line with the increase in credit spread experienced by many European countries during the Great Recession and the subsequent Euro Debt crisis (see, e.g., Gilchrist and Mojon, 2018).

Following the increase in the demand for liquid assets, households reduce their savings in risky assets and their consumption demand. This in turn leads to a reduction in both physical investment and R&D expenditures. Due to the presence of nominal rigidities, the drops in investment and consumption lead to a large drop in domestic output, price and wage inflation, employment and real wages.

Comparing the responses of the model under different calibrations, one can notice that the introduction of labour market asymmetries reduces the responses of wage inflation and real wages, while it amplifies the employment and output response to the liquidity shock. The presence of segmented labour markets thus seems to reduce the elasticity of inflation, wages and marginal costs to employment changes.

Different labour market structures have even larger effects on measures of labour market and consumption inequality. In the case of symmetric labour markets, liquidity shocks do not generate differentials as the responses of the labour market variables for the skilled and unskilled workers are the same. On the contrary, in the presence of labour market asymmetries, substantial differentials arise in response to symmetric shocks. In particular, in the presence of different relative supplies of workers (calibration *Asym. LM 1* in Figure 2) the liquidity shock triggers a strong reduction of the wage skill premium w_t^H/w_t^L and an even stronger increase of the employment rate ratio n_t^H/n_t^L. This happens because wages decline by more for skilled than for unskilled workers, while employment rates decline much faster for the unskilled. Since low skilled workers are the main beneficiary of unemployment benefits, which do not vary with the cycle, consumption inequality between high and low skilled workers is reduced, while the consumption inequality between entrepreneurs and high skilled workers actually increases following the liquidity shock.

To understand these results, notice that the large supply of unskilled workers lowers the equilibrium value of an employment relationship with an unskilled worker. This in turn implies, for a given level of the bargaining power, larger employment fluctuations and less volatile wages in the low skilled segment of the labour market (see, e.g., Hagedorn and Manovskii, 2008). At the same time, the value of a high skilled worker increases, leading to the opposite effects in terms of wage and employment volatility for the skilled workers. Since for the economy as a whole the first effect dominates, the overall effect is a reduction of the elasticity of inflation, wages and marginal costs to employment changes.

These effects of skill mismatch are altered if we also assume differences in bargaining weights and unemployment benefits. In fact, under the calibration *Asym. LM 2*, the change in the wage skill premium is slightly amplified, while the employment ratio reacts by less than under the calibration *Asym. LM 1.* This happens because a lower bargaining power of unskilled workers further reduces the volatility of real wages for the unskilled, while higher unemployment benefits for the skilled workers amplify the reaction of employment in the high skill segment of the labour market. The overall effect is an additional, though quantitatively small, reduction of the elasticity of wage inflation to employment changes.

Consider now a technology shock, represented in Figure 3. The shock corresponds to a 1 percent exogenous decline in technology, capturing for example the productivity slowdown experienced by many countries prior to the Great Recession (see, e.g., Fernald, 2015). Following the productivity slowdown, the value of a worker for the firm decreases, which leads firms to reduce hiring activities and employment. Nominal and real wages decrease simultaneously, partially reducing the incentives for firms to cut jobs. The reductions in productivity, employment and investment lead to a strong and persistent slowdown in production.

The effects of labour market asymmetries on the dynamics of technology shocks are qualitatively similar to the ones of liquidity shocks, but quantitatively larger. Labour market asymmetries strongly amplify the responses of employment and output, while they reduce the variability of wage inflation and real wages. Once again, the wage skill premium declines, while the employment rate ratio between high and low skilled workers increases.

4.3 The role of endogenous productivity

One of the key innovations of our model is the introduction, in the same setting, of endogenous technological growth, search and matching frictions and workers heterogeneity. In our model, observed TFP is endogenous and time varying:

$$TFP_t = Z_t^{\left(\frac{1}{v}-1\right)} A_t \left(SC_t\right)^{1-\alpha} \left(z_t\right)^{\alpha}$$

Measured TFP depends on the exogenous forcing process A_t and on an endogenous component that depends on the utilization rate of capital z_t, on the term capturing the skill composition of the workforce, SC_t, and on the stock of intangible capital, Z_t. The latter grows at an endogenous rate through the accumulation of patents, which in turn depends on the investment in R&D:

$$\Delta Z_{t+1} \equiv \frac{Z_{t+1}}{Z_t} = (1-\delta_Z) + \vartheta_t \frac{S_t^{RD}}{Z_t}$$

Utilization-adjusted TFP controls for capital utilization and is determined endogenously as

$$TFP_t^{util} = Z_t^{\left(\frac{1}{v}-1\right)} A_t \left(SC_t\right)^{1-\alpha}$$

How important is the endogenous innovation channel for the transmission mechanism of the economy? To answer to this question, in this section we compare the dynamics of the growth model with endogenous R&D investment with those of a nested New Keynesian (NK) model with exogenous growth. Specifically, the NK model we consider is a version of our model with constant R&D investment intensity. This is equivalent to specifying an exogenous trend growth component in productivity. To facilitate comparison, the calibration of the benchmark NK model is identical to the one of the growth model under the calibration *Asym. LM 2*.

Figure 4 shows the effects of a liquidity shock on selected aggregate variables in the two models. We find that in both models, TFP strongly decreases following the demand shock. These results are in line with the evidence in Abbritti and Weber (2019), who document a strong TFP decline in european countries following the spikes in credit spreads in 2008 and 2011. Once adjusted for capital utilization, however, TFP only declines in the model with endogenous growth. In the model with exogenous growth, in fact, TFP_t^{util} actually increases on impact, because the negative demand shock, by reducing employment especially in the low-skilled labour market, actually improves the skill composition term SC_t. On the contrary, in the model with endogenous growth the negative demand shock reduces R&D investment and the stock of intangible capital, leading to a persistent reduction of TFP_t^{util}. In turn, the lower productivity leads to a larger decline in price and wage inflation, employment and real wages. For these reasons, the presence of an innovation channel strongly amplifies the negative effects of the liquidity shock on output and TFP. In particular, the presence of R&D investment and intangible capital has two main effects on TFP. First, the TFP collapse following the negative financial shock is more than three times larger. Second, the negative shock permanently shifts downward the trend of the economy, which never reverts back to the old balanced growth path.[9]

The endogenous productivity channel interacts in complex ways with heterogenous labour market institutions. Figure 5 shows the effects of large liquidity and technology shocks on the *levels* of output and TFP for different calibrations of the labour market. Following both the increase in the risk premium and the productivity slowdown, output and TFP drop considerably on impact, and then start to slowly recover. Interestingly, the recovery is much slower in economies with asymmetric labour market structures. This happens for a combination of short run and long run forces: skill mismatch not only amplifies the short run TFP and output collapse, but also reduces the long run growth rates of TFP and output. Since the second effect is found to dominate under our calibrations, economies with asymmetric labour markets converge to a new, lower, trend growth rate.

4.4 Second moments

To further understand the quantitative effects of different labour market structures, Tables 4 and 5 show the second moments of different specifications of the model assuming the presence of both liquidity and technology shocks. The moments are obtained by filtering the actual and simulated data with the HP(1600) filter. The empirical moments correspond to the euro area and cover the sample that starts in 1997q1 and ends in 2015q4.[10]

The results confirm the main insights of the impulse responses. Consider first the effects of labour

[9] The large amplification mechanism of the innovaton channel is confirmed when looking at the effects of technology shocks and at the second moments of the data (see Table 4 and 5).

[10] The model is solved with Dynare ver. 4.5.1 by second-order perturbation methods and applies pruning following Kim et al. (2008). To obtain the simulated moments the model is simulated 500 times for 200 periods. In order to have different starting points, we simulate an additional 200 periods as pre-sample which are not included for the computation of the moments. Second order perturbation methods are only used to improve the accuracy of the solution in the presence of relatively large shocks. Results using a first order solution are similar.

market structures on aggregate variables (Table 4). Introducing skill mismatch and asymmetric labour market institutions increases output volatility by almost 20 percent, from 1.04 of the baseline calibration to 1.27 of the calibration *Asym. LM 2*. Similarly, the relative employment volatility increases from 0.47 to 0.64, while the relative investment volatility increases from 2.07 to 2.25. At the same time, labour market asymmetries reduce relative wage inflation, price inflation and real wage variability.

Consider now the effects of labour market structures on different labour market segments (Table 5). We find that small differences in market structures can generate large differences in labour market dynamics. In fact, under the calibration *Asym. LM 2*, the volatility of real wages of the skilled workers is almost five times larger than the one of the unskilled, while the employment rates of the unskilled are 80 percent more volatile than the ones of the skilled workers. As a consequence, the volatility of marginal labour costs is larger for the skilled workers than for the unskilled workers. However, notice also that in the presence of skill mismatch the relative volatility of marginal labour costs for both high and low skilled workers is reduced with respect to the symmetric case, suggesting that the presence of labour market asymmetries gives firms another margin through which they can limit costs variability.

Finally, compare in Table 4 the second moments of our preferred version of the model, the one with skill mismatch and differences in labour market institutions (calibration *Asym. LM 2*), with the moments of the data. Despite considering only two shocks (the technology and the liquidity shocks), the model *Asym. LM 2* matches remarkably well most of the moments of the data. Specifically, the model tracks relatively well not only the variables it explicitely targets, like the volatility of output and the relative volatility of wage inflation and investment, but also the absolute and relative volatilities of employment, unemployment, TFP and inflation, and the cross-correlations of most variables with output.

4.5 Implications for the Phillips curve

The skill composition of the workforce can have important effects on the elasticity of price and wage inflation to unemployment rates. To show this, we compute Phillips curve-like OLS coefficients both in the actual data for the euro area and in the simulated data from the models:

$$\pi_t^x = \alpha + \beta \left(ur_t - mean(ur_t) \right) + \varepsilon_t$$

where π_t^x denotes price or wage inflation.

Table 6 shows the implied $\beta-$parameters for the data and different versions of the model. As expected, the slope coefficient estimated on the data is negative and significant, with a point estimate $\beta\left(\pi^{W}, ur\right) = -0.59$. Applying the same estimation procedure to the simulated data obtained under the *baseline calibration*, we find that the model also generates a negative correlation between wage inflation and unemployment, even though the elasticity of wage inflation to unemployment is estimated to be -1.88, more than three times the one of the data. Once we allow for labour market heterogeneity, the results of the model get closer to the ones of the data. In fact, allowing for differences in the proportion of high skilled workers, under the calibration *Asym. LM 1*, the slope of the Phillips curve is halved, from -1.88 to -0.81. Similarly, allowing for differences in bargaining weights and unemployment benefits (calibration *Asym. LM 2*) the slope of the Phillips curve decreases even further, to -0.51, getting very close to the one of the data.

Similar results hold for the elasticities of price inflation to unemployment rates ($\beta\left(\pi, ur\right)$ in the table) and the elasticities of marginal costs to unemployment, $\beta\left(mc, ur\right)$. The elasticity of price inflation to marginal costs, instead, does not change significantly across models. This allows us to conclude that labour market heterogeneity between high and low skilled workers strongly reduces the slope of the wage and price inflation Phillips curves, and that this change in the slope is due to a reduction of the elasticity of marginal costs to unemployment changes.

These results are corroborated visually by the left panel of Figure 6, which displays scatterplots of wage inflation rates (annualized) and unemployment rates for different versions of the model. The presence of skill mismatch and labour market asymmetries has two main effects on the Phillips curve: first, it shifts it out, mainly because it increases the steady state unemployment rate of the economy. Second, it lowers its slope, because it decreases the elasticity of real wages and wage inflation to unemployment fluctuations.

4.6 Skill mismatch and the Beveridge curve

Following the Global Financial Crisis, both in the US and in the euro area the Beveridge curve has experienced a significant outward shift.[11] Some researchers and policymakers have related the persistently high rate of unemployment to an increase in sectoral and geographical mismatch between unemployed workers and vacant jobs. This view is consistent with the results of a series of studies that estimate a sizeable decline in the aggregate matching efficiency between vacancies and searching workers, and has lead some authors to study the business cycle implications of matching efficiency

[11] See, e.g, Consolo and Da Silva (2019).

shocks - also called sometimes mismatch shocks (see, e.g., Furlanetto and Groshenny, 2016, and Sala et al., 2012).

The explicit modeling of segmented labour markets and skill mismatch can help to explain endogenously the outward shift of the Beveridge curve following negative shocks. Consider the right panel of Figure 6, which displays scatterplots of vacancies and unemployment rates for different versions of the model. Two results stand out. First, the model is able, independently of the calibration, to reproduce the downward relationship between vacancies and unemployment rates that is referred to as Beveridge curve. Second and more importantly, the labour market structure has a strong effect on the position and slope of this relationship. In particular, the presence of skill mismatch and labour market asymmetries shifts out the Beveridge curve, because it reduces the overall efficiency of the matching process and increases the average unemployment rate in the economy, and makes it flatter.

To shed light on the latter result, Figure 7 plots the evolution of posted vacancies and unemployment following negative liquidity shocks (left panel) and technology shocks (right panel). To facilitate the comparison across models, all variables are expressed in deviations from trend. Consider first the baseline calibration of symmetric labour markets. Following both shocks, vacancies initially decrease and the unemployment rate increases, generating a movement along the Beveridge curve. During the recovery, vacancies increase faster than unemployment rates decline, generating an apparent shift of the Beveridge curve. Therefore, as emphasized by Christiano et al. (2015) in a similar model, one is able to account for the shift in the Beveridge curve, even though the efficiency parameter of the matching function is constant.

The presence of skill mismatch and labour market asymmetries, however, strongly amplifies the outward shift of the Beveridge curve. Consider the calibration *Asym. LM 2*. Although the variables are expressed in deviations from trend, following both shocks the Beveridge curve is considerably flatter and shifts outward by a larger amount. This implies that, in the presence of skill mismatch and different labour market institutions for skilled and unskilled workers, unemployment fluctuations tend to be larger and more persistent than in the absence of these asymmetries, and the labour market takes longer to go back to the steady state of the system.

5 Concluding remarks

This paper investigates the effects of labour market segmentation and workers heterogeneity on unemployment, productivity and business cycle dynamics. To this aim, we build a New Keynesian DSGE model with endogenous productivity, heterogeneous agents, and search and matching frictions in the labour market. The model provides a rich framework to study the effects of different labour market institutions and skill mismatch on income inequality, as well as their implications for the economy as a whole. Moreover, the introduction of endogenous productivity through R&D investment and intangible capital accumulation makes the model an ideal laboratory to study issues related to TFP and labour productivity dynamics.

We have focused on two aspects of labour market heterogeneity: skill mismatch and skill-specific labour market institutions. Skill mismatch is modelled by assuming that the number of unskilled workers is larger than the number of skilled workers, which implies a mismatch between the (high) relative demand and the (low) relative supply of high-skilled workers. Asymmetric, skill-specific, labour market institutions are modelled by assuming that skilled workers have higher bargaining power and get more generous unemployment benefits than the unskilled.

We find that labour market heterogeneity is not only important per se, but also for the general equilibrium effects on labour productivity, unemployment and wages. In the long run, labour market segmentation increases the natural rate of unemployment and reduces the average growth rate of the economy. This happens because the scarcity of high-skilled workers limits firms' profitability and does not fully enable firms to expand R&D investment. This is an obstacle to the endogenous long-term growth mechanism. This shows the relevance of the interplay between the workers' skill set and long-term growth as education has to catch up with technological changes for firms to be able to reap the full benefits of adopting new technologies. In the case that the skill mismatch were to persist, the overall efficiency of the economy would decline, diminishing investment in physical capital and R&D, and leading to sizeable negative effects on TFP growth.

In the short run, the large supply of unskilled workers lowers the equilibrium value of an employment relationship for the unskilled. This in turn implies, for a given level of bargaining power, there will be larger employment fluctuations and less volatile wages in the low-skilled segment of the labour market. Therefore, labour market segmentation reduces the elasticity of wages, hiring and marginal costs to unemployment fluctuations. In particular, this implies a flattening of the Phillips curve and an outward shift of the Beveridge curve. From a monetary policy perspective, labour market heterogeneity coupled with an endogenous productivity mechanism provides a richer framework to better understand wage developments over the business cycle. We leave for future research the analysis of monetary policy and the implications for the inflation targeting framework in the context of a model with labour market heterogeneity.

Overall, our results suggest that taking into account the interaction between workers heterogeneity and labour market institutions is crucial for the analysis of the process of matching workers with jobs. In fact, once we allow for asymmetric labour market institutions that give more power to skilled workers, the average unemployment rate and measures of unemployment inequality are actually reduced. The increased cost of hiring skilled workers reduces the tightness of their labour market, while the tightness of the market for the unskilled increases to more normal levels. The search and matching process becomes more fluid in both markets, slightly increasing average employment, production and growth. Understanding these mechanisms and their implications could be vital in designing policies for the reduction of earning and consumption inequality and for an improvement of the long run prospects of the economy.

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6 Tables and figures

	95Q1-08Q2	08Q3-19Q4	Pre- to post-crisis ratio
Output	2.33	0.80	2.9
Employment	1.29	0.36	3.5
Okun's ratio	0.55	0.46	1.2
Lab. productivity	1.04	0.43	2.4

Table 1: Euro area, average annual growth rates, percentages. The Okun's ratio is computed as the ratio of employment growth to output growth.

Steady State Analysis	Baseline Model $\varphi^H = \varphi^L$	Asym. LM 1 $\varphi^H < \varphi^L$	Asym. LM 2 $\varphi^H < \varphi^L$ $\eta^H > \eta^L$ $b^H > b^L$
Relative variables			
φ^H/φ^L	1	0.50	0.50
$\mu/(1-\mu)$	1	1	1
w^H/w^L	1	1.64	1.83
n^H/n^L	1	1.20	1.09
$w^H n^H/\left(w^L n^L\right)$	1	1.96	2.00
c^E/c^L	3.24	4.13	4.31
c^H/c^L	1.00	1.72	1.90
ur^H	0.05	0.01	0.05
ur^L	0.05	0.17	0.13
θ^H	0.69	1.62	0.74
θ^L	0.69	0.12	0.21
f^H	0.55	0.85	0.57
f^L	0.55	0.23	0.31
mlc^H/mlc^L	1	1.67	1.83
Aggregate Variables			
y	1	0.92	0.92
mpl	0.82	0.79	0.79
n	0.95	0.88	0.90
ur	0.05	0.12	0.10
SC	0.50	0.48	0.48
θ	0.69	0.34	0.33
f	0.55	0.44	0.39
mlc	0.63	0.64	0.64
Δy	0.40	0.23	0.25

Table 2: This table reports comparative statics analysis of the steady state for different calibrations of the model.

Equilibrium						
	ur^H	ur^L	n^H/n^L	w^H/w^L	ur	Δy
Data	0.06	0.11	1.06	2.27	0.10	0.30
Model (Asym. LM 2)	0.05	0.13	1.09	1.83	0.10	0.25

Table 3: This table reports the mean of selected variables of the data and the corresponding steady state values of the model under calibration Asym. LM 2. The empirical data by skills refers to the period 2005-2017. See Footnote 2 for the data sources.

2nd moments	$\sigma(x)/\sigma(y)$					$\rho(x,y)$				
	Data	Base. Model	Asym. LM 1	**Asym. LM 2**	Exog. Growth	**Data**	Base. Model	Asym. LM 1	**Asym. LM 2**	Exog. Growth
π^W	**0.26**	0.36	0.31	**0.26**	0.25	**0.48**	0.71	0.65	**0.61**	0.46
π	**0.12**	0.23	0.20	**0.17**	0.19	**0.40**	0.57	0.54	**0.50**	0.39
w	**0.63**	0.55	0.45	**0.32**	0.33	**0.48**	0.89	0.93	**0.95**	0.99
ur	**4.67**	9.13	4.37	**5.77**	6.10	**-0.86**	-0.81	-0.86	**-0.93**	-0.90
n	**0.47**	0.47	0.60	**0.64**	0.67	**0.83**	0.82	0.86	**0.94**	0.91
i	**2.25**	2.07	2.23	**2.25**	3.24	**0.93**	0.94	0.94	**0.95**	0.99
TFP	**0.75**	0.75	0.68	**0.61**	0.61	**0.96**	0.97	0.95	**0.96**	0.93
$\sigma(y)$	**1.27**	1.04	1.12	**1.27**	1.12	**1.00**	1.00	1.00	**1.00**	1.00

Table 4: This table reports the second moments of the data and the ones of the model under different calibrations. The calibration of the exogenous growth model is identical to the one of the baseline model under the calibration Asym. LM 2.

HP-Filtered Business Cycle								
	$\sigma(x)/\sigma(y)$				$\rho(x_t, y_t)$			
Variable	Base. Model	Asym. LM 1	Asym. LM 2	Exog. Growth	Base. Model	Asym. LM 1	Asym. LM 2	Exog. Growth
$\pi^{W,H}$	0.36	0.42	0.38	0.36	0.71	0.65	0.60	0.49
$\pi^{W,L}$	0.36	0.26	0.20	0.18	0.71	0.64	0.62	0.41
w^H	0.55	0.72	0.63	0.68	0.89	0.93	0.96	0.99
w^L	0.55	0.30	0.14	0.12	0.89	0.92	0.84	0.91
n^H	0.47	0.32	0.43	0.42	0.82	0.75	0.83	0.78
n^L	0.47	0.79	0.77	0.82	0.82	0.86	0.95	0.93
θ^H	11.77	9.36	10.74	10.03	0.76	0.73	0.75	0.73
θ^L	11.77	15.18	13.32	12.90	0.76	0.74	0.86	0.87
mlc^H	1.74	1.64	1.34	1.32	0.72	0.77	0.76	0.71
mlc^L	1.74	1.32	1.18	1.08	0.72	0.63	0.55	0.47

Table 5: This table presents selected HP-filtered macroeconomic moments for different calibrations of the model. The calibration of the exogenous growth model is identical to the one of the baseline model under the calibration Asym. LM 2.

		EA Data	Base. Model	Asym. LM 1	Asym. LM 2	Exog. Growth
Slope P.C.	$\beta\left(\pi^{W},ur\right)$	-0.59	-1.88	-0.81	-0.51	-0.19
	$95\%\ C.I.$	[-0.87,-0.30]	[-2.13,-1.63]	[-0.98,-0.64]	[-0.62,-0.39]	[-0.29;-0.08]
	$\beta\left(\pi,ur\right)$	-0.29	-1.30	-0.60	-0.31	-0.19
	$95\%\ C.I.$	[-0.41,-0.17]	[-1.43,-1.16]	[-0.70,-0.49]	[-0.39,-0.24]	[-0.27,-0.11]
	$\beta\left(\pi,mc\right)$	-	0.56	0.59	0.59	0.60
	$95\%\ C.I.$	-	[0.54,0.59]	[0.56,0.61]	[0.57,0.62]	[0.56,64]
	$\beta\left(mc,ur\right)$	-	-1.77	-0.72	-0.31	-0.22
	$95\%\ C.I.$	-	[-2.07,-1.47]	[-0.91,-0.53]	[-0.45,-0.17]	[-0.34,-0.09]

Table 6: This table reports slope coefficients for different variables and different calibrations of the model. The calibration of the exogenous growth model is identical to the one of the baseline model under the calibration Asym. LM 2.

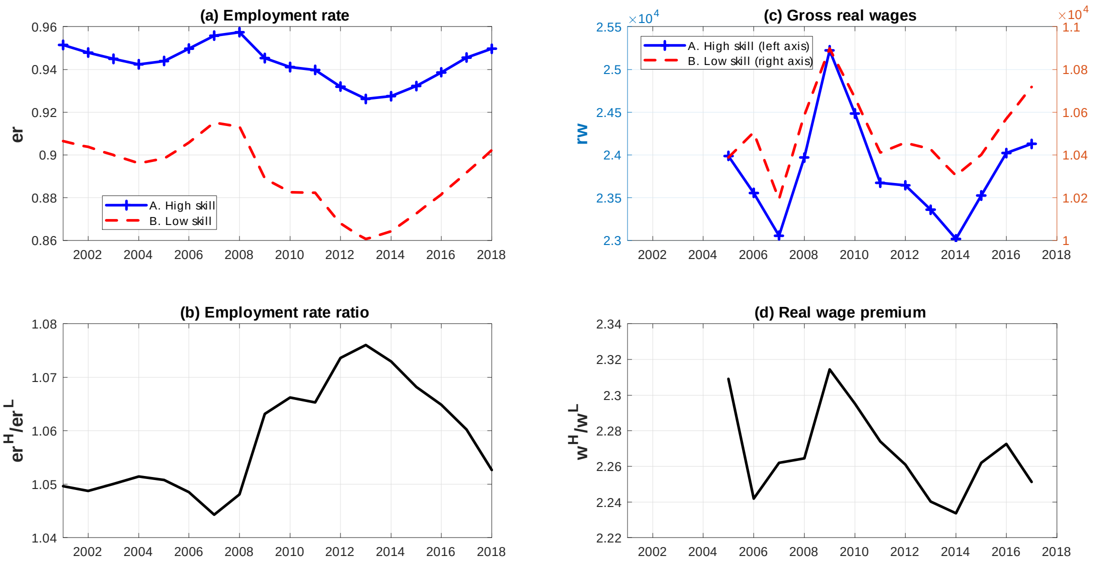

Figure 1: Labour market skills, employment and wage dynamics

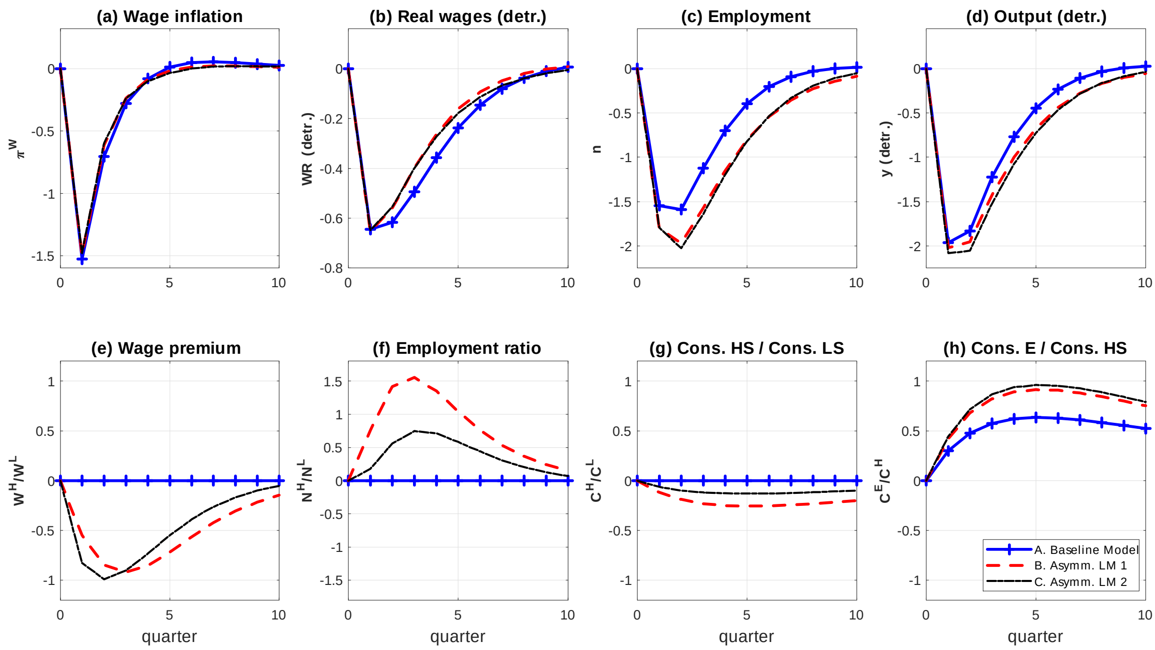

Figure 2: Effect of different labour market structures on aggregate dynamics - liquidity shock

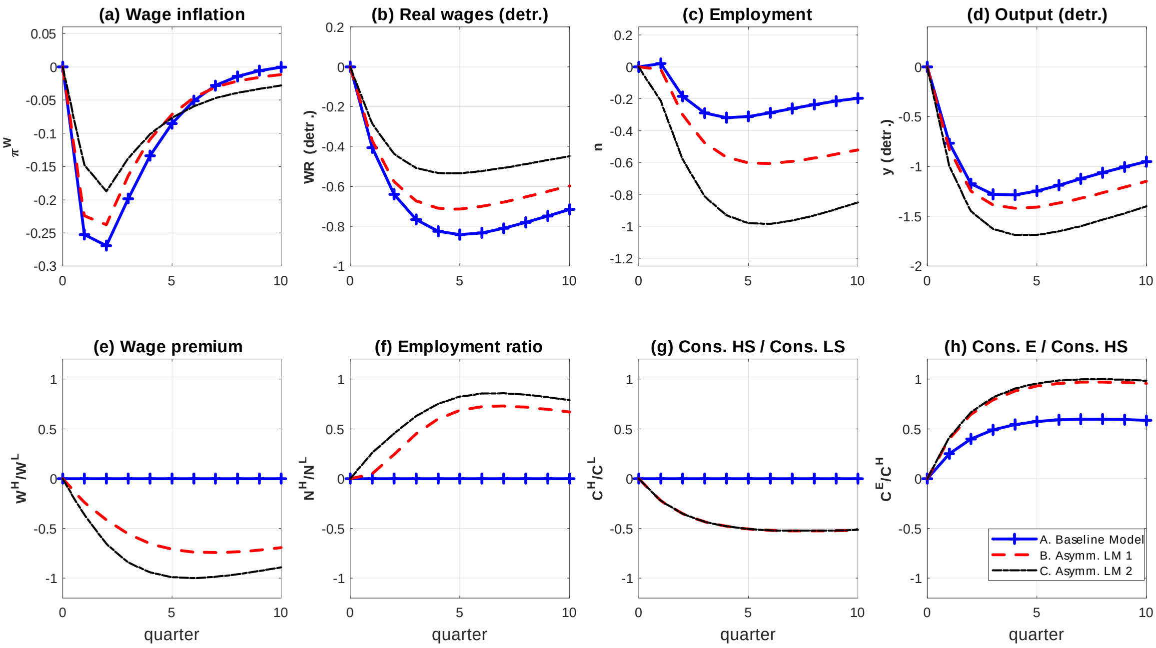

Figure 3: Effect of different labour market structures on aggregate dynamics - technology shock

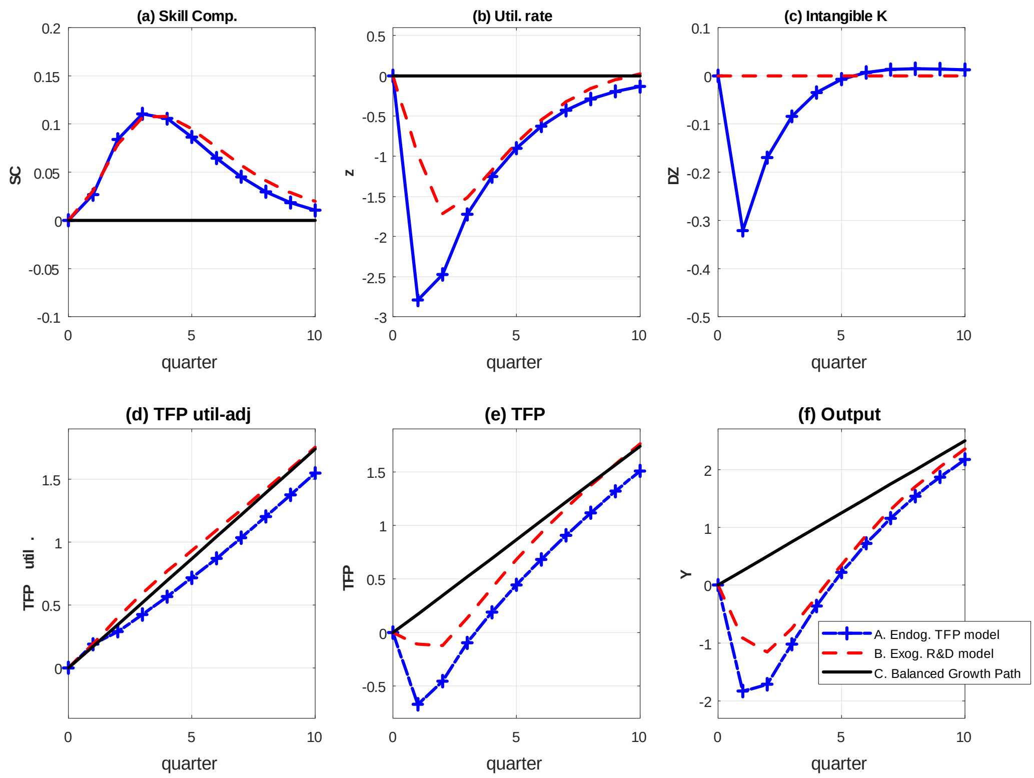

Figure 4: Effect of the endogenous productivity margin on aggregate variables - liquidity shock

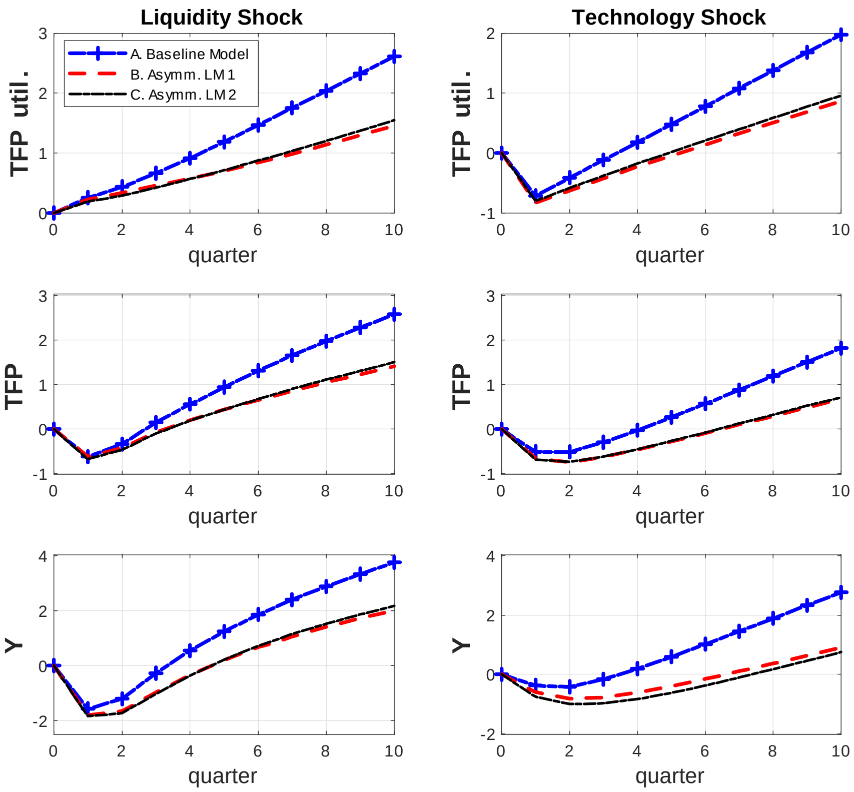

Figure 5: Effect of different labour market structures on the level of output and TFP - liquidity and technology shocks

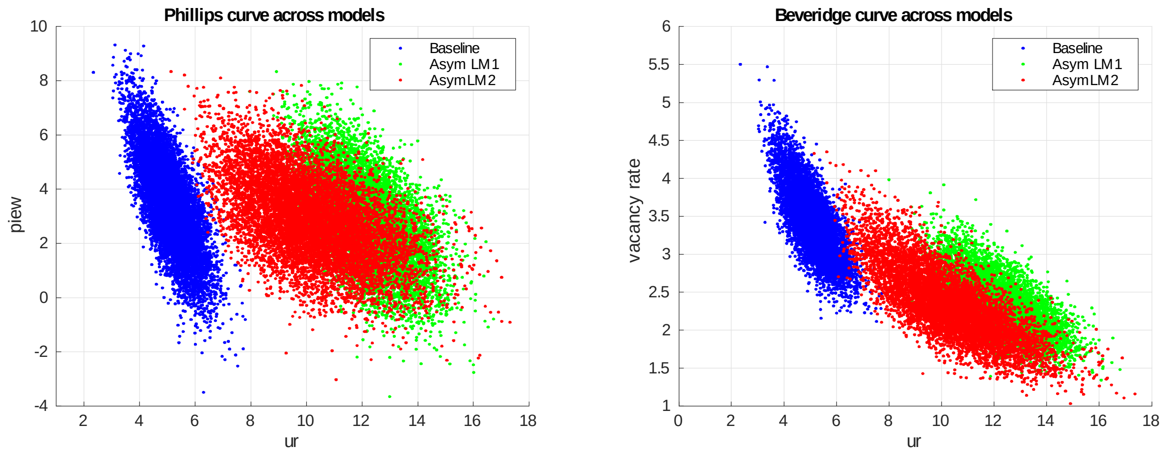

Figure 6: Scatterplots of wage inflation and unemployment rates (left panel) and vacancies and unemployment rates (right panel). The scatterplots are generated from a random simulation (of 8,000 periods) of the model in response to liquidity and technology shocks.

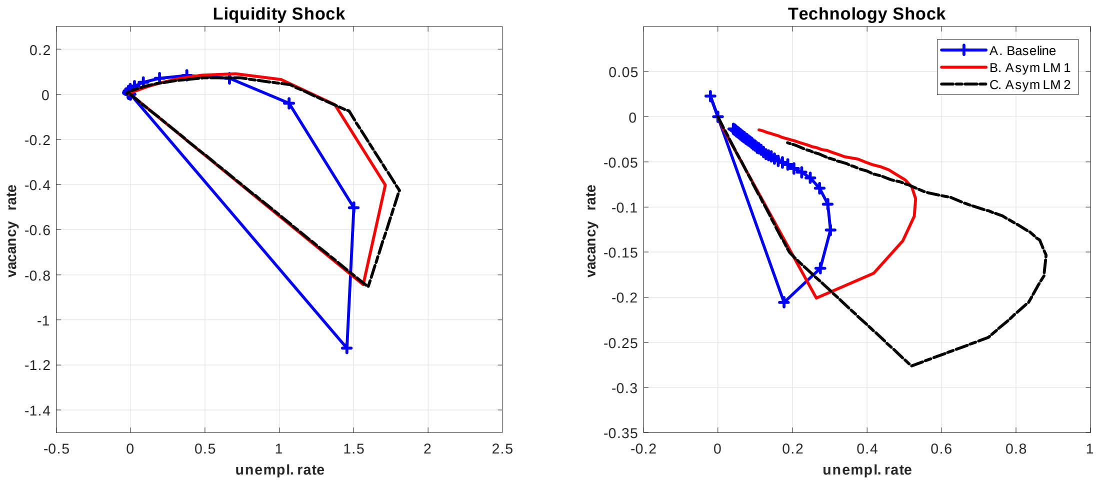

Figure 7: Model-implied Beveridge curves following a liquidity shock (left panel) and a technology shock (right panel). Vacancy and unemployment rates are expressed as deviations from their respective steady state.

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