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Abstract

Supply-side policies take centre stage in the EU's post-pandemic recovery plans. This paper employs a benchmarking approach to quantify the potential impact of structural reforms in the EU Member States. Based on a comprehensive collection of structural indicators and the QUEST-RD model, we evaluate reforms in five policy areas: (i) market competition and regulation; (ii) taxation; (iii) skills and education; (iv) labour markets; and (v) research and development. For each indicator and Member State, we simulate the closing of half of the gap with the EU's best performers, implying ambitious reforms for countries with significant distance to the frontier. For these stylised reforms, we find significant potential gains in employment and output, raising EU GDP by around 2% and 8% after five and twenty years, respectively. In the long run, the policies can increase EU GDP by over 20%. The policies also reduce economic disparities between countries, given different scope for reform. For countries with sizable distance to the best performers, increases in potential GDP could exceed 40% when halving the gap across all indicators. Among the reforms considered here, human capital investment emerges as central for enhancing growth potential. In addition, we find synergies across reforms and countries and assess the sensitivity to alternative assumptions on technology dynamics in our model.

JEL Classification: E02, E24, E61, F43, O41.

Keywords: Structural reforms, benchmarking, supply-side policies, general equilibrium models, European Union convergence.

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1. INTRODUCTION

The EU's post-pandemic recovery plan[1] places supply-side policies at its forefront, recognising their potential to promote sustainable output growth and job creation. Structural reforms can address fundamental obstacles in product and labour markets, reduce tax-related distortions, encourage innovation, and improve education and skills, yielding long-term benefits.

This paper aims to quantify the potential impact of structural reforms in EU Member States, using a benchmarking approach as in Varga and in 't Veld (2014). We collect comprehensive structural indicators across five policy areas: (i) market competition and regulation, (ii) taxation, (iii) skills and education, (iv) labour markets (labour force participation, including of older workers), and (v) research and development (R&D). Improving the performance measured by these indicators is a key goal of many economic reforms. We then map these indicators into the QUEST-RD model designed to assess the reform potential for each country. For each area and country, we apply a distance-to-frontier approach and simulate a gradual closing of half of the gap vis-à-vis the three best EU performers. Closing half the observed gaps implies substantial reform effort, exceeding the ambition typically observed in real-world practice. Nevertheless, this approach illustrates the potential effects of reforms in different areas.

For this task, the QUEST-RD model accounts for a wide range of reform areas and supply-side channels through which reforms may promote growth. It features distortions and market power in product and labour markets, tax wedges, and administrative burdens. Unlike standard models that rely on exogenous technological progress, innovation in our model is endogenous, resulting from the forward-looking investment decisions of market participants. This approach links productivity and economic growth to the underlying market structure, which is susceptible to reforms and policy. We also distinguish between low-, medium-, and high-skilled labour to simulate detailed human capital and educational reforms. Finally, our multi-region structure captures the high openness and interdependence of EU economies. Overall, this comprehensive modelling framework recognises that governments typically cannot dictate economic choices. Rather, policymakers must concentrate on implementing policies that incentivise the private sector to make desirable decisions. This means that modelling approaches must explicitly account for economic decisions to anticipate their responses to policy interventions.

This study yields four main lessons. First, ambitious reforms can potentially yield significant long-term improvements in growth potential. By closing half the gap with top performers in all Member States, the EU's real GDP level could increase by more than 20%. Some countries with the most extensive scope for reform experience considerably larger effects, reaching more than 40% in the long run. Improving the performance across all reform areas considered in our analysis implies real convergence in productivity and GDP per capita. Supply-side policies are thus crucial to reducing the dispersion of real per capita income across EU Member States ("sigma convergence").

Second, while stylised, the model exercise gives a sense of the most promising areas for reform across the Member States and the EU. In the short to medium run, competition and regulation, tax and labour market reforms dominate in terms of GDP effects, and in the longer run, progress on closing the gaps in terms of human capital yields the most significant gains. For example, closing half of the gaps in educational quality and human capital could increase EU GDP by almost 10% relative to the baseline in the long run. These

[1] See, https://next-generation-eu.europa.eu/index_en.

effects are permanent and, therefore, imply lasting improvements in the standard of living in the EU. Notably, the rich cross-country analysis also offers country-specific insights for all Member States.

Third, it is essential to recognise that harvesting the benefits of reforms can take time, as policies often only fully unfold their effects in the medium-to-long run and require design and implementation time. Skill and education reforms, in particular, feature long lags because new graduates enter the labour market only gradually. Therefore, delays in addressing these gaps imply that countries need to catch up even more.

Finally, there are synergies across reforms and countries. The combined growth effect of implementing a range of reforms is greater than the sum of individual reform effects. For instance, a society with higher skills benefits more from reducing entry barriers to innovative activities. Additionally, in the long run, reforms generate positive spillover effects across Member States, increasing growth potential beyond the simple sum of national actions. These positive spillover effects arise without explicitly considering the EU's broader "added-value", such as political economy considerations, economies of scale, or coordination gains. However, in the short run, net spillover effects remain modest for supply-side policies due to competitiveness gains and demand spillover offsetting each other.

The model-based analysis usefully complements empirical estimates, which often face challenging identification issues. Our setup is well suited to capture macroeconomic dynamics, particularly feedback effects and explicit transmission channels. In fact, the macroeconomic effects of structural policies may be quite different from those in specific sectors and failing to acknowledge the general equilibrium channels can reduce incentives for undertaking reforms (Gersbach, 2004). Moreover, given that economic decisions are inherently forward-looking and dynamic, any framework assessing the macroeconomic impact of structural reforms must also be forward-looking and dynamic. Model-based analysis can also shed light on the complementarity of reform areas and interactions across countries. At the same time, it allows for a consistent assessment of broader macroeconomic impacts, such as those on trade, government deficits, and employment. Finally, we can systematically shed light regarding alternative assumptions on model structure and calibration. In this regard, Section 6 considers down- and upside assumptions on R&D productivity, knowledge spillovers, and technological adjustment.

However, despite these advantages, stylised simulations are not directly applicable to assessing concrete reform measures in a particular country. This is due to the difficulty in quantifying the measures' depth and scope and mapping them onto model variables. Firstly, while ambitious reforms can imply large aggregate effects, structural reforms typically work at the *micro*economic level. Devising a macroeconomic methodology to assess concrete policies is, therefore, challenging. Models have limited entry points for reforms in policy simulations, given their limited set of exogenous variables and structural parameters. Consequently, assessments of concrete reforms mostly rely on indirect approaches, such as mapping reforms into indicators that can be used for model simulations (e.g., European Commission, 2016). In fact, in our approach, we focus on the impact of closing half of the distance to the best performers with respect to structural indicators, while the design to achieve this catching-up remains highly stylised. Secondly, *ex-ante* assessments are even more challenging because sufficiently detailed information on the ambition and implementation of particular reforms is typically not yet available. Finally, our simulations do not assume any direct costs associated with the reforms (beyond those affecting the budget directly, such as R&D subsidies). This approach enhances the generality of our findings by ensuring that specific cost assumptions do not influence the model outcomes. While it would be beneficial to have explicit cost assumptions for assessing *specific* policy measures, we thus focus solely on exogenous changes utilising a closing-the-gap methodology, which can be consistent with different concrete costs, as discussed in Section 3. In sum, for these reasons, the results from our benchmarking approach cannot be directly applied to assess concrete reforms.

As a result, the standard practice to quantify the potential impact of structural reforms in the literature has relied on more stylised assessments. Typically, studies examine the growth effects of a single or a few reforms and the literature is mostly concerned with deregulation, such as product and labour market reforms.[2] By contrast, our approach encompasses potential synergies and interactions between reforms.[3] Moreover, in light of the EU's high level of economic integration, we adopt a multi-country perspective in line with Varga and in 't Veld (2014). In general, larger policy-oriented models, such as the QUEST-RD model, are useful because they can quantify a more comprehensive set of (competing) transmission channels and reforms (see, for example, the recent application to the Italian reform plan in D'Andrea et al., 2023).[4]

Another strand of the literature consists of reduced-form regression analyses to study the effects of reforms. This approach typically focuses on intermediate variables such as TFP, employment, investment, or business dynamics.[5] It can serve as a satellite tool which links reforms to specific economic variables, which can then be used to translate the effects of the reforms into shocks for model simulations. For example, our assessment of education reforms also relies on regression estimates linking pupils' scholastic performance to overall productivity (see Section 3.2). This approach can also be applied to a production function approach, which links structural reforms to determinants of potential real GDP, such as employment, investment, or productivity (see, e.g., the OECD framework described in Égert and Gal, 2018).

The next section outlines the QUEST-RD model. Section 3 presents our benchmarking approach and links structural indicators to the modelling framework. Section 4 discusses the transmission and macroeconomic impact of the different reforms, while Section 5 sheds light on synergies and spillovers in the EU. Section 6 conducts a robustness analysis regarding assumptions on endogenous technological change. Section 7 concludes.

2. THE QUEST-RD MODEL

This section presents the most relevant aspects of the model for understanding the macroeconomic effects of structural reforms. These features are isomorphic for all countries. Appendix A provides a detailed description of the individual model elements and their calibration.

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[2] See, for example, Cacciatore (2016a, 2016b), Duval and Furceri (2018) and Gomes et al. (2013).

[3] Similar to our study, Gerali et al. (2016) explicitly consider simultaneous reforms in a single country and, like our study, find synergy effects across reforms.

[4] Annichiarico et al. (2013) use the QUEST-RD model to simulate a wider set of reforms for the Italian economy. For analyses using the IMF's GIMF model, see, e.g., Barkbu et al. (2012), Derek et al. (2014) and Lusinyan and Muir (2013).

[5] See de Haan and Wiese (2022) for a recent application of local projection to analyse product and labour market reforms.

2.1 MODEL OVERVIEW

The QUEST-RD features key elements for the macroeconomic analysis of reforms. Its core consists of optimising households and firms. Similar to standard structural models in the New-Keynesian tradition, it includes monetary and fiscal policy, monopolistic competition and real and nominal rigidities. Given the high degree of economic integration, our model setup covers all 27 Member States and the rest of the world as fully-fledged model blocks.

Following Roeger et al. (2009), the modelling approach devotes special attention to the supply side. First, research and development endogenously determine aggregate productivity, following the semi-endogenous growth paradigm ideas (Jones 1995, 2005, 2022). The production of new patents takes place in research labs, employing high-skilled labour and using the existing stock of domestic and foreign knowledge. Second, distinguishing three types of labour (low-, medium-, and high-skilled) allows shedding light on education and skill-specific labour market policies.

2.2 HOUSEHOLD SECTOR

The household sector supplies labour differentiated by skill (L_t^s), with $s \in \{L, M, H\}$ and receives wage income at rate (W_t^s). The skill shares are exogenous. The households' asset holdings consist of tangible capital (K_t), intangible assets (patents) (A_t), and financial assets (B_t) with the respective returns i_t^K, i_t^A, and i_t. Apart from the rental income, the household sector receives profits (PR_t) from the final goods production sector (PR_t^Y), the intermediate goods sector (PR_t^X), and the research sector (PR_t^A) – see below for details on the production side. Finally, the household sector receives transfers, split into unemployment benefits (BEN_t) and other transfers (TR_t), mostly pensions.
The households pay labour income taxes ($t_t^{w,s}$), consumption taxes (t_t^C) and other (lump-sum) taxes (T_t).[6] The household uses its total income for consumption (C_t) and gross savings. The latter are net purchases of financial assets, ΔB_t, tangible investment, J_t^K including depreciation, and investment in intangibles, J_t^A.

Formally, the representative household maximises intertemporal utility (additively separable in consumption and leisure of the three skill groups):

$$\max U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left(U(C_t) + \sum_{s \in \{L,M,H\}} POP_t^s V^s (1 - NP_t^s - L_t^s) \right), \tag{1}$$

where β is the rate of time preference. The functions characterising the utility of consumption and leisure, $U(\cdot)$ and $V(\cdot)$, respectively, are standard logarithmic (with habits in consumption) and power functions (see Appendix A). POP_t^s is the population share of skill group s. NP_t^s is the respective non-participation rate, which is determined by institutional factors, such as retirement age, years of schooling, and availability of childcare infrastructure. The household maximises (1) subject to a sequence of budget constraints:

$$\begin{aligned} &(1 + t_t^C) P_t^C C_t + \Delta B_t + P_t^K J_t^K + P_t^A J_t^A \\ &= i_{t-1} B_{t-1} + \sum_s POP_t^s (1 - t_t^{w,s}) W_t^s L_t^s + i_{t-1}^K P_{t-1}^K K_{t-1} \\ &+ i_{t-1}^A P_{t-1}^A A_{t-1} + PR_t + BEN_t + TR_t - T_t \end{aligned} \tag{2}$$

and the asset accumulation constraints for tangible and intangible capital: $\Delta K_t = J_t^K - \delta^K K_{t-1}$, and $\Delta A_t = J_t^A - \delta^A A_{t-1}$, with the respective depreciation rates δ^K and δ^A.

[6] The model also features capital income taxes and capital adjustment cost, see the Appendix for further details.

To capture consumption inequality, the household sector also features liquidity-constrained households. These households do not optimise intertemporally; instead, in each period, they consume their disposable income (net wage income plus benefits and net transfers). See the Appendix for additional details.

2.3 FIRMS

The production sector consists of final and intermediate goods producers and the R&D sector.

2.3.1 Final goods (services)

Aggregate final output Y_t is a CES aggregate of the varieties $Y_{j,t}$ indexed by j over the unit interval:

$$Y_t = \left(\int_0^1 \left(Y_{j,t}\right)^{\frac{\sigma_d - 1}{\sigma_d}} dj \right)^{\frac{\sigma_d}{\sigma_d - 1}} . \tag{3}$$

Each variety is an imperfect substitute for varieties produced by other firms. The elasticity of substitution between varieties (σ_d), determines the steady-state final goods mark-up $\sigma_d/(\sigma_d - 1)$. Our simulations will link this mark-up to changes in product market regulation.

The final goods producer j is a monopolistic competitor that maximises profits PR_t^Y:

$$PR_{j,t}^Y = P_{j,t}^Y Y_{j,t} - (1 + ssc_t) W_t L_{j,t}^Y - A_t x_{j,t} P_t^x, \tag{4}$$

where W_t and ssc_t denote the average wage and social security contributions, respectively. Final goods producers hire (imperfectly substitutable) capital services ($x_{j,t}$) and labour ($L_{j,t}^Y$) to produce variety j:

$$Y_{j,t} = A_t^0 \left(L_{j,t}^Y - FC^L\right)^\alpha \left(\int_{m=0}^{A_t} \left(x_{j,m,t}\right)^\theta dm \right)^{\frac{(1-\alpha)}{\theta}} KG_t^{\alpha_G} - FC^Y, \tag{5}$$

where A_t^0, KG_t, FC^L, and FC^Y denote economy-wide (exogenous) multi-factor productivity, public capital, overhead labour, and fixed costs, respectively. The latter creates a wedge between price mark-ups and profits. Labour is a CES aggregate of the three different skill types with:

$$L_{j,t}^Y = \left((\Lambda^L)^{\frac{1}{\mu}} \left(\chi^L L_{j,t}^L\right)^{\frac{1-\mu}{\mu}} + (\Lambda^M)^{\frac{1}{\mu}} \left(\chi^M L_{j,t}^M\right)^{\frac{1-\mu}{\mu}} + (\Lambda^{HY})^{\frac{1}{\mu}} \left(\chi^{HY} L_{j,t}^{HY}\right)^{\frac{1-\mu}{\mu}} \right)^{\frac{\mu}{1-\mu}}, \tag{6}$$

where $L_{j,t}^L$ $L_{j,t}^M$ and $L_{j,t}^{HY}$ denote the employment of low-, medium- and high-skilled workers in final goods production, respectively. Parameters Λ^z (with $z \in \{L, M, HY\}$) govern the corresponding production shares of the different skills, χ^z is the respective efficiency unit, and μ is the elasticity of substitution between different labour-skill types.

2.3.2 Intermediate goods production (manufacturing)

Intermediate goods producers (indexed by m over the interval $[0, A_t]$) rent tangible and intangible capital. The technology has constant returns in tangible capital, whereas intangible capital is a fixed cost for the firm. The production technology is linear $x_{m,t} = K_{m,t}$. The profit of intermediate goods producer i is given by

$$PR_{m,t}^X = P_{m,t}^X x_{m,t} - i_t^K P_t^K K_{m,t} - i_t^A P_t^A. \tag{7}$$

In words, the profits are the difference between revenues and the rental price of physical capital, $i_t^K P_t^K$, and intangible capital, $i_t^A P_t^A$, where P_t^K and P_t^A denote the prices of the physical capital goods and patents, respectively. We assume that firms have to make an initial payment FC^A to cover administrative entry costs and that economic policy can reduce these barriers.

2.3.3 R&D Sector: Semi-Endogenous growth

The research sector creates new designs (ideas) using a knowledge production function with high-skilled labour as input:

$$\Delta A_t = \upsilon A_{t-1}^{\phi}(A_{t-1}^{*})^{\psi}(L_t^{RD})^{\lambda} - \delta^A A_{t-1}. \tag{8}$$

The modelling follows Jones (1995, 2005) semi-endogenous growth model in which υ is the total factor efficiency of R&D production, parameters ϕ ($\phi < 1$) and ψ ($0 \leq \psi < 1$) measure domestic and foreign spillover effects from the accumulated (i.e., existing) domestic (A_{t-1}) and foreign (A_{t-1}^{*}) knowledge stocks, respectively. These technological spillovers mirror the non-rivalry of knowledge: ideas can be used by any number of people at the same time (Romer, 1990). Note, however, that setting $\phi < 1$ avoids the strong scale effects with respect to the domestic level of knowledge that is part of fully endogenous growth models.[7] At the same time, there can be congestion effects ("fishing out ideas"). Technically, λ measures this elasticity of R&D production with respect to the number of researchers (L_t^{RD}). Our robustness analysis in Section 6 will consider different assumptions on these parameters.

Growth (ΔA_t) in this model derives from the pursuit of new technologies by profit-maximising firms. Formally, we assume that the R&D sector is operated by a research institute, which employs high-skilled labour at its market wage, W_t^H (subject to hiring costs, parametrised by γ^{LRD}) and can receive a wage subsidy s_t^{RD}. High-skilled labour is paid the same wages across sectors. The research institute maximises the following discounted profit stream:

$$\max_{L_t^{RD}} E_0 \sum_{t=0}^{\infty} d_t PR_t^A, \tag{9}$$

where d_t is the discount factor of the owner households and profits are given by:

$$PR_t^A = P_t^A \Delta A_t - (1 + ssc_t - s_t^{RD}) W_t^H L_t^{RD} - \frac{\gamma^{LRD}}{2} W_t^H (\Delta L_t^{RD})^2. \tag{10}$$

2.4 FISCAL POLICY

Nominal government debt (B_t) evolves according to:

$$B_t = (1 + i_t)B_{t-1} - R_t^G + P_t^C(G_t + IG_t) + TR_t + BEN_t + s_t^{RD} W_t^H L_t^{RD} + T_t, \tag{11}$$

where government revenues, R_t^G, are made up of taxes on consumption and on labour and capital income. Government expenditure includes government purchases (G_t) and investment (IG_t). Total nominal transfers consist of general social transfers and pension payments.

$$TR_t = \underbrace{\overline{trs} GDP_t^N}_{\text{Social transfers}} + \underbrace{\textstyle\sum_{s \in \{L,M,H\}} PENSRR^s W_t^s NP_t^{55-64,s}}_{\text{Pension payments}}, \tag{12}$$

where the former is set as a constant share ($\overline{trs}$) of nominal GDP for simplicity. For pension payments, we focus on the age group 55-64 as their participation rate will be subject to the reforms considered below. Pension payments are indexed to the skill-specific wages with replacement rate $PENSRR^s$.

Total unemployment benefits are given by:

$$BEN_t = \sum_{s \in \{L,M,H\}} BENRR_t^s W_t^s (1 - NP_t^s - L_t^s), \tag{13}$$

where $BENRR_t^s$ denotes the skill-specific benefit replacement rate.

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[7] Setting $\phi = 1$ implies that increasing the level of resources devoted to R&D translates into a proportionate increase in the long-run per capita growth rate of output. This prediction, however, receives little empirical support and we follow Jones (1995) in setting $\phi < 1$.

Finally, lump-sum taxes (T_t) control the long-run debt-to-GDP ratio according to a standard stabilisation rule. However, in our simulations, this rule will be active only in the long run to isolate the effects of the specific structural reforms. We discuss the specific fiscal assumptions in Section 3.3.

2.5 SKETCHING OTHER MODEL FEATURES

We conclude this section by briefly sketching the remaining (standard) model features, relegating additional details to Appendix A.

Trade. Households, the government, and the final goods sector consume domestic and foreign goods. To facilitate trade aggregation, we assume identical preferences across goods used for private consumption, investment, and public expenditure.

Wage setting. Within each skill group, households supply a variety of labour services. A trade union maximises a joint utility function for each type of labour. It is assumed that types of labour (with their respective population weights) are distributed equally over Ricardian and liquidity-constrained households (based on the respective population shares of the two household groups). We also assume that trade unions can charge an (exogenous) wage mark-up over the reservation wage because labour services are imperfect substitutes. The reservation wage is given as the average marginal utility of leisure divided by the marginal utility of consumption across households. The relevant net real wage, to which the mark-up adjusted reservation wage is equated, is the gross wage adjusted for labour taxes, consumption taxes, and unemployment benefits.

Monetary policy. Concerning monetary policy, which is most relevant for the short-run adjustment, we assume that central banks set the nominal risk-free interest rate according to a Taylor rule targeting consumer price inflation and the output gap. The model accounts for the institutional features of monetary policy in the different Member States (currency union, interest rate peg, or domestic inflation targeting). We relegate the discussion of these model features to the Appendix.

2.6 CALIBRATION

The European Union's Member States have different macroeconomic characteristics, such as skill shares, labour force participation rates, openness, and the size of their public sectors. These differences matter for the transmission of supply-side policies, and therefore our calibration strategy takes this heterogeneity into account.

To calibrate the long-run output ratios, we use country-specific data from national accounts, fiscal data, and trade data. We also use trade statistics data from the FIGARO database provided by EUROSTAT to determine the bilateral import shares and trade openness. We obtained benefit and pension replacement rates from the OECD's benefits statistics database (OECD, 2023) and the European Commission's Ageing Report (European Commission, 2021), respectively.

Reflecting data availability, the labour force is partitioned into three skill groups: low-, medium-, and high-skilled. We define high-skilled workers as those who can potentially work in the R&D sector, such as engineers and natural scientists. Low-skilled workers correspond to the ISCED 0-2 education levels, while the rest of the labour force is considered medium-skilled.[8] We rely on Acemoglu and Autor (2011) to calibrate the elasticity of substitution between different labour types (μ).[9] In the simulations, the Frisch elasticity determines the sensitivity of labour supply to changes in wages. The corresponding values for low-skilled, medium-skilled, and high-skilled labour are different, with low-skilled labour having a higher elasticity in line with empirical evidence.[10]

We rely on Ratto et al. (2009) to calibrate the adjustment cost parameters of the labour market, which are assumed to be the same across countries. Similarly, other behavioural parameters that govern the dynamic adjustment to shocks are based on estimated euro area or EU-wide model versions. We use evidence of average price and wage adjustment frequencies to calibrate price and wage adjustment parameters. The price elasticity of trade corresponds to the estimate by Ratto et al. (2009).

Bottazzi and Peri (2007) and Pessoa (2005) estimate the output elasticities of knowledge production for patent and skilled labour inputs. The growth rate of ideas was obtained from Pessoa (2005) with the assumption of a 5% obsolescence rate. The wage-cost share in the total R&D spending determines the elasticity of R&D to research labour ($\lambda = 0.59$). As reported in the Appendix, we rely on Bottazzi and Peri (2007) to calibrate the knowledge elasticity parameters with respect to domestic ($\phi = 0.44$) and foreign knowledge capital ($\psi = 0.54$), which we report here for the EU. In light of the uncertainty surrounding this calibration, our robustness section also considers alternative assumptions on the spillover parameters.

Appendix A provides further details on our calibration strategy and data sources.

2.7 COMPUTATIONAL APPROACH

Our computational strategy involves solving the full non-linear model using a Newton-Raphson solution algorithm under perfect foresight. Unlike typical macro models which rely on linearised solutions, this approach captures policy-relevant non-linearities, such as synergy effects across reforms. Appendix C provides additional details.

3. MODEL-BASED REFORM BENCHMARKING

This section discusses our structural indicators (Section 3.1) and their mapping into the model (Section 3.2), as well as additional modelling assumptions (Section 3.3) applied in the reform simulations.

3.1 STRUCTURAL INDICATORS AND REFORM BENCHMARKS

To begin, Table 1 presents a comprehensive set of structural indicators for all EU Member States, categorised into five broad areas. These indicators include observable demographic indicators (e.g., skill

[8] Data on skill-specific population shares, participation rates, and wages are obtained from various sources such as the Labour Force Survey, Structure of Earnings Survey, and Science and Technology databases of Eurostat.

[9] Acemoglu and Autor (2011) argue for estimates in the range of 1.6-1.8 on the extended data sample. Therefore, we take 1.7 as our baseline value.

[10] Concerning the elasticity of labour supply, the simulations use a total average Frisch elasticity of 0.25 as the benchmark, as Chetty et al. (2011) suggest for the extensive margin. The corresponding Frisch elasticity values for low-skilled, medium-skilled, and high-skilled labour decline with the skill and income level in our model, in line with the findings of Bargain et al. (2014).

shares, participation rates), fiscal data (e.g., tax rates and unemployment benefits), and constructed indicators (product market regulation (henceforth, PMR), PISA). The table notes provide further details on the data sources.

We calculate a benchmark value for each reform indicator, defined as the average of the three best-performing Member States. The best performers are reported below Table 1.[11] The distance to this benchmark indicates the potential for reforms, with darker shading in Table 1 indicating wider gaps. This benchmarking provides an initial assessment, which we will substantiate with model simulations. The model simulations also estimate the potential macroeconomic effects at different time horizons.

Following Varga and in ’t Veld (2014), we simulate closing half of the gap with the three best performers. Closing half of the gap in the respective areas implies very sizeable reforms, in most cases not attainable in the short run. “Typical” reforms are much less ambitious, as the strong persistence in most indicators suggests. At the same time, closing half of this gap usefully illustrates the potential for reform and economic convergence.[12]

3.2 MAPPING INDICATORS INTO MODEL VARIABLES

To simulate reforms, we map the structural indicators into (exogenous) model variables. Changes in these variables lead to dynamic adjustments of all endogenous variables included in the model (e.g. GDP and employment). Table 2 shows the model counterpart for each indicator, which follows three different strategies. For most indicators, the mapping is direct. For example, we can map observed skill shares or participation rates directly to the corresponding model variables. However, for the PMR indicator, we use an “indirect” mapping to final goods mark-ups in the model. We first calibrate the EU-average final goods mark-up based on profit rates (KLEMS data). For each Member State, we then scale the value using the country-specific PMR indicator.[13] This approach acknowledges difficulties in directly comparing mark-ups across Member States and mapping them directly into our model.[14] Finally, we rely on auxiliary elasticities with productivity for the PISA score, which we link to aggregate productivity based on the elasticities of Égert et al. (2022).[15]

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[11] For unemployment benefits, we consider the EU-average as a target.

[12] We also have experimented with a full closure of the gaps. However, significant model nonlinearities make them sensitive to other modelling assumptions. For example, as we discuss below in Section 6.2, extreme changes in skill shares have strikingly different GDP effects depending on whether the production technology adjusts gradually to the new skill distribution. This sensitivity appears much more relevant for large shocks.

[13] See also Appendix A for additional details.

[14] For example, mark-up estimates can also reflect fixed costs and innovation aspects. Scaling model-based final goods mark-ups with the indicators allows focusing on the product market and competition aspects while ensuring transparency of the underlying economic indicator.

[15] PISA scores usefully complement our simulations on changes in the skill composition as they are tied to the quality of education, signifying the human capital embedded within various skill groups rather than the sheer number of workers. The regression presented in Égert et al. (2022) also accounts for years of education, which further mitigates the risk of double counting.

3.3 FURTHER MODELLING ASSUMPTIONS

3.3.1 Time lags: Design, implementation, and gradual effects

Reforms take time to design and implement, and some require considerable time before being fully reflected in the economy. For example, due to cohort effects, improvements in the education and skills of the labour force are only fully reflected in the long run. Table 2 summarises our assumptions regarding time lags, and we discuss our timing assumptions in the transmission channel of each reform in Section 4.

3.3.2 Credibility and uncertainty of reforms

We simulate the model assuming that all reforms are entirely credible. Under perfect foresight, households and firms face no uncertainty about the overall transition path and new long-run equilibrium. If, by contrast, reforms were not entirely credible, households and firms would reflect this in their investment decisions, leading to lower growth effects.

3.3.3 Costs of reforms

Our simulations mainly disregard the direct budgetary expenses, except for R&D subsidies and reductions in benefit replacement rates. Although explicit cost assumptions are desirable for evaluating specific policy measures, our study only examines exogenous changes using a closing-the-gap methodology. This approach prevents particular assumptions from influencing the model outcomes. For example, if labour force participation rises due to increased provision of child-care facilities or lower taxes, it may incur a direct cost for the government. However, it could also be cost-saving if the reform is implemented through a reduction in unemployment benefits.[16] Nonetheless, in our general equilibrium model, *all* reforms *indirectly* impact the budget, notably through tax base effects or, immediately through savings on early-retirement pension payments in the case of higher participation of elderly workers, as discussed in Section 5.2.

3.3.4 Fiscal policy assumptions

Debt stabilisation. The government targets a constant debt-to-GDP ratio in the long run. However, the simulations assume that the fiscal closure rule (see Appendix, eq. 28) is inactive for the first 50 years. This setting avoids fiscal implications of structural reforms being affected by second-round distortionary fiscal adjustment or debt-consolidation effects. The simulations show considerable improvements in public balances, notably via positive tax base effects, as a result of the reforms.[17]

Expenditure. We assume that (nominal) transfers (excluding pensions and unemployment benefits) are indexed to nominal GDP, and nominal pensions are indexed to wages for each skill group. Government investment and purchases are kept constant as a share of GDP in the simulations.

[16] See Roeger et al. (2021).

[17] In the long run, a lower debt-to-GDP ratio reduces debt financing costs and allows for more fiscal space, which could be "recycled" for higher productive investment or lower taxes. For example, assuming a rebate via distortionary labour taxes would further increase the growth effects but would blur the reform's direct effect. In the long run, we assume that any additional revenue generated by the reform is rebated to households as lump-sum transfers once the closure rule is active. As stressed above, it should be noted that our simulations exclude the cost of reforms and thus give an upper bound of the improvement in indebtedness.

Table 1. **Structural indicators**

		AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	Best 3
Market competition	PMR indicator	1.44	1.69	1.93	1.80	1.30	1.08	1.02	1.29	1.56	1.03	1.37	1.57	1.43	1.32	1.38	1.32	1.19	1.68	1.28	1.54	1.10	1.45	1.34	1.86	1.11	1.29	1.52	1.05
Market regulation	Entry costs (%)	10.4	6.7	7.4	7.0	7.3	8.9	1.2	1.9	2.6	7.3	4.3	1.8	11.4	6.2	2.4	17.0	1.9	4.2	3.0	11.3	5.0	20.7	3.6	5.7	2.6	2.2	6.8	1.6
Tax reform	Labour to consumption tax revenue ratio	2.1	2.0	0.8	1.1	1.7	2.3	1.7	1.2	1.1	1.9	1.5	2.0	0.7	1.2	1.4	1.9	1.4	2.0	1.1	1.0	1.7	1.2	1.2	1.2	2.1	1.4	1.6	0.8
Skill enhancing reforms	Share of high-skilled (%)	8.5	9.0	5.5	6.6	6.5	7.7	11.2	7.7	5.3	6.5	11.3	6.1	5.5	5.6	10.7	3.9	7.3	9.8	5.1	7.6	11.0	6.7	7.9	5.6	12.7	7.5	4.1	11.7
	Share of low-skilled (%)	14.4	21.3	17.5	17.5	6.2	13.4	18.5	9.8	23.2	38.7	9.9	19.6	14.2	15.0	16.3	37.8	5.0	20.7	8.8	44.8	20.4	7.4	47.8	21.0	13.9	11.2	8.6	6.2
	PISA score	491	500	427	438	495	500	501	526	453	482	516	494	472	479	505	477	480	477	487	459	502	513	492	428	503	504	469	518
Labour market reforms	Non-participation (%, 25-55ys):																												
	- low-skilled	17.5	22.2	26.2	13.7	20.1	21.2	22.1	21.8	13.9	13.0	21.5	17.5	20.8	19.6	23.3	20.8	28.5	12.9	20.0	13.6	17.6	26.2	9.5	23.2	15.2	15.0	27.5	11.8
	- medium-skilled	6.9	19.6	18.1	20.4	17.2	16.2	13.9	17.4	27.8	17.8	17.6	15.3	22.9	20.6	31.2	27.7	14.9	22.5	17.3	21.7	15.4	24.8	8.7	27.6	11.6	11.4	18.9	5.3
	- high-skilled	5.9	6.3	4.6	7.5	10.3	6.9	4.0	7.4	5.1	7.0	5.8	5.0	4.6	9.4	6.5	10.9	3.5	5.7	5.5	5.0	4.7	6.4	3.5	3.8	3.5	3.5	11.2	3.5
	Elderly non-participation (%, 55-64ys):																												
	- low-skilled	20.7	24.9	14.1	17.6	18.3	11.6	13.1	9.6	22.3	14.9	17.2	21.8	35.8	18.5	19.4	18.7	8.8	23.5	9.6	18.8	16.2	24.7	15.3	16.3	8.9	29.3	19.7	9.1
	- medium-skilled	9.7	8.3	7.1	5.7	6.6	6.4	5.4	5.7	9.5	5.5	6.8	8.7	11.8	8.6	5.5	6.2	7.4	9.2	7.1	4.0	5.2	11.8	3.5	10.8	3.6	11.1	8.4	3.7
	- high-skilled	4.1	3.6	4.6	1.9	2.9	3.1	1.4	3.6	4.0	3.4	2.9	2.6	3.1	3.0	2.8	2.9	3.5	3.2	5.1	2.8	2.5	3.4	2.7	5.2	1.7	2.5	3.6	1.6
	Benefit replacement rate* (%)	67.6	56.6	32.5	50.5	37.7	51.5	60.7	41.9	40.7	41.9	59.7	49.9	39.2	30.0	62.3	48.0	45.2	57.3	58.0	51.5	48.0	46.9	39.1	33.2	66.0	59.8	40.1	48.7*
R&D measure	R&D subsidy (% GDP)	0.19	0.21	0.00	0.00	0.05	0.00	0.03	0.00	0.01	0.03	0.00	0.28	0.00	0.05	0.18	0.16	0.03	0.00	0.00	0.03	0.15	0.02	0.20	0.01	0.01	0.10	0.03	0.23

Note: Darker shades correspond to larger gaps vis-à-vis the benchmark. Sources: Product market regulation: OECD (2018) PMR indicators; Entry costs: starting business costs in % of income per capita, 2019: World Bank's Doing business database. Labour to consumption tax revenue ratio using the tax rates from DG TAXUD; Skill-shares, non-participation rates, 2019; education expenditures 2019 or latest available: EUROSTAT; OECD PISA score, 2018, (average scores over reading, maths and science), https://pisadataexplorer.oecd.org/ide/idepisa/; Benefit replacement rates, 2019: OECD, Benefits and Wages Statistics. www.oecd.org/els/benefitsandwagesstatistics.htm; average of net replacement rates over 60 months of unemployment, 2019, *we consider the EU-average as a target; R&D tax incentives in %GDP, 2019, OECD Science, Technology and Industry Scoreboard. The best three performing Member States for each reform area are as follows. PMR indicator: DE, DK, ES; entry costs: DK, EE, FR; labour to consumption tax revenue ratio: BG, HR, MT; share of high-skilled: DK, FI, SE; share of low-skilled: CZ, LT, PL; PISA score: EE, FI, PL; Non-participation rate of low-skilled: ES, LU, PT, - medium-skilled: PT, SE, SI, - high-skilled: LT, SI, PT; elderly non-participation of low-skilled: LT, LV, SE, - medium-skilled: MT, PT, SE, - high-skilled: CY, DK, SE; benefit replacement rate: EU average; R&D subsidy: BE, FR, PT.

Table 2. **Mapping structural indicators into the model**

	Measure	Mapping	Model counterpart	Timing assumptions
Market competition and regulation	Product market regulation	Indirect	$\sigma_d/(\sigma_d - 1)$	1 pp/y
	Entry costs (%)	Direct	FC^A	5 ys
Tax reforms	Tax shift from labour to consumption tax	Direct	t^c/t^w	5 ys
Skill enhancing reforms	Share of high-skilled (%)	Direct	POP^H/POP	45 ys
	Share of low-skilled (%)	Direct	POP^L/POP	45 ys
	PISA score	Auxiliary elasticity	A^0	5+45 ys
Labour market reforms	Non-participation (%, 25-55ys):	Direct	NP^s	20 ys
	Elderly non-participation (%, 55-64ys):	Direct	$NP^{55-64,s}$	20 ys
	Benefit replacement rate (%)	Direct	$BENRR^s$	5 ys
R&D measures	R&D subsidy (% GDP)	Direct	s^{RD}	5 ys

Note: This table reports the mapping of structural indicators into model variables.

4. MACRO EFFECTS ACROSS REFORM AREAS

This section discusses the main transmission channels and long-run effects for all reform areas. We also report the GDP impact at different horizons (five and twenty years ahead and the long run) for each reform. Here, we consider the effects of a single reform except the countries included in the benchmark.[18] This set of simulations thus excludes synergies from the joint implementation of reforms, which we discuss in Section 5.

4.1 MARKET COMPETITION AND REGULATION

Many economic reforms aim to improve market competition and reduce entry barriers. Here, we examine the potential impact of two reforms in this policy area: increased competition in the final goods sector and reduced entry barriers in the intermediate goods sector. Our model captures these reforms as exogenous changes in the mark-up of the final goods sector and reductions in fixed costs for the intermediate goods sector. Conceptually, these sectors represent services (final goods) and manufacturing (intermediates). Without further assumptions, the fiscal costs for these reforms are ambiguous and are not included in the simulations.

4.1.1 Increasing competition in the final goods sector

The first reform, an exogenous reduction in price mark-ups, simulates service sector liberalisation and decreases market power for firms. In the model, increased competition prompts firms to lower prices, raising demand and output. Reducing mark-ups improves allocative efficiency, and demand for all production factors (different types of labour and capital) increases. Low-skilled households see the most substantial increase in employment due to higher labour supply elasticities. Capital accumulation increases real wages, and the increased demand for intangible capital stimulates R&D activity, resulting in endogenous growth. Lower domestic prices lead to a competitiveness gain via export prices and improve the trade balance.

[18] Roeger et al. (2008) report simulations for the EU (as a whole) using unit-size shocks (e.g., 1 pp. mark-up shock or 1 pp. tax shift).

The calibration of the mark-up in each Member State is based on information on average EU-wide profit rates and the OECD's product market regulation (PMR 2018) indicator. The reduction in mark-ups is limited to 1 percentage point per year until half of the gap is closed, reflecting the time required for competition-enhancing reforms and potentially gradual market entry of competitors.

As expected, countries with the largest gaps in the PMR indicator experience the most substantial positive GDP impact, e.g., reaching more than 3% for Bulgaria and Romania in the long run (Graph 1). The beneficial effects materialise relatively fast (half of the GDP gains appear after five years). According to the model simulations, if all countries converged halfway to the best performers, EU GDP would increase by more than 1%.

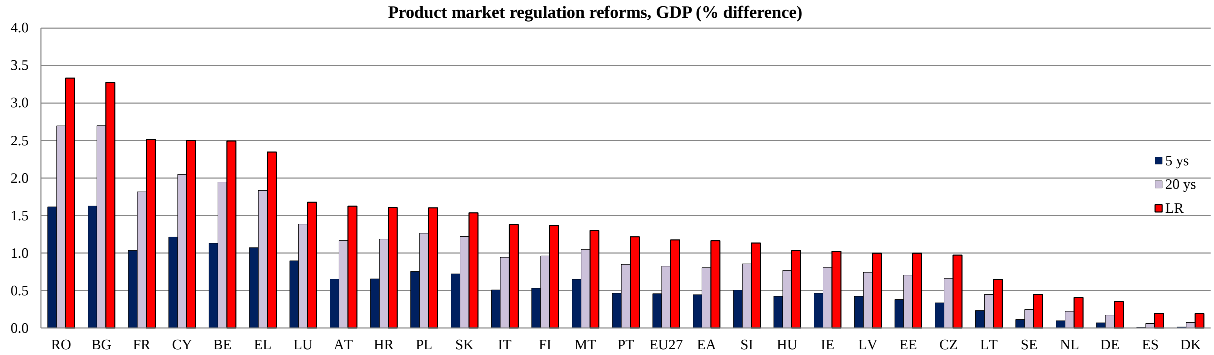
4.1.2 Reducing entry barriers in the intermediate goods sector

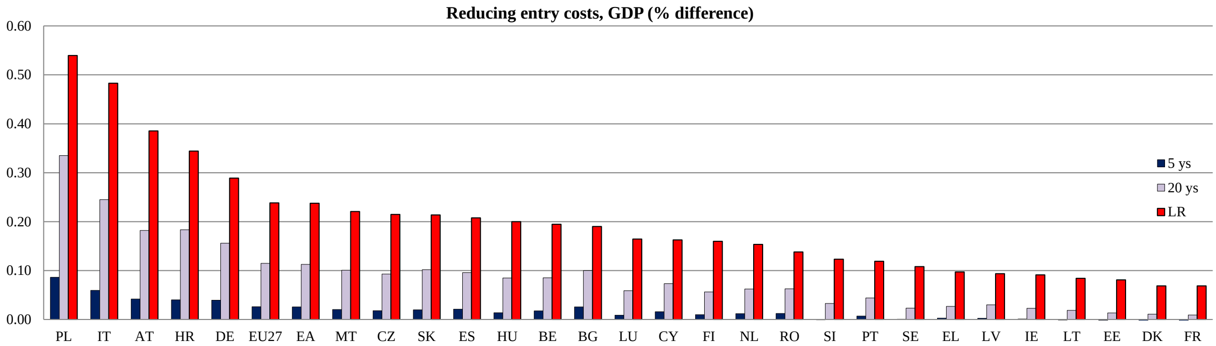
The transformation of ideas into marketable goods and services is at the core of modern market economies. Reforms to reduce entry barriers aim to promote innovation. The model captures these barriers as fixed costs, such as high administrative costs and insufficient financing opportunities for start-ups (e.g., venture capital).

In the model, reducing fixed costs leads to more product innovation, broadening the variety of goods available in the economy. Reducing barriers to entry promotes innovation and attracts knowledge investment by bringing down the required present discounted value generated by the new product. The new entrants and products translate into higher demand for blueprints (R&D) and high-skilled workers and increase knowledge investment. Once integrated into the production of the final goods, more innovative intermediate goods enhance the economy-wide total factor productivity. Ultimately, the innovation process boosts medium and long-term growth. Initially, however, the reallocation of high-skilled workers away from the production of goods and sectors to the R&D sector can reduce output and final goods production.

Compared to product market regulation reforms, the average GDP gains from closing the gaps are smaller. Interestingly, the ranking of entry costs differs from the PMR indicator. Bulgaria, Romania, and Cyprus fare below the EU average, while Germany, with one of the lowest PMR indicators, faces relatively high gaps to the best performers. The most significant gains from entry cost reductions appear in Poland and Italy, with long-run gains of around 0.5% of GDP.

Graph 1. **Competition and product market reforms**





Note: These graphs report the level of real GDP in percent deviation from a no-policy change baseline. Dark blue and light blue bars show effects after 5 and 20 years, respectively, and red bars indicate long-run results. The simulations assume that all countries simultaneously close half of their respective gaps to the best three performing EU Member States. For EA and EU-wide results, we aggregate countries aggregated based on GDP weights. We consider a simultaneous (single) reform in all countries except those included in the benchmark.

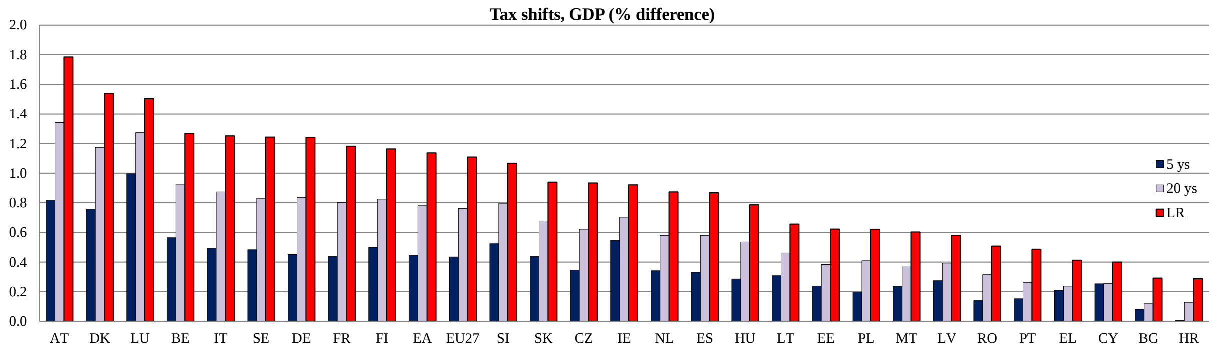
4.2 TAX REFORMS

We now turn to tax reforms and consider a stylised shift from labour to consumption taxes. When labour taxes are high, workers have less net income, discouraging entry into the labour force. Shifting taxes away from labour promotes long-term growth by incentivising increased labour supply. The effects of this switch depend on how the government financed the tax reform. Here, we consider a shift to consumption taxes as a stand-in for a broader set of taxes, including environmental or property taxation. Our simulations assume that the government gradually implements the tax shift over five years and that it is budget-neutral ex-ante. Even ex-post, i.e., when taking into account endogenous changes in tax bases, the positive total revenue effects remain small as the increase in consumption tax revenue initially offsets the decline in labour tax revenue. Gradually higher growth raises revenues and improves the government's budget.

Generally, a household's overall tax burden affects its decision to supply labour. However, lower taxes on wage income specifically reduce distortions on employment decisions and increase employment and output. In our simulations, higher capital investment accompanies the employment gains and stabilises the capital-labour ratio. As a result, real wages return to the baseline level at a higher level of capital and employment. Furthermore, the increase in GDP exceeds the increase in employment and capital due to lasting productivity gains generated by the R&D sector's high-skilled employment and knowledge generation. Despite the increase in consumption taxes, consumer demand increases, particularly for constrained households that consume their net wage and transfer incomes in every period. However, it is worth noting that our model does not capture that the marginal propensity to consume is higher for lower-income groups (here, skill groups). As a result, with progressive income taxes, the tax burden would be shifted to income groups that consume a larger proportion of their income.

The shift to indirect taxes increases output on average by around 1% in the long run. Interestingly, some countries with significant gaps in other reform areas are among the best-performing Member States (Bulgaria, Croatia, Cyprus, and Greece), while there is scope for reform in, e.g., Austria, Belgium, Denmark, Germany, and Sweden.[19]

Graph 2. **Tax shift from labour to consumption taxes**



Note: See the notes below Graph 1 for additional information.

4.3 SKILL-ENHANCING REFORMS

A skilled and educated workforce is crucial to a country's growth and innovation potential. With the necessary skills and knowledge, workers can perform their tasks more effectively, which can increase productivity. Governments can create conditions for innovation and productivity growth by investing in high-skill education. At the same time, education also plays a crucial role in improving social mobility.

Our simulations consider three reforms. The first two are "upskilling" simulations, which i) increase the share of high-skilled workers (thus less medium-skilled workers) and ii) reduce the share of low-skilled workers compensated by an increase in medium-skilled jobs. However, these simulations do not account for education quality standards. Therefore, in our third simulation, we consider general improvements in school education, as measured by the PISA score. The budgetary cost of each of these education reform scenarios is excluded.[20]

Because of cohort effects, it takes time before the labour force fully reflects improvements in skills. We assume a 45-year lag until the workforce fully adapts to changes in the skill distribution. We also include an additional five-year implementation lag for the educational quality reform (PISA).

[19] The size of the labour tax reduction also reflects the levels of the consumption and labour tax rates (and not only their ratio).

[20] There is no clear correlation between educational expenditure in Member States and educational attainment or PISA scores, which precludes a direct link to spending in the three best-performing countries.

In our baseline simulations, we assume that the production technology remains constant despite the changes in the relative supply of skills. However, the endogenous evolution of new technologies and production processes is potentially significant, according to the seminal paper of Acemoglu (1998, 2002). The theory of directed technical change suggests that inventors or firms respond to the skill distribution when developing, adopting or setting up production technology. Our robustness analysis considers this interaction between skills and production technology in more detail (see Section 6).

4.3.1 Increasing the share of high-skilled workers

Policies to increase the share of high-skilled workers directly affect final goods production and R&D activities. Initially, high-skilled workers replace less efficient medium-skilled workers in producing final goods. However, over time, there is a dynamic increase in employment in the R&D sector, resulting in a decline in high-skilled worker wages, a reduction in patent prices, and the entry of new firms. In the medium to long term, increasing the share of high-skilled workers yields a high output effect compared to other human capital investment scenarios due to strong growth effects via R&D employment and patent growth. Increasing the share of high-skilled workers also has positive wage effects on other worker types. As discussed above, the simulation considers the gradual entry of new cohorts into the labour market.

Graph 3 shows that skill improvements are fundamental to lifting the economy's long-run potential. For countries with smaller shares of highly educated workers, the long-run GDP gains are substantial, reaching more than 5% in Croatia and more than 4% in Bulgaria, Greece, Italy, Romania, and Slovakia. With a GDP level of 3.2% above baseline, they remain sizeable for most Member States and the EU on average. In line with our assumptions on cohort effects, most of the effects materialise only in the long run, and the short-run gains remain small.

4.3.2 Increasing average (medium) skills

We now consider an increase in the average skill level in the economy. The shock in the model is designed to gradually increase the share of medium-skilled, resulting in a decrease in the low-skilled share. As the share of medium-skilled workers increases relative to the low-skilled share, the output effect gradually builds up. The additional medium-skilled labour operates more efficiently than the low-skilled workers they replace in producing final goods. As a result, the skill premium relative to the other skill groups (low- and high-skilled) decreases. Due to imperfect substitutability between different types of workers, an increase in the share of medium-skilled workers has positive wage effects, particularly for low-skilled workers. However, since medium-skilled workers do not engage in R&D activities, the overall growth effect remains smaller than for high-skilled investment for shocks of similar size.

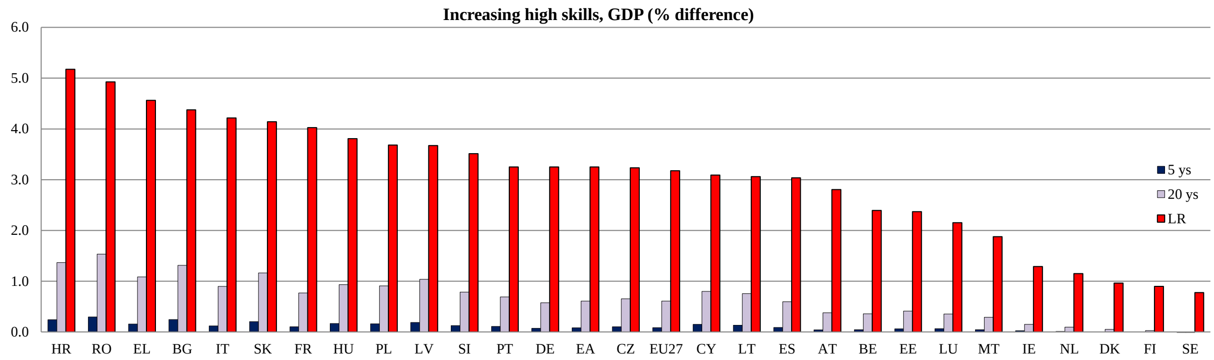
The relative gains for increasing the share of medium-skilled workers are largest for Italy, with long-run GDP effects close to 6%. Upskilling towards medium skills also provides substantial long-run gains in other parts of Europe's south: Malta, Greece, Spain, and Portugal experience a GDP impact of 3%.

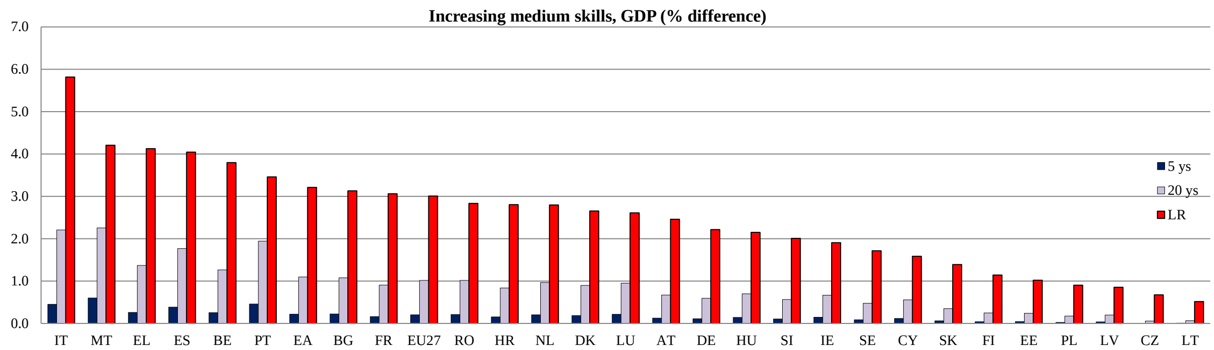
4.3.3 Improving educational quality (PISA)

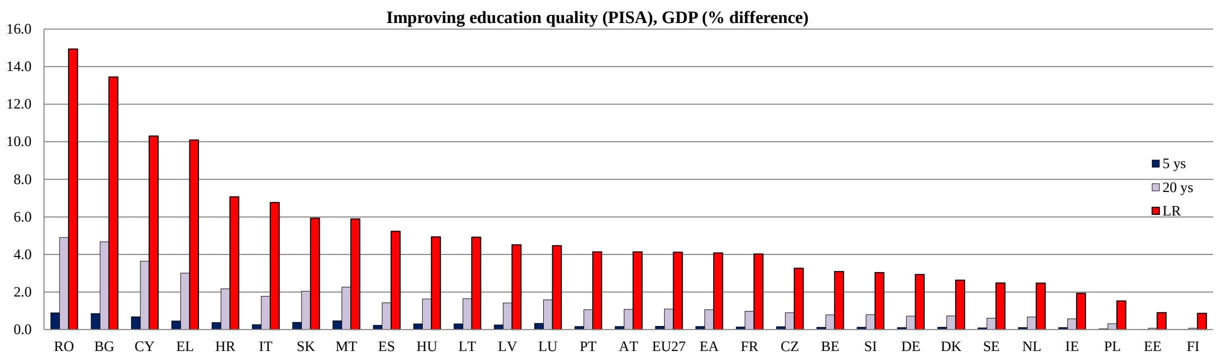
As discussed above, we model educational quality reforms as a gradual improvement in the level of productivity of final output production (A_t^0, eq. 5) based on auxiliary elasticities reported in Égert et al. (2022). The efficiency gain has a permanent positive effect on GDP, consumption, and capital. The increased demand for investment goods stimulates entry into the intermediate goods production sector, which in turn increases the efficiency of capital. Furthermore, the TFP shock positively affects the real wages for all workers. Real wage gains are the strongest for high-skilled workers because of an increase in the demand for R&D, which, in turn, raises the demand for high-skilled workers over-proportionally.

Based on the auxiliary elasticities and the distance to the best performers, improving education quality provides countries with the most significant long-term gains. For Romania and Bulgaria, the long-run effects of closing half of the gap are 15% and 13.4% of GDP, respectively. For Cyprus and Greece, they exceed 10%.

Graph 3. **Skill and education reforms**







Note: See the notes below Graph 1 for additional information.

4.4 LABOUR MARKET REFORMS

We now turn to labour market reforms: increasing labour force participation overall (Section 4.4.1) and for elderly workers specifically (Section 4.4.2), as well as a reduction in the generosity of (long-term) unemployment benefits (Section 4.4.3).

4.4.1 Labour force participation

The labour force is a significant contributor to economic growth. A higher labour force participation rate means more workers are available to contribute to the production of goods and services, leading to increased economic output. Higher participation rates increase the labour force, resulting in improvements in GDP. Participation of (prime age) women is a key example. Although this may require an increase in childcare expenditure, these costs are not modelled here.

Addressing non-participation boosts employment and GDP, with the largest long-run effect in Italy (almost 7% of GDP in the long run). There are large potential gains in Croatia, Romania, and Greece. Ireland, Poland, Belgium, and Slovakia also see considerable scope for increasing labour market participation. Employment gains are the main benefit of these reforms. Graph 5 shows that all labour market reforms considered here could increase EU employment by 5% (with larger increases in many Member States).

4.4.2 Participation of elderly workers (55-64 years)

Raising participation rates for the 55-64 age group has additional advantages. Unlike the previous case, the simulations also capture that raising participation for this age group also reduces early retirement pension payments and generates budgetary savings.[21] However, we do not capture that this may also require more spending on active labour market policies.

While Croatia and Poland remain among those with the largest potential gains, the relative ranking differs somewhat from the labour force participation of prime-age individuals. For example, there is more scope for reform in Belgium, France, and Slovenia.

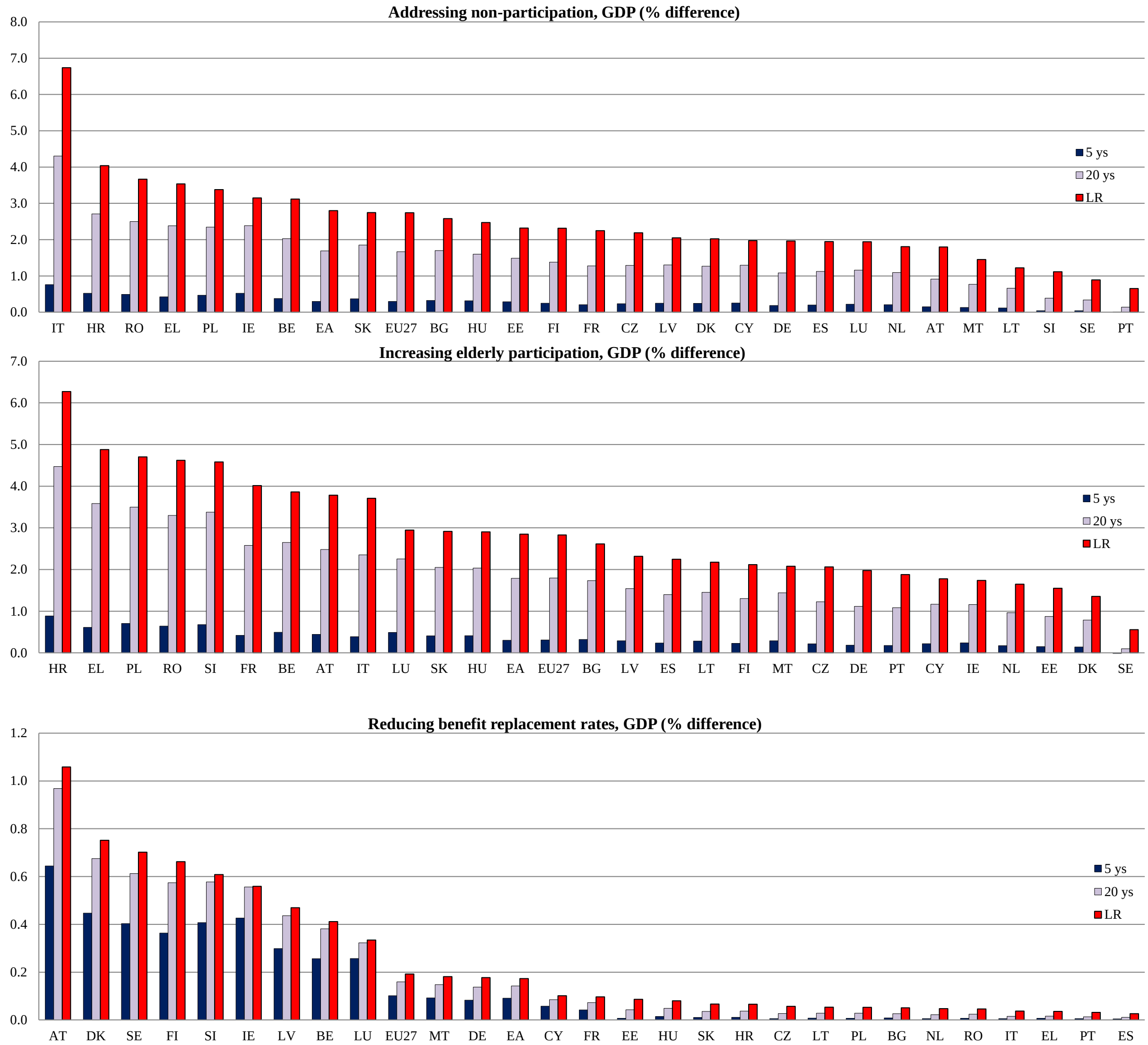
4.4.3 Benefit replacement rates

In the model, lower benefit replacement rates (for this indicator, we consider the EU-average as a target) reduce reservation wages and increase labour supply, implying downward pressure on wages. Although the proportional change in the replacement is the same for the three skill groups, the increase in the employment rate is most prominent for the low-skilled, given their high labour elasticity. Output increases following the boost to employment, but the increase in GDP is initially less than proportional. The GDP effect becomes larger due to an endogenous R&D response. A higher employment rate of high-skilled workers in the R&D sector and increased demand for new patents from new firms in the intermediate sector boost output of the R&D sector and raise total productivity in the long run.

[21] We assume that inactive persons in the 55-64 age group receive transfer payments that are indexed to wages as described in equation (12). The reform reduces the share of the population entering this age group who need transfers from the government.

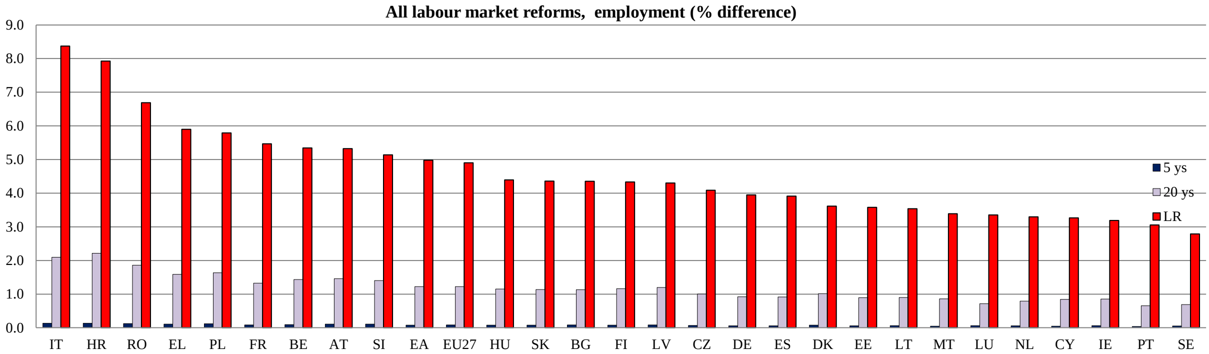
Overall, the GDP effects remain modest and are largest for countries performing relatively strongly in other indicators (Austria, Denmark, and Sweden). Moreover, when interpreting the results, it is important to note that our simulations only partially account for social insurance aspects of unemployment benefits. In this regard, McKay and Reis (2016) show that taking concerns for macroeconomic stabilisation and precautionary savings of workers into account raises the optimal replacement rate. In this sense, the GDP gains of reducing benefit replacement rates might be smaller than reported in Graph 3.

Graph 4. **Labour market reforms: GDP effects**



Note: See the notes below Graph 1 for additional information.

Graph 5. **Labour market reforms: Employment effects**



Note: For compactness, this graph summarises the employment gains for the three reforms (prime-age non-participation, elderly non-participation, and unemployment benefits). The relative performance across reforms aligns with the GDP results depicted in Graph 4. Countries are aggregated based on population weights. See the notes below Graph 1 for additional information.

4.5 R&D MEASURES

Research and development are the central engines of knowledge creation. In our endogenous growth model, companies invest in tangible and intangible assets, including research and development (R&D). Government policies can influence R&D investment through measures such as R&D (wage) subsidies, which reduce the costs of intangible assets and stimulate more R&D activities. R&D spurs patent creation, which can open up new product lines. The policy also involves reallocating high-skilled workers from production to research activities, which increases the demand for such workers. The magnitude of the output effect depends on the elasticity of the supply of high-skilled workers.

The economic response to R&D policies is inherently dynamic in the model. In the short term, the effects on GDP are minimal because of the reallocation of workers, and positive output effects become sizeable in the longer term once the R&D activities have been successfully transformed into marketable products. Countries with limited high-skilled labour and limited potential for substituting high-skilled for medium-skilled workers in production will experience a more significant crowding-out effect of R&D subsidies.

The simulated effects are relatively modest, which, however, reflects the small gaps across Member States.[22] Moreover, it is essential to note that the model only features public subsidies on private R&D, such as wage or tax incentives. Subsidies to R&D in public research institutes or universities could have different transmission channels and less of a crowding-out effect (Akcigit et al., 2021). This difference arises because business-financed R&D programmes focus on applied research, while public institutes and universities concentrate on basic research programmes that are too costly or less profitable for private R&D firms. At the same time, the long-term spillover effects of basic R&D across firms and countries could be larger.

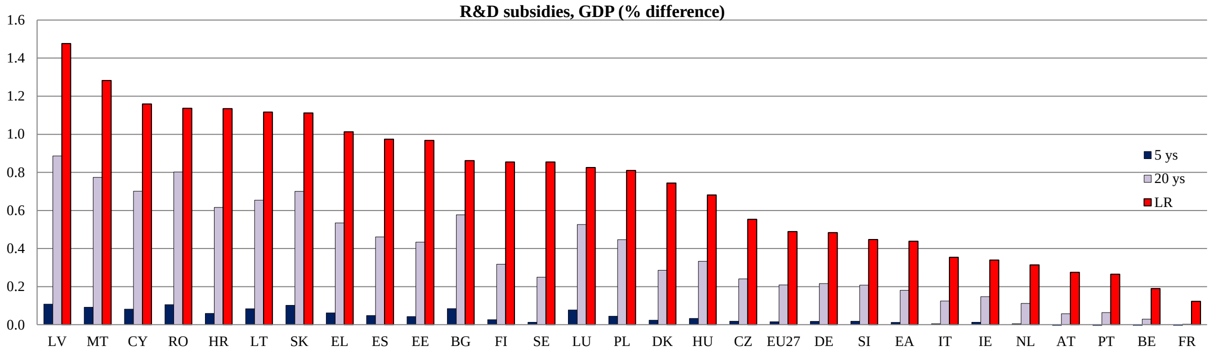
Assuming a broader measure of innovation than R&D subsidies could also result in a different ranking of the Member States. For example, the European Innovation Scoreboard (European Commission,

[22] Put differently, the direct cost impact on the government budget remains small in the simulations.

2023) ranks Denmark as the top innovator in the EU, while Sweden, Finland, the Netherlands, and Belgium are other highly innovative economies.[23]

Finally, we find relatively strong potential for R&D in small open economies (Latvia, Malta, and Cyprus, with the biggest GDP gains). However, given the size of these economies, domestic knowledge creation may play a smaller role in shaping available technological opportunities compared to patents invented by researchers abroad. Another way to interpret R&D activities in our model is as implicit technology adoption or imitation of foreign frontier innovations. Section 6 revisits the effects of R&D policies under alternative assumptions on R&D productivity (intertemporal spillover).

Graph 6. **R&D measures**



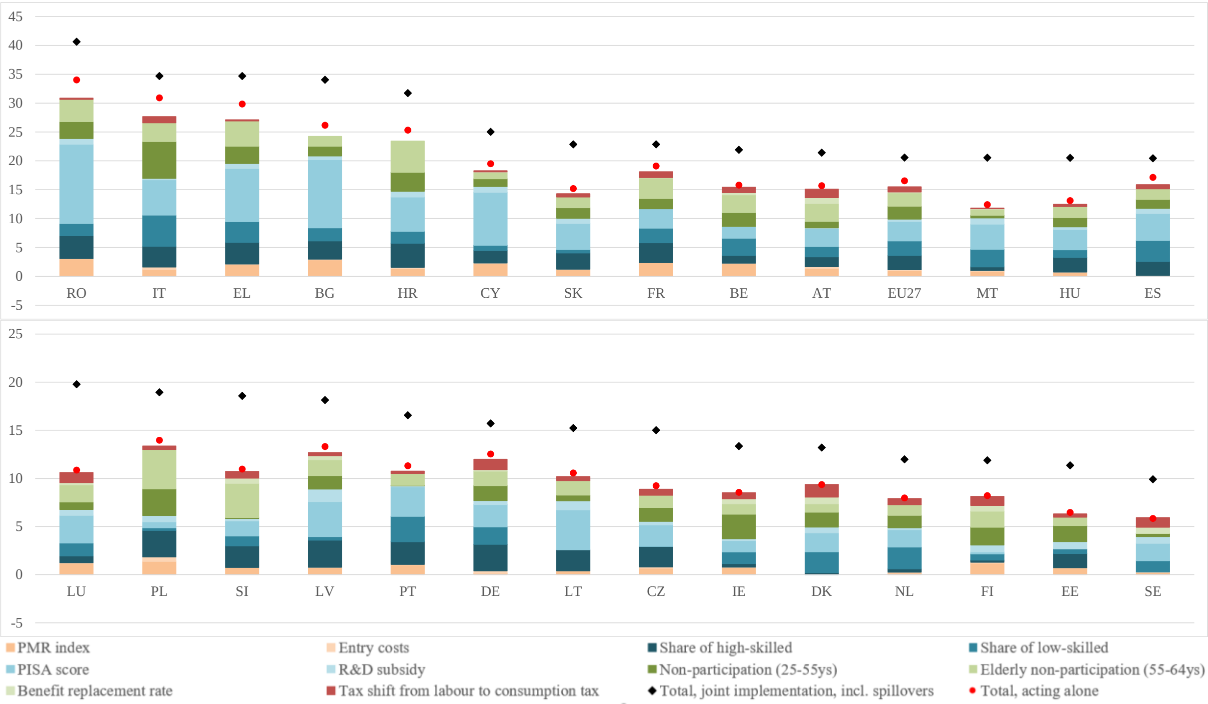
Note: See the notes below Graph 1 for additional information.

[23]The scoreboard assesses the innovation performance of European countries. See https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

4.6 SUMMARY: LONG RUN EFFECTS ACROSS REFORMS

Graph 7 summarises the long-run results of this section, with each colour bar depicting the GDP effects for different reform areas. It also shows spillovers and synergies, with the effects of joint implementation vs acting alone (see discussion in next section).

Graph 7. **Break down of long run effects (GDP %) across countries**



Note: Bars depict GDP effects per country. All graphs report the deviations from a no-policy change baseline. Black diamonds (red circles) refer to a simulation covering all reforms and countries simultaneously, while red report results obtained from simulations run one country at a time (all reforms), thereby ignoring spillover effects arising from joint reform implementation.

5. JOINT IMPLEMENTATION: EU-WIDE EFFECTS

5.1 SPILLOVER AND SYNERGY EFFECTS

The economies of the Member States are highly interconnected. The EU is a single market with the free movement of goods, services, capital, and people. Moreover, 20 Member States share a single currency. Economic developments and policies in one country can therefore have significant spillover effects on the economies of other countries. Moreover, there can be synergy effects across reform areas. Policymakers need to be aware of these effects and consider them when making economic policy decisions.

5.1.1 How large are cross-country spillover effects?

Broadly, the QUEST-RD model distinguishes four types of spillover effects in the EU (see Varga and in ‘t Veld, 2014). The first type is demand spillovers, where growth-enhancing reforms in one country can positively affect import and export flows with partner economies. The second type is competitiveness effects, where measures that reduce labour costs or product market regulation in one country can improve its competitiveness relative to its trading partners. The third type is international financial flows, where reforms that increase the rate of return on capital can lead to capital inflows and exchange rate changes that affect trade flows. The fourth type is knowledge spillovers, where the diffusion of innovations can positively affect the intangible capital formation and R&D. Demand and competitiveness effects are the most significant. Their counterbalancing nature often results in relatively small overall net macroeconomic effects.

Table 3 shows that including spillover effects and synergies increases the EU-wide long-run GDP effect by around one-fourth. Regarding the former, the long-run GDP gains reach 20.6% instead of 16.5% when countries act alone. Based on this calculation, spillover effects add around 4.0% of GDP in the long run. Across countries, simultaneous reforms can lead to larger demand spillovers, but joint competitiveness-improving reforms mitigate adverse effects across countries. With the different channels partly offsetting each other, the role of spillover remains smaller than for the coordinated investment stimulus considered in Pfeiffer et al. (2022). Overall, long-run gains from positive cross-country spillover are sizeable.

5.1.2 Synergies across reforms

Synergies across reform areas within a country are also relevant. For example, a more competitive and knowledge-intensive economy can benefit more from R&D-enhancing policies. Likewise, reforms that raise the share of high-skilled workers amplify the effectiveness of R&D-enhancing policies.

When we aggregate single reforms implemented one country at a time into a synthetic EU-wide effect, the long-run GDP effect amounts to 15.5% (Table 3), which is one percentage point lower than the joint implementation of all reforms in a single country (“Total, acting alone").

Table 3. **EU-wide effects (joint and simultaneous implementation of all reforms)**

Reform areas		E27	Target	GDP % relative to baseline				
				5 years	10 years	15 years	20 years	Long run
Market competition and regulation	PMR	1.29	1.05	0.4	0.6	0.7	0.7	1.0
	Entry costs	7.78	1.65	0.0	0.1	0.1	0.1	0.2
Taxation	Tax shift	1.89	0.84	0.4	0.6	0.6	0.7	0.9
Skills	Share of high-skilled	7.3	11.7	0.1	0.2	0.4	0.6	2.5
	Share of low-skilled	21.1	6.2	0.2	0.5	0.7	1.0	2.5
	PISA score	492.3	518.3	0.2	0.5	0.8	1.1	3.4
Labour market	Non-participation (25-54ys):	10.6	6.2	0.3	0.7	1.1	1.6	2.3
	Elderly non-participation (55-64ys):	9.4	4.7	0.3	0.7	1.2	1.7	2.3
	Benefit replacement rate	50.0	48.7	0.1	0.1	0.1	0.1	0.2
R&D measure	R&D subsidy	0.10	0.23	0.0	0.1	0.2	0.2	0.4
Total, single EU-wide reforms				*2.1*	*4.0*	*5.9*	*7.8*	*15.5*
Total, joint implementation, incl. spillovers				**2.1**	**4.1**	**6.2**	**8.5**	**20.6**
Total, acting alone				**2.1**	**4.0**	**6.0**	**8.0**	**16.5**
Spillovers				0.0	0.0	0.2	0.5	4.0

Note: GDP effects of EU-wide reforms. "Total, single EU-wide reforms" aggregates the effects across reforms without considering complementarities across reform areas. "Total, acting alone" aggregates simulations run one country at a time (all reforms), thereby ignoring spillover effects arising from joint reform implementation. "Total, joint implementation, incl. spillovers," reports a simulation covering all reforms and countries simultaneously, thereby capturing spillover effects and synergies across reforms and Member States. "Spillovers" is the difference between the "Total, joint implementation, incl. spillovers," and the "Total, acting alone" lines. Small rounding errors are possible.

5.2 REFORM DYNAMICS AND WIDER MACRO EFFECTS

This section discusses the dynamic impact of the different reform types on main macroeconomic variables, such as GDP, employment, private consumption, and debt ratios. Overall, the impact of reforms depends on the identified performance gaps and the relative contribution of different reforms changes over time.

Consider first the level of real GDP. In the short run, labour, tax, and product market reforms have the largest positive effects (Graph 8A). More significant output effects may be attainable in the short run with faster implementation, and product market reforms may have a higher impact if introduced faster than labour market reforms. In the long run (i.e., the new steady state), reforms targeting human capital are key to improving economic performance in the EU. While education and innovation reforms may not deliver significant growth effects in the short to medium run, they become sizeable once the labour force fully reflects improved skills and education. In our stylised simulations, closing half of this skill gap accounts for around half of the total EU-wide GDP gains induced by all reforms.

Employment gains are mainly driven by those reforms that boost labour force participation (Graph 8B). The reform shifting from low- to medium skills is also accompanied by positive employment effects due to a lower steady-state unemployment rate for medium-skilled workers. The tax shift lowers the tax burden on workers and contributes positively to employment. Employment is growing by only slightly less than output in the first twenty years, reflecting that most of the output gains over this period stem from higher labour inputs. But in the long run, employment increases by only about one-third of the total output gain as productivity effects from skill efficiency (PISA improvements) and higher R&D dominate.

The reforms also boost domestic demand. Participation and human capital reforms are central to growth in private consumption, while the reduction in entry costs and product market regulation spurs private investment (Graphs 8C and 8D). For both demand components, the spillovers are sizeable, with larger gains when acting all together (black line) compared to acting alone (red dashed line).

The stylised reforms have positive budgetary effects (Graph 8E). In the long run, a tax rule targets the baseline debt ratio, and the debt-to-GDP ratio (mechanically) returns to the baseline. But over the first two decades, this rule is "switched off". Abstracting from additional tax (or expenditure) changes is not realistic, but this approach provides a more transparent understanding of the debt implications. Importantly, by excluding these adjustments, the compounding (snowball) effects of lower interest payments on the outstanding debt come into play, leading to significant reductions in the debt-to-GDP ratios.

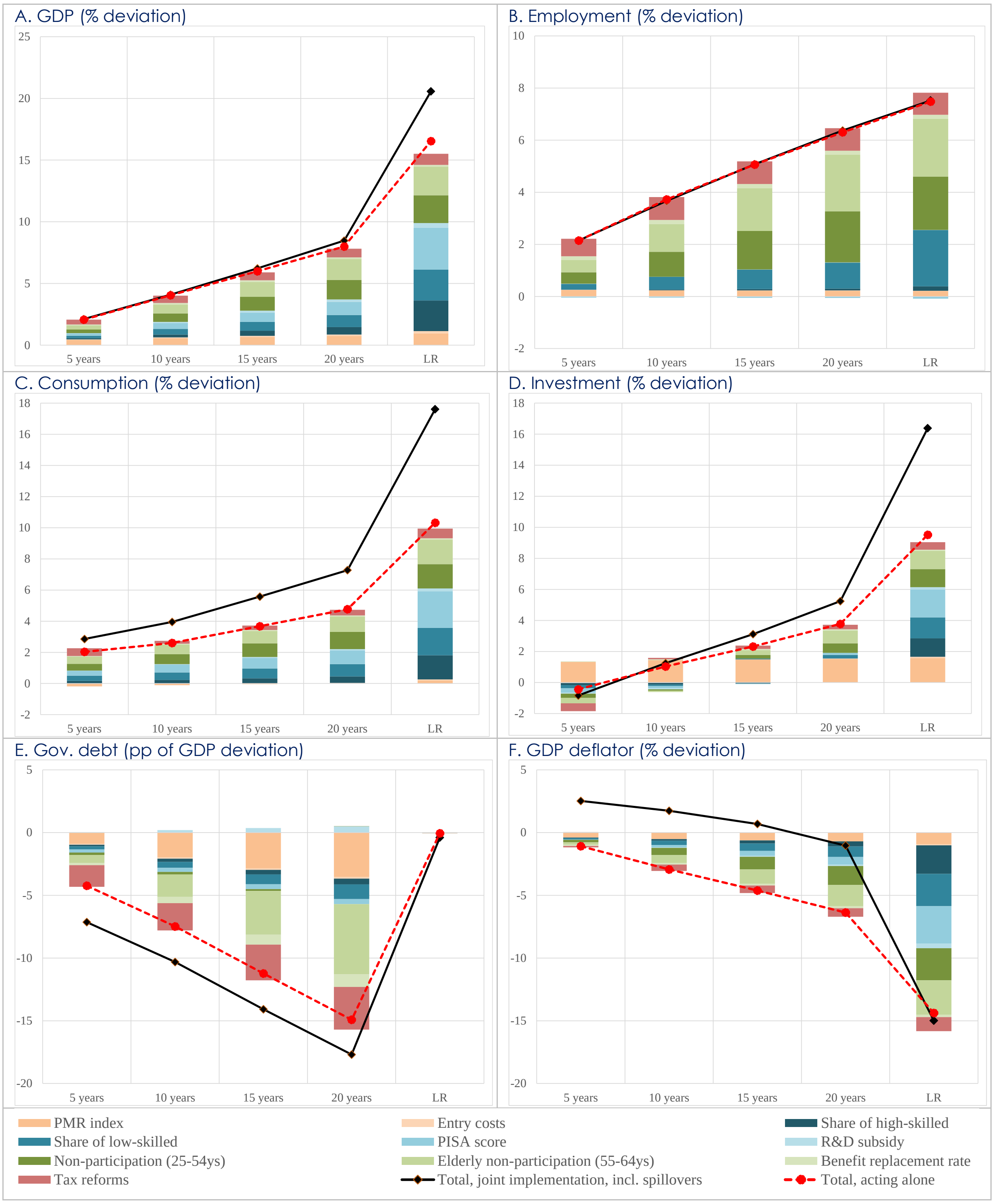
In addition, it should be noted that no "costing" of reforms has been included, while upskilling and education (PISA scores) reforms will require more spending. These costs are not captured here.[24] The tax reform is simulated as ex-ante revenue-neutral but the growth-inducing effects boost tax revenue and lower the debt ratios. The only reform for which our simulations include a direct budgetary impact is the increased participation of the 55-64 age group. This reform reduces transfer payments to early retired workers and has direct budgetary savings.

Overall, based on these stylised assumptions, the debt-to-GDP ratio falls by 15 pps after 20 years (and even more for some Member States – see Appendix B). However, it has to be emphasised that these

[24] We explored benchmarking educational spending on the best-performing countries but found educational attainment not proportional to spending. This indicates there could be important differences in the efficiency of spending, and we opted for excluding the costs completely. The outcomes for the debt ratios shown here should thus be seen as an extreme upper bound of likely improvements in indebtedness.

are upper bounds. Structural reforms are associated with costs, and these are not included in these simulations.

Graph 8. **Broader macro effects a joint implementation of all reforms across the EU**



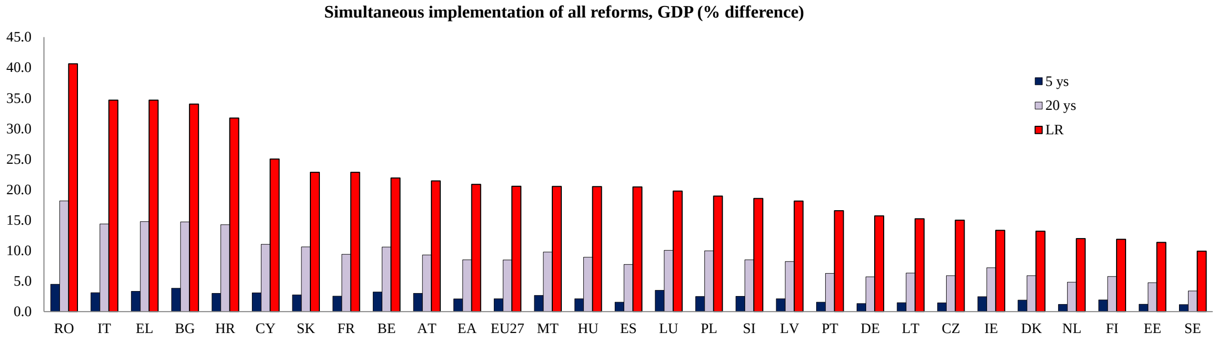
Note: These graphs show simulation results for the EU-27, aggregating the individual countries. Bars depict effects per reform (implemented EU-wide). All graphs report the deviations from a no-policy change baseline. The black line refers to a simulation covering all reforms and countries simultaneously, while red lines report results obtained from simulations run one country at a time (all reforms), thereby ignoring spillover effects arising from joint reform implementation.

The reforms improve competitiveness and lead to a reduction in the GDP price level over time (Graph 8F). Initially, there can be some inflationary effects as the productivity improvements are phased in gradually over a long time, and anticipatory effects boost demand, while supply-side improvements materialise later (by assumption). This is particularly strong in the full scenario with all countries acting together, when the competitiveness improving effects are partly cancelled out by similar reforms in other countries, but the demand boosting effects are stronger. In the long run, the price level falls significantly.

5.3 ADDRESSING ECONOMIC DISPARITIES

5.3.1 Effects for all Member States

Graph 9. **Joint implementation of all reforms across the EU, by Member State**



Note: This graph reports the level of real GDP in percent deviation from a no-policy change baseline. The simulations assume that all countries simultaneously close half of their respective gaps to the best three performing EU Member States. The results refer to a simulation covering all reforms and countries simultaneously.

Graph 9 summarises the distribution of GDP effects among the EU's Member States. The simulation results show that closing half of the gaps leads to the largest GDP gains in Romania, Bulgaria, Greece, and Italy, while Sweden, Finland, Estonia and the Netherlands witness the smallest increases. In line with the identified gaps, the potential GDP gains observed in the study could thus reduce income disparities in the EU. Compared to Southern European Member States, Central and Eastern European countries generally have a more favourable tax structure (with a higher share of indirect taxes) and higher participation rates. Therefore, they may benefit less from reforms in these areas. The catching up and the diffusion of technology can still lead to further convergence in GDP-per-capita terms.

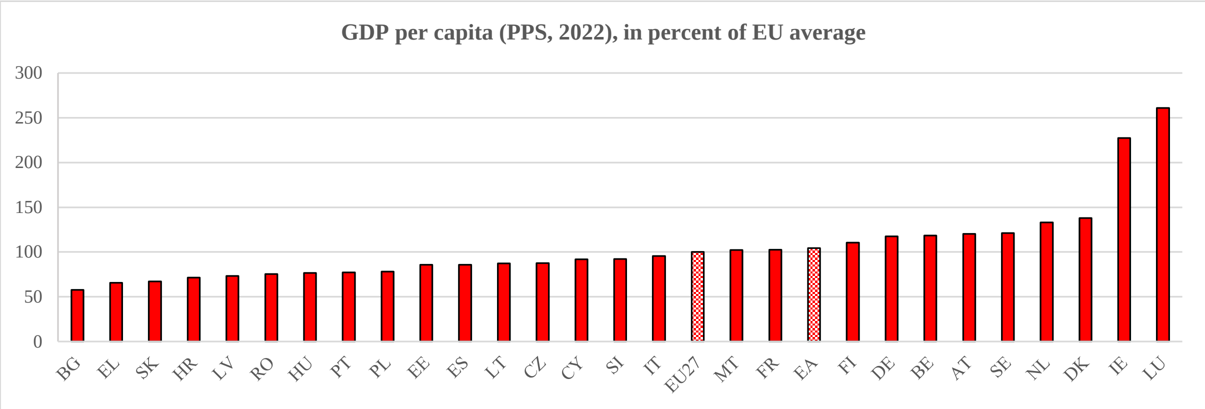
5.3.2 Further factors

Despite the significant GDP gains shown in Graph 9, considerable GDP per capita and productivity gaps would remain across the EU. Graph 10 shows GDP per capita dispersion across the EU MS measured in purchasing power standards (PPS). The GDP-per-capita differences are large, with Bulgaria's per-capita income in PPS reaching only around 58% of the EU average.

Overall, the economic performance across EU Member States results from a complex interplay of various factors, including those considered in our study above. In this sense, our simulations provide a ballpark estimate of the scope for economic reform in the EU. While closing half of the gaps improves real economic convergence, considerable differences in living standards remain. We now discuss some additional factors not explicitly included in the exercise.

First, we have focussed only on some dimensions of human capital, which could be defined more broadly. For example, Bloom and Van Reenen (2007) suggest that management practices explain a large share of cross-country differences in firm productivity. In addition, we have considered only one measure of educational quality (PISA scores), while differences in education levels and skills of the workforce matter more broadly than assumed here. Matching skills to the right jobs is equally important.[25]

Graph 10. **GDP per capita across the EU**



Note: This graph reports GDP per capita (measured in power purchasing standards) relative to EU average (EU27=100). All data refer to 2022. Source: AMECO.

Second, the (typically unobserved) quality of private and public capital affects economic performance. Countries with well-developed infrastructure, such as transportation, communication, and energy, tend to have higher productivity levels.[26] At the same time, the quality of a firm's capital stock is difficult to measure, including intangible capital, reputation, IT, and organisational structure. Within an economy, these quality differences can have spillover effects on the productivity levels of other firms, reinforcing these channels.

Third, larger markets tend to foster greater competition, which can lead to higher productivity levels. We capture this aspect using the PMR indicator and entry costs benchmarking. More generally, Member States that are more integrated with the global economy - through trade, investment, science, and society at large - may also experience higher potential GDP. Integration into the global economy is moreover linked to corporate tax competition. For example, Ireland and the Netherlands have benefited from their position as hubs for multinational companies and international trade.

Finally, many interrelated factors contribute to economic disparities in the EU. Without going into detail, this list includes historical and geographical factors, immigration, the attraction of global talent, property rights and the rule of law more broadly. At the same time, as mentioned above, catching up and spreading technology can continue to result in a convergence of GDP per capita.

[25] Varga and in 't Veld (2014) also consider employment protection legislation reforms as productivity-enhancing based on the results reported by Bassanini et al. (2009).

[26] Pfeiffer et al. (2022) analyse the role of public investment in the context of NextGenerationEU.

6. SENSITIVITY

To assess the robustness of the model predictions, this section considers alternative assumptions regarding technological change. Section 6.1 analyses the role of R&D spillover parameters, in particular, more pessimistic assumptions on R&D productivity. On the upside, Section 6.2 considers (a stylised variant) of directed technical change in the sense that firms adjust their production technology in line with the skill distribution.

6.1 IMPLICATIONS OF IDEAS GETTING HARDER TO FIND AND ADDITIVE GROWTH

Bloom et al. (2020) explore the idea that exponential growth in technology is becoming harder to achieve over time. According to the authors, evidence across different industries and aggregate data shows that more and more research effort (the effective number of researchers) is required to offset the declining research productivity trend.

In principle, our semi-endogenous growth framework in the model aligns with this notion, however, applying a different calibration. To see this, rewrite the idea production function (eq. 8) as:

$$\frac{\Delta A_t}{A_{t-1}} = \upsilon A_{t-1}^{-\beta^{RD}} (L_t^{RD})^{\lambda} - \delta^A, \tag{14}$$

where we have divided both sides by A_{t-1} and defined $\beta^{RD} = 1 - \phi > 0$.[27] For clarity, and in line with Bloom et al. (2020), we also omit the effects of the foreign knowledge stock. A higher β^{RD} implies that ideas are getting harder to find, or, more accurately, "Exponential Growth Getting Harder to Achieve?" (p. 1109), as the authors suggest as an alternative paper title.[28]

Finally, note that our setup includes knowledge depreciation, parametrised by δ^A. By contrast, the stylised model employed by Bloom et al. (2020) omits the obsolescence of knowledge.[29] As a result, innovation in their model results in permanent productivity increases. This conceptual difference withstanding, our robustness check follows the results of Bloom et al. (2020) and sets $\beta^{RD} = 3.1 \cdot \lambda$, implying a more pessimistic view of R&D productivity compared to our baseline.[30] We also exclude foreign spillovers ($\psi = 0$). Overall, this recalibration applies substantially more pessimistic assumptions on R&D productivity. Table 4 summarises these assumptions.

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[27] To ease comparison, our notation broadly follows Bloom et al. (2020), pp. 1134-1136.

[28] Characterising the balanced growth path shows that the long-run growth rate of productivity (g_A) is proportional to the rate of population research effort ($g_{L^{RD}}$): $g_A = \lambda g_{L^{RD}} / \beta^{RD}$. Thus, β^{RD} parametrises the difficulty of translating research effort into productivity growth, i.e., the extent to which ideas are getting harder to find. It also straightforward to see the implications of fully endogenous models ($\beta^{RD} = 0 \leftrightarrow \phi = 1$). In this case, the growth rate of productivity follows effective research effort $\Delta A_t / A_{t-1} = \upsilon (L_t^{RD})^{\lambda}$.

[29] Alston and Pardey (2022) also raise this point using examples from agriculture.

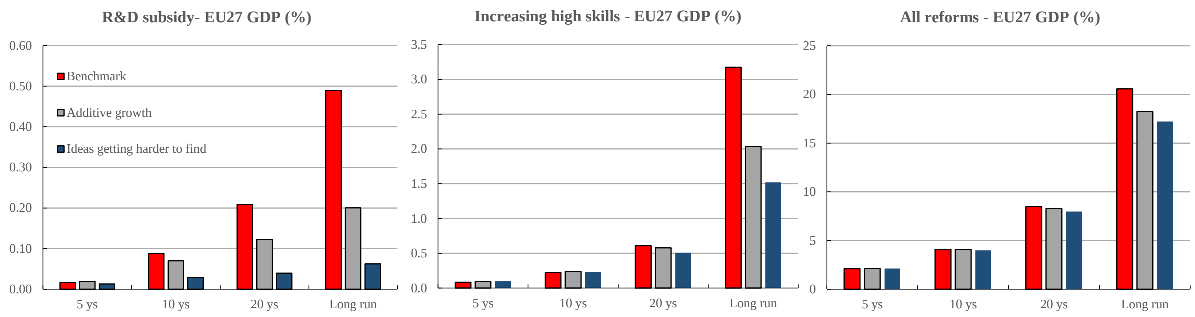
[30] Following Bloom et al. (2020), Appendix A, we scale the unadjusted dynamic diminishing returns by λ to account for the "stepping on toes"-effect, i.e., we scale their estimated unadjusted diminishing return parameter for the aggregate economy with the value of 3.1 (Table 7, p. 1134) by our country-specific λ parameters.

Table 4. **Semi-endogenous growth parameters across model variants (EU-27 values)**

	Implied β^{RD} (EU-27)	Foreign spillover included
Benchmark	0.56	yes
Ideas getting harder to find (Bloom et al. 2020)	1.8	no
Additive growth (Philippon, 2022)	1	no

Graph 11 demonstrates that this (re-)calibration significantly reduces the growth effects of R&D policies and increases in high-skilled workers. Compared to our benchmark, the differences for all reforms are also considerable, with long-run GDP gains several percentage points (of GDP) below the benchmark presented in Section 4. Because R&D spillover assumptions mainly affect the long run, the differences across simulations increase over time.

Graph 11. **Sensitivity I: Implications of ideas getting harder to find and additive growth**



Note: Benchmark (red bars) refers to the simulation results presented in Section 4 ($\phi = 0.44$ and $\psi = 0.54$ for the EU) based on Bottazzi and Peri (2007). "Ideas getting harder to find" (blue bars) considers the calibration with stronger diminishing returns ($\phi = -0.8$ for the EU) and no foreign spillover effects ($\psi = 0$) based on Bloom et al. (2020). "Additive growth" (grey bars) considers $\phi = \psi = 0$ (for the EU). All other simulation assumptions follow the benchmark.

Additive growth. Empirical evidence from Philippon (2022) supports the idea that increments in TFP growth are stable over long periods. While Bloom et al. (2020) and our semi-endogenous benchmark model also recognise departures from exponential growth, Philippon (2022) estimates a simple stochastic TFP process and finds $\beta^{RD} \approx 1$ (or $\phi \approx 0$), supporting the idea of linear, additive productivity growth.

In additional model simulations, we specifically consider this case (see Table 4). By excluding foreign spillover and setting $\beta^{RD} = 1$, equations (8) and (14) are modified as follows $\Delta A_t = \upsilon(L_t^{RD})^{\lambda} - \delta^A A_{t-1}$. In this "additive growth" variant, productivity increments (ΔA_t) become independent of the current level of TFP (except for the depreciation term): New patents contribute to the stock of knowledge, but they do not directly influence the next period's TFP growth.

Graph 11 (grey bars) illustrates that the additive growth model variant diminishes the GDP effects of knowledge-based policies. However, the differences from the benchmark model are less pronounced compared to the calibration suggested by Bloom et al. (2020).

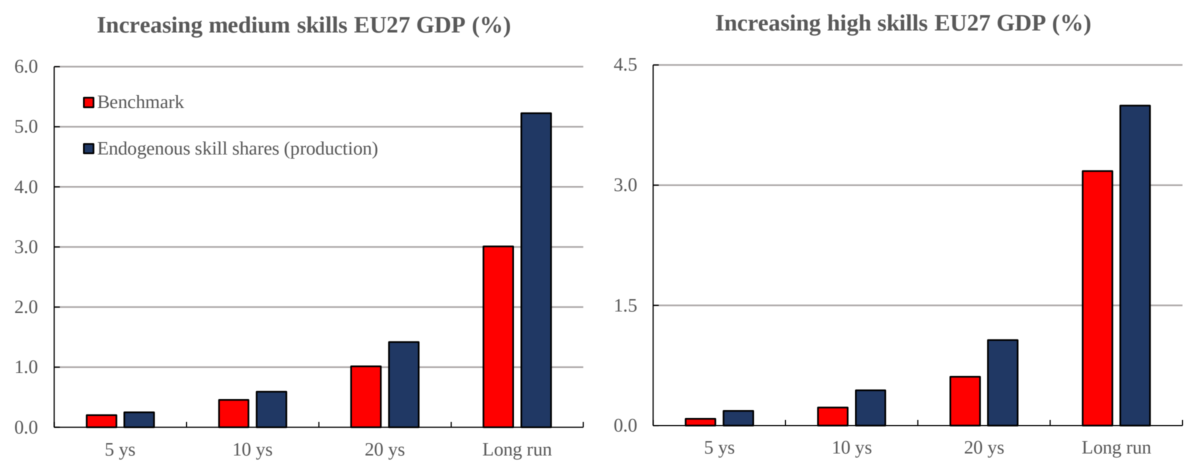
6.2 STYLISED DIRECTED TECHNICAL CHANGE: SKILL DEMAND AND SUPPLY

As discussed above, our baseline simulations assume that the production technology (eq. 6) remains constant despite changes in the relative supply of skills. However, the theory of directed technical change, developed by, e.g., the seminal work of Acemoglu (1998, 2002), suggests that investors and firms respond to changes in the economic environment, such as the share of high-skilled workers, by directing innovation activities accordingly.

We now present a simple alternative to capture this interaction between skills and production technology, leaving more micro-founded technology dynamics (e.g., based on expanding variety or task-based models) for future work. Recall that in our standard model, labour employed in the production of final goods is a CES aggregate with constant share parameters across skills. By contrast, this ad-hoc robustness check assumes the production shares of the different skills (Λ_t^z with $z \in \{L, M, HY\}$) are time-varying and respond directly (in each period) to changes in the relative skills supply, i.e. $\Lambda_t^z = \frac{pop_t^z}{pop_t}$:

$$L_{j,t}^Y = \left((\Lambda_t^L)^{\frac{1}{\mu}} \left(\chi^L L_{j,t}^L\right)^{\frac{1-\mu}{\mu}} + (\Lambda_t^M)^{\frac{1}{\mu}} \left(\chi^M \left(L_{j,t}^M - FC^L\right)\right)^{\frac{1-\mu}{\mu}} + (\Lambda_t^{HY})^{\frac{1}{\mu}} \left(\chi^{HY} L_{j,t}^{HY}\right)^{\frac{1-\mu}{\mu}} \right)^{\frac{\mu}{1-\mu}} \tag{15}$$

Graph 12. **Sensitivity II: Linked skill shares in final goods production**



Note: Benchmark refers to the main simulation results presented in Section 4, while "Endogenous skills shares (production)" considers the final goods production function based on eq. 15.

Based on this setup, we revisit the effects of increasing medium and high skills (Sections 4.3.1 and 4.3.2, respectively). Graph 12 shows that accounting for this stylised form of technology adoption leads to more significant gains from increasing skills compared to our benchmark simulations. If technology successfully adjusts, long-run GDP gains from closing the gap with respect to low-skilled shares could almost double. These results also suggest further substantial complementarity across reforms, such as R&D and education policies.

In experiments not reported here, we found that the assumptions on technology dynamics become even more critical for larger shocks and countries with large gaps to the best performers. For example, a full closure of the skill gap for countries with the lowest shares of high skills can even imply negative long-run output effects under the assumption of constant production technology.

7. CONCLUSION

This paper presents a quantitative analysis of the potential macroeconomic impact of structural reforms in the EU Member States. We use a benchmarking approach to compare countries based on structural indicators covering five policy areas: market competition and regulation, taxation, skills and education, labour markets, and research and development. Using a structural macroeconomic model, we simulate a closing of the gap, i.e., a gradual catch-up with the best-performing EU Member States.

The modelling results suggest that halving the gaps across all indicators could lead to significant gains in employment and output, raising EU GDP by more than 2% and 8% after five and twenty years, respectively, and 20% in the long run. In countries with significant scope for reforms, halving the gap across all indicators could yield potential GDP level gains exceeding 40%. We find synergies across reforms and countries and identify human capital as central to enhancing the EU's growth potential. While stylised, the simulations provide a roadmap to prioritise policy areas with the most significant potential for improvement relative to the performance of the other Member States. However, since economic disparities are multifaceted, the results should not be narrowly interpreted as if reforms should be limited to the areas identified in this analysis.

We conclude with a note of caution, acknowledging the stylised nature of our assumptions and simulations. While closing half of the gap to the best performers in our analysis implies significant reforms, particularly for some Member States, it is important to note that real-world reforms in practice tend to be less ambitious. Furthermore, by design, our simulations assume substantial improvements as measured by our structural indicators without specifying the precise details of the reforms. However, the actual impact is contingent upon various factors, including the reform design, associated costs, and the execution process. Thus, the potential impact of reforms may vary and could be smaller than our analysis suggests.

8. REFERENCES

Acemoglu, D. (1998). Why do new technologies complement skills? Directed technical change and wage inequality. *The Quarterly Journal of Economics*, *113*(4), 1055-1089.

Acemoglu, D. (2002). Technical change, inequality, and the labor market. *Journal of Economic Literature*, *40*(1), 7-72.

Acemoglu, D., and Autor, D., 2011. Skills, tasks and technologies: implications for employment and earnings. In: Card, D., Ashenfelter, O. (Eds.). In: Handbook of Labour Economics, 4B. North-Holland, Amsterdam, pp. 1043–1171

Alston, J. M. & Pardey, P. G., 2022. Are Ideas Really Getting Harder to Find? Staff Papers 320517, University of Minnesota, Department of Applied Economics.

Akcigit, U., Hanley, D., & Serrano-Velarde, N. (2021). Back to basics: Basic research spillovers, innovation policy, and growth. *The Review of Economic Studies*, *88*(1), 1-43.

Annichiarico B., F. Di Dio, & F. Felici (2013), Structural Reforms and the Potential Effects on the Italian Economy, *Journal of Policy Modeling*, 35(1), pp. 88-109.

Bargain, O., Orsini, K., Peichl, A., 2014. Comparing labor supply elasticities in Europe and the United States: New results. Journal of Human Resources 49, 723-838.

Barkbu, M. B., Rahman, J., & Valdes, M. R. O. (2012). *Fostering growth in Europe now*. International Monetary Fund, Staff Discussion Note, 12/07.

Bassanini, A., Nunziata, L., & Venn, D. (2009). Job protection legislation and productivity growth in OECD countries. *Economic Policy*, *24*(58), 349-402.

Bloom, N., & Van Reenen, J. (2007). Measuring and explaining management practices across firms and countries. *The Quarterly Journal of Economics*, *122*(4), 1351-1408.

Bloom, N., Jones, C. I., Van Reenen, J., & Webb, M. (2020). Are ideas getting harder to find? *American Economic Review*, *110*(4), 1104-1144.

Bottazzi, L., & Peri, G. (2007). The international dynamics of R&D and innovation in the long run and in the short run. *The Economic Journal*, *117*(518), 486-511.

Cacciatore, M., Duval, R., Fiori, G., & Ghironi, F. (2016). Short-term pain for long-term gain: Market deregulation and monetary policy in small open economies. *Journal of International Money and Finance*, *68*, 358-385.

Cacciatore, M., Duval, R., Fiori, G., & Ghironi, F. (2016b). Market reforms in the time of imbalance. *Journal of Economic Dynamics and Control*, *72*, 69-93.

Ciapanna, E., Mocetti, S., & Notarpietro, A. (2022). The macroeconomic effects of structural reforms: An empirical and model-based approach. *Economic Policy*.

Chetty, R. (2012). Bounds on Elasticities with Optimisation Frictions: A Synthesis of Micro and Macro Evidence on Labor Supply. *Econometrica* 80: 968-1018.

D'Andrea, S., D'Andrea S, Di Bartolomeo, G., D'Imperio, P., Infantino, G., & Meacci, M. (2023). Structural Reforms in the Italian National Recovery and Resilience Plan: A macroeconomic assessment of their potential effects, Luiss SEP, Working Paper 5/2023.

De Haan, J., & Wiese, R. (2022). The impact of product and labour market reform on growth: Evidence for OECD countries based on local projections. *Journal of Applied Econometrics*, *37*(4), 746-770.

Derek, A., Hunt, B. & Snudden, S., (2014), Fiscal consolidation in the euro area: How much pain can structural reforms ease? *Journal of Policy Modeling*, 36 (5), p. 785-799.

Duval, R., & Furceri, D. (2018). The effects of labor and product market reforms: The role of macroeconomic conditions and policies. *IMF Economic Review*, *66*, 31-69.

Égert, B., de la Maisonneuve, C., & Turner, D. (2022). A new macroeconomic measure of human capital exploiting PISA and PIAAC: Linking education policies to productivity. *OECD Economic Department Working Papers*, (1709), 1-31.

Égert, B., & Gal, P. (2018). The Quantification of Structural Reforms. *The Political Economy of Structural Reforms in Europe*, 132.

European Commission (2016), "The economic impact of selected structural reform measures in Italy, Spain, France and Portugal", *ECFIN Institutional paper 23*, April 2016.

European Commission (2021), "The 2021 Ageing Report: Economic and Budgetary Projections for the EU Member States (2019-2070)", *ECFIN Institutional paper 148*, April 2021.

European Commission (2023), "European Innovation Scoreboard 2023" Directorate-General for Research and Innovation.

Gerali, A., Notarpietro, A., & Pisani, M. (2016). Macroeconomic effects of simultaneous implementation of reforms. *International Finance*, *19*(1), 42-65.

Gersbach, H. (2004). Structural reforms and the macroeconomy: The role of general equilibrium effects (pp. 9-22) in Solow, R. (Ed.), *Structural Reform and Economic Policy*, Palgrave Macmillan UK.

Gomes, S., Jacquinot, P., Mohr, M., & Pisani, M. (2013). Structural Reforms and Macroeconomic Performance in the Euro Area Countries: A Model-Based Assessment. *International Finance*, *16*(1), 23-44.

Lusinyan L. & D. Muir (2013), Assessing the Macroeconomic Impact of Structural Reforms: The Case of Italy, IMF Working Paper No. 13/22.

Jones, C. I. (1995) "R&D-Based Models of Economic Growth" *Journal of Political Economy*, Vol. 103 (4), pp. 759-84.

Jones, C. I. (2005) "Growth and Ideas" in Philippe Aghion & Steven Durlauf eds. *Handbook of Economic Growth*, vol. 1, Part B, Amsterdam: North-Holland, pp. 1063-1111.

Jones, C. I. (2022). The past and future of economic growth: A semi-endogenous perspective. *Annual Review of Economics*, *14*, 125-152.

McKay, A., & Reis, R. (2016). The role of automatic stabilisers in the US business cycle. *Econometrica*, *84*(1): 141-194.

OECD (2023), Benefits in unemployment, share of previous income (indicator). Doi: 10.1787/0cc0d0e5-en.

Pessoa, A. (2005). "Ideas" driven growth: The OECD evidence. *Portuguese Economic Journal* 4, 46-67.

Pfeiffer, P., Varga, J., & in ‘t Veld, J. (2022). Quantifying spillovers of coordinated investment stimulus in the EU. *Macroeconomic Dynamics*: 1-23.

Philippon, T. (2022). *Additive Growth* (No. w29950). National Bureau of Economic Research.

Ratto, M., Roeger, W., & in ‘t Veld, J. (2009). QUEST III: An Estimated Open-Economy DSGE Model of the Euro Area with Fiscal and Monetary Policy. *Economic Modelling* 26: 222-233.

Roeger W., J. Varga & J. in ‘t Veld (2008), Structural reforms in the EU: a simulation-based analysis using the QUEST model with endogenous growth, *European Economy Economic Paper* no. 351. http://ec.europa.eu/economy_finance/publications/publication13531_en.pdf

Roeger W., J. Varga & J. in ‘t Veld (2009) , “Modelling the Lisbon Strategy: Analysing policies to promote knowledge investment with an endogenous growth model”, *Comparative Economic Studies*, 51: 520-39.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5, Part 2): 71-102.

Varga, J., Roeger, W., & in ’t Veld, J. (2014). Growth Effects of Structural Reforms in Southern Europe: The Case of Greece, Italy, Spain and Portugal. *Empirica* 41: 323-363.

Varga, J., & in ’t Veld, J. (2014). The Potential Growth Impact of Structural Reforms in the EU: A Benchmarking Exercise. European Economy Economic Papers, No. 541.

9. APPENDIX A: THE MODEL

This appendix provides a detailed description of the underlying model, i.e. without the simplifications introduced for the clarity of exposition and focus in the model description in the main text. The model economy is populated by households, final and intermediate goods producing firms, a research industry, a monetary authority, and a fiscal authority. Firms in the final goods sector produce differentiated goods, which are imperfect substitutes for goods produced abroad. Final goods producers use a composite of intermediate goods and three types of labour: low-, medium-, and high-skilled. Non-liquidity constrained households buy the patents of designs produced by the R&D sector and license them to the intermediate goods producing firms. The intermediate sector is composed of monopolistically competitive firms, which produce intermediate products from rented capital input, using the designs licensed from the household sector. The production of new designs takes place in research labs, employing high skilled labour and making use of the commonly available domestic and foreign stock of knowledge. Technological change is modelled as increasing product variety, following Jones (1995, 2005) semi-endogenous growth framework with endogenous R&D.

9.1 HOUSEHOLDS

The household sector consists of a continuum of household. A share $(1\text{-}\varepsilon)$ of these households is not liquidity constrained and indexed by $r \in [0,\ 1\text{-}\varepsilon]$. These households have access to financial markets, where they can buy and sell domestic assets (government bonds), accumulate physical capital, which they rent out to the intermediate sector, and they also buy the patents of designs produced by the R&D sector and license them to the intermediate goods producing firms. The remaining share ε of households is liquidity-constrained and indexed by $k \in (1\text{-}\varepsilon, 1]$. These households cannot trade in financial and physical assets and consume their disposable income each period ("hand-to-mouth"). For each skill group, indexed by s ($s \in \{L, M, H\}$), we assume that both types of households supply differentiated labour services to unions, which act as wage setters in monopolistically competitive labour markets. The skill shares are exogenous. The unions pool wage income and distribute it in equal proportions among their members. Nominal rigidity in wage setting is introduced via quadratic adjustment costs for changing wages.

9.1.1 Non liquidity-constrained households

Households that are not liquidity-constrained maximise an intertemporal utility function in consumption and leisure subject to a budget constraint. These households make decisions about consumption ($C_{r,t}$), and labour supply ($L^s_{r,t}$), the purchases of investment goods ($J^K_{r,t}$), government bonds ($B^G_{r,t}$) and bonds issued by other domestic and foreign households ($B_{r,t}$, $B^F_{r,t}$), the renting of the physical capital stock ($K_{r,t}$), the purchases of new patents from the R&D sector ($J^A_{r,t}$), and the licensing of existing patents ($A_{r,t}$). The households receive wage income (W^s_t), unemployment benefits (BEN^s_t), transfer income from the government ($TR_{r,t}$), interest income (i_t, i^G_t, i^F_t, i^K_t and i^A_t), and corporate profits from final, intermediate good and R&D producing firms denoted by $PR^Y_{r,t}$, $PR^X_{r,t}$ and $PR^A_{r,t}$. Hence, not liquidity-constrained households face the following Lagrangian over the sequences of $\Omega^r \equiv \{C_{r,t}, L^s_{r,t}, B_{r,t}, B^F_{r,t}, J^K_{r,t}, K_{r,t}, J^A_{r,t}, A_{r,t}\}_{t=0}^{\infty}$:

$$\max_{\Omega^r} \mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left(U(C_{r,t}) + \sum_{s \in \{L,M,H\}} POP^s_t V^s\left(1 - NP^s_{r,t} - L^s_{r,t}\right) \right)$$

$$-E_0\sum_{t=0}^{\infty}\lambda_{r.t}\frac{\beta^t}{P_t}\left(\begin{array}{c}(1+t_t^C)P_t^C C_{r,t}+B_{r,t}+B_{r,t}^G+e_tB_{r,t}^F+P_t^K\left(J_{r,t}^K+\Gamma^J\left(J_{r,t}^K\right)\right)+P_t^AJ_{r,t}^A\\ -(1+i_{t-1})B_{i,t-1}-\left(1+i_{t-1}^G\right)B_{r,t-1}^G-(1+i_{t-1}^F)e_tB_{r,t-1}^F\\ -\sum_{s\in\{L,M,H\}}POP_t^s\left((1-t_t^{w,s})W_t^sL_{r,t}^s+BEN_t^s\left(1-NP_{r,t}^s-L_{r,t}^s\right)\right)\\ -(1-t^K)(i_{t-1}^K-rp^K)P_{t-1}^KK_{r,t-1}-t^K\delta^KP_{t-1}^KK_{r,t-1}\\ -(1-t^K)(i_{t-1}^A-rp^A)P_{t-1}^AA_{r,t-1}-t^K\delta^AP_{t-1}^AA_{r,t-1}\\ +T_{r,t}-TR_{r,t}-PR_{r,t}^Y-PR_{r,t}^X-PR_{r,t}^A\end{array}\right)$$

$$-E_0\sum_{t=0}^{\infty}\lambda_{r,t}\xi_{r,t}\beta^t\left(K_{r,t}-J_{r,t}^K-(1-\delta^K)K_{r,t-1}\right)$$

$$-E_0\textstyle\sum_{t=0}^{\infty}\lambda_{r,t}\psi_{r,t}\beta^t\left(A_{r,t}-J_{r,t}^A-(1-\delta^A)A_{r,t-1}\right), \qquad \text{(A1)}$$

where s is the index for the corresponding low- (L), medium- (M) and high-skilled (H) labour type respectively ($s\in\{L,M,H\}$), and POP_t^s is the population share of skill group s. We assume that liquidity and non-liquidity households has the same skill group shares. The budget constraints are written in real terms with the price for consumption, investment and patents (P_t^C, P_t^K, P_t^A) and wages (W_t^s) divided by the GDP deflator (P_t) and e_t is the exchange rate as the price in domestic currency of one unit of foreign currency. All firms of the economy are owned by non liquidity-constrained households who share the total profit of the final and intermediate goods sector firms and the research sector, $PR_{r,t}^Y, PR_{r,t}^X$ and $PR_{r,t}^A$. As shown by the budget constraints, the households pay consumption taxes (t_t^C), wage income taxes ($t_t^{w,s}$), and capital income taxes (t^K) less depreciation allowances ($t^K\delta^K$ and $t^K\delta^A$) after their earnings on physical capital and patents, and other (lump-sum) taxes ($T_{r,t}$). When investing into tangible and intangible capital the household requires premia rp^K and rp^A in order to cover the risk on the return to these assets. $NP_{r,t}^s$ stands for the share of non-participants (inactives) and $1-NP_{r,t}^s-L_{r,t}^s$ is the ratio of unemployed per skill group. The non-participation rate is determined by institutional factors, such as retirement age, years of schooling, and availability of childcare infrastructure.

The utility function is additively separable in consumption and leisure. We assume log-utility for consumption and allow for habit persistence:

$$U\left(C_{r,t}\right)=(1-h^c)ln\left(C_{r,t}-h^c\bar{C}_{r,t-1}\right). \qquad \text{(A2)}$$

Preferences for leisure are given by:

$$V^s\left(1-NP_{r,t}^s-L_{r,t}^s\right)=\frac{\omega^s}{1-\kappa}(1-NP_{r,t}^s-L_{r,t}^s)^{1-\kappa} \qquad \text{(A3)}$$

with κ>0. The parameter κ is common across all three skill groups, but it needs to be multiplied by $\frac{1-NP^s-L^s}{L^s}$ to obtain the Frisch elasticity of labour supply, $\frac{1}{\kappa}\frac{1-NP^s-L^s}{L^s}$, which is skill-specific in light of skill-specific steady-state employment rates.

The parameter ω^s differs across the skill groups (s). In particular, ω^s needs to be skill-specific to reconcile the utility function with differences in skill-specific steady-state employment rates. The parameter ω^s also accounts for the different population shares of the three skill groups in order to scale the weight of skill-specific leisure in aggregate utility.

The investment decision w.r.t. real capital is subject to convex adjustment costs, which are given by:

$$\Gamma^J(J_{r,t}^K) = \frac{\gamma^K}{2}\frac{(J_{r,t}^K)^2}{K_{r,t-1}} + \frac{\gamma^I}{2}(\Delta J_{r,t}^K)^2 \ . \tag{A4}$$

The first-order conditions of the household with respect to consumption, financial and real assets are given by the following equations:

$$\frac{\partial \mathcal{L}_0}{\partial C_{r,t}} => U_{r,t}^C - \lambda_{r,t}(1+t^C)\frac{P_t^C}{P_t} = 0 \tag{A5a}$$

$$\frac{\partial \mathcal{L}_0}{\partial B_{r,t}} => -\lambda_{r,t} + E_t\left(\lambda_{r,t+1}\beta(1+i_t)\frac{P_t}{P_{t+1}}\right) = 0 \tag{A5b}$$

$$\frac{\partial \mathcal{L}_0}{\partial K_{r,t}} => E_t\left(\lambda_{r,t+1}\frac{\beta P_t^K}{P_{t+1}}\left((1-t^K)(i_t^K - rp^K) + t^K\delta^K\right)\right) - \lambda_{r,t}\xi_{r,t} + E_t\left(\lambda_{r,t+1}\xi_{r,t+1}\beta(1-\delta^K)\right) = 0 \tag{A5c}$$

$$\frac{\partial \mathcal{L}_0}{\partial J_{r,t}^K} => -\left(1 + \gamma^K\left(\frac{J_{r,t}^K}{K_{r,t-1}}\right) + \gamma_I \Delta J_{r,t}^K\right) + E_t\left(\frac{1}{1+i_t}\frac{P_{t+1}^K}{P_t^K}\gamma_I \Delta J_{r,t+1}^K\right) + \xi_{r,t}\frac{P_t}{P_t^K} = 0. \tag{A5d}$$

Not liquidity-constrained households buy new patents of designs produced by the R&D sector (J_t^A) and rent their total stock of designs (A_t) at rental rate i_t^A to intermediate goods producers in period t. Households pay income tax at rate t^K on the period return from intangibles. Hence, the first-order conditions with respect to R&D investments are given by:

$$\frac{\partial \mathcal{L}_0}{\partial A_{r,t}} => E_t\left(\lambda_{r,t+1}\frac{\beta P_t^A}{P_{t+1}}\left((1-t^K)(i_t^A - rp^A) + t^K\delta^A\right)\right) - \lambda_{r,t}\psi_{r,t} + E_t\left(\lambda_{r,t+1}\psi_{r,t+1}\beta(1-\delta^A)\right) = 0 \tag{A6a}$$

$$\frac{\partial \mathcal{L}_0}{\partial J_{r,t}^A} => -\frac{P_t^A}{P_t} + \psi_{r,t} = 0. \tag{A6b}$$

Therefore, the rental rate can be obtained from (A6a), (A6b) and (A5b):

$$i_t^A = E_t\left(\frac{i_t - \pi_{t+1}^A + (1-t^K)\delta^A}{1-t^K}\right) + rp^A \tag{A6c}$$

where $\pi_{t+1}^A \equiv \frac{P_{t+1}^A}{P_t^A} - 1$.

Equation (A6c) states that households require a rate of return on intangible capital, which is equal to the nominal interest rate minus the rate of change of the value of intangible assets and also covers the cost of economic depreciation plus a risk premium.[31]

9.1.2 Liquidity-constrained households

Liquidity-constrained households do not optimise intertemporally, but simply consume their current disposable income at each date. Real consumption of household k is, thus, determined by the net wage income plus benefits and net transfers:

$$(1+t_t^C)P_t^C C_{k,t} = \sum_{s\in\{L,M,H\}} POP_t^s\left((1-t_t^{w,s})W_t^s L_{k,t}^s + BEN_{s,t}(1 - NP_{k,t}^s - L_{k,t}^s)\right) + TR_{k,t} \ . \tag{A7}$$

[31] The risk premium is left out in equations (5) and (6) in the main text for simplicity and given that it is not essential for the scenarios analysed in the paper.

9.1.3 Wage setting

Within each skill group, a variety of labour services are supplied, which are imperfect substitutes to each other. A trade union maximises a joint utility function for each type of labour. It is assumed that types of labour, with their respective population weights ($pop_{s,t}$), are distributed equally over not liquidity-constrained ("Ricardian") and liquidity-constrained households. We also assume that trade unions can charge an (exogenous) wage mark-up ($1/\eta_t^s$) over the reservation wage. The reservation wage is given as the marginal utility of leisure (V^{1-L}) divided by the marginal utility of consumption (U^C), aggregated over Ricardian and liquidity-constrained households. The relevant net real wage, to which the mark-up adjusted reservation wage is equated, is the gross wage adjusted for labour taxes, consumption taxes, and unemployment benefits, which act as a subsidy to leisure. Thus, the wage equation is given as:

$$\frac{(1-\varepsilon)V^{1-L_{r,t}^S}+\varepsilon V^{1-L_{k,t}^S}}{(1-\varepsilon)U_t^{C,r}+\varepsilon U_t^{C,k}} = \frac{\frac{\vartheta^S-1}{\vartheta^S}(1-t_t^{w,S})W_t^S - BEN_t^S}{(1+t_t^C)P_t^C}$$
$$+\frac{\gamma^{w,s}}{\vartheta^s}(1+\pi_t^{w,s})\pi_t^{w,s} - \beta E_t\left(\frac{\bar{\lambda}_{t+1}}{\bar{\lambda}_t}\frac{\gamma^{w,s}}{\vartheta^s}(1+\pi_{t+1}^{w,s})\frac{L_{t+1}}{L_t}\left(sfw\pi_{t+1}^{w,s}+(1-sfw)\pi_{t-1}^{w,s}\right)\right) \tag{A8}$$

for $s \in \{L, M, H\}$ where $\pi_{t+1}^{w,s} \equiv \frac{W_{t+1}^s}{W_t^s} - 1$, ϑ^s is the elasticity of substitution between labour varieties within each skill-group and $\bar{\lambda}_t \equiv (1-\varepsilon)\lambda_{r,t} + \varepsilon\lambda_{l,t}$. We allow for wage stickiness by assuming that the fraction $(1-sfw)$ of workers ($0 \leq sfw \leq 1$) forms expectations of future wage growth on the basis of wage inflation in the previous period.

9.1.4 Aggregation

The aggregate of any household specific variable $X_{h,t}$ in per capita terms is given by:

$$X_t = \int_0^1 X_{h,t}dh = (1-\varepsilon)X_{r,t} + \varepsilon X_{k,t} \tag{A9}$$

Hence, aggregate consumption and employment are given by:

$$C_t = (1-\varepsilon)C_{r,t} + \varepsilon C_{k,t} \tag{A10}$$

and

$$L_{s,t} = (1-\varepsilon)L_{r,t}^s + \varepsilon L_{k,t}^s, \tag{A11}$$

for which we assume that both households have the same employment level for a given skill, i.e. $L_{r,t}^s = L_{k,t}^s$.

9.2 FIRMS

9.2.1 Final output producers

Each firm produces a variety of the final good ($Y_{j,t}$) that is an imperfect substitute for varieties produced by other firms. There are a continuum of varieties indexed by *j* over the unit interval. Aggregate final output Y_t is a CES aggregate of the varieties $Y_{j,t}$:

$$Y_t = \left(\int_0^1 \left(Y_{j,t}\right)^{\frac{\sigma_d - 1}{\sigma_d}} dj \right)^{\sigma_d/(\sigma_d - 1)} , \tag{A12}$$

where σ_d is the elasticity of substitution between varieties. Given the imperfect substitutability, firms are monopolistically competitive in the goods market and face a demand function for their output:

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\sigma_d} Y_t. \tag{A13}$$

Since each firm produces a variety of the domestic good, which is an imperfect substitute for the varieties produced by other firms, it acts as a monopolistic competitor facing a demand function with a price elasticity given by σ_d. Final output of firm j ($Y_{j,t}$) is produced using labour aggregate (L_t^Y) and A_t varieties of intermediate inputs ($x_{j,m,t}$) with an elasticity of substitution $\frac{1}{1-\theta} > 1$. The labour and intermediate good aggregate is combined with a Cobb-Douglas technology, subject to overhead labour, FC^L, and fixed costs, FC^Y:

$$Y_{j,t} = A_t^0 \left(L_{j,t}^Y - FC^L\right)^{\alpha} \left(\int_{m=0}^{A_t} \left(x_{j,m,t}\right)^{\theta} dm\right)^{\frac{(1-\alpha)}{\theta}} KG_t^{\alpha_G} - FC^Y \tag{A14}$$

where A_t^0 and KG_t denote economy-wide (exogenous) multi-factor productivity and public capital respectively. Labour is a CES aggregate of the three different skill types with:

$$L_{j,t}^Y = \left((\Lambda^L)^{\frac{1}{\mu}} \left(\chi^L L_{j,t}^L\right)^{\frac{\mu-1}{\mu}} + (\Lambda^M)^{\frac{1}{\mu}} \left(\chi^M L_{j,t}^M\right)^{\frac{\mu-1}{\mu}} + (\Lambda^{HY})^{\frac{1}{\mu}} \left(\chi^{HY} L_{j,t}^{HY}\right)^{\frac{1-\mu}{\mu}} \right)^{\frac{\mu}{\mu-1}} \tag{A15}$$

where $L_{j,t}^L$ $L_{j,t}^M$ and $L_{j,t}^{HY}$ denote the employment of low-, medium- and high-skilled workers in final goods production, respectively. Parameters Λ^z (with $z \in \{L, M, HY\}$) govern the corresponding production shares of the different skills, χ^z is the respective efficiency unit, and μ is the elasticity of substitution between different labour-skill types. Note that high-skilled workers can work in final goods production and the R&D sector as well. Therefore, the total number of high-skilled ($L_t^{H,total}$) should be equal to the number of high-skilled employed in the final goods (L_t^{HY}) and in the R&D sector (L_t^{RD}), respectively:

$$L_t^{H,total} = L_t^{HY} + L_t^{RD}. \tag{A16}$$

We account for the productivity-enhancing effects of infrastructure investment by including the public capital stock (KG_t) in the production function (A14).

An elasticity of substitution between low, medium, and high skills above unity in the labour CES function (A15) of final goods production implies stronger relocation effects between types of labour than a Cobb-Douglass function in response to changes in the relative wage. The CES function for labour by skill also determines the degree to which labour can be reallocated between the final goods production and the research sector (see A.2.3 below), since only high-skilled workers can work in both sectors. A higher elasticity of substitution between skills in the final goods production sector makes it easier to reallocate high-skilled labour between production and research. Fixed costs FC^Y define the minimum efficient scale of production in the final goods sector. These fixed costs are a standard feature of current macroeconomic models. See, for example, Smets and Wouters (2003), the ECBs Area-Wide Model (Christoffel et al., 2008), or the European Commission's QUEST model (Ratto et al., 2009) for the Euro Area, and Christiano et al. (2005) for the US. Fixed costs, FC^Y, are needed in order to reconcile relatively high mark-up estimates with low profit rates. For a discussion see, e.g., Hall (1988), or Rotemberg and Woodford (1999). Fixed costs in our model means that in order to produce a certain level of output for final demand, a fixed amount of the final output is used as input for production, i.e., the amount of production FC^Y cannot be used for final consumption or investment.

Overhead labour, FC^L, as the second type of fixed costs in final goods production relates to administrative and management work that is independent of the scale of production. Administrative and managerial work is medium-skilled according to our classification of skill groups.

The fixed costs in final goods production are important for our results. In particular, the effect of reforms on profits is driven by the fixed costs in final goods production. When the scale of production increases, fixed costs become relatively less important, and profits increase for a given steady-state price mark-up.

The final goods producer *j* is a monopolistic competitor that maximises profits $PR^Y_{j,t}$:

$$PR^Y_{j,t} = P^Y_{j,t} Y_{j,t} - (1 + ssc_t)(W^L_t L^L_{j,t} + W^M_t L^M_{j,t} + W^H_t L^{HY}_{j,t}) - A_t x_{j,t} P^x_t \quad \text{(A17)}$$

where ssc_t denotes the social security contributions.

In a symmetric equilibrium, the demand for labour and intermediate inputs is given by:

$$\eta_t P^Y_{j,t} \alpha \frac{Y_{j,t} + FC^Y}{L^Y_{j,t}} \left(\frac{L^Y_{j,t}}{L^z_{j,t}}\right)^{\frac{1}{\mu}} (\Lambda^z)^{\frac{1}{\mu}} (\chi^z)^{\frac{\mu-1}{\mu}} = W^z_t, \;\; z \in \{L, M, HY\} \quad \text{(A18a)}$$

$$\eta_t P^Y_{j,t} \alpha \frac{Y_{j,t} + FC^Y}{L^Y_{j,t}} \left(\frac{L^Y_{j,t}}{L^M_{j,t} - FC^L}\right)^{\frac{1}{\mu}} (\Lambda^M)^{\frac{1}{\mu}} (\chi^M)^{\frac{\mu-1}{\mu}} = W^M_t \quad \text{(A18b)}$$

$$P^x_{m,t} = \eta_t P^Y_{j,t} (1-\alpha)\left(Y_{j,t} + FC^Y\right) \left(\int_0^{A_t} \left(x^m_{j,t}\right)^{\theta} dm\right)^{-1} \left(x^m_{j,t}\right)^{\theta-1} \quad \text{(A18c)}$$

$$\eta_t = 1 - \frac{1}{\sigma_d} - \frac{\gamma_P}{\sigma_d}\left(\beta E_t \left(\frac{\lambda_{r,t+1}}{\lambda_{r,t}} \frac{Y_{j,t+1}}{Y_{j,t}} \pi_{j,t+1}\right) - \pi_{j,t}\right), \pi_{j,t} \equiv \frac{P^Y_{j,t+1}}{P^Y_{j,t}} - 1 \quad \text{(A18d)}$$

where $P^x_{m,t}$ is the price of intermediate goods and η_t is the Lagrange multiplier associated with the production technology.[32] Equation (A18d) defines the price mark-up factor as a function of the elasticity of substitution and price adjustment costs. Following the empirical literature, we allow for backward-looking elements in price setting by assuming that the fraction 1-sfp of firms indexes prices to past inflation, which leads to the specification:

$$\eta_t = 1 - \frac{1}{\sigma_d} - \frac{\gamma_P}{\sigma_d}\left(\beta E_t \left(\frac{\lambda_{r,t+1}}{\lambda_{r,t}} \frac{Y_{j,t+1}}{Y_{j,t}} (sfp E_t \pi_{j,t+1} + (1 - sfp)\pi_{j,t-1})\right) - \pi_{j,t}\right) \quad \text{(A18d')}$$

with $0 \leq sfp \leq 1$.

The elasticity of substitution between intermediates and labour in final goods production (A14) is one factor that determines the reallocation between capital and labour in case of a change in relative factor prices. Another factor affecting capital-labour substitution is the substitutability between workers of different skills in the final goods labour CES (A15) because blueprints for intermediates are produced

[32] Note that η is inversely related to the steady-state net mark-ups in the final goods sector (mup^Y): η=1/(1+ mup^Y).

with high-skilled labour (see A.2.3 below). If high-skilled workers are not easily substitutable in the final goods labour CES, this constrains the production of intermediates.

9.2.2 Intermediate goods producers

The intermediate sector consists of monopolistically competitive firms, which have entered the market by licensing a design from domestic households and by making an initial payment (FC^A) to overcome administrative entry barriers. Capital inputs are also rented from the household sector for a rental rate of i_t^K. Firms, which have acquired a design, can transform each unit of capital (K_t^m) into a single unit of an intermediate input ($K_{m,t} = x_{m,t}$) and maximise their profits:

$$PR_{m,t}^x = P_{m,t}^x x_{m,t} - i_t^K P_t^K K_{m,t} - i_t^A P_t^A. \tag{A19}$$

The intermediate goods producers set prices with a mark-up over marginal cost, so that intermediate goods prices are given by:

$$P_t^{m,x} = \frac{i_t^K P_t^K}{\theta}. \tag{A20}$$

The no-arbitrage condition requires that entry into the intermediate goods producing sector takes place until the present discounted value of profits ($DPR_t^{m,x}$) is equated to the monetised value of entry barriers:

$$DPR_t^{m,x} = FC^A, \text{ and } DPR_t^{m,x} = PR_t^{m,x} + d_t(1-\delta^A)DPR_{t+1}^{m,x} \tag{A21}$$

where d_t is the discount factor of the owner households.

9.2.3 R&D sector

Innovation corresponds to the discovery of a new variety of producer durables that provides an alternative way of producing the final good. The R&D sector hires high-skilled labour ($L_{RD,t}$) and generates new designs according to the following knowledge production function:

$$\Delta A_t = \upsilon A_{t-1}^{\phi}(A_{t-1}^*)^{\psi}(L_t^{RD})^{\lambda} - \delta^A A_{t-1}. \tag{A22}$$

In this framework, we allow for international R&D spillover, following Bottazzi and Peri (2007). The parameters ψ ($0 \leq \psi < 1$) and ϕ ($\phi < 1$) measure the foreign and domestic spillover effects from the aggregate international and domestic stock of knowledge (A_t^* and A_t), respectively. Negative value for these parameters can be interpreted as the "fishing out" effect, i.e., innovation decreases with the level of knowledge, while positive values refer to the "standing on shoulders" effect and imply positive research spillovers. Note that $\phi = 1$ would yield the strong scale effect feature of endogenous growth models with respect to the domestic level of knowledge. Parameter ν can be interpreted as total factor efficiency of R&D production, while λ measures the elasticity of R&D production on the number of researchers (L_t^{RD}). The domestic and foreign knowledge stocks grow at rate g_A along the balanced growth path. We assume that the R&D sector is operated by a research institute, which employs high skilled labour at its market wage, W_t^H. We also assume that the research institute faces an adjustment cost (γ^{LRD}) of hiring new employees and maximises the following discounted profit stream:

$$\max_{L_t^{RD}} E_0 \sum_{t=0}^{\infty} d_t \left[P_t^A \Delta A_t - (1 + ssc_t - s_t^{RD})W_t^H L_t^{RD} - \frac{\gamma^{LRD}}{2} W_t^H (\Delta L_t^{RD})^2\right] \tag{A23}$$

where d_t is the discount factor that corresponds to the stochastic discount factor of the owner households. High-skilled labour is paid the same wages across sectors: W_t^H and the research sector can receive a wage subsidy s_t^{RD}.

9.3 POLICY

On the expenditure side we distinguish between government consumption (G_t), government investment (IG_t), government transfers (TR_t) and unemployment benefits (BEN_t), where:

$$BEN_t = \sum_{s\in\{L,M,H\}} POP_t^s BENRR_t^s W_t^s (1 - NP_t^s - L_t^s) \tag{A24}$$

with $BENRR_t^s$ denoting the skill-specific benefit replacement rate.

Total nominal transfers consist of general social transfers and pension payments.

$$TR_t = \underbrace{\overline{trs}GDP_t^N}_{\text{Social transfers}} + \underbrace{\sum_{s\in\{L,M,H\}} PENSRR^s W_t^s NP_t^{55-64,s}}_{\text{Pension payments}} \tag{A25}$$

where the former is set as a constant share ($\overline{trs}$) of nominal GDP for simplicity. For pension payments, we focus on the age group 55-64 as their participation rate will be subject to the reforms considered below. Pension payments are indexed to the skill-specific wages with replacement rate $PENSRR^s$.

The government provides subsidies (SUB_t) on physical capital and R&D investments in the form of depreciation allowances and R&D wage subsidies:

$$SUB_t = t^K(\delta^K P_{t-1}^K K_{t-1} + \delta^A P_{t-1}^A A_{t-1}) + s_t^{RD} W_t^H L_t^{RD}. \tag{A26}$$

Government revenues, R_t^G, are made up of taxes on consumption and on labour and capital income, net of a depreciation allowance, i.e. $R_t^G \equiv P_t^C C_t + \sum_{s\in\{L,M,H\}} POP_t^s W_t^s L_t^s + t^K(i_{t-1}^K - rp^K)P_{t-1}^K K_{t-1} - t^K\delta^K P_{t-1}^K K_{t-1} + t^K(i_{t-1}^A - rp^A)P_{t-1}^A A_{t-1} - t^K\delta^A P_{t-1}^A A_{t-1}$. Government debt ($B_t$) evolves according to:

$$B_t = \left(1 + i_{t-1}^g\right)B_{t-1} + G_t + IG_t + TR_t + BEN_t + SUB_t - R_t^G, \tag{A27}$$

where $i_t^g = \left(1 - \rho^{ig}\right)i_{t-1}^g + \rho^{ig}\left(i_t + \psi_t^{rg}\right)$ accounts for a gradual pass-through of policy rates into effective government financing costs associated with the maturity structure of government debt. The implied average maturity on the outstanding public debt stock is $\frac{1}{\rho^{ig}}$. The debt-elastic endogenous risk premium on the newly issued government debt is given by $\psi_t^{rg} = \bar{\psi}^{rg}\left(\frac{B_{t-1}}{Y_{t-1}} - b^T\right)$. b^T denotes the government debt target.

Lump-sum taxes (T_t) control the debt-to-GDP ratio according to the following rule:

$$\Delta T_t = dum_t\left[\tau^B\left(\frac{B_{t-1}}{Y_{t-1}} - b^T\right) + \tau^{DEF}\Delta\left(\frac{B_t}{Y_t}\right)\right] \tag{A28}$$

where τ^B captures the sensitivity with respect to deviations from the government debt target, and τ^{DEF} controls the sensitivity of the tax rule w.r.t. changes in the debt-to-output ratio. dum_t is an exogenous switch (set to either 0 or 1) that allows to temporarily turn off the lump-sum tax stabilisation.

Monetary policy sets the nominal risk-free interest rate (i_t) according to the following Taylor rule:

$$i_t = \gamma^{ilag} i_{t-1} + (1-\gamma^{ilag})\left(r^{EQ} + \pi^{TAR} + \gamma^{inf}(\pi_t^C - \pi^{TAR}) + \gamma^{ygap}\hat{y}_t\right). \tag{A29}$$

The central bank has a constant inflation target (π_{TAR}), and it adjusts interest rates whenever actual consumer price inflation ($\pi_t^C \equiv P_t^C / P_{t-1}^C - 1$) deviates from the target, and it also responds to the output gap($\hat{y}_t$), via the corresponding γ^{inf} and γ^{ygap} coefficients. The monetary policy rule includes inertia in nominal interest rate adjustment, determined by γ^{ilag}. The output gap is defined as deviation of capital and labour utilisation from their long-run trends.

9.4 TRADE LINKAGES

In order to facilitate aggregation, we assume that households, the government and the final goods sector have identical preferences across goods used for private consumption, investment and public expenditure. Let $Z_t \in \{C_t, I_t, G_t, IG_t\}$ be the demand of households, investors or the government as defined in the previous section, then their preferences are given by the following utility function:

$$Z_t = \left((1-s_m)^{1/\sigma_x}(Z_t^D)^{(\sigma_x-1)/\sigma_x} + s_m{}^{1/\sigma_x}(Z_t^M)^{(\sigma_x-1)/\sigma_x}\right)^{\sigma_x/(\sigma_x-1)} \tag{A30}$$

where s_m is the share parameter (steady-state trade openness) and σ_x is the elasticity of substitution between domestic (Z_t^D) and imported goods (Z_t^M).

Total imports (M_t) are a CES bundle of bilateral imports from foreign regions *f*:

$$M_t = \left(\sum_f (s^f)^{\frac{1}{\sigma_1}} M_t^{f\,\frac{\sigma_1-1}{\sigma_1}}\right)^{\frac{\sigma_1}{\sigma_1-1}} \tag{A31}$$

where σ_1 is the elasticity of substitution between imports of different origins (M_t^f), s^f is the steady-state share of region *f* in the domestic economy's imports.

Aggregate international stock of knowledge (A_t^*) is the weighted average of the trading partner's knowledge stock where the weights are the steady-state share of region *f* in the domestic economy's import (s^f) as in equation A31 above:

$$A_t^* = \sum_f s^f relsize^f A_t^f \tag{A32}$$

where A_t^f is the level of knowledge stock in the trading partner country denoted by f , and $relsize^f$ is its relative size compared to the country's size, expressed as the ratio of steady-state GDP.

9.5 CALIBRATION

We calibrate our model in a multicountry setting for all 27 EU Member States and the rest of the world in fully-fledged model blocks. We select behavioural and technological parameters in order to replicate important empirical ratios, such as labour productivity, investment, consumption to GDP ratios, the wage share, the employment rate, and the R&D share, given a set of structural indicators describing market frictions in goods and labour markets, tax wedges, and skill endowments.

9.5.1 Goods market

We identify the intermediate sector as the manufacturing sector (mostly R&D-intensive subsectors of manufacturing), and the final goods sector as the aggregate of all remaining market sectors. The manufacturing sector resembles the intermediate sector along various dimensions. First, this sector is more R&D- and patent-intensive. Second, a large fraction of the manufacturing sector supplies innovative goods (in the form of investment goods, but also innovative consumer goods). Final goods sectors, including services, on the other hand, are typically not subject to large (patented) innovations, but rely on organisational changes possibly in relation to new technologies supplied by the investment goods' sector. The two sectors also differ in the degree of competition, with manufacturing showing smaller mark ups compared to final goods sectors. To calibrate our mark-ups, we calculate profit rates using National Accounts data and a Jorgensonian definition of the user cost of capital, which incorporates interest rates, depreciation rates, and investment price changes, and is further adjusted for implicit tax rates. Based on the most recent EU KLEMS data, we found that the average mark-up for final goods in the EU is 12%. The country-specific mark-ups are calculated as follows. We calculate an aggregate PMR index for the EU (PMR_{EU}) as the GDP-weighted average of the 2018 PMR indices (OECD PMR database, 2018 overall indicator):

$$PMR_{EU} = \sum\nolimits_{co \in EU} PMR_{co} GDP_{co} / GDP_{EU}$$

Using the estimated aggregate mark-ups, τ_{EU} for the EU (DG ECFIN estimates) we calibrate the country-specific mark-ups proportional to ratio of the country's PMR index to the aggregate EU PMR index:

$$\tau_{co} = \tau_{EU} \frac{PMR_{co}}{PMR_{EU}}.$$

We use the starting business costs expressed in terms of income per capita from the World Bank's Doing business database to calibrate the entry costs (FCA) in the intermediate sector (www.doingbusiness.org). We calibrate the corresponding variable based on the 2019 data series.

9.5.2 Knowledge production technology

Empirical evidence on the output elasticities of knowledge production w.r.t. patent and skilled labour inputs has been provided by Bottazzi and Peri (2007), and Pessoa (2005). The growth rate of ideas was obtained from Pessoa (2005) with the assumption of a 5% obsolescence rate. In our model, the R&D elasticity w.r.t. research labour (λ) is determined by the wage-cost share in the total R&D spending. We rely on Bottazzi and Peri (2007) to calibrate the knowledge elasticity parameters w.r.t. domestic and foreign knowledge capital. The authors estimate the ratios of $\lambda/(1-\phi)$ and $\psi/(1-\phi)$ that helps to pin down the value of ψ for the calibrated λ parameters above. We rely on their regression specification without the US (column V, Table 4). Finally, these values together with the long-run growth rate of intangible capital (g_A) and population growth (n) determine the remaining ϕ elasticities using the semi-endogenous growth formula of $g_A = \frac{\lambda n}{1-\psi-\phi}$. The initial stock of domestic knowledge is calibrated from the countries' R&D expenditure as a percentage of GDP using the perpetual inventory method, $A_t = \frac{R\&D}{g_A+\delta_A}$, and A_t^* is derived from equation (A32).

9.5.3 Labour market and the skill composition of the labour force

We rely on Ratto et al. (2009) to calibrate the adjustment cost parameters of the labour market. The labour force is disaggregated into three skill-groups: low-, medium- and high-skilled labour. We define high-skilled workers as the segment of the labour force that can potentially be employed in the R&D sector, i.e. engineers and natural scientists. Our definition of low-skilled corresponds to the standard classification of ISCED 0-2 education levels. The rest of the labour force is considered to be medium-skilled. Data on skill-specific population shares, participation rates and wages are obtained from the Labour Force Survey, Structure of Earnings Survey, and the Science and Technology databases of Eurostat. The elasticity of substitution between different labour types (μ) is one of the major parameters addressed in the labour-economics literature. We rely on Acemoglu and Autor (2011) which updated the seminal reference for this elasticity parameter by Katz and Murphy (1992). Acemoglu and Autor (2011) argues for estimates in the range of 1.6-1.8 on the extended data sample, therefore, we take 1.7 as our baseline value. Concerning the elasticity of labour supply, the simulations use a total average Frisch elasticity of 0.25 as the benchmark, as suggested by Chetty et al. (2011) for the extensive margin. The corresponding Frisch elasticity values for low-skilled, medium-skilled, and high-skilled labour decline with the skill level in our model, in line, e.g., with the findings in Bargain et al. (2014). We obtained benefit and pension replacement rates from the OECD's Benefits and Wages Statistics database, and from the European Commission's Ageing Report (European Commission, 2021), respectively.

9.5.4 Fiscal, monetary and trade variables

We use Eurostat data for the breakdown of government spending into consumption, investment, and transfers, and we use effective tax rates on labour, capital and consumption to determine government revenues. The baseline government consumption and debt-to-GDP ratios reflect their average ratios observed over the last 5 years. As for government investments, we use the average over the last 20 years because public investments financed from the EU Cohesion Funds can distort current public-investment spending data over several years during their programming period. The monetary policy parameters are adopted from Ratto et al. (2009). Trade openness and bilateral trade shares match data from the FIGARO database (Remond-Tiedrez and Rueda-Cantuche, 2019). The price elasticity of trade corresponds to the estimate in Ratto et al. (2009).

Country-specific macroeconomic variables that characterise the steady state of the model are calibrated on the basis of national accounts, fiscal data, and trade data from Eurostat. Behavioural parameters that govern the dynamic adjustment to shocks are based on earlier estimates of version of the QUEST model (see Burgert et. al. 2020 for detailed list of parameter calibration). Table A.1 below summarises the common parameter values that are used across all regions. Table 1 in the main text presents the set of structural indicators for all EU Member States that we include in our model: demographic indicators (e.g. skill shares, participation rates), fiscal data (e.g. tax rates and unemployment benefits), and constructed indicators (product market regulation (henceforth, PMR), PISA). The table notes provide further details on the data sources. Finally, Table A.2. presents the parametrisation of the R&D block in our model.

Table A.1. Model parameters – common values across all regions

Parameter	Value	Description
β	0.997	Discount factor Ricardian households
h^c	0.7	Habit persistence in consumption
$1/\kappa$	0.25	Average labour supply elasticity
γ_L	25	Head-count adjustment costs parameter
γ_P	20	Price adjustment costs parameter
γ_K	20	Capital adjustment cost
γ^w	120	Wage adjustment cost
sfp	0.9	Share of forward-looking price setters
sfw	0.9	Share of forward-looking wage setters
σ_x	1.2	Elasticity of substitution in total trade
σ_1	0.99	Elasticity of substitution between import sources
α	0.6	Cobb-Douglas labour parameter
α^G	0.12	Cobb-Douglas public capital stock parameter
ϑ^s	6	Elasticity of substitution between labour varieties within skill-groups
μ	1.7	Elasticity of substitution between labour skills
δ^K	0.015	Depreciation rate tangible capital stock
δ^A	0.013	Depreciation rate intangible capital stock
δ^G	0.013	Depreciation rate public capital stock
τ^B	0.01	Tax rule parameter on debt
τ^{DEF}	0.1	Tax rule parameter on deficit
ρ^{ig}	0.0312	Debt maturity parameter
$\bar{\psi}^{rg}$	0.0075	Risk premium parameter on debt
γ^{ilag}	0.82	Interest-rate smoothing in Taylor rule (standard times)
γ^{inf}	1.5	Reaction to inflation in Taylor rule
γ^{ygap}	0.05	Reaction to output gap in Taylor rule

Table A.2. **Model parameters – parameters of the R&D block**

Country	R&D labour in % of total employment	R&D % GDP	λ	ϕ	ψ
AT	2.06	3.57	0.55	0.47	0.50
BE	2.13	3.51	0.62	0.41	0.56
BG	0.55	0.94	0.75	0.28	0.69
CY	0.46	0.83	0.58	0.45	0.53
CZ	1.31	2.13	0.59	0.43	0.54
DE	2.14	3.51	0.68	0.35	0.62
DK	1.89	3.41	0.46	0.56	0.42
EE	1.06	1.88	0.50	0.52	0.45
EL	0.82	1.51	0.59	0.43	0.54
ES	0.84	1.39	0.54	0.48	0.49
FI	1.83	3.21	0.47	0.55	0.43
FR	1.42	2.54	0.56	0.46	0.51
HR	0.67	1.31	0.55	0.47	0.51
HU	0.93	1.76	0.53	0.49	0.49
IE	0.86	1.32	0.53	0.49	0.48
IT	0.96	1.67	0.53	0.49	0.49
LT	0.67	1.10	0.58	0.45	0.53
LU	0.79	1.32	0.61	0.41	0.56
LV	0.42	0.73	0.59	0.44	0.54
MT	0.38	0.63	0.47	0.55	0.43
NL	1.45	2.45	0.59	0.44	0.53
PL	0.86	1.51	0.59	0.43	0.54
PT	0.90	1.63	0.66	0.37	0.60
RO	0.33	0.53	0.76	0.27	0.70
SE	2.03	4.25	0.37	0.65	0.34
SI	1.34	2.34	0.65	0.38	0.60
SK	0.56	0.93	0.58	0.44	0.53

Note: Two-letter country codes follow EU conventions.
(https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Country_codes)

Additional references:

Acemoglu, D., and Autor, D., 2011. Skills, tasks and technologies: implications for employment and earnings. In: Card, D., Ashenfelter, O. (Eds.). In: Handbook of Labour Economics, 4B. North-Holland, Amsterdam, pp. 1043–1171

Bargain, O., Orsini, K., Peichl, A., 2014. Comparing labor supply elasticities in Europe and the United States: New results. Journal of Human Resources 49, 723-838.

Bottazzi, L., and Peri, G., 2007. The international dynamics of R&D and innovation in the long run and in the short run. Econ. J. 117, 486–511.

Burgert, M., Roeger, W., Varga J, in ‘t Veld J., and Vogel L. (2020). A Global Economy Version of QUEST: Simulation Properties. European Economy Discussion Papers, No. 126.

Canton, E., and Thum-Thysen, A., 2015. Estimation of service sector mark-ups determined by structural reform indicators. European Economy Economic Papers 547.

Chetty, R. (2012). Bounds on Elasticities with Optimisation Frictions: A Synthesis of Micro and Macro Evidence on Labor Supply. Econometrica 80: 968-1018.

Christiano, L., Eichenbaum, M., Evans, C., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. J. Polit. Econ. 113, 1–45.

Christoffel, K., Coenen, G., Warne, A., 2008. The New Area-Wide Model of the euro area: a micro-founded open-economy model for forecasting and policy analysis. ECB Working Papers 944

Hall, R., 1988. The relation between price and marginal cost in U.S. industry. J. Polit. Econ. 96, 921–947.

Jones, C. I. (1995) “R&D-Based Models of Economic Growth” Journal of Political Economy, Vol. 103 (4), pp. 759-84.

Jones, C. I. (2005) “Growth and Ideas” in Philippe Aghion & Steven Durlauf eds. Handbook of Economic Growth, vol. 1, Part B, Amsterdam: North-Holland, pp. 1063-1111.

Katz, L., Murphy, K., 1992. Changes in relative wages, 1963-1987: Supply and demand factors. Q. J. Econ. 107, 35–78.

OECD (2022). OECD 2018 PMR database. https://www.oecd.org/economy/reform/indicators-of-product-market-regulation/

OECD (2019), PISA 2018 Results (Volume I): What Students Know and Can Do, PISA, OECD Publishing, Paris, https://pisadataexplorer.oecd.org/ide/idepisa/).

Pessoa, A., 2005. "Ideas" driven growth: The OECD evidence. Portuguese Economic Journal 4, 46-67.

Ratto, M., Roeger, W., & in ’t Veld, J. (2009). QUEST III: An Estimated Open-Economy DSGE Model of the Euro Area with Fiscal and Monetary Policy. Economic Modelling 26: 222-233.

Remond-Tiedrez I., and Rueda-Cantuche, J. M. (eds.) 2019. EU inter-country supply, use and input-output tables - Full international and global accounts for research in input-output analysis (FIGARO). Eurostat and the Joint Research Center – JRC (https://ec.europa.eu/eurostat/web/products-statistical-working-papers/-/ks-tc-19-002)

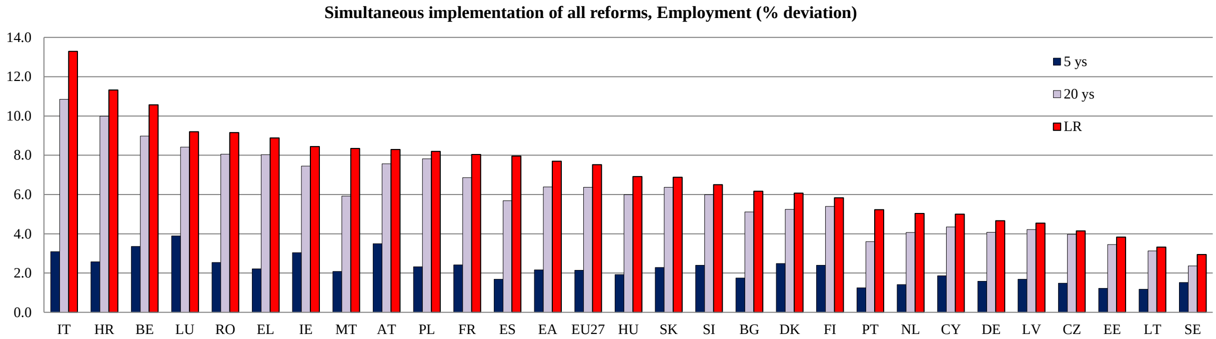
Roeger, W., 1995. Can imperfect competition explain the difference between primal and dual productivity? Journal of Political Economy 103, 316-330.

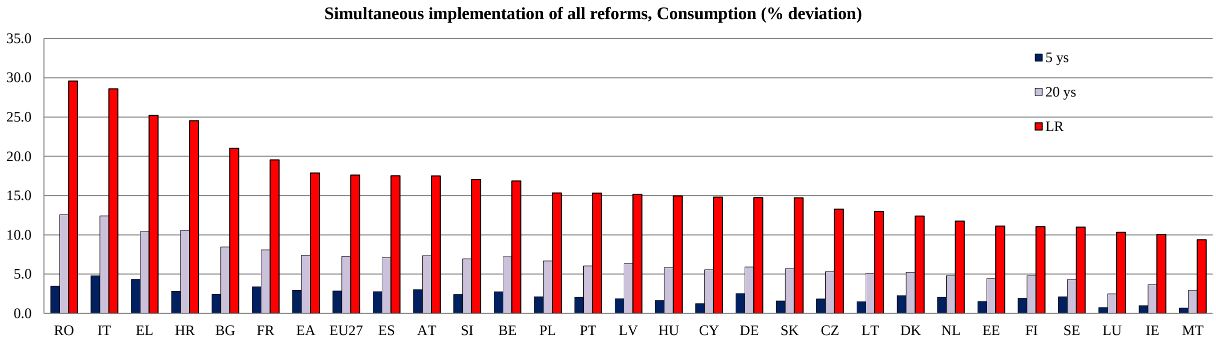
Rotemberg, J., Woodford, M., 1999. The cyclical behavior of prices and costs. In: Woodford, M., Taylor, J. (Eds.). In: Handbook of Macroeconomics, 1A. North-Holland, Amsterdam, pp. 1051–1135.

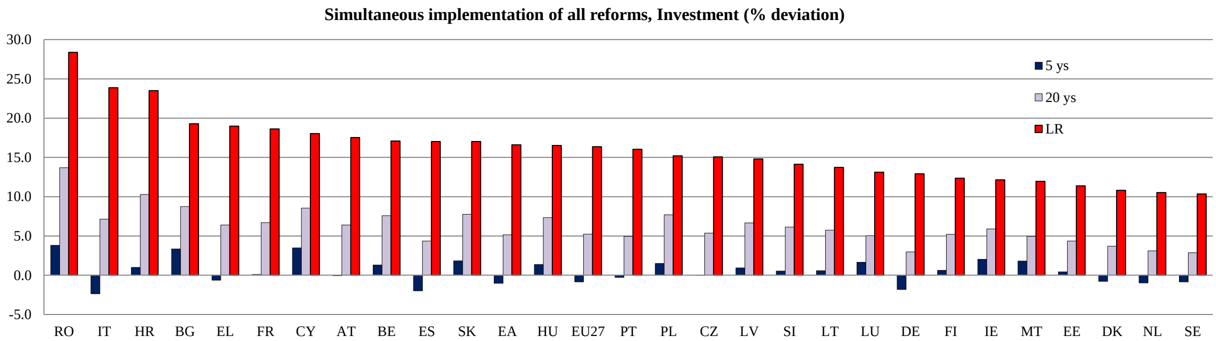
Smets, F., and Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the Euro Area. J. Eur. Econ. Assoc. 1, 1123–1175.

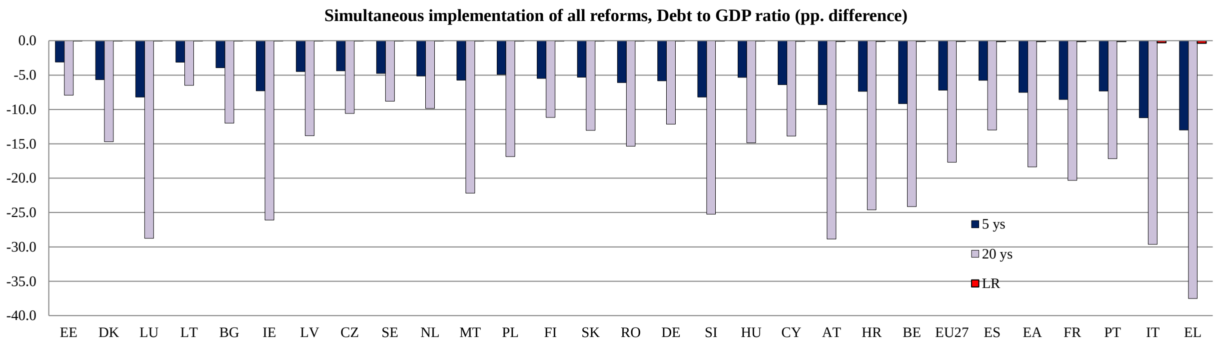
10. APPENDIX B: OTHER MACROECONOMIC VARIABLES

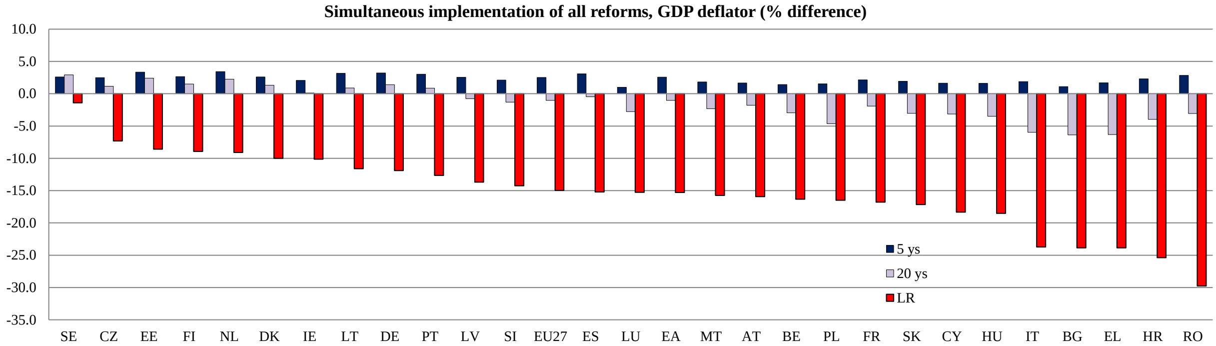
Graph B1. **Other macroeconomic effects by Member States**











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11. APPENDIX C: SOLUTION ALGORITHM

We solve the nonlinear model by a Newton-Raphson solution algorithm as developed by Laffarque (1990), Boucekkine (1995) and Juillard (1996), and implemented in the TROLL software. Let y_t $(n \times 1)$ and x_t (k× 1) be vectors of endogenous and exogenous variables respectively. The model can be written compactly as:

$$f_t(y_{t-1}, y_t, E_t y_{t+1}, x_t) = 0$$

where f_t is a vector of n nonlinear dynamic equations. The presence of predetermined state variables y_{t-1} and forward-looking expectations (jump variables) $E_t y_{t+1}$ introduces simultaneity across time periods. A way of solving the model (with starting date t) is to stack the system for the T+1 periods:

$$F(z, x; t) = \begin{bmatrix} f_t(z_t, x_t) \\ \vdots \\ f_{t+j}(z_{t+j}, x_{t+j}) \\ \vdots \\ f_{t+T}(z_{t+T}, x_{t+T}) \end{bmatrix} = 0$$

where $z_{t+j} = (y_{t+j-1}, y_{t+j}, E_t y_{t+j+1})$. This stacked system of equations is then solved with the Newton-Raphson method subject to the predetermined variables y_{t-1} and the terminal conditions y_{t+T+1}.

References Appendix C:

Boucekkine, R. (1995). An Alternative Methodology for Solving Nonlinear Forward-Looking Models. Journal of Economic Dynamics and Control 19: 711-734.

Juillard, M. (1996). DYNARE: A Program for the Resolution and Simulation of Dynamic Models with Forward Variables Through the Use of a Relaxation Algorithm. CEPREMAP Working Paper, No. 9602.

Laffargue, J. (1990). Résolution d'un Modèle Macroéconomique avec Anticipations Rationneles. Annales d'Economie et Statistique 17: 97-119.

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