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R & D tax credits and their macroeconomic impact in the EU: an assessment using QUEST III

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Foreword

This publication is a technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based insights into the role and macroeconomic impact of R & D tax credits across the EU, in order to support policymaking in this area. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication.

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Abstract

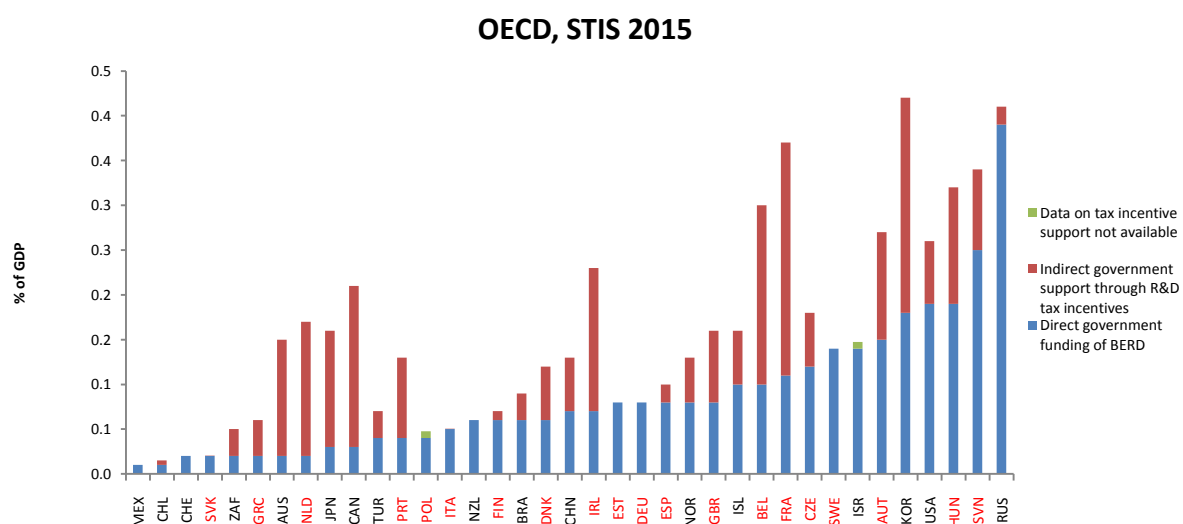
R & D tax credits are currently used by 25 Member States as a means to stimulate R & D investment and, ultimately, economic growth and employment. This paper is a first attempt to provide an in-depth analysis of the structural economic factors that, other things being equal, affect or condition the potential macroeconomic impacts of expanding (or start implementing) R & D tax credit schemes. The analysis is based on the European Commission's QUEST III semi-endogenous growth model. Our main conclusion is that, while the short- and medium-term impacts of increased R & D tax credits on Member States' GDP and other macroeconomic aggregates are overall significantly positive, there remains space to substantially improve the cost-effectiveness of these policies.

1 Introduction

In the action plan 'Investing in Research' from 2003, the Commission recommended supporting private investments in research. In particular, concerning tax measures, it recommended to 'improve fiscal measures for research on the basis of formal evaluations, mutual learning and the application of principles of good design such as simplicity, low administrative cost and stability'.

Some Member States such as France and the United Kingdom were already making use of R & D tax credits at the time of the action plan (since 1984 and 2000, respectively), but this recommendation was subsequently adopted by many others, making tax credits a widely used instrument in the EU as a way to subsidise R & D. In 2014, a total of 25 Member States used some form of tax credits to subsidise R & D (European Commission, 2017) ⁽¹⁾. The total amount of foregone tax revenue is estimated at more than EUR 12 billion (OECD, 2014). The chart below shows the latest data on the tax credit-subsidy mix across countries (EU countries highlighted in red). In some countries such as Belgium and France, the total value of foregone tax revenue via tax credits is higher than the value of government direct expenditure on R & D subsidies.

Figure 1. Tax credit-subsidy mix across OECD countries (EU countries in red)



Despite the increasing relevance of tax credits as a tool for R & D investment stimulation in the EU, ex ante evaluations of their potential macroeconomic effects do not abound. In particular, studies in the same vein as the present one do not provide an investigation of the structural factors behind the observed cross-country differences in the impact of R & D tax credits on macroeconomic variables. As noted in Veugelers (2016), 'where the macro models are as yet underexploited and where they would be a very useful R & D policy instrument is in assessing which framework conditions need to be in place to improve the impact of public R & D funding instruments, such as grants and tax credits'.

A brief survey of the related literature confirms the latter point. For instance, Roeger et al. (2008) provide an analysis of tax credits and R & D wage subsidies using QUEST in the context of a general analysis of the impact on R & D investment at the EU level of a wider set of different measures. However even though an explanation is provided on the main mechanisms behind the general implications of an increase in tax credits, these are not country-specific, and no exhaustive comparison across countries is undertaken to

⁽¹⁾ Germany is a particular case, as it does not rely on any type of fiscal support to private R & D.

disentangle the main structural factors behind the observed differences in impacts. D'Auria et al. (2009) provide a more in-depth analysis of the structural factors affecting the net impact of R & D tax credits. They exploit cross-country variation in a number of deep parameters and regress the model-generated impacts on main macroeconomic variables on the value of these parameters in different countries. Even though it adds a deeper layer of analysis compared to Roeger et al. (2008), the analysis in D'Auria et al. (2009) is not only focused on tax credits, but also takes a horizontal stance in that many different policies are analysed at the same time. In addition, in contrast to our contribution, the authors do not provide an analysis of which countries are bound to benefit more from an expansion of R & D tax credits. Hence, we view this paper as an improvement to pre-existing contributions in two main respects. First, it provides a more focused analysis of the drivers behind the impact of R & D tax credits across countries. Second, it attempts to quantify the country-specific internal rates of return of R & D tax credit policies.

Our paper will attempt to address these two problems by focusing in depth and solely on the analysis of the macroeconomic impact of volume tax credits. For the purpose of analysing the impact of volume tax credits for R & D across 28 Member States, we use the European Commission's QUEST III model. In particular, we conduct an exercise where we simulate, for each Member State, the impact of a 0.1 % of GDP permanent increase in tax credits for R & D. To be precise, the simulated shock consists of an increase in tax credit rates such that, for each country, the additional R & D investment generated equals 0.1 % of GDP (i.e. in the new scenario, 'tax-credited' R & D investment is 0.1 % of GDP higher compared to baseline). By analysing the differences in outcomes for the individual Member States, we will gain insight into how different macroeconomic contexts influence the effectiveness of R & D tax credits.

The remainder of the paper is structured as follows. In Section 2, a brief overview of different types of R & D policy instruments is provided, including a discussion of their advantages and disadvantages. Section 3 provides a brief review of the most recent literature, including both theoretical and empirical contributions. In Section 4, the results of the simulations of the impact of higher R & D tax credits on the main macroeconomic indicators, such as GDP growth, employment and total factor productivity (TFP) for each Member State, are presented ⁽²⁾. Section 5 provides a detailed analysis of the structural factors explaining the observed cross-country differences in the shape and magnitude of the impact of tax credit shocks ⁽³⁾. Finally, Section 6 summarises the main policy relevant conclusions.

2 Tax credit schemes as policy instruments

One difficulty in analysing the effect of tax credit schemes for R & D is that there are many different types. A scheme may for example be based on the total volume of R & D performed by a firm or it may be an 'incremental' scheme which only rewards 'new' R & D. It may be subsidising the salaries of researchers or it may be based on total investment in R & D. Schemes may also allow payments to the firm of tax credits if companies have a deficit. In such schemes with 'tax grants', a tax credit may become very similar to a normal grant, in particular if there are further conditions attached to the 'tax grants' (e.g. beneficiaries required to be innovative SMEs).

Compared to grants, tax credits are usually considered to be more flexible and to involve fewer administrative costs. The main disadvantage compared to grants is that tax credits cannot be targeted at particular types of R & D projects to the same extent. However, the major point to be stressed is that these two policy instruments fulfil different objectives, corresponding to two opposite strategies, both theoretically and in practice. A table in the annex summarises the main advantages and drawbacks of each instrument.

⁽²⁾ Using the European Commission's QUEST III model, June 2016 version.

⁽³⁾ To avoid confusion with terminology, we use the term 'structural factors' throughout this document to refer to the fundamental/underlying characteristics of an economy which tend to remain stable over time (e.g. economic institutions).

As mentioned before, individual tax schemes for R & D may also differ in nature and focus (volume versus incremental, tax credits based on the wage of researchers, etc.) Keeping in mind these aforementioned differences in policy instruments and designs, the analysis conducted subsequently concerns volume-based R & D tax credits only.

3 Literature review: impact of tax credit schemes for R & D

In this section we provide a very brief overview of both the empirical and theoretical evaluations made thus far in the related literature⁽⁴⁾. As other large subsidy schemes, most of the tax credit schemes for R & D have been subject to national evaluations and in some of these evaluations, econometric techniques have been applied *ex post* to assess the extent to which R & D tax credits resulted in additional investments (so-called **additionality** or **bang-for-the-buck** indicators). The results of these evaluations are mixed. Conclusions are also ambiguous in studies which analyse the overall net welfare impact of such policies, arguably a more important metric to evaluate the success of R & D tax credit policies (Parsons and Phillips (2007), Garza et al. (2014)).

Moreover, although tax credits have been included as part of some analyses of the effects of large packages of R & D reforms in previous papers, at the EU-28 level there has been no comprehensive evaluation of the effect of tax credits for R & D. One question of particular interest for the cross-country dimension is whether the national R & D tax schemes are to some extent competing with each other. Evidence at state level in the United States points to the potentially negative social impact of such competition (Wilson, 2005), even though in theory tax competition could be beneficial if it funnels R & D investment where it is needed the most.

As noted by Moncada-Paterno-Castello et al. (2014), although positive impacts of tax credit schemes are generally found in the literature, these schemes should be combined with other instruments to avoid crowding out some types of firms. Additionally, these authors stress the need to assess the success of schemes in terms of the additional innovation spurred by them. A further recommendation in terms of R & D subsidy policies is that, in light of the evidence, large firms and high-tech sectors seem to benefit more, particularly when subsidies target earlier phases of knowledge creation (**R vs D**) and more risky projects.

Despite these policy recommendations, from the literature reviewed, it seems that there is still mixed evidence as to what type of firms are most stimulated by different R & D policies and what the best policy mix is, as noted by Gaillard and Straathof (2015). Given the additional fact that there exist very few studies that analyse whether additional R & D investments actually translate into higher innovation rates⁽⁵⁾, one of the main messages of these authors is that simply introducing an R & D tax incentive or making an existing one more generous might not suffice. This is because if framework conditions for innovation are lacking in a particular country, then these policies might just be a 'waste' of government resources. We will shed light on this problem by analysing the macroeconomic factors that should be in place for R & D tax credit policies to be effective.

Among the theoretical, model-based studies, Mulkay (2013) conducts an evaluation of the major reform implemented in 2008 in France⁽⁶⁾ by employing a micro-simulation model of a panel of R & D-performing firms. The study shows that the long-run budget multiplier is about 0.7⁽⁷⁾. The author also underlines that this is arguably a lower bound of the effect of tax credit policies, as potential positive spillover effects are not captured. The latter effects are precisely what the current paper tries to capture, thereby offering a

(4) A summary of the extended literature (e.g. the complementarity versus substitutability debate between tax credits and other policy instruments, such as subsidies) is beyond the scope of this paper.

(5) A point stressed in Moncada-Paterno-Castello et al. (2014).

(6) This reform consisted of both an increase in the level of tax credit rates (up to 30 %) and an increase in the maximum threshold.

(7) The authors define this multiplier as the ratio of additional private R & D expenditures to foregone tax revenue associated with the tax credit.

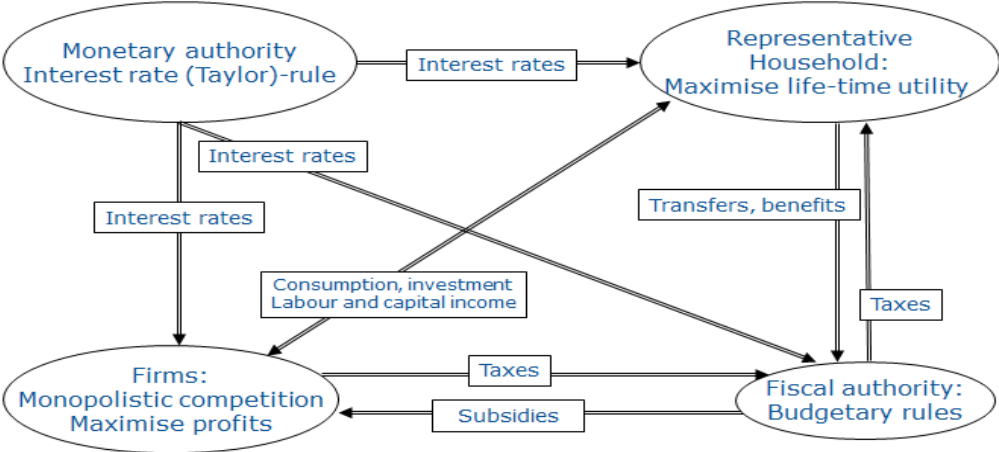
more informative measure of the effectiveness of R & D tax credits. This is because, working at the macro level, we should expect to capture (in the long term) the intra and inter-country spillovers corresponding to increased R & D investments due to the increase in volume tax credits, as shown in the simulations in the next section.

This paper adds to the previously discussed body of literature in several ways. First and foremost, as mentioned before, we aim at focusing on R & D tax credit policies only and analysing the structural factors that mediate in the response of macroeconomic variables to changes in these policies, for a large set of countries. Second, there is a case for updating the results of previous papers as most of these rely on outdated values of crucial parameters (e.g. elasticities) and may thus give a different picture altogether. Third, as opposed to previous contributions, an emphasis will be put on understanding in depth the main factors driving the differences in outcomes across countries, so as to be able to deliver more precise policy recommendations at the country level ⁽⁸⁾.

4 QUEST III simulations

QUEST III is a DSGE (dynamic stochastic general equilibrium) model which was originally developed by the Directorate-General for Economic and Financial Affairs for the analysis of fiscal and monetary policies. A general equilibrium model is characterised by a system of equations that describe the economy as a whole (i.e. includes goods, labour and capital markets) and the interactions among its agents. The equations governing the economy are derived from the optimisation behaviour of agents (e.g. households that maximise lifetime utility) and are thus based on microeconomic theory. The resulting system of equations is solved simultaneously. Figure 2 offers a schematic representation of the current version of the QUEST III model.

Figure 2. QUEST III model



The model has been extended in various ways since it was first built. The current version is a semi-endogenous growth model currently calibrated for 28 Member States as a 'three country model' ⁽⁹⁾. The model features an endogenous R & D sector (not shown in the chart above) where ideas/patents are generated by a household-owned hypothetical

⁽⁸⁾ On top of these three goals, there are other issues to explore in future research. For instance, the approach to modelling tax incentives for R & D and its structure could be enriched by focusing on the different types of instruments available to Member States (e.g. tax credits versus R & D subsidies, researcher wages tax credits versus firm profits tax credits, etc.). At the moment, only (level) tax credits are represented in the model.

⁽⁹⁾ i.e., the model includes the economy of a particular Member State, along with its interactions with the rest of the euro area and the rest of the world outside euro area

research institute which employs high-skilled labour. It also features a final good sector, producing a homogenous good, and an intermediate good sector, where monopolistically competitive firms produce different varieties of inputs used by final good firms. A key element of the model for our purposes is the R & D production function, as it represents the main channel through which the transmission mechanism of R & D policies operates ⁽¹⁰⁾.

We proceed by simulating, for each Member State, the impact of a 0.1 % of GDP permanent increase in tax credits for R & D. To be precise, the simulated shock consists of an increase in tax credit rates such that, for each country, the additional R & D investment generated equals 0.1 % of GDP (i.e. in the new scenario, 'tax-credited' R & D investment is 0.1 % of GDP higher compared to baseline). By analysing the differences in outcomes for the individual Member States, we will gain an insight into how different macroeconomic contexts influence the effectiveness of R & D tax credits. For the reasons set out in the next sections, the impact of such policy differs substantially across Member States.

As a second exercise, we calculate the **rates of return** associated with such policy, defined in terms of additional GDP generated per euro foregone in tax revenue. As opposed to microeconomic, partial equilibrium analyses, be they static (Parsons and Philips, 2007) or dynamic (Garza et al., 2014), these calculations represent a novelty in the literature, as they are based on a general equilibrium, dynamic, DSGE model with semi-endogenous R & D. Tax credits are modelled in QUEST III as decreasing the overall cost to households of purchasing patents ⁽¹¹⁾. In this sense, they can thus be seen as a subsidy to the acquisition of patents. In addition, through the conditions for optimal investment in patents and bonds by households, this parameter ultimately affects the equilibrium rental cost of intangible capital. As shown in the next section, an increase in the tax credit rate lowers the user cost of capital, which in turn raises profits in equilibrium, thereby spurring the creation of new intermediate goods and, ultimately, growth.

It is important to note that this approach is not without caveats. First, the current version of QUEST III models innovation as a function of patented ideas generated by R & D investments. This is a somewhat limited view of both R & D and innovation, as there are other channels through which these two can take place that the model abstracts from (e.g. demand-driven innovation). The simulated impacts are therefore likely to be somewhat conservative. Second, the simulations are likely to underestimate the impact of R & D, especially for relatively long time horizons, since QUEST III, like most models in the literature, does not capture events such as break-through innovations. Third, some Member States have very large starting levels of R & D tax credit rates, and so for them it is not unlikely that the marginal returns (in terms of e.g. output) from further increases in rates are not high ⁽¹²⁾. These issues notwithstanding, such a cross country comparison is still interesting as the focus is mainly on highlighting the macroeconomic factors impacting the effectiveness of R & D tax credits. Furthermore, it is possible with this approach to identify important new questions concerning the factors behind the effectiveness of R & D subsidy schemes.

⁽¹⁰⁾ For detailed information on the model and its structure, see Roeger et. al (2008).

⁽¹¹⁾ Note that households in the model are the ultimate owners of all firms, including those in the intermediate good-producing sector. In order to start a new product line, a patent is required. Hence, it is households ('entrepreneurs') that create new firms in the intermediate good sector by weighing the cost of buying a patent against the present value of the stream of profits they will earn from producing the new intermediate (developed in the R & D sector).

⁽¹²⁾ By using the term 'marginal' in this paper, we refer to the effect of a small increase in the tax credit rate on the main macro variables: output, employment and TFP. It is important to bear in mind that the final marginal impact on these variables is conditioned by many intermediate effects, such as the marginal impact of R & D tax credits on R & D investment.

The following graphs show the deviations from baseline in the path followed by GDP, employment and TFP, over both the short-to-medium and long terms, following an increase of 0.1 per cent of GDP in tax-credited R & D investment in all 28 Member States.

Figure 3. Response of GDP to an increase in the tax credit rate such that tax-credited additional R & D investment equals 0.1 % of GDP

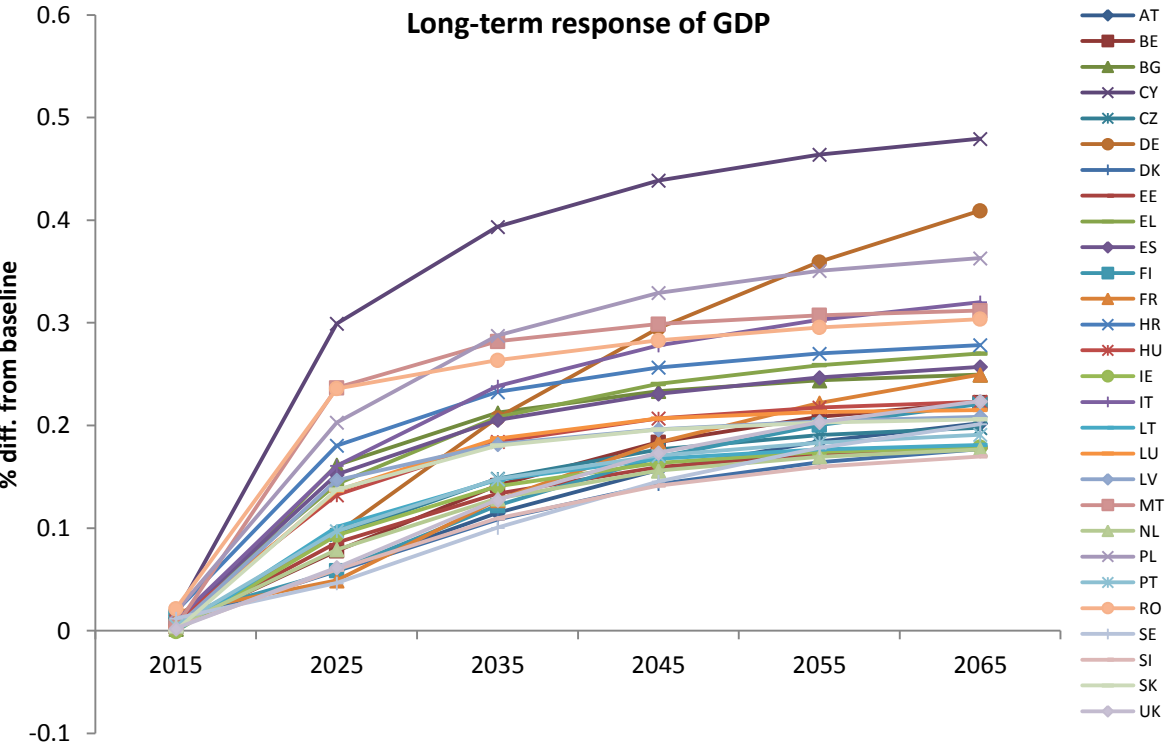
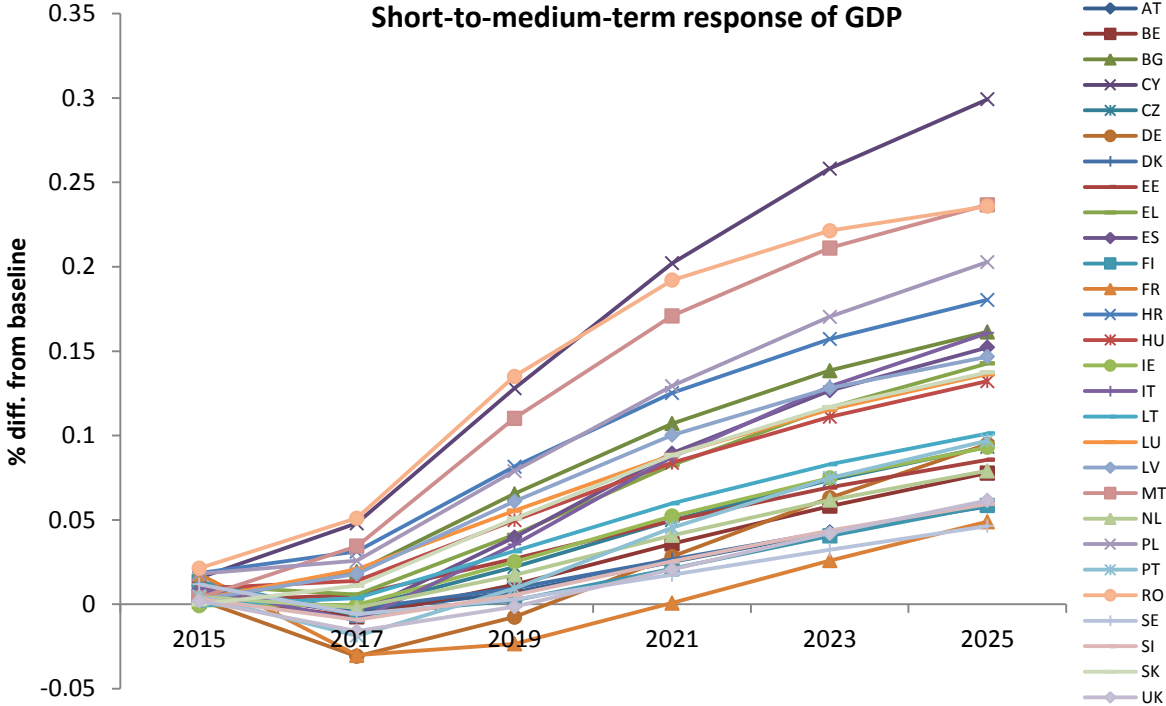


Figure 4. Response of aggregate employment to an increase in the tax credit rate such that tax-credited additional R & D investment equals 0.1 % of GDP

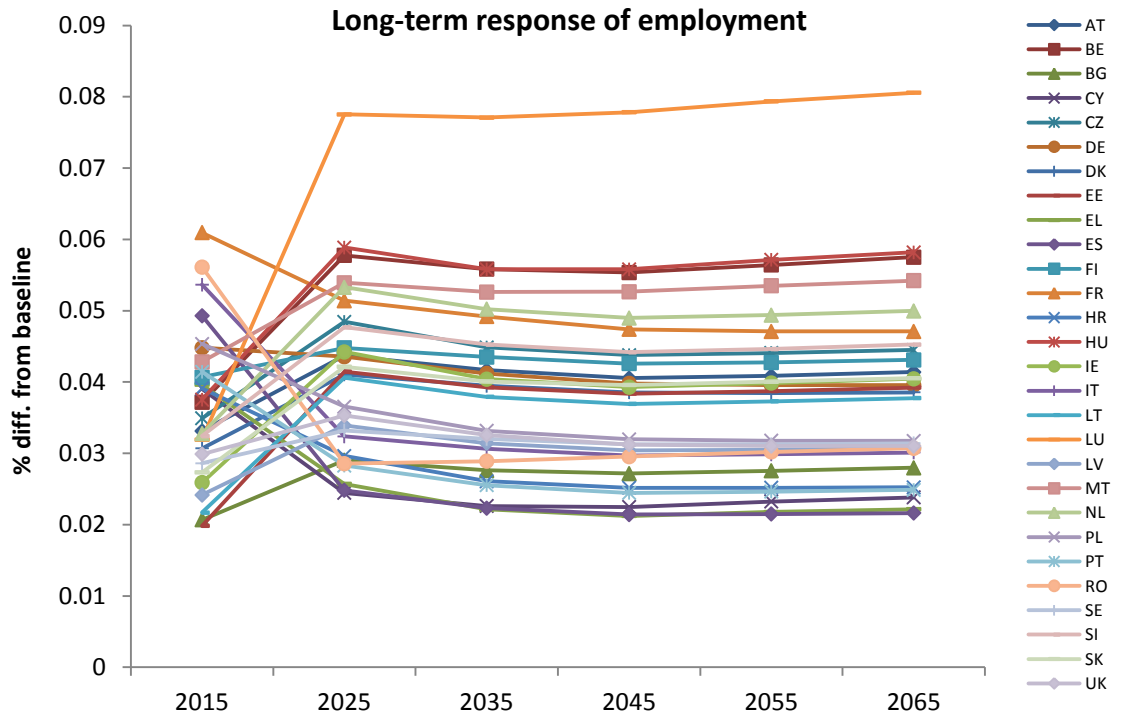
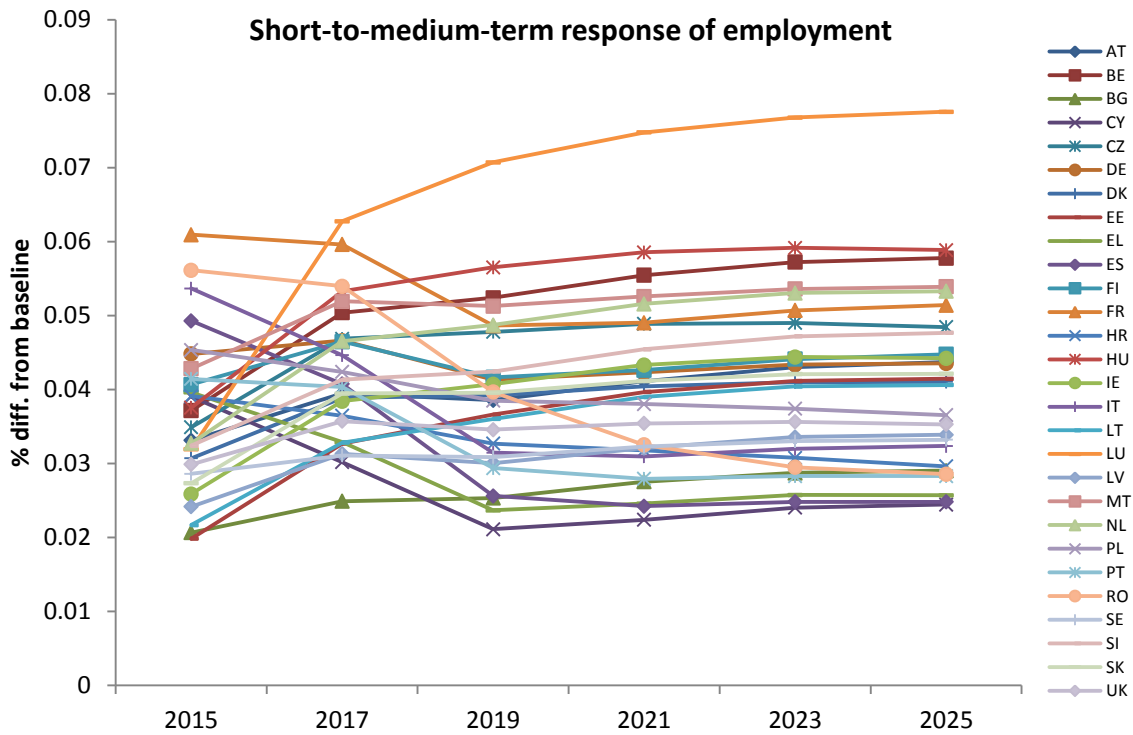
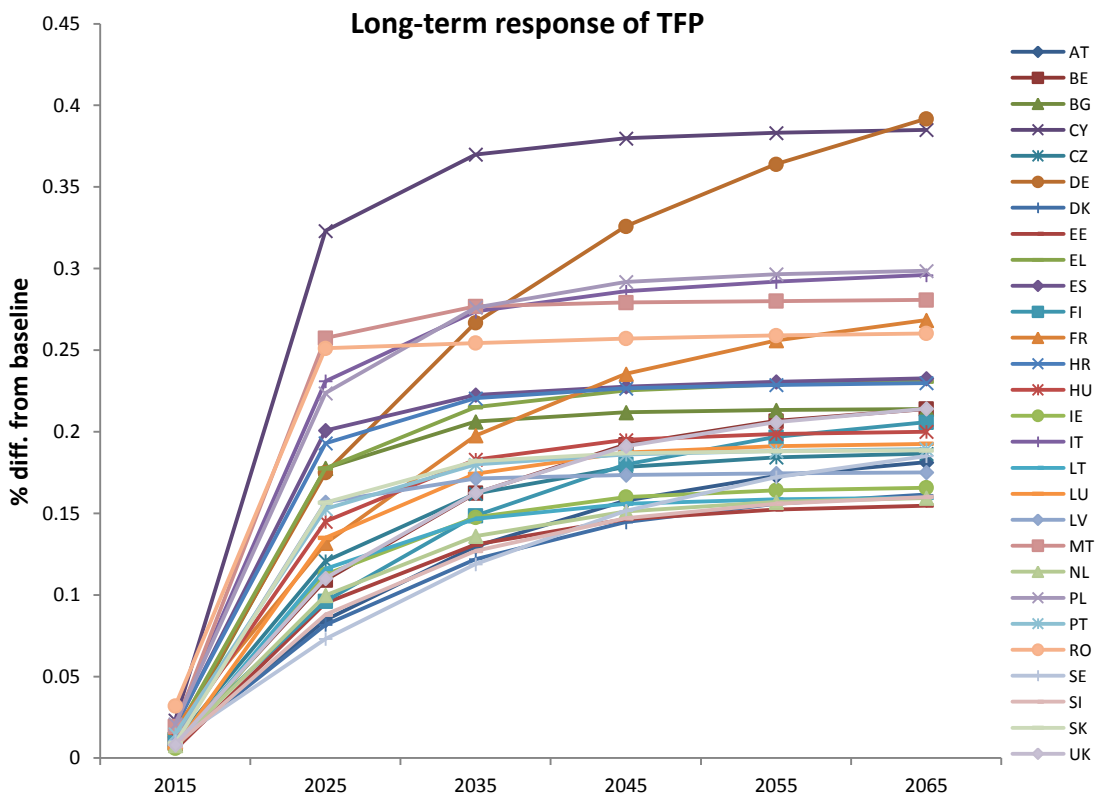
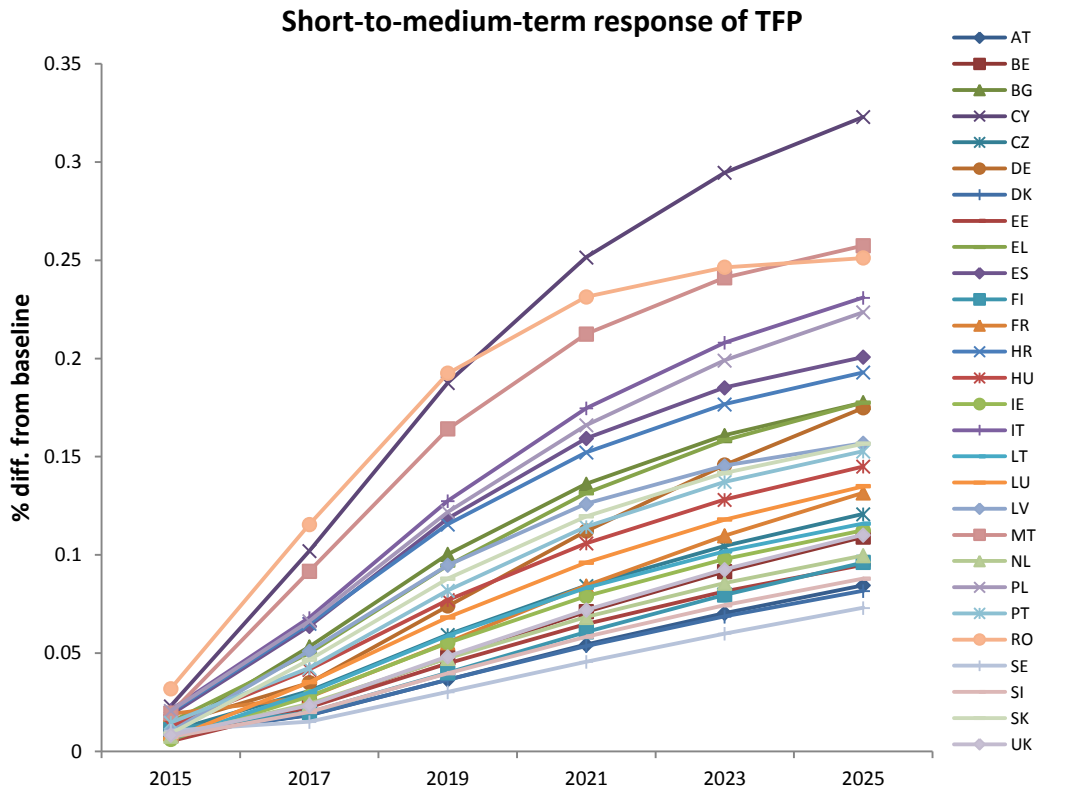


Figure 5. Response of TFP to an increase in the tax credit rate such that tax-credited additional R & D investment equals 0.1 % of GDP



In brief, the general evolution of GDP and employment can be explained as follows: R & D tax credits reduce the cost of intangibles and increase R & D activities, resulting in the production of more patents, which can be used to open up new product lines. On the labour market, this is accompanied by a reallocation of high-skilled workers from the

production to the research sector due to increased demand for this type of workers in the latter sector. If the drain of high-skilled workers from the final good sector to the R & D sector is sufficiently large, final good-producing firms might reduce output even if they increase hiring of low- and medium-skilled workers. Indeed, because of the reallocation of high-skilled workers, the initial effects on GDP can be positive or negative depending, among other things, on the elasticity of substitution among the different types of labour. Nevertheless, the size of these effects is small in the short term. Substantial, positive output effects materialise in the longer term, once the initial push and the momentum generated in R & D activities yield their fruits in the form of marketable products. Despite the increase in the efficiency of all factors of production in all countries (as shown in the last figure), brought about by the higher stock of ideas, employment (at all skill levels) is higher in the new equilibrium. This is due to the surge in aggregate demand ensuing from higher incomes for households, which more than compensates for the labour-saving effect of the increase in TFP.

The effects of a more generous R & D tax credit policy vary significantly across countries: in 2025, the increase in GDP in Cyprus, with respect to the **business-as-usual** baseline scenario, is about 0.25 percentage points larger than in France. A country that deserves special attention is Germany, as it is the only one without an initial tax credit policy in place. Germany's path exhibits a steep slope for GDP after 2025. This can be explained in turn by the trajectory for TFP, which is the ultimate precursor of income growth over the long term. In fact, it can be seen from the last figure that the evolution of GDP is a mirror image of that for TFP, and that the path for the latter variable is steepest also for Germany. The reason why Germany is able to reap larger benefits in the very long run compared to the rest of the EU is that it departs from the highest levels for the stock of knowledge and TFP among all Member States and therefore it converges to a higher level of overall productivity in the new equilibrium. Because of the higher productivity and the bounded supply of all types of workers, real wages in Germany also reach the highest level among all countries in terms of the difference with respect to baseline in the long run. This deters the hiring of new workers to a greater extent than in other countries, and thus the rise observed in German employment in the long run is somewhat in the middle of the distribution of the size of employment effects in the sample of countries considered. Employment levels are boosted most strongly in Luxembourg, both in the short and medium-to-long terms, owing to a combination of factors, including relatively low increases in real wages.

France is another special country in the sample, as it exhibits the highest value of the R & D tax credit rate. As apparent from Figure 3, the initial response of GDP in France is among the most negative ones (along with Germany's), remaining subdued over the medium term and picking up only towards the longer term. This response in output mainly owes to the relatively more intense outflow of labour input from the final good production sector to the R & D sector. In fact, Figure 4 shows that total employment in France experiences the second largest surge, after Luxembourg. The reason for this high sensitivity of employment to the policy shock is in turn partly related to the very high initial value for the capital income tax rate in France (see discussion in the next section).

5 Core equations and comparative cross-country analysis of tax credit shock effects

In order to investigate in more detail the issues just discussed, an analysis of the structural factors behind the different behaviour observed in the Member States can be carried out by examining the equations of the model governing the trajectory for the different variables. In particular, it can be shown that following an increase in the tax credit rate of the same magnitude, the higher the capital income tax rate, the larger the reduction in the user cost of intangible capital. This can be seen algebraically, from the equilibrium condition of the user cost of R & D capital, i_t^A :

$$i_t^A = \frac{(1 - \tau^A) \left(1 + i_t - (1 + g_{PA}) (1 + \pi_{t+1}^A) (1 - \delta^A) \right) - t^K \delta^A}{1 - t^K} + rp_t^A + \varepsilon_t^{rp^A} \quad (1)$$

where τ^A represents the tax credit/subsidy rate and t^K is the capital income tax rate. This equation has an intuitive interpretation, as it shows that the user cost of capital depends, among other things, negatively on the tax credit rate and positively on the risk premium demanded by capital owners (rp_t^A), the ongoing interest rate and the rate at which the stock of ideas depreciates (δ^A)⁽¹³⁾. It can also be seen that the user cost of ideas depends negatively on the capital income tax rate (t^K). Differentiating the former expression with respect to the tax credit rate and calculating the partial derivative of the resulting expression with respect to the capital income tax rate, we obtain:

$$\frac{\partial i_t^A}{\partial \tau^A} = - \frac{1 + i_t - (1 + g_{PA}) (1 + \pi_{t+1}^A) (1 - \delta^A)}{1 - t^K} < 0 \quad (2)$$

$$\frac{\partial i_t^A / \partial \tau^A}{\partial t^K} = - \frac{1 + i_t - (1 + g_{PA}) (1 + \pi_{t+1}^A) (1 - \delta^A)}{(1 - t^K)^2} < 0 \quad (3)$$

Thus, we can see that t^K amplifies the impact of a change in τ^A ⁽¹⁴⁾. Intuitively, a higher capital income tax rate in a given country means that hiring either type of stock of capital in the economy is comparatively more expensive than in other countries. A decline in the user cost of capital leads to a higher demand for patent licences arising from intermediate good firms. This can be seen from the free entry/no-arbitrage condition:

$$\pi_t = p_x x_t - i_k^t P_c^t k_t = \frac{i_t^A P_t^A}{DEF_t} + FC_A (i_t^A + P_t^{A,trend} + \pi_t^A) \quad (4)$$

where the left-hand side represents the period profits of the representative firm in the intermediate goods sector and the right-hand side represents the total costs that need to be borne to operate in that sector, namely fixed costs and licencing fees. This condition implies that a decrease in the user cost of capital drives an initial positive wedge between period profits and entry costs, attracting new firms into the sector until profits are driven down to exactly match the costs, so that no more profits from arbitrage can be realised. As established before, in countries with relatively high capital income taxes, a reduction in the user cost of capital alleviates costs faced by intermediate good firms to a greater extent than in countries with lower tax rates, which fosters new intermediate businesses and thus more purchases of patents/ideas from households.

Another important element mediating in the overall effect of the increase in tax credits is the parameter capturing the elasticity of R & D production to high-skill labour input, λ , located in the technology of production of R & D:

$$\Delta A_t = v_t A_{t-1}^\phi L_{A,t}^\lambda \quad (5)$$

where A_t represents the stock of ideas/patents in period t , $L_{A,t}$ is the share of high-skilled labour devoted to R & D, ϕ represents the elasticity of substitution of R & D production with respect to the domestic stock of knowledge and v_t is a parameter capturing the overall efficiency of technology (as well as technology diffusion from other countries).

For a country with high values of λ relative to other countries, a greater demand from patents arising from an increased τ^A will be satisfied, all else equal, by relatively more hiring of researchers in the R & D sector and a relatively smaller change in the prices of

⁽¹³⁾ The rest of the terms in the expression do not deserve further attention for the purposes of this paper and can be effectively ignored by the uninformed reader.

⁽¹⁴⁾ It is worth noting that the level of the user cost of capital does not influence the marginal effect of a change in τ^A since $\frac{\partial^2 i_t^A}{\partial \tau^A} = 0$.

patents. Indeed, a much higher increase in R & D employment is what drives the observed stronger rise in economy-wide employment during the first period after the shock in countries such as the Czech Republic and Denmark (see Figure 2). This can also be shown analytically in the expression governing the demand for researchers by R & D producing firms:

$$W_t^H = \left[\underbrace{\lambda P_t^A v_t A_{t-1}^\phi L_{A,t}^{\lambda-1}}_{MPL} - \underbrace{\frac{\gamma_A (W_t^H \Delta L_{A,t} + W_{t+1}^H)}{(1+r_t) \Delta L_{A,t+1}}}_{MADJ} \right] / (1 + \varepsilon_{t,WRD}) \quad (6)$$

where the first (MPL) and second (MADJ) terms on the right-hand side represent the marginal productivity and the marginal adjustment cost of R & D labour, respectively ⁽¹⁵⁾. In addition to the elasticity of R & D production to high-skilled labour, λ , the main parameters and variables in the equation above are: the price of patents, P_t^A , the stock of patents/ideas in t , A_t , the wage rate of researchers, W_t^H , the number of high-skilled workers employed in the R & D sector (researchers), $L_{A,t}$, the elasticity of substitution of R & D production with respect to the domestic stock of knowledge, ϕ , t and the variable capturing the overall efficiency of R & D, v_t . Since the MPL term is increasing in λ , a higher value for this parameter leads, all else equal, to a higher demand for R & D labour by R & D producing firms. As can be seen from the equation above, a higher $L_{A,t}$ results in an equilibrium with higher marginal adjustment costs, lower marginal productivity of R & D labour, a larger stock of ideas and a higher level of GDP. A similar argument applies for higher values of the elasticity of substitution of R & D production with respect to the domestic stock of knowledge, ϕ , and the steady state value for the overall efficiency of R & D, v_t ⁽¹⁶⁾. Moreover, countries with lower intrinsic adjustment costs for R & D labour (captured by parameter γ_A) will, *ceteris paribus*, enjoy a higher equilibrium level of $L_{A,t}$ and, thus, higher values for patents and GDP.

It is also worth noting that the initial number of researchers plays an extra role in determining the marginal effect of a change in tax credits: the lower the stock of R & D labour, the higher its marginal productivity, given the decreasing marginal productivity of researchers, and thus the higher the impact of any policy change conducive to raising R & D investment, all else equal ⁽¹⁷⁾.

The following table shows the values of the different parameters mentioned above as well as the initial values of R & D labour and R & D intensity for all the countries simulated:

⁽¹⁵⁾ The denominator captures the option for the model's user to introduce a shock to R & D wages ($\varepsilon_{t,WRD}$). For our purposes, this term can effectively be ignored as the simulations were run with $\varepsilon_{t,WRD} = 0$.

⁽¹⁶⁾ Strictly speaking, v_t is not a constant parameter as it changes over time as a function of the R & D stocks of external trading partners, among other factors. The initial level will still magnify the transmission mechanism of a tax credit shock, irrespective of its further evolution.

⁽¹⁷⁾ Note that this holds in the very long run, since initially other factors may play a more prominent role. In general, the impact of structural factors, such as technology parameters, is only felt in the long run, given the sluggish nature of R & D dynamics.

Table 1. Cross-country values of selected parameters and initial values for tax credit rates, R & D intensity and the share of researchers in total labour supply

	τ^A	λ	ν	R & D intensity (% GDP)	$L_{A,0}$	ϕ	t^K
AT	0.119	0.398	0.213	0.034	0.012	0.619	0.250
BE	0.108	0.465	0.309	0.027	0.010	0.555	0.355
BG	0.126	0.645	1.282	0.009	0.004	0.386	0.235
CY	0.134	0.551	1.077	0.006	0.002	0.476	0.260
CZ	0.185	0.496	0.484	0.022	0.010	0.478	0.180
DE	0.010	0.496	0.298	0.032	0.012	0.548	0.222
DK	0.019	0.473	0.255	0.036	0.016	0.548	0.235
EE	0.139	0.482	0.416	0.016	0.007	0.542	0.081
EL	0.088	0.652	1.301	0.010	0.004	0.377	0.239
ES	0.276	0.777	1.745	0.014	0.007	0.257	0.253
FI	0.031	0.441	0.231	0.036	0.015	0.578	0.299
FR	0.232	0.526	0.404	0.026	0.010	0.497	0.469
HR	0.133	0.672	1.598	0.009	0.004	0.361	0.235
HU	0.156	0.595	0.776	0.016	0.006	0.435	0.214
IE	0.241	0.569	0.580	0.017	0.008	0.456	0.130
IT	0.049	0.777	1.752	0.015	0.007	0.257	0.370
LT	0.139	0.582	0.751	0.011	0.006	0.447	0.098
LU	0.020	0.594	0.659	0.014	0.008	0.432	0.239
LV	0.139	0.738	2.027	0.008	0.005	0.299	0.099
MT	0.135	0.773	2.091	0.009	0.006	0.265	0.235
NL	0.171	0.547	0.431	0.022	0.011	0.477	0.137
PL	0.022	0.542	0.738	0.011	0.004	0.484	0.190
PT	0.263	0.773	1.700	0.015	0.007	0.261	0.295
RO	0.126	0.879	7.658	0.004	0.002	0.164	0.235
SE	0.070	0.335	0.152	0.040	0.014	0.679	0.306
SI	0.159	0.477	0.331	0.028	0.011	0.546	0.196
SK	0.102	0.685	1.439	0.010	0.005	0.349	0.167
UK	0.166	0.495	0.363	0.019	0.010	0.527	0.357

In the table above the values of the elasticity of substitution of R & D production with respect to the domestic stock of knowledge (ϕ) and the overall efficiency level of R & D production (ν_t) deserve special attention. As discussed in D'Auria et al. (2009), the calibration procedure for parameter ϕ relies on both econometric estimations carried out in the literature and the theoretical restrictions/equations of the model in equilibrium. Hence, its final value will partly depend on the observed long-run growth rate of population and patents as well as on the relationship between other related parameters estimated in the literature. Likewise, the variable governing the overall efficiency level of R & D production, ν_t , is calculated residually from the technology of production of ideas/patents after having calibrated the values for the remaining parameters/variables there ⁽¹⁸⁾.

Inspection of the previous table and the graphs in the previous section reveals a number of important results. The results in Section 4 show that, by 2035, the countries which exhibit the largest GDP gains are Cyprus, Poland, Malta and Romania. These countries' R & D intensities in the initial period are among the lowest relative to the other countries in the sample, which makes them experience larger changes, all else equal ⁽¹⁹⁾.

⁽¹⁸⁾ For a more detailed explanation on the calibration and estimation of the parameters see D'Auria et al. (2009).

⁽¹⁹⁾ Indeed, as discussed in D'Auria et al. (2009), '... countries with low R & D intensity (R & D investment as a percentage of GDP and research labour, L_A) gain the most from R & D promoting policies. This is partly

However, this does not invalidate the fact that countries such as Italy and Cyprus, which depart from both relatively sizeable levels of R & D intensity and physical capital income tax rate, rank rather high in terms of the size of GDP impacts. This is especially true in the very long run, as the influence of the initial value for R & D intensity fades away over time and deep parameters gain more importance. Also, these structural factors can partly offset the effect of the dissimilar magnitude of the tax credit shock across countries, even **only** after 20 years from now. This can be seen in the particular case of Italy. Despite departing from a middle-range value for R & D intensity, relatively higher values of (i) the elasticity of R & D output to the number of researchers (λ); (ii) the efficiency level of R & D (v_t); and (iii) the capital income tax rate yield a GDP impact in 2035 which is the fifth highest ⁽²⁰⁾.

Therefore, we can conclude that deep parameters in the R & D production technology as well as policy parameters (such as the capital income tax rate) play a more important role for macroeconomic outcomes in the long run. By contrast, the starting level of variables such as R & D intensity are more important determinants over the short to medium run. Our results and the explanation of cross-country differences are thus fully consistent with the findings in D'Auria et al. (2009).

6 Rate-of-return calculations

From a policy perspective, an interesting way to gauge the effectiveness of measures aimed at stimulating R & D investment and, ultimately, productivity, employment and GDP growth is through the use of some definition of rate of return (ROR) ⁽²¹⁾. The majority of the empirical literature has focused on two important concepts: **additionality** and **crowding-out**.

Thus, in principle, the objective of the policymaker should be to maximise the additionality effect while minimising the crowding-out effect. However, from a macroeconomic viewpoint, the concern is not so much on the additional R & D investment generated by a certain policy measure as opposed to the wider impact on the main aggregates (GDP, employment, productivity, etc) ⁽²²⁾.

The advantage of using a macroeconomic model such as QUEST III is that it models the R & D sector in a way that captures all these ingredients. We are thus in a good position to evaluate the overall return to an R & D policy aimed at increasing private R & D investment. One option is to compute what has been coined in the literature as the 'social rate of return' ⁽²³⁾⁽²⁴⁾. This measure gives the newly generated income arising from an additional unit of R & D investment. Due to the nature of the model, the newly generated income includes, besides the direct effect of private R & D investment on output, the feedback effects arising from spillover externalities.

The general formulation of the social rate of return (SROR) defines it as the present discounted value of the cumulated period rates of return (in terms of GDP gains):

due to the fact that the 0.1 % of GDP policy measure implemented to boost the knowledge sector represents a proportionally stronger shock for countries investing less in R & D and is proportionally smaller for the R & D intensive countries...'

⁽²⁰⁾ While it is ranked 14th in terms of R & D intensity (from the lowest).

⁽²¹⁾ Also known more informally as **bang-for-the-buck** indicators.

⁽²²⁾ Indeed, as argued in Hall et al. (2009), 'in endogenous growth models ... the social rate of return of R & D should include, besides the output expansion ..., the intertemporal spillover effects, namely the increase in knowledge that will lead to more knowledge in the future and the capital gain effect that allows a decrease of the knowledge investment in favor of more consumption in the future'.

⁽²³⁾ As pointed out in Hall et al. (2009), Griliches first applied this concept to the impact of research in hybrid corn. These authors assert that 'much work on the social returns to R & D has been done on agriculture in the form of detailed case studies and estimations of producer and consumer benefits'.

⁽²⁴⁾ The related literature includes the analysis in Jones and Williams (1998), who employ an endogenous growth model to show that along a balanced growth path, the social rate of return can exceed the marginal productivity of R & D by a factor of 2 to 4.

$$SROR = \sum_{t=1}^T \left(\frac{1}{1+r} \right)^t \left(\frac{\Delta Y_t}{\Delta RD_t} \right) \quad (7)$$

where r is a constant discount rate (usually the long-term real interest rate) and where ΔY_t and ΔRD_t are the changes (in absolute value) in GDP and R & D investment, respectively, between any periods t and $t-1$. For our purposes, however, deviations are taken with respect to the value in the same period prevailing in the baseline scenario instead (i.e. $\Delta Y_t = Y_{t,TAXCR} - Y_{t,BASE}$).

In addition to this social-rate-of-return measure, which can be applied to all types of R & D policies, including R & D subsidies, another measure that is widely used in the examination of the effectiveness of R & D tax credit policies is an **R & D rate of return** (ROR) indicator. As noted in Mohnen and Lokshin (2009), testing for additionality amounts to comparing tax expenditures with the extra amount of R & D spending by firms and hence it involves the computation of the RDROR⁽²⁵⁾. At the economy-wide level, this indicator is generally defined as the present, discounted value of the ratio of period changes in R & D investment to period foregone tax revenue over a given time horizon:

$$RDROR = \sum_{t=1}^T \left(\frac{1}{1+r} \right)^t \left(\frac{\Delta RD_t}{\Delta FTAXREV_t} \right) \quad (8)$$

where RD_t and $FTAXREV_t$ represent R & D investment (private, public or total) and foregone fiscal revenue due to R & D tax credits in period t , respectively, and where the deviations are analogously defined as before for GDP.

In this paper, we propose a measure which is a hybrid between the SROR and the RDROR indicators introduced above. In particular, this combined SROR-RDROR measure gives the sum of the present value of the additionally generated GDP (with respect to baseline) in each period divided by the sum of the present value of foregone revenue in each period, over a certain time horizon. Algebraically,

$$SROR - RDROR = \left(\frac{\sum_{t=1}^T \left(\frac{1}{1+r} \right)^t \Delta Y_t}{\sum_{t=1}^T \left(\frac{1}{1+r} \right)^t \Delta FTAXREV_t} \right) \quad (9)$$

This indicator has the advantage, compared to the other indicators discussed above, of directly being able to capture the amount of income generated relative to the fiscal cost following the policy's implementation. The following table shows the calculated SROR-RDROR returns calculated in this way for all the Member States in our sample for 10-year-apart time horizons (ranging from 20 up to 100 years from the present):

(25) Also known in the literature as the 'incrementality ratio', 'cost effectiveness ratio' or 'tax sensitivity ratio'.

Table 2. SROR-RDROR measures at different time horizons ⁽¹⁾

	20 years	30 years	40 years	50 years	60 years	70 years	80 years	90 years	100 years
AT	0.44	0.66	0.83	0.95	1.05	1.13	1.19	1.23	1.27
BE	0.55	0.80	0.98	1.11	1.20	1.27	1.33	1.37	1.40
BG	1.13	1.39	1.54	1.65	1.72	1.77	1.81	1.84	1.87
CY	1.88	2.33	2.62	2.81	2.95	3.06	3.14	3.20	3.25
CZ	0.61	0.82	0.96	1.05	1.12	1.17	1.21	1.24	1.26
DE	0.77	1.25	1.63	1.94	2.19	2.39	2.57	2.72	2.85
DK	0.49	0.71	0.87	0.99	1.08	1.15	1.20	1.24	1.28
EE	0.63	0.83	0.97	1.06	1.12	1.17	1.21	1.23	1.26
EL	1.00	1.30	1.49	1.62	1.72	1.79	1.85	1.89	1.93
ES	0.89	1.14	1.29	1.40	1.48	1.54	1.59	1.62	1.65
FI	0.50	0.77	0.97	1.13	1.25	1.34	1.42	1.48	1.53
FR	0.30	0.53	0.70	0.84	0.95	1.03	1.10	1.16	1.21
HR	0.40	0.49	0.54	0.57	0.60	0.62	0.63	0.64	0.65
HU	0.57	0.71	0.80	0.86	0.90	0.93	0.95	0.97	0.99
IE	0.61	0.80	0.93	1.01	1.07	1.11	1.14	1.17	1.18
IT	1.12	1.48	1.71	1.87	2.00	2.10	2.17	2.23	2.29
LT	0.71	0.92	1.04	1.13	1.19	1.23	1.26	1.29	1.30
LU	1.04	1.29	1.43	1.52	1.58	1.63	1.66	1.68	1.70
LV	1.01	1.22	1.34	1.42	1.47	1.51	1.55	1.57	1.59
MT	1.52	1.79	1.95	2.05	2.12	2.18	2.21	2.24	2.27
NL	0.54	0.74	0.87	0.96	1.02	1.07	1.10	1.13	1.15
PL	1.50	1.90	2.15	2.33	2.45	2.54	2.61	2.67	2.71
PT	0.54	0.73	0.85	0.93	0.99	1.04	1.07	1.10	1.12
RO	1.52	1.74	1.88	1.98	2.05	2.10	2.14	2.18	2.20
SE	0.38	0.61	0.78	0.93	1.04	1.13	1.20	1.26	1.31
SI	0.41	0.60	0.74	0.83	0.91	0.96	1.00	1.03	1.05
SK	0.95	1.17	1.29	1.38	1.43	1.47	1.50	1.53	1.55
UK	0.42	0.66	0.83	0.97	1.07	1.15	1.22	1.27	1.32

⁽¹⁾ GDP data for year 2015, used in the computation of these figures, is from Eurostat (last updated as of 15.6.2016). The monetary value of foregone tax revenue is computed inside the model, and thus depends on the current calibration of the initial values and parameters involved in its calculation. Present-value calculations are based on a 1.3 % discount rate.

The figures in Table 2 reflect the 2015 value (in euros) of the sum over a specific number of years of the additional GDP that is generated by the stream of foregone tax revenues over the same period. Thus, for example, an increase in tax-credited R & D investment equivalent to 0.1 % of GDP in Belgium leads to EUR 1.20 worth of additional GDP per euro foregone in tax credits 60 years from now.

Inspection of this table reveals a number of interesting points. First, for all countries, the return to R & D tax credits measured by the SROR-RDROR rises with the time horizon considered. As discussed previously, this is due to the lag with which R & D investments yield their return; as time evolves, increases in GDP become relatively larger relative to changes in foregone tax revenue, and this will be picked up by the SROR-RDROR, which is a present-value measure for the return. Second, there exist mixed results across countries in terms of whether their SROR-RDROR measure lies below or above one for relatively close time horizons. This in turn depends on the factors outlined before and is further discussed below. Values of the SROR-RDROR below one suggest that the policy

might not be efficient as it might lead to a net loss of resources⁽²⁶⁾. Third, for all countries the SROR-RDROR is larger than one when computing all new income and foregone tax revenue flows during at least the next 80 years from now, implying that R & D tax credit policies are always cost-effective when their effects are taken into consideration for a sufficiently long period of time.

Turning to the specific countries' experiences, it is readily observed that differences among some of them are not only quite remarkable but change and invert signs with the chosen time horizon. For instance, the countries benefiting the most in the shortest time horizon considered (20 years) are Cyprus, Malta and Romania, whereas Cyprus, Germany and Poland are the ones achieving the highest return in present-value terms when considering the effects over the next 100 years. The main predictors of the value for the SROR-RDROR for relatively long time horizons are the same as the ones that were identified before as important determinants of the short-run impact on GDP (e.g. R & D intensity and number of researchers). The size of the return when including a longer time horizon is a combination of the specific starting levels of R & D tax credits and the structural parameters discussed above.

Indeed, both Germany and Poland have relatively low initial values of tax credit rates, which imply they suffer lower fiscal revenues losses compared to other countries, all else equal, given the likely presence of nonlinearities in the relationship between foregone tax revenue and the level of tax credit rates. By the same token, France, which features the highest starting tax credit rates, not only has the lowest SROR-RDROR (0.3) when calculated using the flows up to 20 years from now, but also shows a very flat profile for this rate of return against the different time horizons, reaching a modest EUR 1.21 (in 2115) of additional GDP for each euro foregone in tax revenue in a 100-year horizon. This again points to the existence of decreasing returns to tax credit rises since the fall in tax revenue is sizeable enough to outweigh the overall increase in GDP (in itself sluggish), even when considering a 60-year horizon (so that the GDP/FTAXREV falls). Similar cases are those of Portugal and Slovenia: featuring relatively high tax credit rates, their SROR-RDROR measures reaches the EUR 1 threshold only after considering changes up to 70 years from now.

Spain is the exception in this regard; despite having the highest initial tax credit rate among all Member States analysed, the tax credit policy is socially beneficial already within a 30-year horizon, as the SROR-RDROR is equal to EUR 1.14 for that time horizon. This is due in turn to the other factors, especially structural, that mediate in the net effect on GDP and tax revenue and hence the SROR-RDROR measure. In particular, the Spanish R & D sector is characterised by a relatively low share of researchers in total employment ($L_{A,0}$), a high elasticity of R & D output with respect to the number of researchers (λ) and a high overall efficiency coefficient of R & D (v_t).

The four Member States which achieve a SROR-RDROR above unity already within the first 20 years after the shock share a number of structural features, consistent with the observations in the previous section. First, they exhibit high levels of total efficiency of the R & D production technology (v_t), relative to the rest of the countries.²⁷ Second, they also rank relatively high in terms of the productivity parameter of high-skilled labour (λ). Third, their stock of researchers is relatively low. The case of Poland is different as it does not seem to follow this pattern for all the factors discussed, except the share of researchers in total labour, which is the second lowest. The remaining factors behind this high SROR-RDROR are a high elasticity of the current stock of ideas to the past one and

⁽²⁶⁾ It is worth noting that, as opposed to traditional definitions of the RDROR measure (see Mohnen and Lokshin (2009)), the cost effectiveness ratio employed here captures **all** the external effects involved in R & D investment. Thus, in countries where SROR-RDROR < 1, R & D tax credit can be deemed as not cost-effective in the light of the model.

⁽²⁷⁾ Romania and Italy top the ranking of R & D production efficiency levels.

the third lowest initial tax credit rates (implying a smaller change in foregone fiscal revenue) ⁽²⁸⁾.

7 Concluding remarks

In the light of the model, the main conclusions that follow from this analysis are that countries with higher fiscal pressure, higher contribution rates of past ideas to the current stock of ideas, higher overall efficiency of the R & D technology and/or where the elasticity of R & D output to high-skilled labour (i.e. researchers' productivity) is higher, may experience stronger aggregate economic impacts from establishing or expanding R & D tax credit policies.

Concerning the impact on GDP, an increase in the tax-credited portion of R & D investment leads to an increase in aggregate income, at least in the very long run. The evolution of GDP, especially in the long-term, is a mirror image of that for TFP, and the trajectory for the latter variable is steepest for Germany. The main reasons for why Germany tops the ranking in terms of the impact in long-run GDP is that it departs from the highest levels for the stock of knowledge and TFP among all countries and so it can converge to a higher level of overall productivity in the new equilibrium. Germany's relatively more productive R & D technology leads to relatively higher demand for researchers accruing from the R & D sector, which exerts upward pressure on the real wages of high-skilled workers in Germany. As a result, real wages also reach the highest increase with respect to baseline in the long run among all countries, which deters the hiring of new workers to a greater extent than in other countries. Hence, the rise observed in German employment in the very long run is somewhat in the middle of the distribution of the size of employment effects in the sample of countries. Employment levels are boosted most strongly in Belgium, owing to a combination of factors, including relatively low increases in real wages.

From a policy perspective, it is arguably more interesting to analyse indicators that are informative about the cost-effectiveness of R & D policies, such as the social rate of return (SROR) or **bang-for-the-buck** (RDROR) measures. In this paper, we have proposed an indicator which is effectively a combination of the SROR and RDROR measures present in the related literature. This metric gives the present value of the amount of additional GDP generated for each euro foregone in tax revenue due to higher tax credits. According to this indicator, and considering only the effects over the next 20 years, a rise in R & D tax credits can only be deemed efficient for a limited number of the sample of Member States analysed (namely Italy, Malta, Poland and Romania). This apparent lack of significant effects at the economy-wide level can be explained by the sluggishness with which the fruits borne by R & D policies such as the one examined in the paper arise in the model: it takes, on average, at least a 50-year time horizon in order for the benefits of higher R & D tax credits to exceed their fiscal costs. All countries eventually achieve economic gains that outweigh the fiscal costs of this policy, but the promptitude with which they are realised hinges on both the specific economic situation and the structural characteristics of each country.

An interesting corollary of the analysis above is that, although some countries may make relatively important GDP gains, the policy change may still be cost ineffective for them. A good example of this is France, whose GDP gains are relatively much higher than in other countries (not least because of its high capital income taxes), yet the fiscal loss is quite burdensome, resulting in a SROR-RDROR measure below one, even for relatively long time horizons. In the case of France this may be due to the relatively generous R & D tax incentives already in place, which imply that the marginal return to further R & D tax credits may be quite low.

⁽²⁸⁾ It is important to note that the net intermediation effect of all these factors will differ across countries, as they are in themselves affected by the myriad parameters and initial conditions present in the model. We have attempted in this paper to identify the main factors behind the observed results. An exact evaluation of all the economic conditions that may impact on the observed outcomes is beyond the scope of this paper.

Tax credits for R & D have been taken up by a large number of Member States to support private R & D. Even though this is positive, the paper stresses that the effectiveness of R & D tax credits is very dependent on the specific macroeconomic situation of individual Member States, and not all Member States therefore benefit to the same extent from introducing R & D tax credits. This question merits further econometric and model-based analysis. The paper has not analysed, for instance, to what extent there may be tax competition between Member States. Neither do we analyse the impact of tax credits on entry conditions for firms in situations where these instruments mainly benefit large (incumbent) firms. To the extent that the latter holds, there is a risk that they may result in less competition and less entry, by supporting existing incumbent firms. This potentially negative effect on market competition from tax credits targeted to large firms would need to be weighed against the higher aggregate R & D investment they spur. The question of the optimal design of R & D tax credit schemes to avoid such problems remains an important policy issue. These two issues on tax competition and the market structure effects of R & D tax credits are potentially fruitful avenues for future research.

In relation to the immediately previous discussion, a word of caution is in order. First, any model-based exercises and results are subject to a number of uncertainties and weaknesses, mainly related to the choice of assumptions and the particular mechanics present in the model. Therefore,, the conduct of robustness checks is an avenue for future work that would lend enhanced credibility and stability to the results obtained. Second, the QUEST model, albeit a strongly robust platform for analysing other types of policies, suffers from a number of drawbacks that arguably render it not the most adequate platform for the impact analysis of R & D policies. Besides the issues pointed out in Section 4, a number of limitations are discussed in Di Comite and D'Artis (2015). As argued there, despite this model being suitable for assessing the impact of R & D and innovation policies over time, as it features inter-temporal optimisation, it is limited on a number of other fronts (e.g. absence of a distinction between private and public R & D investment, assumption of only one type of innovation, absence of human capital accumulation, impossibility to capture increases in the quality of R & D investment, etc). Some of these issues are in the process of being addressed, while others represent potential avenues for future work in this area.

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Annex -pros and cons of R & D tax credits versus R & D subsidies

	Pros	Cons
Tax credits	<ul style="list-style-type: none"> • Freedom on type of R & D expenditure • Low administrative costs • Addresses asymmetric information problem • Measures are more neutral as they encourage investment in R & D for all firms, particularly SMEs (although specific sectors may also be targeted). 	<ul style="list-style-type: none"> • Excessively risky/poor-quality projects (high short-term returns) • Often benefit larger firms more compared to firms that face large fixed costs and are financially constrained (e.g. SMEs).
Subsidies	<ul style="list-style-type: none"> • Can be targeted to projects with high social returns • Theoretically, competition between firms ensures that public funds are used for the best R & D projects • May be used to reduce the effects of economic cycles on firms' R & D investments • May provide the only feasible means of R & D support to financially constrained firms (e.g. SMEs). 	<ul style="list-style-type: none"> • High administrative costs • Causes distortions on the markets for the allocation of resources between different R & D fields and firms • Might lead to inefficient allocation of R & D effort • Project selection tends to reward lobbies.

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