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R&D TAX INCENTIVE POLICY FOR PROMOTING R&D AND INNOVATION IN EUROPEAN COUNTRIES: CROSS-COUNTRY STUDY

PhD DISSERTATION

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R&D Tax Incentive Policy for promoting R&D and Innovation in European Countries: Cross-Country Study

By

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Declaration

I declare that this dissertation has been composed solely by myself and is entirely the result of my own work, except where stated otherwise by reference or acknowledgment, and that this work has not been submitted for any other degree or professional qualification except as specified.

Signed: Katsiaryna Marmilava

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Introduction

Due to the contribution that research and development (R&D) makes to productivity and long-term economic growth (Romer, 1990; Aghion and Howitt, 1992) and its high social returns (Hall, Mairesse, and Mohnen, 2010; Bloom, Schankerman, and Van Reenen, 2013) governments are motivated to find appropriate ways to encourage R&D expenditure. R&D tax incentives as a market-based instrument to support business R&D have grown increasingly popular over the last two decades, and as of today are in place in the majority of European countries. Since R&D capital is internationally mobile the development of competitive and attractive tax incentive policy is high on governments' agendas. On the other hand, tax incentives as government expenditures should be justified and consistently evaluated to conclude if the intended policy outcome has been achieved.

There is a large body of studies aimed at evaluating the effectiveness of R&D tax incentives; however, often they apply different methodological approaches, which make the results less comparable. While most studies evaluate the effect of tax incentives on a country level, there are only a few studies (for example, OECD, 2020b; Thomson, 2017) that assess the overall effect of tax incentives in a cross-country setting. Moreover, there is a lack of such analysis conducted for only European countries. While empirical research on the effectiveness of R&D tax incentives is a topic often paid attention to in the literature, the development of the theoretical framework of tax incentive policies and methodological approaches to analyse its relative attractiveness lags behind. The B-index model developed by Warda (1997) to assess the relative generosity of the tax systems in stimulating business R&D is widely used today for the analysis of policy attractiveness; however, it describes only potential tax support that may be provided by the tax system and does not reflect perceived attractiveness of tax incentives by firms which may affect tax incentive take-ups. Therefore, it cannot be a complete measure of the attractiveness of tax incentives. Furthermore, successful implementation of R&D tax incentive policy may play a crucial role in the policy effectiveness; however, there are no studies found which would define and evaluate the relative efficacy of policy implementation, as well as the main drivers of its heterogeneity among countries. Moreover, there is a need to conduct additional research on the desired characteristics of R&D tax incentive schemes, since the main efforts in this direction were made by the European Commission and took place in 2014. While policymakers introduce tax incentives based on their own expertise, there is a need to establish a conceptual framework on how decisions on the introduction and selection of the generosity of new R&D incentives should be made.

Addressing the existing gaps in the literature, the *aim of this research* is to develop theoretical and methodological aspects of R&D tax incentive policy as well as to provide empirical evidence on its effectiveness in a cross-country setting.

The research is intended to answer the following *research questions*:

1. What is the role of R&D tax incentives in the policy mix to promote R&D and innovation?
2. What are the main practices of R&D tax incentive policy utilised in European countries?
3. How can the decision-making process involved in the introduction and selection of the generosity of tax incentives be structured?
4. What could be a measure of efficient implementation of R&D tax incentives applicable for cross-country comparisons?
5. Are R&D tax incentives effective in incentivising additional R&D and innovation in European countries from a cross-country perspective?

6. Is there a positive association between business R&D expenditure and productivity in European countries from a cross-country cross-industry perspective?

7. What factors play a role in successful implementation of R&D tax incentive policy?

8. How can the effect of more efficient implementation of R&D tax incentives on private R&D investment be evaluated in a cross-country setting?

9. What are the best practices of R&D tax incentive schemes?

10. What are the methodological aspects of enhancing comparability of R&D tax incentive evaluations?

The *objectives* of the study are:

1. investigating the role and the main practices of R&D tax incentive policy utilised in European countries;

2. developing a decision-making model on the introduction of R&D tax incentive schemes and their generosity;

3. analysing the methodological framework underlying the assessment of tax incentives attractiveness and effectiveness;

4. developing a methodology for assessment of the efficient implementation of R&D tax incentive policy;

5. evaluating the first- and second-order effects of R&D tax incentives in terms of additional R&D investment and patent applications in a cross-country setting;

6. assessing the strength of association between business R&D expenditure and productivity in a cross-country cross-industry setting;

7. investigating the reasons behind heterogeneous efficiency of R&D tax policy implementation in European countries;

8. modelling the effects of changes in the efficiency of tax incentive policy implementation on business R&D investment;

9. identifying best practices and desired features of tax incentive schemes;

10. developing a methodological framework enhancing the cross-country comparability of R&D tax incentive evaluations.

Based on the results of the research the following *thesis statements* have been formulated:

1. R&D tax incentives play an increasingly important role in the policy mix to promote private R&D investment and dominate over direct funding of R&D in most European countries.

To verify this thesis statement, the changes in the structure of government support of business R&D were investigated for a set of European countries from 2001 to 2017. The analysis showed that the amount of tax support significantly increased during this period and became a prevailing measure of government support; meanwhile, most countries continued supporting business R&D by direct measures.

2. The policy decisions on implementation and generosity of R&D tax incentives should be consistent and take into account the state of the government budget, the given country's involvement in the international tax competition for foreign R&D capital, and the elasticity of foreign and domestic business R&D investment to the size of tax stimuli.

To make this thesis statement, the historical experience of the introduction of R&D tax incentives and changes in the generosity of R&D tax incentive schemes have been investigated. Logical methods such as comparison and induction were used to build a theoretical decision-making model on implementing and selecting the generosity of R&D tax incentives.

3. The novel indicator of the tax incentive implementation (utilisation) rate can be used as an additional measure of relative attractiveness of R&D tax incentive schemes and as a methodological tool for an assessment of the efficient implementation of R&D tax incentives.

To support this thesis statement, it was demonstrated that the current methodological framework – the B-index – acts as a notional measure of tax support that potentially can be provided; however, it does not reflect other aspects of tax incentive schemes which may affect tax incentive take-ups (such as, for example, attractiveness of tax incentives in terms of their availability, simplicity, and ease of use). The developed indicator of tax incentive implementation (utilisation) rate allows the generosity of tax incentives to be linked with practical implementation of tax incentive policy while taking into account the actual amount of tax support received by firms. The specific tax incentive implementation rates have been modelled for European countries based on the features of national R&D tax incentive systems and the reporting practices on R&D tax expenditures, and further compared to draw conclusions about the relative attractiveness and efficiency of implementation of R&D tax incentive schemes.

4. R&D tax incentives lead to positive first- and second-order effects in terms of additional R&D business investment and the number of patent applications.

To support this thesis statement, a structural equation model was estimated based on the data of 18 European countries for 2015 and 2017, years for which the most comprehensive and reliable data are available. According to preferred models the additional business investment in R&D due to tax incentives was estimated at 1.63 in 2017 and 1.08 in 2015. The figures are in line with the recent OECD microBeRD project (OECD, 2020b) which reports the additionality ratio of 1.409 based on the sample of ten OECD countries (nine European countries and Australia) for the period 2016–2019. The number of additional patent applications by countries' residents is estimated at an average of 59 per 0.10 per cent of tax support in GDP, suggesting that 32.3 per cent of total patent applications in 2017 were due to R&D tax incentives. For the year 2015, on average 37 additional patent applications were induced by 0.10 per cent of tax support in GDP, i.e. 20.5 per cent of total patent applications by countries' residents were due to R&D tax incentives. The model also assessed the additionality in business investment in R&D induced by the direct support of gross expenditure on R&D (GERD). The estimated coefficients are 1.429 for 2017 and 1.671 for 2015, which are in line with the OECD microBeRD project estimates for direct support of business R&D being at 1.373 (the OECD analysis covered twelve European countries and five OECD non-European countries for the period from 2016 to 2019). The higher additionality of direct funding over R&D tax incentives in 2015 could be explained by it being a post-crisis period when many businesses facing difficulties in financing their R&D activities more often used tax incentives as substitutes for their own R&D expenditure, while government funding had a more restrictive nature and often had to be complemented by partial financing of R&D projects through the firm's own funds. The alternative models specified for 2017 and 2015 years have demonstrated that direct government support of R&D outside the business sector brings higher additionality than government support of GERD in terms of growth in business R&D expenditure (1.586 in 2017 and 1.832 in 2015); that is, the government funding of R&D of other sectors, such as higher education institutions, government organisations and non-profit institutions controlled by the government which perform or provide R&D services has a more sizable effect on business investment in R&D. This can be explained by the fact that such types of funding increase the quality of R&D personnel, lead to better infrastructure supporting R&D, and increase the overall level of R&D expertise, which in turn improves the institutional framework for conducting R&D and attracts more business R&D investment. The effect of the corporate income tax rate was not of prime interest; however, based on the 2017 model results it is assessed that a 1 percentage point reduction in a corporate income tax rate leads to a 0.24 per cent increase in business-financed R&D. All estimated effects in the preferred models are significant at 0.01 and 0.05 levels.

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5. There is a strong positive association between business R&D and productivity.

To support this thesis statement a correlation coefficient between business R&D (BERD) and productivity has been assessed at a cross-country cross-industry level (based on NACE Rev. 2 at the 2-digit level) for a number of European countries for which the relevant data were available. The analysis revealed a strong positive association between business R&D and productivity in medium-high technology industries (except for "Manufacture of other transport equipment") and in medium-low technology industries based on the Eurostat high-tech classification of manufacturing industries; a medium-strong and strong positive association in high-technology industries; a lower yet medium-strong positive association for low-technology industries and for "Information service activities"; and a low and not significant correlation coefficient for other high-tech knowledge-intensive services, such as "Telecommunications" and "Computer programming, consultancy and related activities". Therefore, considering that most commonly European countries do not differentiate R&D tax incentives by industrial sectors, the third-order effects of R&D tax incentives in the form of productivity growth may be expected primarily from sectors which have a strong positive association between business R&D expenditure and productivity.

6. Strength of institutions in a country plays an important role in the efficient implementation of R&D tax incentives.

To support this thesis statement, a cluster analysis was conducted based on the computed tax incentive implementation rates of 18 European countries, data on the generosity of R&D tax incentives – tax subsidy rates – provided by the OECD statistics, and the institutional characteristics of countries derived from the World Economic Forum's Executive Opinion Survey, and reflected in the Global Competitiveness Report. Factor analysis was applied to group institutional characteristics into one factor, "strength of institutions", which is highly correlated with the tax incentive implementation rate. The analysis of variance revealed significant differences among the clusters in terms of the tax incentive implementation rate and strength of institutions; however, not in terms of the generosity of R&D tax incentives. This can mean that the main driver of the policy effectiveness is not the potential generosity of R&D tax incentives, but how these tax incentives are implemented and used, along with the institutional framework of a country.

The European countries were grouped into three clusters. The first cluster mainly consists of the British Isles and Scandinavian countries, which have the highest tax incentive implementation rates (the mean is 0.98) and strongest positions in institutional characteristics (the mean is 5.5 in a scale from 1 to 7); the second cluster consists of Western European countries with the average tax incentive implementation rate (TIIR) at 0.80 and the mean value of 4.7 for "strength of institutions"; the third cluster has the lowest average TIIR at 0.29 and the lowest average score for institutions (3.5) consisting of mainly Central and Eastern European countries.

Therefore, the institutional framework of a country should be taken into account when implementing R&D tax incentives. Tax incentive policy supported by strong institutions may encourage firms to use tax incentives.

7. The benchmark tax incentive implementation rates can be used in the modelling of potential additionality effects of R&D tax incentives in countries that have similar institutional characteristics but are lagging behind in terms of the efficiency of implementation of R&D tax incentives.

While institutional parameters of countries are more stable over time, the differences in TIIRs among countries with similar institutional characteristics may be caused by specific features of the tax incentive schemes such as their simplicity, ease of use, lower compliance cost and others, which may be more easily adapted by policymakers. Based on similarity in the institutional setting, the benchmark countries with their TIIRs were identified and applied to countries lagging behind in terms of the efficiency of implementation of R&D tax incentive policy. The analysis revealed that while the latter countries improve their delivery of R&D tax incentive policy, all other things being equal, the average business-financed R&D in the analysed European countries may increase by 0.016 percentage points from 0.73 per cent of GDP to 0.75 per cent of GDP. Further analysis may be applied to adjust the differences in TIIRs caused by the design features of tax incentive schemes, such as limitations in the use of tax relief.

8. Current practices in benchmarking and ranking R&D tax incentive schemes should be further developed and complemented by the additional design features of R&D tax incentive schemes.

Currently there is only one in-depth study conducted by CPB Netherlands Bureau for Economic Policy Analysis in consortium with other organisations (European Commission, 2014a) that ranks R&D tax incentive schemes across multiple jurisdictions in Europe and few non-European countries. Among all other features in the tax incentive design, it considers the refund option of tax scheme available for young firms as the best practice, since innovative firms are not likely to make profits in the first years of their operation. However, tax support in the form of refunds can be also justified for SMEs due to limited financing capabilities of such firms (the United Kingdoms' R&D tax allowance scheme is an example of a good practice). In countries with constrained government budgets an R&D tax credit scheme may be refunded at a discount. Good practice examples of refund options for large companies can be the R&D tax credit in Belgium and the French R&D tax credit ("Crédit d'Impôt Recherche") which are refundable after five and three years, respectively (for the part which is not used). Such a design will incentivise large companies to conduct profitable activity, at the same time providing some certainty in the recovery of their R&D expenditures. Although tax incentives with a strict novelty requirement of "new to the world" are considered by the European Commission as best practices, they may be less available for firms and may not sufficiently cover potentially innovative companies. In such a case the novelty requirement "new to the firm" ("new to the country") may be considered as good practices in countries which are lagging behind in terms of innovation. At the same time, a patent box regime introduced in such a country will incentivise the creation of high-quality patented inventions. Since currently the benefit due to the scheme is restricted by the actual R&D activities performed in a given country according to the OECD's Base Erosion and Profit Shifting Plan, firms have limited possibilities to shift their income and oversubsidising is less likely to take place.

Some additional features of R&D tax incentives should be added to the assessment of good practices, such as taxability of R&D tax relief, treatment of costs of R&D audits, eligibility of qualified prototype and pilot model expenses, applicability of tax relief based on timing of R&D expenditures incurred, availability of advance approval for future R&D projects, and the possibility to redeem tax relief against other taxes instead of receiving cash-refunds. Accounting for the aforementioned features will allow improving the benchmarking practices and more fully account for desirable design features.

9. Developed methodological framework of the B-index for loss-making firms and approaches to TIIR computation will allow increased cross-country comparability of the estimates of the R&D tax incentives' effectiveness and the efficiency of their implementation.

To demonstrate the potential sources of discrepancies among studies, the tax price of R&D was modelled according to different approaches to its computation applied in R&D tax incentive evaluations. The results showed that the tax price of R&D may significantly vary based on the methodology used, which may further affect estimates of policy effectiveness. To improve cross-study comparability of the estimates of the R&D tax incentives' effectiveness, an approach to R&D tax price computation was developed to account for carry-forward provisions (i.e. modelling carry-forwards for deductible R&D expenses; discounting tax credits based on the average period of their recovery) and cash refunds (discounting cash refunds of R&D tax credits where applicable). The developed methodology will allow more precise estimation of the tax price of R&D for loss-making firms and will lead to more reliable estimates of the effectiveness of R&D tax incentives.

The comparability of the introduced measure of TIIR can be improved by:

– calculating the weighted tax subsidy rates for European countries where such data are not currently available, especially those which impose limitations on the use of R&D tax incentives;

– estimating R&D tax expenditures on an accrual basis (accrual estimates allow disregarding the differences in TIIRs that may arise due to better economic conditions of firms affecting their profitability status);

– reporting of R&D expenditure on net of tax basis (will better reflect the size of tax stimuli and will lead to more precise estimates of TIIRs);

– aligning tax incentives used for the computation of the B-index and for the estimating the amount of tax support of R&D (tax incentives that are not modelled in the B-index should be excluded from the amount of tax support for the purpose of calculating TIIRs).

The research *contributes to the existing literature* on the methodological aspects of the B-index framework (Warda, 2001, 2005), which is widely used in the recent studies assessing the effectiveness of R&D tax incentives (Agrawal, Rosell, and Simcoe, 2020; Dechezlepretre et al., 2020; Guceri and Liu, 2019; Rao, 2016; Holt, Skali, and Thomson, 2021) and official countries' evaluations of R&D tax incentive policy (Scott and Glinert, 2020; Fowkes, Sousa, and Duncan, 2015). Moreover, it supplements the existing literature presenting the evidence of additionality of R&D tax incentives in a cross-country setting (OECD, 2020b; Thomson, 2017). It further contributes to the studies on the desired characteristics of R&D tax incentive schemes (European Commission, 2014a). The research identifies *a novel method* for assessing the effectiveness of implementation of R&D tax incentives through TIIR (TIUR) and demonstrates its applicability in policy analysis. Furthermore, summarising the historical experience of the introduction of R&D tax incentives schemes and current trends in R&D policy applications, *a new decision-making model* on the introduction and selection of the generosity of R&D tax incentives is developed that can support policymakers.

The OECD and Eurostat *data sources* were extensively used in the research. Specifically, "Science, Technology and Patents" by the OECD provided data on R&D tax incentive indicators (i.e. the amount of tax support of R&D and tax subsidy rates on R&D expenditure) and research and development statistics, complemented by more detailed statistics of Eurostat on gross domestic expenditure on R&D by sectors of performers and source of funds and statistics on business enterprise R&D expenditure by NACE Rev. 2 activity and source of funds, and by size class and source of funds derived from "Science and Technology" database. Supplemented by other OECD and Eurostat datasets (such as "Industry and Services", "National Accounts", "Globalisation", "Industry, Trade and Services structural business statistics"), these data were the core of the investigation. Additionally, the database of the World Intellectual Property Organization (WIPO) served as a source of data on the number of resident patent applications by country, and the Global Competitiveness Report published by the World Economic Forum informing about countries' institutional scores served as a basis for the cluster analysis.

The study *consists of three chapters*. The first chapter describes the role of tax incentives in promoting business R&D and main practices used in shaping R&D tax incentive policy in European countries. The main choices in the policy design are investigated and a decision-making model on implementation and generosity of R&D tax incentives is introduced. The methodological approaches to R&D tax incentive evaluations and the evidence on the policy effectiveness are described.

The second chapter describes the drawbacks of the B-index model as a sole indicator of the attractiveness of the R&D tax incentive system, and suggests a novel complementary approach to analysing the attractiveness of tax incentives considering efficacy of their implementation, namely the tax incentive implementation (utilisation) rate. It further develops and evaluates a structural model of first- and second-order effects of R&D tax incentives in European countries. The strength of association between productivity and business R&D expenditure is assessed at a cross-country cross-industry level as a potential source of positive third-order effects of tax incentives.

The third chapter investigates the heterogeneity in the efficiency of implementation of R&D tax incentives in European countries and the potential factors which may cause such differences. The strength of association between tax incentive implementation rate and strength of institutions in European countries is assessed. Cluster analysis is conducted to group countries based on similarities in their institutional framework and efficacy of policy implementation. Furthermore, the application of tax incentive implementation rate in the policy analysis is demonstrated; the relevant TIIRs are calculated and analysed for 20 European countries (including Turkey) from 2001 to 2019; in addition, modelling of tax support and additional business R&D investment is performed based on the benchmark countries' TIIRs. The chapter further describes the benchmarking of European R&D tax schemes and proposes additional criteria to identify best practices. The necessity of improving the cross-study comparability of existing methods of estimating the tax price of R&D is pointed out, and new approaches for its computation are introduced. The directions of improving the comparability of the introduced measure of TIIR are described.

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CHAPTER 1. SHAPING RESEARCH AND DEVELOPMENT (R&D) TAX INCENTIVE POLICY: METHODOLOGY AND PRACTICES

1.1 The role of R&D tax incentives in the policy mix for supporting business research and development

Research and development (R&D) tax incentives have become an increasingly important instrument in the policy mix to stimulate private R&D in many countries around the world. Over the past several decades the number of OECD countries promoting R&D tax incentive schemes has increased from twelve in 1996, to nineteen in 2006, to thirty in 2018 (OECD, 2019a). Moreover, most countries have made many changes to tax incentive schemes to increase their generosity and attractiveness. Along with the persistent direct government funding of R&D in most OECD countries, the total government support of R&D has increased significantly.

From the classical point of view, underinvestment in R&D is justified due to the high risks associated with R&D activity and decreased innovator's benefits due to knowledge spillovers. However, currently this is no longer the sole justification for the public support of private R&D. Most countries have been adopting goals-based policies considering R&D as a key driver of productivity and economic growth. The Europe 2020 strategy emphasised the impact of R&D on long-term growth and employment and set the aim of increasing combined public and private investment in R&D to 3 per cent of GDP by 2020 (European Commission, 2010). In support of this strategy, all EU Member States set individual goals for the desired level of business R&D that can be achieved by raising either domestic or external R&D investment. Given the mobile nature of R&D investment and intellectual property (IP), governments strive to provide more beneficial tax treatment, engaging in international tax competition and adapting their R&D tax incentive policies to general trends.

Governments can choose between two main ways to support private R&D spending: direct financing (such as grants, subsidies and the like) or tax stimuli for R&D, or a combination of the two. Direct financing helps to support strategic goals of state R&D policy by providing support for a limited number of carefully reviewed R&D projects; however, it leaves the market little freedom to choose which research and development should be conducted and how. If a country's project selection process is not clear enough and is rooted in political interests, it can discourage firms from even undertaking R&D projects, especially those with high risk or a low private rate of return. In such a climate, tax incentives are more neutral (and hence favourable) to R&D performers as they encourage firms to take more initiative based on their own market insights. Moreover, in today's globalised competition and fast-changing technology environment, firms might be better allocators of resources as they can react more quickly to technological and market changes (Carvalho, 2011). At the same time direct measures may be better suited to support R&D activity in areas of public interest which provide "common goods", such as defence or a clean environment. They may also be a better option when prompt support of R&D efforts is dictated by societal needs, for example, vaccine development ensuring public health security in emergencies.

In the early 2000s direct financing of R&D was the main measure of government support of business R&D, while indirect government support through tax incentives was provided in only nine European countries (Figure 1).

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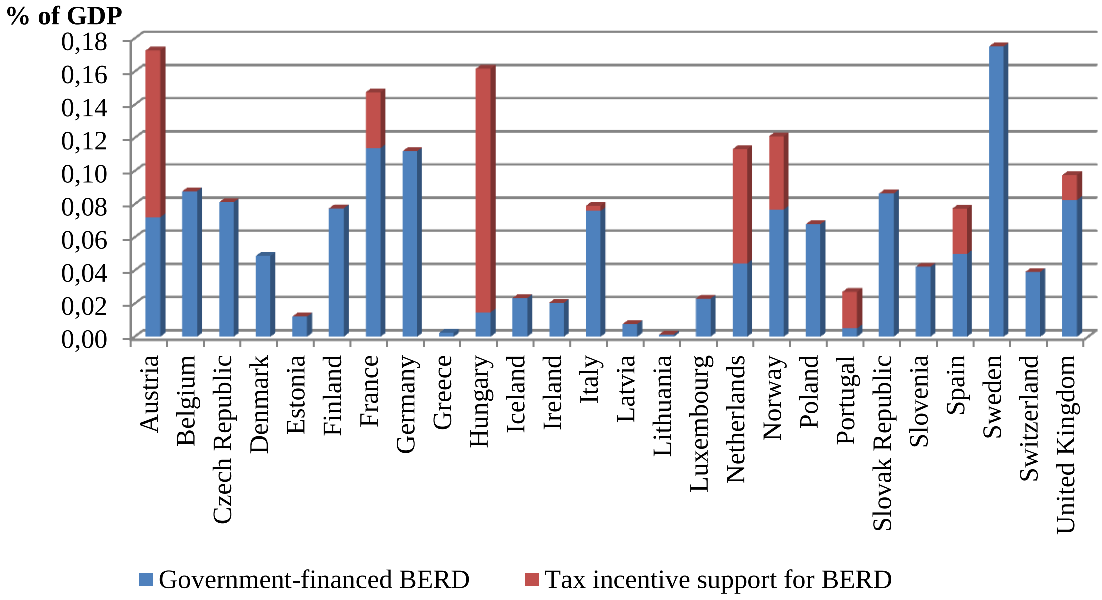

***Figure 1* – Direct government funding and tax support for business R&D in European countries, 2001**

Note: figures for Austria are for 2002, for Hungary 2004, for tax incentive support in Norway 2002, for Luxembourg and Switzerland 2000, for Spain 2002.

Source: own construction based on the OECD Science, Technology and Patents Database – R&D Tax Incentive Indicators, July 2021 (OECD, 2021a.).

The highest amount of tax support for business enterprise R&D expenditure (BERD) as a percentage of GDP was provided in Hungary, Austria, and the Netherlands, which prevailed over direct financing in those countries, followed by Norway, France, Spain, Portugal, the United Kingdom and Italy with less significant R&D tax support. At the same time the coverage of BERD by tax incentives differed significantly: while in Hungary 41.6 per cent of BERD was financed through tax incentives (note the low level of BERD – 0.35 per cent of GDP), in Austria the share of supported business R&D expenditure was 7.3 per cent (where BERD is 1.38 per cent of GDP), and 7.1 per cent in the Netherlands (where BERD is 0.98 per cent of GDP) (OECD, 2021b).

In the following years, the internationalisation of the markets and the strategic focus of many OECD countries on R&D as a key factor of competitiveness and economic growth brought new attitudes towards R&D tax incentive policies. While direct financing can be applied to a limited number of applicants (OMC Crest Working Group, 2006), tax incentives are more suited in principle to encourage R&D activities oriented towards the development of applications that have the potential to be brought to the market within a reasonable timeframe (DSTI/IND/STP, 2016). Therefore R&D tax incentives can be a better means of attracting the R&D activities of multinational corporations, which typically account for a substantial share of business R&D expenditure. Besides, compared with direct subsidies, tax incentives tend to be more compliant with international trade and competition rules (OECD, 2014). Exemptions from international agreements made tax support for R&D one of the few ways that governments could help domestic firms improve competitiveness without direct state aid.

From 2001 to 2017 the distribution of direct and indirect (tax incentive) support for private R&D was changing among European countries. Many of them introduced R&D tax incentive schemes that align with direct government measures, resulting in an increase in total government support provided. The most significant growth of total government support for

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R&D in GDP was in Belgium (0.28 percentage points), France (0.25 pp), the United Kingdom (0.20 pp), Iceland (0.21 pp) and Ireland (0.17 pp). While in Iceland the growth was equally attributable to the increase in direct and tax support for R&D, in Belgium, France, the United Kingdom and Ireland, it was mainly affected by R&D tax incentive policies (Figure 2).

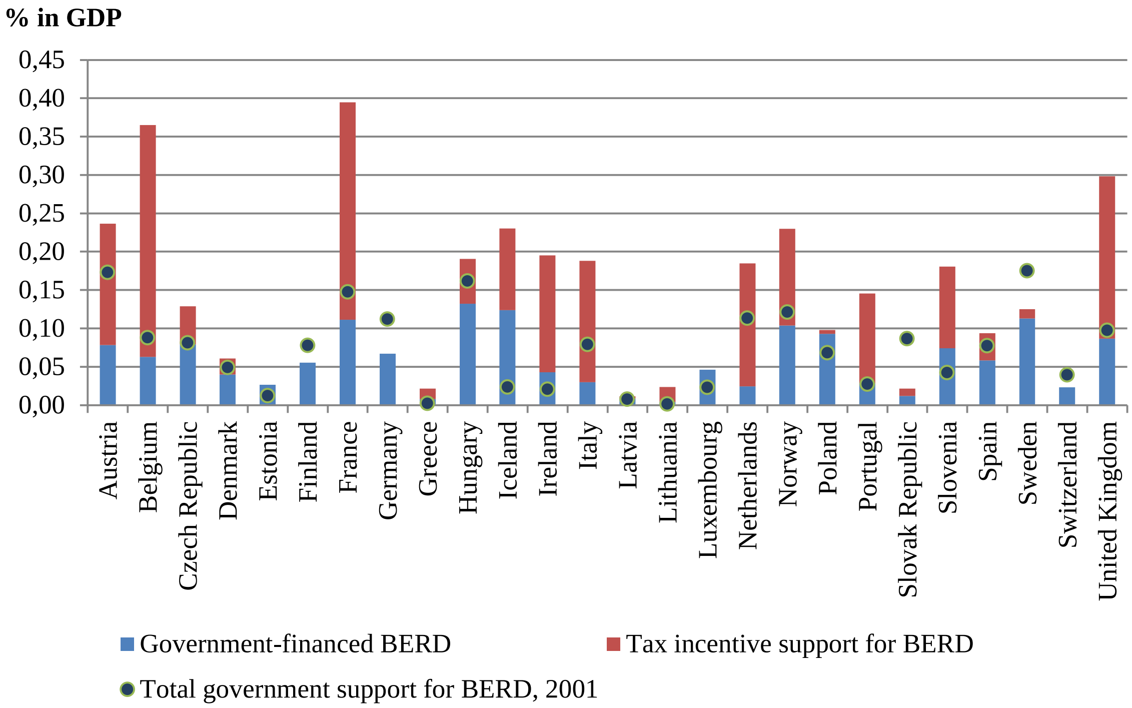

Figure 2 **– Direct government funding and tax support for business R&D in European countries, 2017**

Note: figures for Greece are for 2016.

Source: own construction based on the OECD Database – R&D Tax Incentive Indicators, July 2021 (OECD, 2021a).

Direct financing over the same period decreased significantly in the Slovak Republic, from 0.09 per cent of GDP in 2001 to 0.01 per cent of GDP in 2017, and in Sweden from 0.18 per cent to 0.11 per cent of GDP. Besides, they were among the last countries to introduce R&D tax incentives (2014 in Sweden, 2015 in the Slovak Republic[1]), providing relatively low tax support (around 0.01 per cent of GDP). In Italy the decrease in direct financing of private R&D, from 0.08 per cent to 0.03 per cent of GDP, was offset by tax support, which grew since the adoption of more generous R&D tax incentive schemes from 0.05 per cent in 2015 to 0.18 per cent of GDP in 2017.

In contrast, direct support of R&D in Hungary over the period 2004–2017 increased from 0.01 per cent to 0.13 per cent of GDP (with a temporary drop in 2016), while tax support of R&D dropped from 0.15 per cent to 0.06 per cent of GDP, mainly due to reductions in corporate tax and social security contribution rates, which decreased the significance of tax incentives.[2] Some countries (Germany [up to 2020], Switzerland, Finland[3]) do not offer R&D tax incentives or have adopted a limited amount of them (for example, Denmark up to the end of 2019 offered tax credit for deficit-related expenditures only); however, they have

[1] Until 2015, an R&D tax allowance in the Slovak Republic was only available to grant recipients.

[2] In Hungary the value of R&D tax deductions is directly linked to the corporate income tax rate (R&D tax allowance) and social contribution rate (SSC exemption).

[3] The R&D tax incentive scheme introduced by Finland in 2013–2014 was only temporary.

a relatively high level of business investment in R&D due to overall high competitiveness of their national economies (2.03 per cent, 2.26 per cent, 1.59 per cent and 1.78 per cent of GDP, for the afore-mentioned countries, respectively, with the EU average at 1.14 per cent of GDP in 2017) (OECD, 2021b). At the same time, the proportion of business enterprise R&D expenditure financed by the business sector from abroad constituted only 6 per cent in Germany in 2015, and only 4 per cent in Denmark (having decreased from 11 per cent in 2003), while in some countries which adopted R&D tax incentive schemes the percentage was higher (for example, 19 per cent in Austria, 16 per cent in the United Kingdom, 14 per cent in Belgium and in Hungary, 12 per cent in Norway, and 10 per cent in the Netherlands) (Eurostat, 2021a). Therefore, government support of R&D, particularly through R&D tax incentives, may play a role in the internationalisation of R&D investment.

1.2 Implementation of R&D tax incentive policy: main stages and choices

1.2.1 Design and administration of R&D tax incentives

Appropriate design of R&D tax incentive policy is found crucial for its effectiveness (OECD, 2003; European Commission, 2003). When considering the implementation of tax incentives, policymakers should precisely answer the following questions:

1. Which activities, industries, and types of firms are to be encouraged?
2. What forms of tax incentives should be considered?
3. What will the administrative process be?
4. What methods will be used to evaluate the effectiveness of the selected tax incentives?

Most often countries do not limit eligibility to particular industries, but instead may define qualifying features of products and services, or designate broad fields to be eligible. For example, in Belgium, the company must certify that the aim of R&D is to develop products and services that are innovative in the domestic market and will not have a negative impact on the environment (or that the company has taken steps to mitigate that impact). In Italy the R&D tax credit is extended to apply to innovation expenditure in the field of "green transition" and Industry 4.0 digital innovation (Deloitte, 2020a).

Additional key aims of introducing tax incentives policies are to provide support to small and medium-sized enterprises (SMEs); to stimulate cooperation between industry and public research institutions and universities; and to encourage patenting activity.

Since small businesses have high innovation potential but greater financial and technical constraints, some countries have more generous tax incentives for small firms (for example France, Netherlands, the United Kingdom, and Norway) (see Table 1).

Collaboration between universities and industry is critical for innovation and technology transfer, skills development, and the generation of new enterprises. A study by Dumont (2013) on Belgium's R&D tax credits showed that a scheme focusing on research cooperation had a larger positive impact than other schemes (up to July 2008 the payroll withholding tax exemption rate was higher for R&D personnel in companies that cooperate with a university, a higher education institution in the European Economic Area, or a scientific institution registered by the Council of Ministers). Until 2020, tax credit rates for the R&D tax credit in Italy (enforced by the Legge di Stabilità 2015 and replaced by a new tax scheme in 2020) were raised for R&D collaboration with universities and public research institutions. In Finland, currently, the tax deduction for R&D-related research cooperation expenditures is only available as the R&D expenditure tax supporting scheme (introduced in 2021). Companies receive an additional tax deduction of 50 per cent on the costs of research and innovation projects carried out in collaboration with universities and research institutes. In Hungary, volume-based rates of R&D tax allowance for deductible R&D expenses are increased from 100 to 300 in case of cooperation with Hungarian universities or public research institutes.

Table 1 **– Targeted R&D tax incentives**

Country	Firm size	Activity
Belgium		Patenting activity
Italy		Patenting activity Collaboration (until 2020)
Poland		Patenting activity
Netherlands	SME	Patenting activity
Norway	SME	
Spain		Patenting activity
United Kingdom	SME	Patenting activity
Ireland		Patenting activity
Hungary		Patenting activity Collaboration
France	SME	Patenting activity
Lithuania		Patenting activity
Slovakia		Patenting activity
Finland		Collaboration

Note: blank spaces indicate no targeting in these areas.
Source: own construction based on OECD (2022), Deloitte (2020b).

Countries can adopt special tax regimes for intellectual property (IP) to increase innovation activities and foster global leadership in patented technology. The research by Bradley, Dauchy, and Robinson (2015) found that patent boxes – regimes which provide a lower effective corporate tax rate on income derived from patents – may increase new patenting activity by three per cent for each percentage point decrease in taxation. Furthermore, such regimes can create attractive tax environments for the allocation of IP into the country and promote multinational firms to shift their profits from patents from other jurisdictions that will bring additional income to the state in the form of taxes. A study by Alstadsæter et al. (2018) reviewed the impact of patent boxes on patent filing location. The use of patent boxes by the global top 2,000 corporate R&D investors was examined (that accounts for approximately 90 per cent of all global R&D spending). They found that patent boxes have a strong effect on attracting patent filings, particularly for high-quality patents (by value). The paper by de Rassenfosse (2014) notes that over a dozen countries had adopted patent box policies, with two different objectives: attracting mobile IP income (for example, Hungary); and incentivising innovation (for example, Belgium). The author states that a policy aimed at attracting mobile IP income requires an aggressive lowering of the headline tax rate and 'opens the door to a fiscal race to the bottom as more and more countries seek to offer patent box regimes'. Research results obtained by Griffith, Miller and O'Connell (2010) suggest that patent boxes lead to movement of patent holdings towards countries with patent box regimes and away from those without them.

Given the rapid spread of IP tax regimes over the last decade, their implementation could be a reactive measure to maintain tax competitiveness; however, this may result in overall lower welfare due to loss of tax revenues (Griffith et al., 2014, 2010; de Rassenfosse, 2015; Evers, Miller, and Spengel, 2013).

The next question that should be resolved is how to design and implement R&D tax incentives to encourage R&D investment at an appropriate amount to meet economic and political objectives.

R&D tax incentives can take different forms: tax credits, tax allowances, and accelerated

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depreciation associated with investments in R&D. Tax credit allows for the deduction of a certain percentage of R&D expenditures from tax liabilities (according to the tax credit rate). It may apply to either the absolute value of a company's R&D expenditures (volume-based approach), to the increase in R&D spending over a calculated base level (incremental-based approach), or to a combination of both.

The incremental approach is less common as it provides limited or no encouragement to businesses whose R&D spending fluctuates or remains at a steady level (for instance in times of macro-economic volatility). Indeed, incremental-based schemes encourage firms to adopt a cycling R&D behaviour to maximise the benefits of tax incentives (Hollander, Haurie, and L'Ecuyer, 1987). Moreover, they have higher administrative and compliance costs and may distort R&D investment planning (they make a gradual increase in R&D investment more attractive).

Thus, many countries over the last few years have replaced their more complex hybrid volume and incremental-based schemes with simpler and more generous volume-based schemes (for instance, France in 2008, Ireland in 2015, and Italy in 2020) (see Table 2).

Table 2 **– R&D tax incentives by type of tax scheme**

	Level of R&D	Increment of R&D	Hybrid
R&D tax credits	United Kingdom (large firms) France (from 2008) Belgium Netherlands Germany Ireland (from 2015) Austria Iceland Ireland Norway Hungary Italy (from 2020)	Italy (until 2020)	Spain Portugal France (until 2008) Ireland (until 2015)
R&D allowances	Belgium United Kingdom (SMEs) Denmark Hungary Romania Slovenia Greece Lithuania Hungary Slovak Republic (grant recipients)*		Czech Republic Slovak Republic

*Note: *R&D tax allowance provided exclusively to recipients of public funded grants.*
Source: own construction based on OECD (2020a) and Deloitte (2020b).

R&D tax credit in some countries (e.g. Spain and Portugal) is both incremental and volume-based, even though either of these tax schemes could be mutually exclusive.

Tax allowances enable firms investing in R&D to deduct more from their taxable income than they actually spend on R&D. For example, in the United Kingdom small and medium-sized companies qualify for a 230 per cent super deduction of qualifying expenses. In Hungary, a 200 per cent super deduction is granted for qualifying expenditure where the R&D activities are carried out within the scope of the taxpayer's business activities.

Although there is not a big difference between tax credits and tax allowances in the reduction of the after-tax cost of R&D (as they can be made equivalent), tax credits have become a more popular measure. This tendency can be explained from an administrative point of view. As tax allowances vary with the corporate tax rate, they need to be adjusted to these rate changes, thereby causing additional administrative difficulty (Lester and Warda, 2014).

As R&D expenditure may precede revenue generated by innovation by several years, it is good practice to provide a carry-over facility and the option to receive the benefit even in the case of a company not being profitable (cash refunds). This is especially relevant for young companies that typically are not profitable in the first years of their operation. For example, in France, a volume-based tax credit may be carried forward for three years. If it is not utilised within this period, the taxpayer is entitled to a refund. Indeed, new companies, young innovative companies, SMEs, and companies with financial issues can request an immediate refund of unutilised credits.

Table 3 **– Treatment of excess claims by country**

	Carry-forward	Refund
R&D tax credits	Belgium Ireland France Spain Portugal United Kingdom Hungary	Norway Belgium (after five years) Ireland France (SMEs; large firms after 3 years) Spain United Kingdom (large companies) Austria Germany Iceland Ireland Italy Norway Denmark
R&D allowances	United Kingdom Belgium Netherlands Denmark Slovak Republic Czech Republic Greece Hungary Lithuania Romania Slovenia	United Kingdom (SMEs)

Source: own construction based on OECD (2020a).

The United Kingdom provides cash credits for SMEs in a loss position up to 32.63 per cent of qualifying expenditure. Cash credits are available as well as for large companies under the R&D expenditure credit scheme if the company does not have corporate tax liabilities. Unused benefits may be carried forward for utilisation in future periods. In Belgium there is no immediate refund of tax credit. If it is not utilised it can be refunded only after 5 years.

Where a government seeks to maintain control over the budget allocated to tax incentives, it can put a ceiling on the amount that a firm can claim. There are two types of ceilings: a cap on the absolute amount of R&D that can be claimed (Norway, France, Austria, Portugal), or a cap on the maximum amount of the tax incentive that can be deducted (Hungary, Italy, Spain). Limits can be defined as absolute amounts or as a percentage. While the presence of an absolute upper ceiling reduces the overall cost of support by limiting the absolute amount of R&D expenditure or tax relief that a firm can claim, it may also reduce the incentive effect at the margin among large firms, which typically have higher levels of R&D. In contrast,

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proportional limits reduce tax support for all eligible firms regardless of their size. For example, in Hungary, the R&D tax credit can be applied to reduce up to 80 per cent of tax liabilities. Meanwhile, Norway limits the absolute amount of qualifying expenditures. The maximum base is 25 million Norwegian krone in the tax year for projects based on the taxpayer's own R&D and projects based on R&D purchased from institutions approved by the Research Council. In the case of a rapid increase in R&D activity, the limiting of the maximum amount of tax relief as a percentage of corporate tax liability may reduce the risk of a significant decrease in tax payments and provide a certain level of corporate tax revenues.

Threshold-dependent rates imply a discrete reduction in the size of the R&D tax credit or allowance rate once qualified R&D spending surpasses a pre-defined threshold amount. For example, in France an R&D credit is equal to 30 per cent for the first 100 million euro of qualifying R&D expenditure incurred during the tax year. The rate is reduced to 5 per cent for qualifying R&D expenditure exceeding that amount.

A ceiling is applied by most of the countries that use R&D tax incentive schemes and serves to spread R&D budgets over time and over subcontractors, and can be an indirect way to target tax incentives based on firm size.

If countries wish to stimulate at least the base amount of a company’s R&D investments they can put a floor on R&D expenditure. This type of limitation is less common and used in only a few European countries in the form of a base amount of an incremental part of the scheme (Portugal, Spain, the Slovak Republic, the Czech Republic). Setting a floor on R&D expenditure can have the practical advantage of avoiding administrative costs that are high compared to the fiscal incentive, but can put young innovative firms at a disadvantage, as they tend to have lower R&D budgets.

Another popular form of tax incentives is accelerated depreciation provisions for R&D capital that allows recovery of the investment more quickly than the underlying economic depreciation of the long-lived asset (an immediate write-off, e.g. in Spain and the United Kingdom, or accelerated write-off of expenditures, e.g. in Belgium and France). According to OECD R&D statistics (OECD, 2021c), capital expenditure accounts for less than 10 per cent of total R&D expenditure across most OECD countries, which lowers the significance of such incentives for taxpayers.

When designing expenditure-based R&D tax incentives eligible expenses must be defined. They may include current R&D expenditures or parts thereof (for example, wages), capital R&D expenditures or parts thereof (for example, machinery and equipment or buildings), and all expenditures for R&D (current and capital). Qualifying all R&D tax expenditures enlarges the incentive for companies, but increases the public cost of the policy. For example, in Germany only current expenditures are eligible for tax credit. In France eligible expenditures include general and administrative expenses, depreciation allowances for R&D assets, staff expenses, contract research costs, patent costs and costs of technological monitoring, while materials used in the research process do not qualify. While Spain and France allow accelerated depreciation only for machinery and equipment, in the United Kingdom and Belgium it is applied for all capital R&D expenditures. In Sweden only wages and salaries paid to R&D personnel are qualifying expenditures.

Tax incentives based on the wage bill paid to researchers have a practical advantage in lowering administration and compliance costs and can be considered better practice from the point of view of spillover effects (European Commission, 2014a). At the same time, if scientists’ labour supply is inelastic, such types of incentives may have an upward effect on the wages of R&D workers due to a rise in their demand and not lead to a real increase in R&D effort[4].

[4] Such an effect was described by Goolsbee (1998) for federal R&D spending in 1968-1994, which was mainly allocated in defence and space sectors (around 70 per cent of federal R&D spending).

Government can provide tax incentives in the form of a reduced corporate tax rate (for example, a “patent box” or “innovation box” regime). The types of IP that qualify for preferential tax treatment vary. For instance, in addition to patents, Italy includes “know-how”, designs and models as qualified IP for tax benefit purposes. In the Netherlands only SMEs may include unprotected IP in the innovation box.

By combining different schemes, government can achieve several policy goals. For instance, the Netherlands offers fiscal incentives on labour costs (“WBSO”), R&D tax allowances for capital costs and certain current costs (consumables) (merged with WBSO scheme in 2016), and an innovation box. Belgium, in addition to payroll withholding tax credit, innovation box and R&D tax credit for capital expenditure, also offers accelerated depreciation for assets used in R&D. Thus, some countries simultaneously stimulate R&D investments, patenting activity, and spillovers.

After designing tax incentives some important administrative questions should be resolved: the necessity of pre-approval of qualified R&D expenditures and requirements for mandatory documentation to support the claim. Sometimes usage of pre-approval may be explained by particular features of the R&D tax credit. For instance, in Belgium for the application of an R&D investment deduction applied to R&D investments beneficial to the environment, the taxpayer must file a claim for environmental certification through regional authorities. Most countries do not require initial approval, but oblige firms to maintain supporting evidence (e.g. information, records, documentation) in the event of an audit by tax authorities (e.g. the Czech Republic, Lithuania, Italy). Other countries have record-keeping substantiation requirements only for particular entities, depending on the level of R&D expenses (e.g. France), or those firms who chose to obtain a cash refund for unutilised tax credits instead of carry-forward provisions (e.g. Spain). The absence of approvals mentioned above lowers administrative barriers to the utilisation of tax incentives, but reduces government control of qualifying R&D expenditures.

1.2.2 Determining the generosity of R&D tax incentives

When adopting R&D tax incentive schemes the government has to determine its level of generosity. In terms of international competition for R&D capital tax incentives should be aimed not only at reinforcing the internal R&D base, but also at making the country more attractive to external R&D investment. The key indicator which allows cross-country comparisons of the generosity of R&D tax incentives, known as the B-index, was developed by Warda and McFetridge (1983), and is widely used with some extensions by OECD countries today to monitor changes in the level of attractiveness of R&D tax treatment. The B-index is calculated as the present value of before-tax income that a firm needs to generate in order to cover the cost of an initial R&D investment and to pay the applicable income taxes (Warda, 2001). The notional tax subsidy rate, calculated as 1 minus the B-index, shows how many monetary units of government tax support are provided for an additional monetary unit of R&D outlay.

Determining the potential generosity of R&D tax incentives is important when implementing R&D tax incentives or introducing changes in tax treatment for R&D in order to predict possible outcomes of the policy. The decision-making process involved in adopting R&D tax incentive schemes and determining its generosity can be described with a model (Figure 3). The model can be applied by countries which prioritise innovation development of the economy and recognise the importance of tax assistance in achieving R&D state targets.

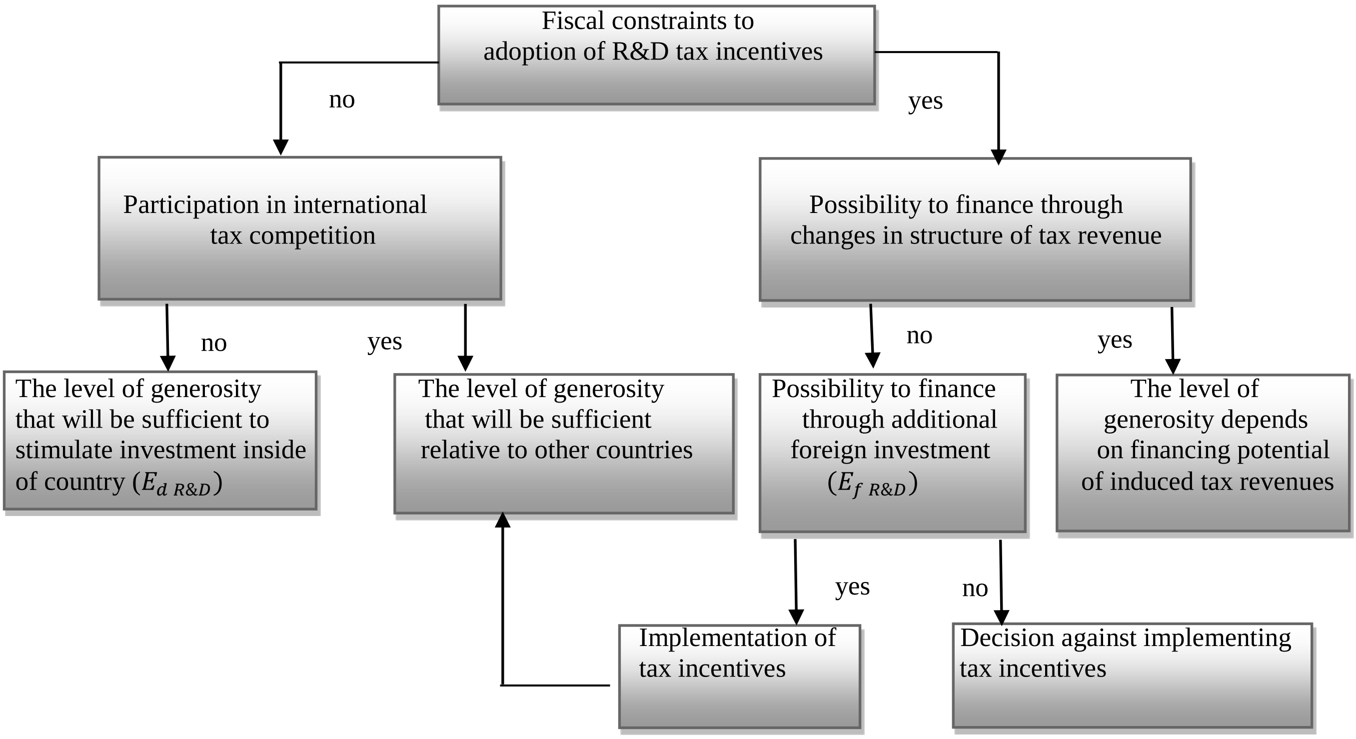

Figure 3 **– Decision making model on implementation and generosity of R&D tax incentives**

Note: $E_{d\ R\&D}$ and $E_{f\ R\&D}$ indicate elasticities of domestic and foreign business investment, respectively, to R&D tax incentives.

Source: own construction.

The key points in the decision-making process are the existence of fiscal constraints to the adoption of R&D tax incentives and the country's openness to international investment. A country which has disciplined public finances has more flexibility when designing tax incentive schemes. However, in the presence of fiscal constraints, a government should consider possibilities to finance future tax relief. It may decide to increase tax revenues through changes in its structure (for example, by increasing tax rates, broadening the tax base or removing unjustified tax expenditures), or it may introduce R&D tax incentives, expecting that they will attract additional investment primarily from the foreign business sector that will contribute to tax revenues of the domestic economy. In this case, the elasticity of foreign R&D investment to tax parameters is important.

Thus, after joining the European Union in 2004 the Czech Republic and Slovenia introduced R&D tax incentives in 2005, expecting that with lowered entry barriers to foreign direct investment these tax benefits may attract additional foreign investment in R&D. At the same time, the existing Member States responded to increased competition from the new entries by similarly adopting R&D tax incentives, or increasing the generosity of existing R&D tax incentives. For example, Ireland launched its R&D tax incentive scheme from 2004, Belgium offered additional R&D tax incentives in 2005 and Italy in 2007, while France increased the generosity of existing R&D tax incentives in 2004 by incorporating a volume-based element in its incremental scheme (the tax incentive could be applied additionally to the absolute amount of R&D rather than to the increment only). Furthermore, the specific objective of France's 2008 R&D tax credit reform replacing the hybrid scheme by volume-based was both to attract foreign R&D investments and deter French firms from relocating their R&D to other countries (Mairesse and Ientile, 2008).

When designing R&D tax support measures it should be taken into account that the distribution of foreign R&D investment and foreign direct investment varies; moreover, generous tax incentives do not always lead to additional R&D investment. For example, Spain and Portugal offer generous tax incentive schemes for R&D; however, BERD financed by business sector from abroad constituted only 0.03 per cent of GDP in Spain, and only 0.01 per cent of GDP in Portugal in 2017, which is significantly lower than in other European countries providing tax support for BERD (for example, 0.12 per cent in Slovenia, 0.16 per cent in the Netherlands, 0.34 per cent in the Czech Republic, 0.42 per cent in Austria, and 0.14 per cent in Hungary and the United Kingdom) (Eurostat, 2021a). At the same time, foreign direct inflows in Portugal and Spain were at 3.1 and 3.2 per cent of GDP respectively, which is higher than the European Union (28) average (2.1 per cent of GDP) (OECD, 2021d). The reason behind the low elasticity of foreign R&D investment to tax parameters in these countries can be hidden in the fact that their economies are for the large part specialised in activities of low or medium-low technological intensity. Thus, for example, in 2017 R&D expenditure of foreign affiliates in high and medium-high manufacturing as a percentage of their total R&D spending in industry and construction constituted about 90 per cent in Belgium, Hungary, Austria, Finland, Portugal and the Czech Republic, while in Romania almost all R&D expenditure of foreign affiliates (97.8 per cent) were attributed to high and medium-high technology sectors.[5] Therefore, attracting foreign R&D investment in Spain and Portugal by means of tax incentives can prove more difficult.

Some countries have provided an evaluation of their R&D tax incentives in order to assess whether the R&D tax relief is internationally competitive. A review of the Ministry of Finance of Ireland as a part of Budget 2013 revealed that the R&D tax benefit scheme appeared to be an important aspect in tax competition over R&D location decisions and played an important role in attracting foreign direct investment to Ireland (European Commission, 2014a). The evaluation of the Netherlands in 2019 set as one of its objectives to assess whether the WBSO scheme for R&D wage costs contributed to achieving an internationally competitive business climate for R&D-intensive activities (de Boer et al., 2019a). Based on survey results, 34 per cent of companies stated that the WBSO gives the Netherlands a head start over other locations, while through the interviews it was revealed that particularly large R&D intensive companies see WBSO as an important element of Dutch business climate which contributes to attracting or retaining R&D activities in the Netherlands.

If a country relies on tax incentives to spur growth predominantly in domestic R&D investment, it will likely have to factor in a certain time lag before it sees the growth in productivity and tax revenues that those incentives are expected to engender. In such a case, the budget deficit brought about by the R&D tax incentives can be financed through changes in the structure of tax revenues. Historical evidence suggests that during the 2008 global financial crisis, when many European countries had growing budget deficits, Belgium, France, Ireland, the Netherlands, Portugal, Slovenia, and the United Kingdom were among those countries that increased the generosity of their R&D tax incentives, while Lithuania began offering generous R&D tax incentives in 2008 to support private investment (Figure 4). At the same time, various measures were implemented in those countries to offset the negative impact of the tax stimulus on their national budgets. For example, Portugal and the United Kingdom raised their personal income tax rates, whereas Ireland and the Netherlands increased their Social Security Contribution rates. While Lithuania and Ireland chose to up

[5] High- and medium-high manufacturing industries are defined according to Eurostat classification based on NACE Rev. 2.2-digit level.

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their VAT rates, France levied new taxes on financial transactions.

The Czech Republic, Spain and Hungary, who had been offering generous tax incentives in 2007 going into the financial crisis, decided they had to limit their generosity in order to maintain fiscal stability. Taking the opposite approach, Austria, Greece and Italy, which had been relatively stingy with their R&D tax incentives, kept an even keel during the crises, while Norway, which had a significant budget surplus, was in the enviable position of being able to continue supporting private R&D investment through generous tax incentives.

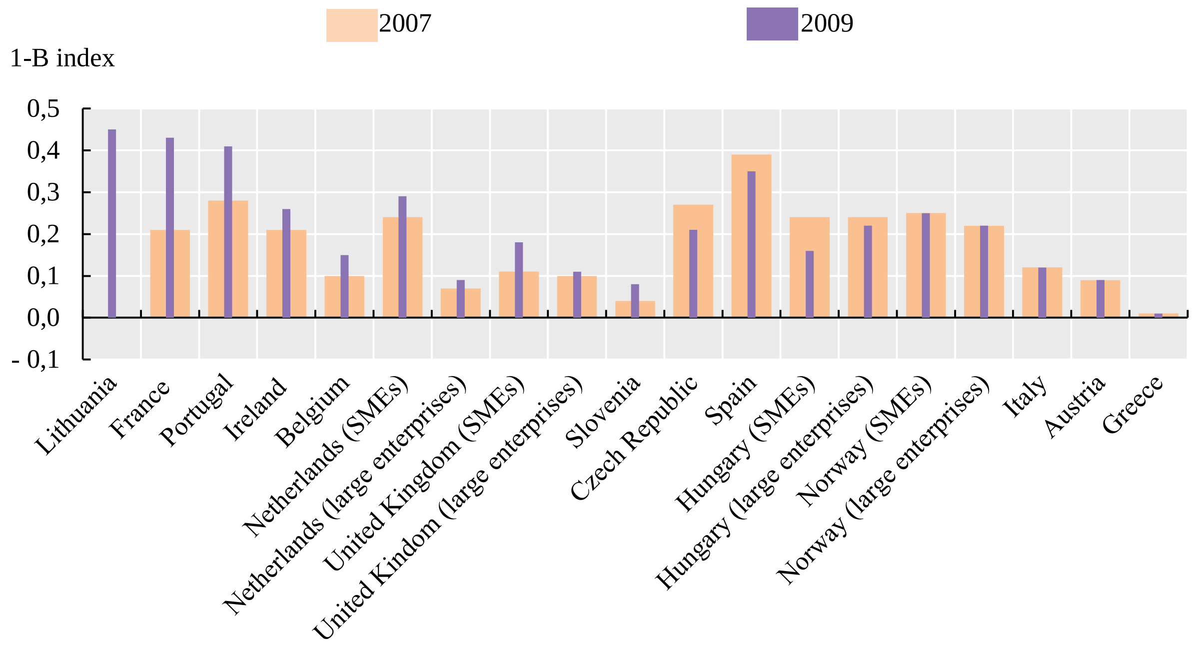

Figure 4 **– Generosity of R&D tax incentives before and during the 2009 financial crisis**

Note: Hungary, the Netherlands, the United Kingdom, and Norway differentiate implied tax subsidy rates depending on the firm's size. Figures for Hungary and Slovenia refer to 2010 instead of 2009, when the changes to R&D tax incentive schemes were introduced.

Source: own construction based on OECD statistics, R&D Tax Incentive Indicators (OECD, 2021a).

A country's openness to foreign investment plays an important role in shaping R&D tax incentive policy.[6] Some countries have a lower degree of openness due to different sort of barriers (for example, investment and trade barriers, restrictions on the labour market, and so on.). As such, they should structure their tax incentives in such a way as to make them attractive primarily for domestic R&D investors, therefore avoiding losses from unwarranted R&D tax giveaways. In fact the evidence suggests that countries with lesser trade openness, such as Italy and Turkey (OECD, 2020c),[7] have lower foreign direct investment stocks relative to GDP and less generous R&D tax incentives. The tax subsidy rate for profit-making enterprises in 2017 was 0.09 in Italy and 0.06 in Turkey,[8] while the OECD median was estimated at 0.19 for SMEs and 0.11 for large enterprises (OECD, 2021a).

As non-tax barriers decline, investment decisions and location of investment become more

[6] Openness here is understood as the degree to which non-domestic actors participate in a domestic economy.

[7] According to the World Indicators of Skills for Employment (WISE) Dataset as of 2014 as the latest year available.

[8] Turkey and Italy do not differentiate tax support depending on the fitrm's size.

tax sensitive (Bernardi, Fumagalli, and Candullia, 2006). If a country has a favourable investment environment and may benefit from additional foreign investment, the generosity of R&D tax incentives is to be determined on a competitive basis. Since tax incentives can affect location choices for R&D investment especially between countries that are similar in other respects, a country while set out to design tax support should refer to the one provided by keen rivals. As an example, Portugal first introduced its R&D tax incentive scheme ("SIFIDE") in 1997 using the Spanish tax incentive scheme as a reference to remain attractive for R&D investment, particularly in relation to its neighbour Spain. Among the reasons for the changes to SIFIDE in 2001 was the change made to the Spanish tax incentive scheme, and that 'the Portuguese tax incentive scheme must remain competitive to similar systems' (Carvalho and Corchuelo, 2013).

In many countries, overall tax relief for business research and development may be greater than governments originally intended when they designed tax support of business R&D expenditures. This may be compounded by the rising generosity of tax incentives for R&D observed in recent years, the full cost of which is not always transparent because R&D tax incentives are "off budget" as a tax expenditure (OECD, 2015). To maintain control over the budget allocated to tax incentives, most governments put a ceiling on the absolute amount of R&D that can be claimed, or on the maximum amount of the tax incentive that can be deducted. Some countries require pre-approval of R&D projects or accreditation of R&D performers for which tax incentives can be claimed and introduce budgetary limits by rationing the number of approved claims. In these cases R&D tax incentives take on features of direct subsidies, which can decrease their attractiveness.

1.2.3 Evaluation of the effectiveness of R&D tax incentives

When designing R&D tax incentives, policymakers should already clearly identify which data will be needed for their evaluation, and how to collect these data. Evaluation is essential in monitoring effectiveness of R&D tax incentives. The main questions that should be answered are: do tax incentives achieve their objectives and to what extent? Clark and Arnold (2005) proposed measuring three types of effects (Figure 5).

The first- and second-order effects normally arise at the firm level, while third-order effects occur at the economy or international level. Moreover, all these effects can reinforce each other through a feedback loop.

Since the main objective of expenditure-based R&D tax incentives is to stimulate private investment, input additionality is a central question. The empirical analysis amounts to comparing the tax expenditures with the additional amount of R&D spent by firms. The policy is said to lead to additional R&D if firms spend in excess of the amount of tax incentives they receive from the government. The policy is clearly ineffective if investment displacement occurs – that is, when firms simply substitute government tax support for private R&D financing.

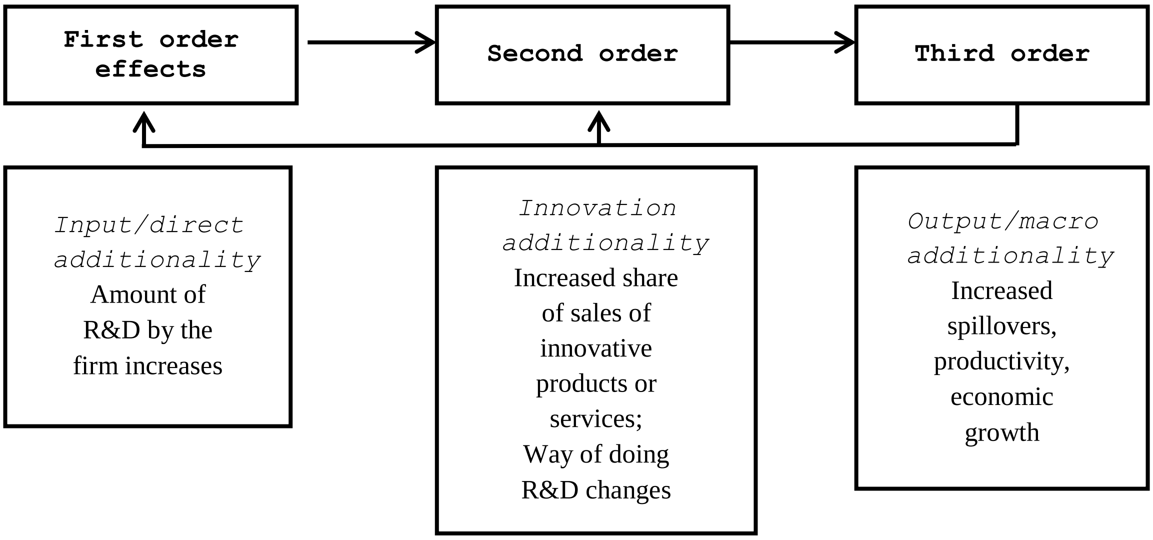

***Figure 5* – Effects from fiscal R&D incentives**

Source: *own construction based on Clark and Arnold (2005).*

Beyond the induced R&D, there remains the question of whether this additional R&D is efficient in generating innovation output (innovation additionality) and ultimately improves economic performance and net welfare (macro additionality). There are different approaches and methodologies that can be used in the evaluation of tax incentive effectiveness (Figure 6).

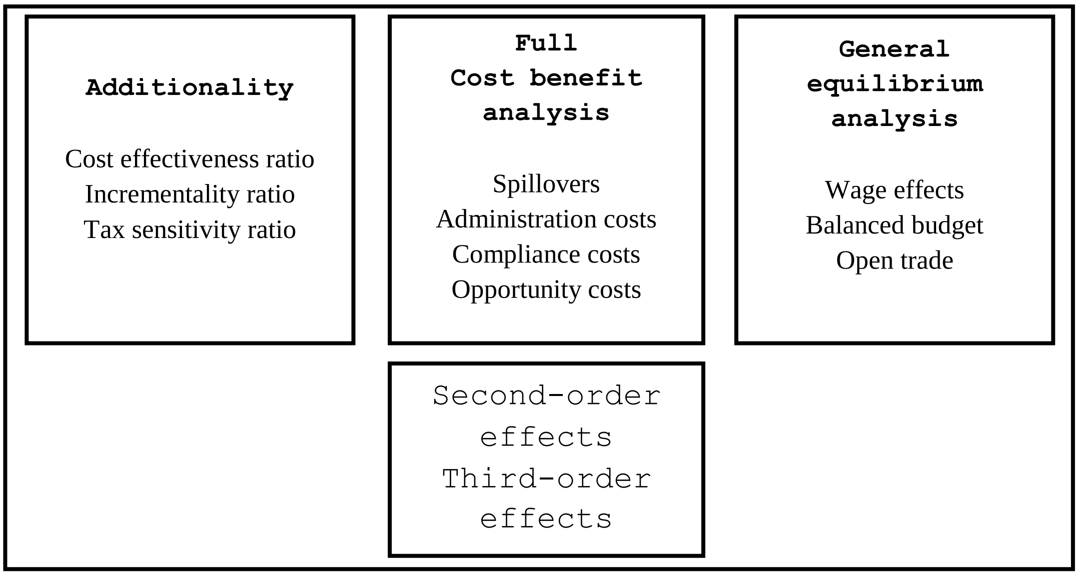

***Figure 6* – Reconciling evaluation notions**

Source: Mohnen and Lokshin (2008).

Testing for additionality generally involves the computation of the "bang for the buck" (BFTB). It is measured by dividing the amount of R&D generated by the R&D tax incentives by the net tax revenue loss (tax expenditures or taxes forgone). The BFTB is also known in the literature as the "incrementality ratio", "cost effectiveness ratio", "tax sensitivity ratio" or "inducement rate" (Parsons and Phillips, 2007).

When calculating tax expenditures, one should consider the change in the firms' tax positions, since the tax credits can be taxable themselves (Hall and van Reenen, 2000).

To isolate the effect of R&D tax incentives on R&D two main approaches can be used:

1. a structural modelling approach;
2. a quasi-experimental econometric evaluation approach.

The *structural approach* has been adopted by institutions such as the U.S. Government Accounting Office (GAO 1989) and the OECD (1997), and it has been developed by several authors such as Hall (1993), Mairesse and Mulkay (2004, 2008) and Lokshin and Mohnen (2007a, 2009).

This approach involves the following steps for estimating the effect of the tax credit on R&D expenditures:

1. computation of the impact of the tax credit on the "effective price of R&D" faced by the firm, or more generally on the "user cost of R&D capital" (actual costs of R&D) for the firm;
2. specification and estimation of an econometric model that relates the changes in the firm's R&D expenditure to changes in the effective price of R&D or in the user cost of R&D capital (elasticity coefficient of R&D expenditure with respect to the user cost of capital is estimated).

Structural modelling allows the evaluation of future reforms and separation of short-term (1 year) from long-term effects (5–15 years). The necessity of distinguishing these types of effects arises due to the fact that induced R&D may take time to show up because of adjustment costs in R&D (devising projects, finding scientists and engineers, and so on). In addition, the long-term effect may be larger because an increase in R&D investments adds to the firm's knowledge base, thereby increasing the marginal payoff of future R&D investments.

A difficulty of the structural approach may be in reverse causality between the amount of R&D expenditure and the user-cost of R&D (Gaillard-Ladinska et al., 2015). A number of R&D tax credit schemes share the characteristic that the size of the tax credit is dependent on the amount of R&D performed, i.e. the lower tax credit rates apply to the higher amount of performed R&D. The user cost of R&D capital thus increases with the level of R&D expenditure, which leads to potential underestimation of the effectiveness of the tax credit. In the absence of a social experiment or suitable instrumental variable, some studies try to reduce this problem by controlling for lagged R&D expenditure and fixed firm effects using a dynamic panel data estimator (examples are Baghana and Mohnen (2009) and Harris et al. (2009)).

The *quasi-experimental evaluation approach* statistically constructs a control group and compares the growth rate of R&D expenditure from before to after the policy reform, for firms just below and just above the eligibility ceiling. It provides convincing ex-post additionality estimates, but unlike the structural approach, it does not allow for the simulation of the impact of changes in the features of the tax credit. Furthermore, it often makes no distinction between short-term and long-term effects.

A comprehensive computation of the effectiveness of R&D tax incentives generally requires a *full cost-benefit analysis* that would compute the total (direct and indirect) costs and benefits related to the R&D tax incentive. On the benefit side, it would mean not just computing the amount of additional R&D but also the return on that R&D. This requires looking into the existence of second-order and third-order effects, i.e. the effects on innovation behaviour and on an economic performance measure like productivity or profitability. Another kind of secondary effect that should be included is an increased producer surplus accompanying an expanded R&D capital stock. A proper analysis of benefits requires incorporating R&D spillovers, which can be positive (knowledge externalities or rent) or negative (market stealing or obsolescence).

The main components of costs are:

1. foregone tax revenues, assessed by taking into account the opportunity cost of public funds;
2. compliance costs of R&D performing firms applying for R&D tax incentives (for example, hiring consultants, accountants, financial experts);
3. tax administration costs of governmental bodies administering the R&D program (for example, hiring auditors, tax officers).

The idea of the analysis is not to estimate all of these various elements, but to conduct a sensitivity analysis by simulating the benefit-cost ratio using ranges of reasonable estimates of R&D, to see what patterns of estimates of the various components that matter would produce positive net results. The limits of the approach are thus mainly due to very imprecise estimations of these various components.

While econometric techniques are well suited to capturing effects that may be quantified in a sensible way, they are not appropriate for identifying behavioural additionality, i.e. changes in the way firms understand R&D and how R&D decisions are made. Here, surveys are a more relevant method. Surveys can be used to assess respondents' views on a tax incentive scheme and its administrative complexity, for example, whether they understand the scheme and how easy they find it to claim tax support. Furthermore, surveys can validate other methods of investigation such as econometric analysis. However, surveys suffer from some weaknesses such as strategic answering, respondent bias in order to maximise respondents' benefit from the R&D tax incentive scheme, high costs of design, implementation and analysis (Warda, 2008). When assessing additionality there is also a suspicion that firms may not know how much R&D they would have done in the absence of tax incentive schemes. To diminish the biases, direct and indirect questions can be applied but there is a trade-off, as using too many questions may produce less credible results (Busom, 2008). The quality of survey answers may also depend on the respondent's status and position within the organisation. To cope with this weakness, in order to reduce systematic biases the survey should be addressed to the financial officers responsible for the decision-making process for utilisation of tax incentives.

After the assessment of R&D tax effectiveness, a government should reach a decision on whether a tax incentive scheme should be continued, modified or abandoned. Thus, it is necessary to take into account a time gap between the introduction of the tax incentive and different types of effects arising (particularly second- and third-order effects). Frequent and substantial policy changes are likely to strongly reduce the effectiveness of policies – regardless of their design (Westmore, 2013).

1.3 Empirical evidence on the effectiveness of R&D tax incentive policy in European countries

The decision to evaluate R&D tax incentives is often based on an ex-post policy need and rarely on an upfront commitment. Having an upfront commitment to evaluate provides an opportunity to ensure that the necessary data are collected. The data available for evaluation will significantly influence the methods used.

The European Commission and European Union Scientific and Research Committee (CREST) identified the following evaluation principles that can be followed by policymakers (European Commission, 2006):

1. the aims and objectives of R&D tax incentives should be clearly defined, as a prerequisite to their proper evaluation;
2. evaluation of tax incentives should focus on:

– direct additionality of tax incentives;
– behavioural additionality of tax incentives;
– testing whether tax incentives have met their specific objectives and whether their delivery and administration mechanism was efficient;
3. the wider societal effects of tax incentives should also be evaluated, but preferably in the broader context of the policy mix supporting investment in research and innovation;
4. tax incentives should be evaluated using a variety of different and complementary methods, aimed not only at estimating their impact but also at estimating their efficiency and administration costs;
5. policymakers should clearly identify which data will be needed for their evaluation, and how to collect these data when designing tax incentives;
6. the independence of evaluators and evaluation processes, whose results should be published and used to inform policy improvements, is important.

At the same time European Commission concludes that evaluation may be based on country-specific approaches, its own experience with tax incentives, unique socio-economic needs and values.

Despite many countries having implemented R&D tax incentives, not all of them conduct official evaluations (i.e. by the government or on behalf of the government by a third party) of their tax incentive policies.

Countries that introduced tax incentives recently may have a lack of information for longitudinal studies and use surveys as the sole source of evaluation. Before the implementation of tax incentives policymakers should define what data is needed for further evaluation of tax incentive policy, what data is missing and how this can be remedied. CREST recommends evaluators to use already available data to avoid any extra burden on companies; otherwise the data have to be collected at a modest cost.

The main sources of data are national statistical agencies and administrative databases assembled by the operating agency for the tax incentive.

Some evaluations use variables for the assessments based on literature review rather than on country's statistical data. For example, the Canada 2007 evaluation uses incrementality ratios and external rates of return (spillovers) from a review of the literature to build a partial equilibrium model (Parsons and Phillips, 2007). Some countries, such as the Netherlands, Norway, and France, extensively use existing statistical databases. For example, for an official evaluation in the Netherlands the panel data were created for the period 2006-2010 using multiple institutional sources, such as the Central Bureau of Statistics and the NL Agency, which administers the tax incentive. The data formed a basis for econometric analyses. The Community Innovation Survey was used to estimate first- and second-order effects, while Production Statistics served for estimation of the third-order effects. Additionally, Business Finance Statistics, Economic Demographic Statistics, and Statistics of National Accounts were used to construct control variables (Verhoeven et al., 2012). An empirical study conducted by Mulkay and Mairstudy (2013) for France relies on the combination of four unique datasets over the period 2004-2010: R&D surveys, administrative tax data, patent datasets, and the Fichier bancaire des entreprises (FIBEN) dataset of the Banque de France, which is used to control for firms' economic and financial characteristics.

Intention and methods used in evaluation depend on policy aims that may include attracting internationally mobile R&D, inducing firms to start conducting R&D, and supporting firms to conduct R&D jointly with universities or other public research institutions.

The most common way to verify whether a tax incentive policy is effective is to test for additionality as opposed to crowding out of R&D (when a firm fully or partly substitutes private R&D financing by tax support). Some rigorous studies find that one euro of foregone tax revenue on R&D tax credits raises expenditure on R&D by less than one euro (Cornet and Vroomen, 2005; European Commission, 2008; Lokshin and Mohnen, 2012; Mulkay and Mairesse, 2013). For example, Cornet and Vroomen (2005) in their evaluation of the effectiveness of changes in the R&D incentive scheme in the Netherlands examined the result of two changes in the Dutch WBSO system that were introduced in 2001: the increase of the ceiling of the first tax bracket from 68,067 euro to 90,756 euro and the introduction of the starter's facility that provides an extra 20 per cent tax credit for firms in the first tax bracket. Using counterfactuals analyses, the authors find that the increase of the first tax bracket ceiling yields a BFTB of only 10 to 20 cents and the introduction of the starter's facility a BFTB of 50 to 80 cents.

Hall and Van Reenen (2000) and Lokshin and Mohnen (2008) note that measuring the bang for the buck (BFTB) is important, but that this does not replace a social cost-benefit analysis. Even if the BFTB lies below one, the scheme may still result in generating higher welfare due to the positive spillover effects. Furthermore, it is more appropriate to compare the whole sequence of costs and benefits in discounted present value terms, as they may be spread out over time because of adjustment costs in R&D, delays in getting the R&D tax credits, or intertemporal connections between tax credits as in the case of incremental R&D tax credits (Dagenais, Mohnen, and Therrien, 2004; Lokshin and Mohnen, 2009).

It should be noted that relabelling and changes in input prices can lead to an overestimation of the impact of R&D tax incentives. The introduction of R&D tax incentives can induce firms, especially those that alredy perform R&D activity, to relabel some non-R&D expenditure as R&D-related. This can be the case for countries with lower control over R&D tax incentive schemes. For example, the study of Chen et al. (2021) finds that 24.4 per cent of the increase in reported R&D in response to a Chinese tax incentive programme was due to relabelling. Only few studies conducted for European countries, to our knowledge, directly investigated relabelling of R&D expenditure and found no signs of it (for example, Guceri and Liu (2019) and Dechezlepretre et al. (2020) for the United Kingdom). A study by Bozio, Irac, and Py (2014) which assesses the impact of 2008 reform of the French research tax credit, suggests checking the possibility of relabelling by evaluating the second-order effects of R&D tax incentives. Poot et al. (2002) in their evaluation of the Dutch tax credit scheme (WBSO) assume that since R&D projects are assessed by the government agency non-R&D activities will not be approved; therefore, they conclude that all R&D tax expenditures are related to 'bona fide' R&D work. It should be noted that relabelling can be justified for firms that were not very precise in classifying their R&D expenditure before the policy change (European Commision, 2014a).

A number of studies have examined the effects of tax incentives on various measures or aspects of innovation (e.g. patents, the share of innovative products in total sales, the propensity to come up with products that are new to the firm or new to the market). For example, Czarnitzki et al. (2011) examines the effect of R&D tax credits on innovation by Canadian manufacturing firms for the period from 1997 to 1999. They find that R&D tax credit has a positive impact on the firm's decision to conduct R&D, and leads to a higher number of product innovations, as well as increased sales shares of new and improved products. Furthermore, firms receiving a tax credit have a higher probability of introducing new products, both to the national Canadian market and to the world market. The 2007 Netherlands' evaluation found a significant positive effect of R&D intensity on the share of turnover from new products and services. Since the WBSO scheme significantly affected the amount of R&D expenditure (i.e. the estimated additionality was at 1.72), it was concluded that WBSO scheme indirectly improves innovation performance of firms (De Jong and Verhoeven, 2007). According to the 2007 Norwegian evaluation (Cappelen, Raknerud, and Rybalka, 2007), the SkatteFUNN tax credit is found to contribute to an increase in the rate of innovation in firms. It helps develop new production processes and to some extent new products for the firm. Moreover, the evaluation reveals that the strongest impact of the tax credit scheme is on the behaviour of firms with no or limited previous R&D activity. The positive effect of the tax incentive scheme SkatteFUNN on innovation is also found in the 2018 evaluation (Benedictow et al., 2018). Westmore (2013) shows that R&D tax incentives are positively related with patenting in a country-level analysis of 19 OECD states. He estimated that a decrease in the B-index of 0.05 raises the number of patents per capita by around 2.5 per cent.

The direct evidence on the impact of R&D tax incentives on productivity is limited. Caiumi (2011) found that the Italian R&D tax incentive program did overall raise the productivity of firms. The impact is, however, very heterogeneous across less and more productive firms. Caiumi notes that the impact was stronger for firms on the lower bound of the productivity distribution.

Lokshin and Mohnen (2007b) used a simultaneous-equations model constructed based on the model proposed by Crépon, Duguet and Mairesse (1998) to estimate the effects of tax incentives on firm's R&D, innovation output and productivity. They report a short-run elasticity of R&D to the user cost of R&D 0.77, an elasticity of the share of innovative sales to the R&D intensity of 0.52, and total elasticity of productivity with respect to tax credit equal to 0.028, implying that a 10 per cent increase in tax credits would increase (labour) productivity by 0.28 per cent.

Despite the hypothesis that additional R&D expenditure induced by the incentive is likely to be less productive than the firm's average (Ientile and Mairesse, 2009), Benedictow et al. (2018) show that R&D induced by the Norwegian R&D tax incentives contributes in the same way to productivity as other R&D.

Several studies have been concerned with the effect of R&D tax credit on wages (price effects). Goolsbee (1998) analysed federal spending on R&D in the United States during the period from 1968 to 1994. He found that a rise in R&D spending by 10 per cent results in an immediate rise in the wages of researchers by one per cent and by another two per cent in the following four years. He concluded that by ignoring this effect, the additionality of government R&D spending may be overestimated by 30 per cent to 50 per cent. This effect was measured during a period with substantial variation in government expenditure, which might explain part of the size of the effect.

A positive relation was also found for the Norwegian SkatteFUNN scheme, where for every 100 000 kroner per R&D man-year that a firm received through the tax credit, each R&D worker received about 33 000 kroner as a wage increase (Hægeland and Møen, 2007). They also noted that this effect is largely driven by small and medium-sized companies, where the subsidy of 100 000 kroner resulted in an average wage increase of 53 000 kroner.

Dumont (2013) confirmed the relationship between R&D tax credits and rise in R&D wages for Belgium. Regressing an average wage (in logarithm) for R&D personnel on the amount of partial exemption from advanced payment he found a statistically significant positive effect on the average wage for the Young Innovative Companies and the partial exemption from advanced payment for R&D personnel with PhD or master's degrees (based on different estimations). Thus, for example, the results suggest that one euro spent on a regional subsidy or partial exemption from advance payment for R&D personnel with master's degree is associated with a wage rise ranging from 0.15 to 0.45 euros.[9] Lokshin and Mohnen (2013) found that the elasticity between the effective rate of the Dutch payroll tax withholding R&D tax credit and average R&D wage is 0.2 in the long run.

While most studies estimate impact on wages related to payroll withholding tax credits, the

[9] Such an upward effect on wages was not found for R&D personnel in companies that cooperate with a university, a higher education or a scientific institution.

impact on wages of corporate income tax credits may be different. As corporate income tax credits usually apply to both capital expenditure and researcher wages, it could be that researcher wages are less strongly affected by this type of tax credit and that the reverse applies for the prices of other types of R&D-inputs (European Commission, 2014a).

A comprehensive cost-benefit analysis is rarely conducted in countries' evaluations since it requires a wider range of assessment criteria. Parsons and Phillips (2007) calculated the net welfare gain of R&D tax incentives following the cost-benefit framework suggested by Lattimore (1997). From a comprehensive survey of estimates reported in the literature, they take the median values of the R&D incrementality ratio (0.86) and of the domestic external rate of return to R&D (0.56), and compute an average marginal excess burden of taxation of 0.27. The compliance and administration costs in proportion of the tax incentives provided are set at 8 per cent and 2 per cent, respectively. For these parameter values, they estimate a net welfare effect per dollar of tax expenditure of 10.9 per cent. Mohnen and Lokshin (2008) carried out simulation experiments and derived an estimate of net welfare gain from R&D tax incentives in the Netherlands of 16 per cent, which is close to the reported value by Parsons and Phillips (2007).

Researchers apply different estimating strategies in their evaluations of effectiveness of R&D tax incentives, such as treatment evaluation methods (e.g. matching estimators, difference-in-differences analysis), structural methods, and survey or questionnaire methods.

The treatment evaluation methods consist in running quasi-experiments or constructing counterfactuals. Matching estimators compare the average R&D effort of firms that receive R&D tax credits with the average R&D of firms that do not but that are otherwise similar, for instance in having the same likelihood of receiving R&D tax credits but preferring not to apply for them (Czarnitzki, Hanel, and Rosa, 2004; Corchuelo and Martínez-Ros, 2008; Duguet, 2012; Hallépée and Garcia, 2012; Bunel and Hadjibeyli, 2021). The matching method relies on the assumption that all explanatory variables are observed and that the selection into the tax incentive is random, conditional on observed variables. However, there may be unobserved differences between the two groups, such as interest in research and innovation or excessive fear of tax audits and the bureaucracy involved. In this case, the matching method yields a biased estimator and suffers from the lack of comparability of the matched firms. The difference-in-differences estimator compares the R&D of firms in the control and treated groups before and after a policy change (Cornet and Vroomen, 2005; Guceri and Liu, 2019; Agrawal, Rosell, and Simcoe, 2020). The weakness is that there may remain unobservable time-varying differences between the two groups which affect R&D expenditure. In regression discontinuity design the R&D of firms that are affected should be compared with those that are unaffected by an exogenous discontinuity in the treatment function, for example firms just below and just above a ceiling in the conditions for being eligible to receive R&D tax credits (Haegeland and Moen, 2007; Dechezlepretre et al., 2020). If the number of observations is limited, researchers face a trade-off between too wide and too narrow a sample below and above the discontinuity. In general, quasi-experimental methods can be seen as less theory-driven methods, and as such may provide more objective estimates (Cerulli, 2010).

Structural econometric methods rely on the simulated user cost of R&D, which corresponds to the cost faced by the firm if it benefits from R&D tax incentives. These methods are not straightforward to implement and may require good instruments to handle the endogeneity of the tax credit (i.e. when the effective price of R&D varies with the amount of R&D expenditure). However, unlike quasi-experiments they allow the simulation of the impact of changes in the features of the tax credit. These methods are widely used in studies on the effectiveness of R&D tax incentive schemes (for example, by Rao (2016), Lokshin and Mohnen (2012)).

Surveys on R&D tax incentives are often conducted for countries' official evaluations of tax incentive policy to complement econometric analyses (for example, Economic Evaluation of the R&D Tax Credit in Ireland in 2010, 2013; Evaluation of Dutch R&D tax credit scheme (WBSO) in 2019, 2012, 2007, and 2002).

Comparability across country evaluations is important for learning about the relative impact of different policy designs. But in practice it is a challenging task as evaluations use a range of methods, metrics and data sources, as well as having different objectives.

Therefore, when introducing tax incentives governments should clearly identify the aims and possible results of such policy. The policy effectiveness will depend on the design of the incentives themselves, administrative mechanism, timely and reliable assessment of the effects that will lead to appropriate conclusions, and further improvements. Analysing input additionality should be a key point in any evaluation. Other aspects of the scheme must be viewed in light of the effects on R&D investment. The accumulated international experience and advances in the R&D policy design and evaluation practices should be considered by policymakers in order to offer attractive and competitive tax incentive schemes.

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CHAPTER 2. CROSS-COUNTRY ANALYSIS OF ATTRACTIVENESS AND EFFICIENCY OF R&D TAX INCENTIVES

2.1 The B-index framework for evaluating generosity of R&D tax incentives

Parameters of tax incentive schemes rarely stay constant over time. Governments may wish to give an additional boost to R&D or increase the stimulus for a particular target group. A proper evaluation of improved or alternative R&D tax incentives requires tax indicators which show the generosity of tax schemes and significance of anticipated changes from firms' perspective.

The main tax indicator applied in the literature (Hall, 1993; Bloom, Griffith, and van Reenen, 2002; Dagenais, Mohnen, and Therrien, 2004; Mairesse and Mulkay, 2004) to assess tax assistance to investment in R&D is the B-index.

The B-index was introduced by Warda and McFetridge (1983) in their research "Canadian R&D Incentives: Their Adequacy and Impact" as a measure of generosity of R&D tax incentives and their relative adequacy.[10] The adequacy of tax incentives in relative terms was supposed 'if they are as generous as those of other countries facing similar circumstances' (Warda and McFetridge, 1983, page 4). Moreover, the B-index was used to demonstrate how the incentive to do R&D varies across firm sizes, regions, and types of activities within Canada, and to estimate the extent to which R&D in Canada would decline if it were treated the same for tax purposes as other types of investment. In a Report prepared by the Conference Board of Canada in 1997 the B-index was used as a measure of the relative attractiveness of tax systems of different Canadian provinces (Warda, 1997). In the next edition of the Report the comparison of R&D tax treatment in Canada was extended to other major industrial countries (Warda, 1999). In 2000 the B-index was adopted by OECD as an R&D tax policy indicator (e.g. STI Outlook, STI Scoreboard), and later was suggested for use as a tool for international benchmarking of the attractiveness of R&D tax systems (Warda, 2001).

The generic formula of the B-index is as follows (Warda, 2005):

$$B\text{–}index = \frac{(1-A)}{(1-\tau)}, \tag{1}$$

where A is the present value of depreciation allowances, tax credits, and other R&D tax incentives available (so as $(1-A)$ is the present value of the after-tax cost of R&D), and τ is a corporate income tax rate.

Algebraically, the B-index is a ratio of the net cost of one marginal monetary unit spent on R&D, after all quantifiable tax incentives have been accounted for, to one monetary unit of the income net of corporate income tax. In other words, the B-index specifies the pre-tax income needed for a "representative" company to break even on a marginal, monetary unit of R&D outlay, taking into account provisions in the tax system that allow for an enhanced treatment of R&D expenditures (Warda, 2005; OECD, 2013, 2019a).

The formula can be adjusted to different tax parameters of R&D tax incentive. Below there

[10] The underlying theoretical framework is based on the approach to measurement of the user price of capital developed by Hall and Jorgenson (1967). Later, King and Fullerton (1984) expanded the model with the aim of deriving marginal effective tax rates (METR) on various types of investment. The B-index represents the tax component of METR; however, qualitatively the B-index gives the same results as the METR (Warda, 2001; Jung, 1989).

are examples of the B-index calculation in cases of taxable and non-taxable tax credit (Formulas 2 and 3, respectively), and investment allowance (Formula 4):

$$B\text{–}index_{TC} = \frac{1 - x\tau - yz\tau - c(1-\tau)}{1-\tau}, \tag{2}$$

$$B\text{–}index_{NTC} = \frac{1 - x\tau - yz\tau - c}{1-\tau}, \tag{3}$$

$$B\text{–}index_{d} = \frac{1 - yz\tau - xw\tau}{1-\tau}, \tag{4}$$

where $B\text{–}index_{TC}$ – B-index for taxable tax credit; $B\text{–}index_{NTC}$ – B-index for non-taxable tax credit; $B\text{–}index_{d}$ – B-index for investment allowance (deduction); x – proportion of current R&D expenditure; y – proportion of capital R&D expenditure; z – present value of tax depreciation allowances ($z = 1$ is equivalent to current expensing); c – tax credit rate; and w – investment allowance (super deduction) rate (Warda, 2006; Warda, 2007).

The amount of tax subsidies to R&D is then calculated as follows:

$$Rate\ of\ tax\ subsidy = 1 - B\text{–}index\,. \tag{5}$$

Based on Formula (5), the lower the B-index the higher the value of the tax subsidy, and therefore, the more favourable tax treatment of R&D cost (Warda, 2001).

The B-index model can include many components of the R&D cost structure and applicable tax provisions (Warda, 2005):

– current R&D expenditure, including wages and salaries of R&D personnel and the cost of materials used in the R&D process;

– capital expenditures incurred in R&D that can be immediately expensed;

– capital expenditures (e.g. the cost of machinery and equipment, facilities and buildings) that have to be depreciated, usually over the useful life of the capital input (according to declining balance or straight line methods);

– additional tax allowances on R&D expenditure;

– tax credits that are applied against income tax payable (taxable or non-taxable).

The model does not capture the considerations related to depreciation of the output of the R&D and does not account for deductions allowed for interest payment on loans.

For consistent comparisons, the model measures country B-indexes under constant and uniform technical assumptions:

– proportion of current and capital R&D expenditures is 90 per cent and 10 per cent, respectively for all countries;

– wages and salaries (a component of current costs) are assumed to represent 60 per cent of total R&D expenditures;

– capital expenditures are divided equally between machinery and equipment (5 per cent), and buildings (5 per cent);

– the model is expressed in present value terms (net return over time) – it is assumed that for all the countries compared, the discount rate is constant and holds at 10 per cent.

In case the cost of investment is fully deductible and there are no additional R&D tax incentives, the value of "A" will be equal to the corporate income tax rate "τ", implying a value of the B-index equal to 1, and therefore the value of tax subsidy will equal 0. At first sight, this seems to signify that the tax system does not provide generous R&D tax provisions. However, this is not the case as the benchmark of the B-index refers to immediate expensing, which implies a favourable tax treatment compared to the tax treatment of other investments that have to be depreciated over time (Palazzi, 2011). Indeed, the studies on the effect of corporate income taxation on capital accumulation show that immediate expensing of investment expenditures, as for instance assumed under a corporate cash-flow tax[11], is optimal since the fiscal neutrality is achieved by harmonising investment incentives on a common basis. The B-index will vary from 1 only when R&D expenditures are not fully deductible ($A < \tau$) or are more than fully deductible ($A > \tau$).

The main shortcomings of the B-index model:

– initially, only corporate income taxes and related incentives were incorporated (the model excluded incentives related to personal income, value added, property taxes, as well as taxes on wealth and capital); however, lately the model was extended to include tax incentives applied through employer social security contributions and withholding taxes for R&D personnel;

– the model does not consider the treatment of the cost of financing (tax deductions of the cost of debt constitute an overall tax incentive for R&D);

– the B-index considers investment at the margin and does not reflect the tax treatment of infra-marginal investment and profits;

– the B-index is sensitive to the degree of symmetry between the tax treatment of R&D expenditures and the tax treatment of income derived from R&D (thus, for example, reduction in the B-index attributable to a tax credit, provided at a given rate, is larger the higher is the corporate income tax rate);

– the model refers to "representative" firms in their class for which caps or ceilings that limit the amount of eligible expenditures or tax support are not applicable (OECD, 2018a; Warda, 2006; Palazzi, 2011; Clark).

Palazzi (2011) additionally highlights that the B-index overestimates the tax burden on R&D activities by assuming the case of a closed economy where the return on investment is taxed at the domestic corporate income tax rate. Consequently, the tax gains as a result of cross-border tax planning are not considered. However, currently many European countries are following the Base Erosion and Profit Shifting Action Plan and implementing its recommendations (for example, regarding the design of controlled foreign company rules), which prevents taxpayers from inappropriate income shifting. Therefore, we consider that this drawback of the B-index is not fully justified. In the paper "Taxation and Innovation" Palazzi (2011) also reports that since the B-index ignores the differences between tax and economic depreciation of capital costs, the differences between true tax and economic depreciation would not be assessed in relation to the true tax treatment of finance. From our point of view, since the B-index is a tax parameter it should focus primarily on the tax price of R&D for an investor.

Originally the model assumed the existence of no tax exhaustion: it made no distinction between non-refundability and refundability provisions of tax incentives, and carry-forward and carry-back provisions did not alter B-index values, either. The challenging macroeconomic environment, particularly in the initial phase of the global economic crisis, has dented the profitability of many companies making operating surplus negative in many countries' corporate sector. This called into question the relevance of the headline B-index as a representative indicator for all R&D-performing companies. In recognition of the fact that there are significant differences in the provisions made by countries for scenarios in which companies cannot immediately realise the entire value of tax incentives on R&D, the B-index formula was further developed by the OECD in 2013 for loss-making companies or companies which do not have sufficient profit to fully benefit from the tax incentive. The B-index formula has been generalised as follows (OECD, 2013):

[11] The basic principle of a corporate cash-flow tax is to levy a charge on the net cash flow to the company resulting from its real economic activities (King, 1987).

$$B\text{–}index = \frac{1 - \tau(x + (1 - x)\,\psi)\,\theta}{1 - \tau\,(x + (1 - x)\,\psi}, \quad (6)$$

where x = 1 if the firm has a sufficiently large profit to claim the incentives, x = 0 otherwise; and ψ is the present value adjustment factor for the allowance (or equivalent incentive) in the scenario with an insufficiently large profit base: ψ = 1 if the incentive is fully and immediately refundable in the "loss" case, and $0 < \psi < 1$ if the incentive can be carried forward.

The present value of an allowance or a tax credit which can be carried forward is calculated based on the assumption of a constant probability of returning to profit (arbitrarily set to 50 per cent) according to Formula (7):

$$\psi(T, \lambda, i) = [1 - (\frac{\lambda}{1 + i})^T](\frac{\lambda}{1 + i)})/(1 - \left(\frac{\lambda}{1 + i}\right), \quad (7)$$

where λ is a probability of returning to profit; T is a time limit for carrying forward special credits and allowances; and i is an interest rate (assumed to be 10 per cent).

It can be noted that the adjustment factor will be higher for tax credits which can be carried forward indefinitely than for those which can be carried forward for a limited number of years ($\psi(T, \lambda, i) < \psi(\infty, \lambda, i)$).

Therefore, the B-index represents a summary measure widely used to assess the attractiveness of R&D tax incentives. Despite some limitations, it enables cross-country comparisons of the generosity of tax systems to encourage private R&D. However, potential generosity of the tax system (maximum full value of tax benefits) is only one dimension of the attractiveness of R&D tax incentives, and does not reflect other attributes of R&D tax incentives. Thus, for example, it does not inform policymakers about successful implementation of R&D tax incentive policy, which affects tax incentive uptakes. This calls for a need to complement the analysis of attractiveness of tax treatment of R&D by additional indicators which could reflect behavioural responses of the business enterprise sector to tax treatment. This issue will be a focus of the following section.

2.2 Tax incentive implementation rate as a novel approach for analysing the attractiveness of R&D tax incentives

According to the B-index methodology the more favourable the tax treatment of R&D, the lower a country's B-index and, other things being equal, the greater the amount of R&D that will be conducted by its corporate residents (McFetridge and Warda, 1983). Additionally, when there is a worldwide pool of R&D opportunities, a low B-index attracts "footloose" R&D. However, this approach, while considering only a notional level of tax support, does not account for other important effects related to adopted R&D tax incentives. Thus, an effective application procedure is crucial for the pool of beneficiary firms. They might be discouraged from applying for a tax incentive when they face uncertainty about the compliance cost. The complexity of R&D tax incentives due to potential interactions with other tax breaks or direct financing, as well as non-transparent mechanisms of their calculation, causes biases that can be a reason for a refusal from application and use of R&D tax incentives by taxpayers. Since the B-index does not reflect the behavioural responses of taxpayers to tax incentives it should be analysed along with the actual amount of government tax support for R&D in GDP. The results are presented in Figure 7. For countries that have different tax treatment of R&D for large firms and SMEs (i.e. the United Kingdom, Norway, the Netherlands) tax subsidy rates were calculated based on the share of SMEs in the total amount of tax support for BERD.

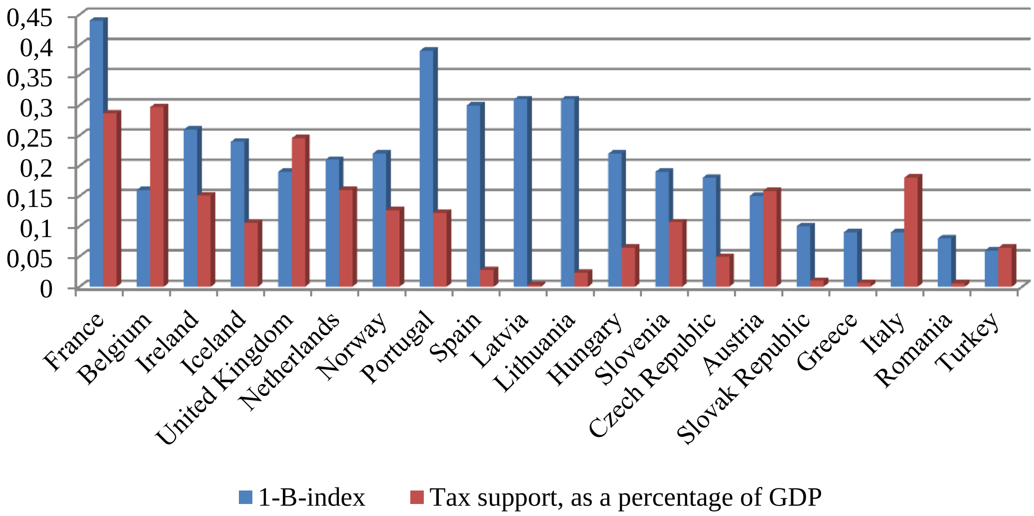

Figure 7 **– Tax subsidy rate for R&D expenditures and the actual level of tax incentive support of BERD, 2017**

Source: own construction based on OECD statistics, R&D Tax Incentive Indicators (OECD, 2021a).

From Figure 7 it can be seen that some of the countries which provide generous tax incentives as measured by the tax subsidy rate have a lower share of actual tax incentive support to GDP (for example, Spain, Lithuania, Latvia). On the opposite side, Belgium, providing less generous tax incentives, has a higher level of tax support for R&D than the Netherlands, Ireland, the Czech Republic, and some other countries. These differences may arise due to different levels of business-financed R&D in GDP, as well as due to the availability of tax support administered by government officials and behavioural responses of taxpayers to the tax treatment.

To link the generosity of tax incentives and practical implementation of tax incentive policy we have developed an indicator that can be meaningful for international comparisons of attractiveness of R&D tax incentives. It can be described with the following formula:

$$R\&D\ tax\ incentive\ implementation\ rate = \frac{\dfrac{Tax\ support, as\ a\ \%\ of GDP}{Business - financed\ R\&D, as\ a\ \%\ of GDP^{12}}}{1 - B - index}. \quad (8)$$

The proposed indicator may be named in two ways: the tax incentive implementation rate (TIIR) to emphasise how government succeeds in implementation of R&D tax incentive policy (such as creating a clear mechanism for the usage of tax incentives, transparent application procedure, delivering information about new tax incentives to taxpayers, etc.), or the tax incentive utilisation rate (TIUR), indicating whether business finds it reasonable to claim and use tax incentives for R&D.

The numerator in Formula (8) shows how much tax support as a percentage of GDP is received by one per cent of business-financed R&D in GDP, or the share of business-financed R&D supported by R&D tax incentives if multiplied by 100.[13] The total ratio shows the

[12] In the formula the business-financed GERD (or BERD) by domestic and foreign business-enterprise sectors (where applicable) should be considered depending on the eligibility of certain R&D expenditures.

[13] For ease of calculation relative measures to GDP are used rather than absolute figures. However, this depends

amount of normalised tax support[14] as a percentage of GDP generated by one unit of tax subsidy, or the share of business-financed R&D supported by tax incentives attributable to 1 unit of tax subsidy. Therefore, the indicator illuminates the effect of different levels of business-financed R&D expenditure in GDP among countries on the amount of tax support provided.

TIIR is meaningful primarily for cross-country comparisons of the successful implementation of R&D tax incentive policy. In a single country analysis it can be used when changes to tax incentive schemes are introduced, reflecting the responsiveness of firms to them, otherwise other methods can be sufficient. For example, if the generosity of R&D tax incentives remains constant over time the change in the magnitude of R&D tax expenditures or the number of taxpayers using the scheme can be analysed.

The formula of TIIR (8) is general and should be adapted to each country's specific circumstances.

The following features of national R&D tax incentive systems and the reporting on R&D tax expenditures should be taken into account:

1. differentiation of tax support based on the firms' size;
2. existence of refundable and carry-over provisions, and their modelling in the B-index;
3. the method of measurement of government tax relief for R&D;
4. tax treatment of subcontracting costs;
5. existence of limitations in R&D tax relief.

These features along with their accountability in the formula will be discussed consequentially.

Countries which target their R&D tax incentives by firm size have different estimates of tax subsidy rates for SMEs and large firms. In this case, a weighted average estimate for all types of firms should be computed. In case of limited data on the amount of tax support distributed among different types of firms (large and SMEs), the weighted average B-index may be computed based on the share of their R&D expenditures in total business expenditure on R&D. According to the OECD (2019b), SMEs' share in tax support tends to be closely aligned with SMEs' share in BERD.

Where countries perform evaluations of the R&D tax support provided to the business sector, the more precise amounts from such reports can be drawn upon. As of 2017, three counties in the analysed dataset differentiated their R&D tax incentives by firm size. These are Norway, the United Kingdom and the Netherlands. While in Norway the tax subsidy rate slightly differs for large firms and SMEs (0.21 and 0.23 respectively), in the other two countries the difference in tax support is more pronounced (0.10 and 0.27 in the United Kingdom, and 0.15 and 0.31 in the Netherlands, for large firms and SMEs respectively). Therefore, the estimates of the weighted average B-index may significantly affect the computation of TIIR. For computations of the weighted average B-index for the United Kingdom the information on the amount of tax support by type of the scheme from HM Revenue and Customs was used (the shares are calculated in Appendix 1). The Netherlands publishes annually its "Focus on research & development", where uptake of the current scheme WBSO is reflected, and the recent data are derived from "Evaluatie WBSO 2011–2017" (de Boer et al., 2019b). Since R&D tax allowance (RDA) used in the Netherlands as a separate tax incentive from 2012 to 2015 (merged with WBSO in 2016) has been providing equal support for large firms and SMEs, the data on the shares of SMEs and large firms benefitting from the scheme is not taken into account. For Norway, the share of SMEs in total tax support is used from the OECD Summary report on indicators of tax expenditures (OECD, 2019b).

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on the user of the methodology.

[14] Tax support normalised by the level of business-financed R&D.

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For consistent estimates of countries' specific tax incentive implementation rates, the B-indexes in different scenarios (profit- and loss-making firms) should be opposed to the amount of tax support, which can be estimated on an accrual or cash basis. Accrual reporting means that the recording of the provision of tax relief occurs when R&D generating the basis for claiming tax relief has taken place. Therefore, a measure of tax relief on an accrual basis is based not only on relief earned and claimed in the current year, but also on relief which may be carried over. For countries which provide accrual-based estimates, B-indexes for profit scenario were used in the computation of TIIR. At the same time, a number of countries provide cash-based estimates of government tax relief for R&D, that is, the claim is recognised by the government when it is paid in cash or used to decrease the tax liability of the firm. If these countries offer refundable provisions the B-indexes for profit- and loss-making scenarios will coincide. Some biases may arise in the computation of TIIR when only carry-over provisions are adopted (no cash refunds) or modelled in the B-index. To connect cash-based estimates with B-indexes in both scenarios the share of firms that could not fully benefit from available R&D tax incentives due to an insufficient amount of income in the total amount of tax support should be estimated. Considering the lack of such information, the assumed share of 50 per cent was used in the computations. Since the B-indexes for loss-making firms just slightly differ from those for profit-making, this assumption will not distort our estimates. The countries' specific features related to the choice of relevant B-index scenario used in the computation of TIIR are summarised in Appendix 2.

The treatment of subcontracting costs should be taken into account in order to estimate the amount of R&D expenditure used for normalisation of tax support of R&D. In some countries (e.g. Belgium, Netherlands, Hungary) only the performer of R&D activity may apply for tax incentives, while most European countries provide tax incentives for the funder of R&D activity, which means that subcontracted R&D expenditure may also qualify for tax support. Italy and the United Kingdom, when supporting a funder of R&D activity, allow tax benefits to be claimed for R&D contracted to firms by the business sector from abroad (in the United Kingdom under the large company scheme only). Some countries (e.g. Austria, Ireland, the Slovak Republic and Romania) allow either the performer or the funder to make a claim for tax benefits; however, there is no double tax relief. In Turkey the tax benefit can be received by both parties in equal proportion. Eligibility criteria may also relate to the nature of the contractual relation between the contractor and contracted party. Austria and Ireland exclude R&D contracted to related parties from R&D expenditure eligible for tax benefits. The countries' specific features on eligibility of subcontracting costs are summarised in Appendix 3, based on which the respective indicators of R&D expenditure that potentially may be eligible for tax incentives are identified. The ceilings on the contracted expenditure that exist in some countries are not taken into consideration due to the lack of information on the distribution of such R&D expenditure, as well as the limitations in subcontracting R&D expenditure to particular performers (for example, in the Czech Republic and in Greece expenditure on external services for R&D qualifies for tax relief only when provided by public institutions such as universities or research centres).

In general, the B-index model assumes that ceilings and floors are not binding. In countries which offer tax benefits redeemable against social security contributions and payroll withholding taxes, tax offsets by construction are limited to tax liability (for example, in Belgium, France, Hungary, the Netherlands, Spain, and Turkey). However, some of these countries impose additional limitations on the amount of tax relief that can be claimed. For example, in Turkey the full-time-equivalent support personnel who benefit from social security contributions cannot exceed 10 per cent of the number of total full-time R&D personnel. In Hungary, tax relief can be validated up to the gross wages of 500,000 Hungarian forint (HUF) per month (HUF 200,000 in case of PhD students or doctoral candidates). In

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Spain, 60 per cent of the annual wage bill for qualified research staff may benefit from tax incentive. France adopted a ceiling for SSC reduction at the employee and company level, while the Netherlands and Belgium did not use additional limitations for the amount of tax relief (Belgium imposes a limitation only from 2018, which was caused by the extension of the scheme to researchers with bachelor degrees – withholding tax exemption for bachelor degree holders is capped at 25 per cent of the total withholding tax exemption applied for masters and doctorate holders). Some countries do not limit the amount of tax benefits from R&D tax credit and R&D tax allowance (e.g. Greece, Latvia, Lithuania (for profit-making firms)[15], Romania, Slovenia, Belgium, and the United Kingdom (for RDEC scheme)), while others impose various types of limitations on the amount of R&D expenditure. For example, Norway limits the amount of qualifying R&D expenditure for ScatteFUNN scheme per project, per firm, and per year (for intramural R&D including procured from entities other than approved R&D institutions, subcontracted R&D to approved R&D institutions, and the sum of the two). Such limitations affect mainly large firms, making the scheme less generous.

To account for the effect of ceilings OECD has recently developed an experimental indicator "weighted" tax subsidy rate. It is computed for countries whenever data or proxy measures for the distribution of eligible R&D spending are available. The comparison of the two subsidy rates is presented in Figure 8.

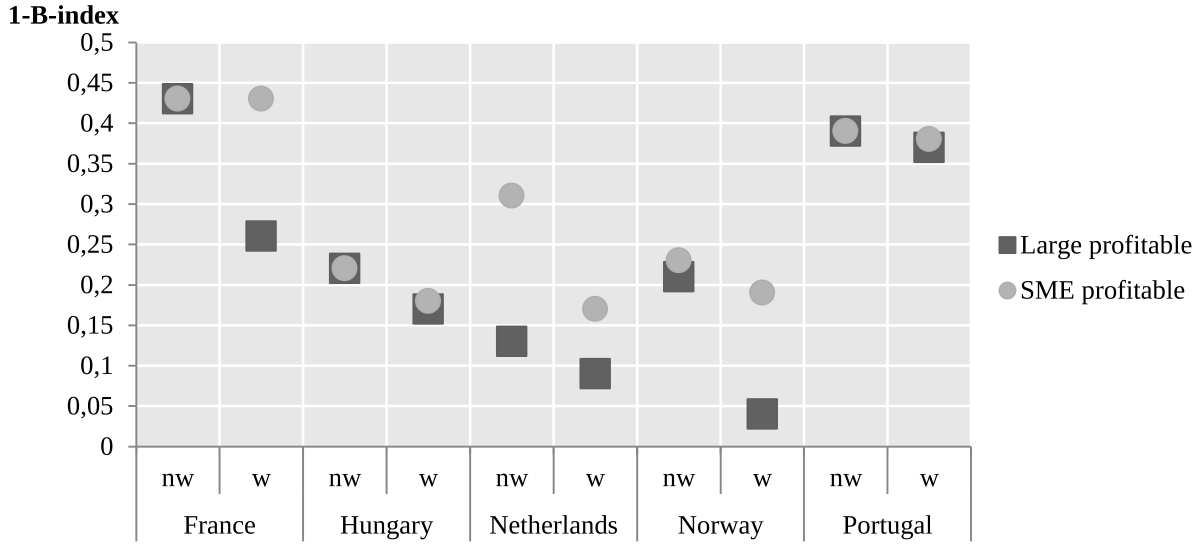

Figure 8 **– Weighted vs. non-weighted implied tax subsidy rates on R&D expenditures, 2017**

1-B-Index, by firm size (profit scenario)

Note: *nw = non-weighted, w = weighted. Figures for the Netherlands are for 2018. Figures do not reflect preferential provisions for start-ups, young firms or a specific subset of SMEs (for example, innovative SMEs).*

Source: own construction based on OECD, 2018a; OECD, 2019a.

Therefore, for these countries (namely, France, Hungary, the Netherlands, Norway, and Portugal) the weighted tax subsidy rates were used in the computation of TIIRs, which allows estimates to be more precise. Since in France and Portugal weighted tax subsidy rates differ for large firms and SMEs, the proportion of tax support for SMEs was used according to the

[15] In Lithuania the limitation of the tax benefits for loss-making firms only – the amount of carry-forward losses may not exceed 70 per cent of taxable profit of a particular accounting year.

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OECD R&D tax incentive database (OECD, 2020d) to arrive at the average weighted tax subsidy rate estimates. The results of the countries' estimated TIIRs are presented in Figure 9.

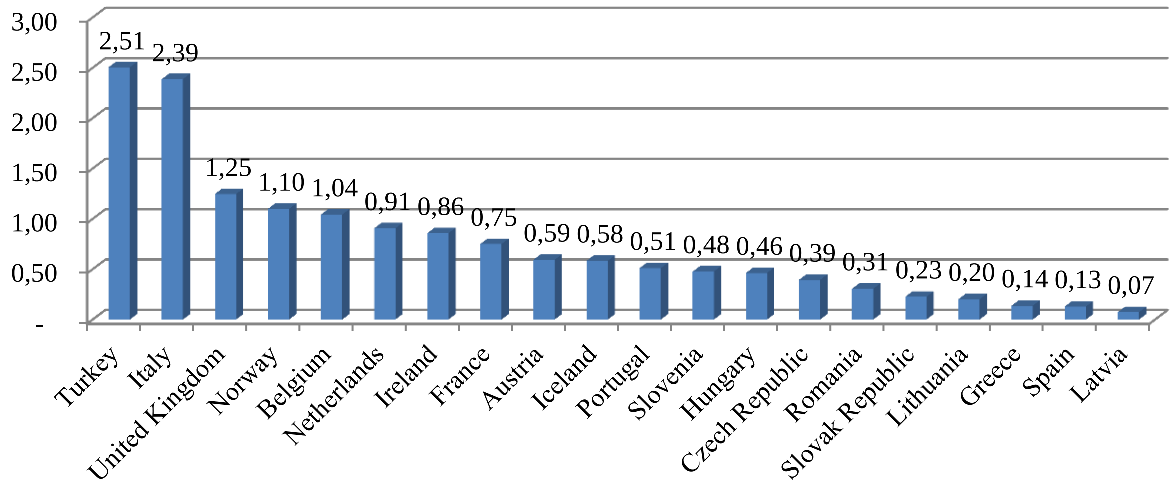

***Figure 9* – R&D tax incentive implementation (utilisation) rate, 2017**

Note: figure for the Netherlands is for 2018, for Romania for 2016.
Source: own construction.

As can be seen from the figure, the highest tax incentive implementation rates are in Turkey and Italy, which can largely be explained by the low generosity of tax incentives in these countries, namely 0.09 for Italy and 0.06 for Turkey[16] for profit-making firms, while the average in the analysing set of countries was 0.21 for SMEs and 0.18 for large profit-making firms taking into account weighted tax subsidy rates for some countries. Therefore, the ease of availability of tax incentives in these countries can be related to low tax expenditures on R&D in the national budgets. The highest use of R&D tax incentives, at a given level of generosity, is observed in the United Kingdom, Norway, Belgium, and the Netherlands, while the lowest tax incentive utilisation rates are in the Slovak Republic, Lithuania, Greece, Spain, and Latvia. Low TIUR can signal low interest in tax incentives in these countries due to lack of awareness, existence of administrative barriers to the usage of tax incentives, or high compliance costs to firms. Therefore, tax incentives in these countries can be less attractive to firms due to less efficient implementation of the R&D tax incentive policy.

The next question that should be considered is whether the R&D tax incentive implementation rate is associated with the level of business-financed R&D. To test this hypothesis we build a plot to identify the relative position of the countries based on these two indicators (specifically, based on the deviations of these indicators from the sample mean) (Figure 10).

[16] Italy and Turkey do not differentiate tax support by firm size.

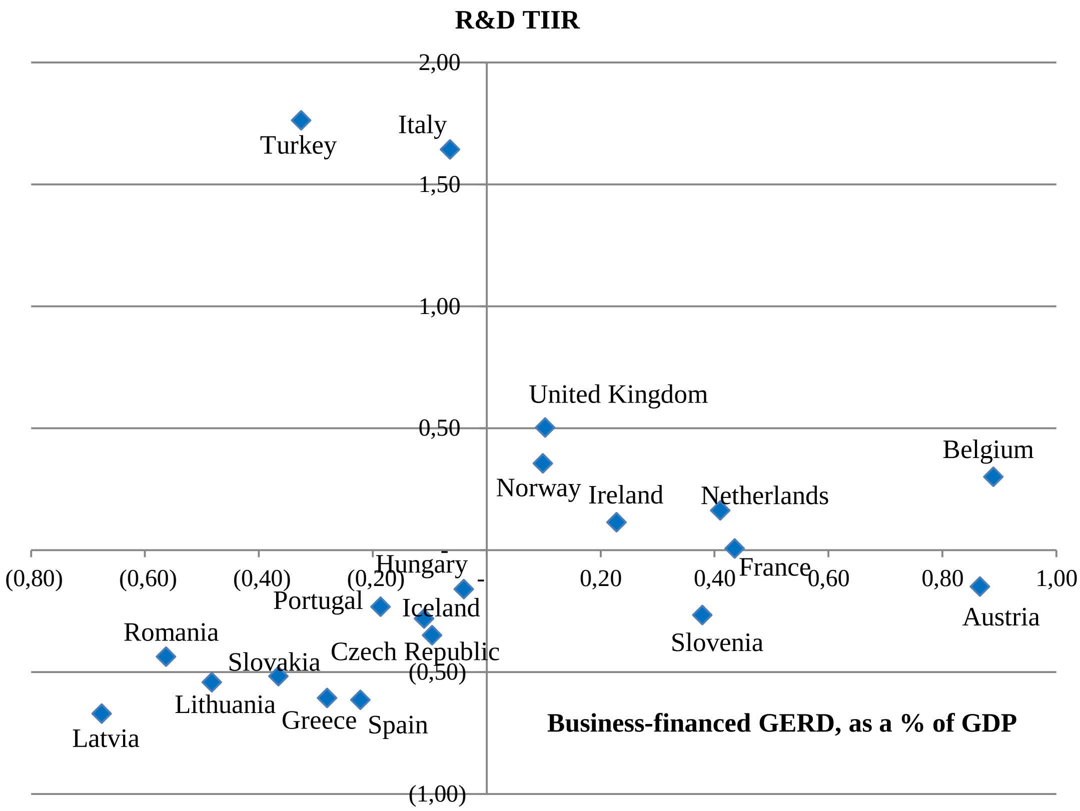

Figure 10 **– Countries' relative position based on the level of business-financed GERD, as a percentage of GDP and R&D tax incentive implementation rate, 2017**

Notes: figures for the Netherlands are for 2018, for Romania for 2016. For Ireland business-financed GERD as a percentage of modified GNI is estimated.

Source: own construction.

The level of business-financed GERD for Ireland was estimated relative to modified gross national income. The reason for this is an overestimated country's GDP, which can distort country's relative position in the level of business-financed GERD in conjunction with TIIR. In 2015 Ireland's economy grew by 26.3 per cent, mostly due to the tax avoidance strategies of a few large multinationals. To exclude globalisation effects and estimate the real size of the economy, Ireland has introduced new indicator, "modified GNI"[17], which was used in the computation to increase comparability across countries.

As can be seen from Figure 10, countries with lower R&D tax incentive implementation rates have lower levels of business-financed GERD as a percentage of GDP. Despite high TIIRs in Turkey and Italy, these countries have a relatively low level of business-financed GERD, which can partly be explained by the low generosity of existing R&D tax incentives. Therefore, these countries should be excluded in testing the strength of association between the two indicators.

As can be seen from Figure 11, the R&D tax incentive implementation rate is positively correlated with business-financed GERD. The correlation coefficient is at 0.678, which indicates a strong positive association between variables.

[17] To produce Modified GNI, Gross National Income is adjusted for factor income of redomiciled companies, depreciation on R&D service imports, and trade in IP depreciation on aircraft leasing.

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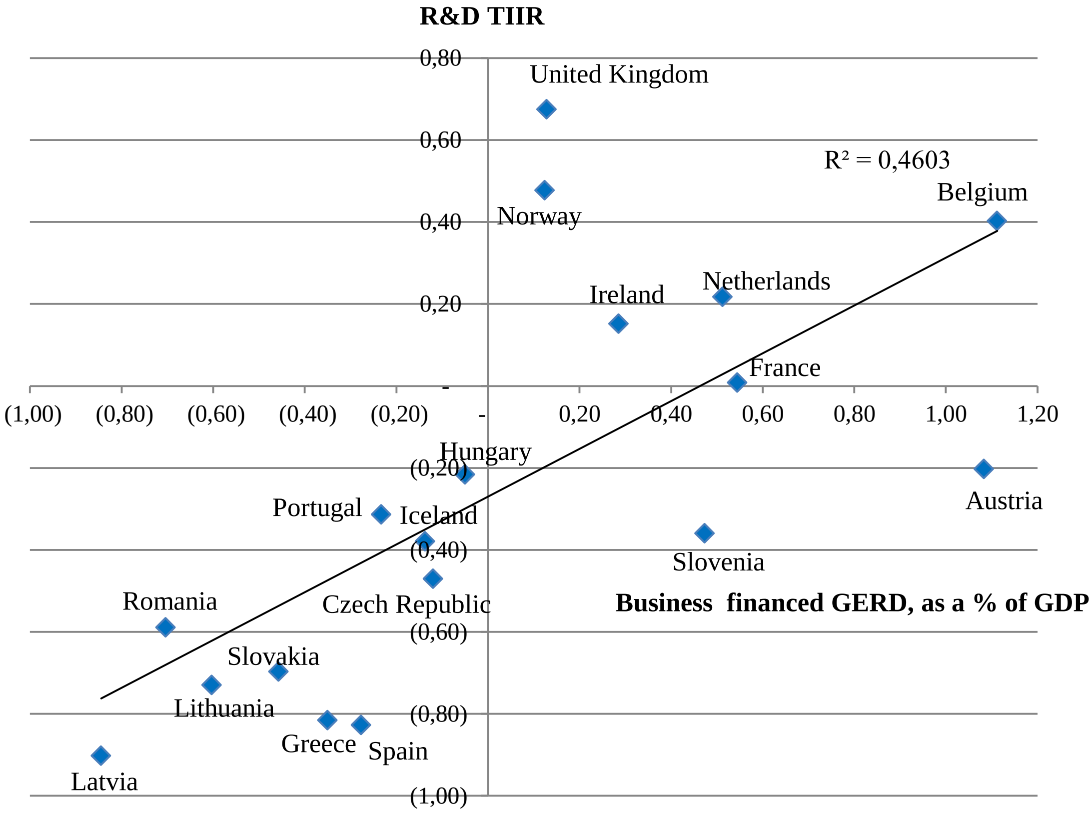

Figure 11 **– The strength of association between business-financed GERD and R&D tax incentive implementation rate, 2017**

Notes: figures for the Netherlands are for 2018, for Romania for 2016. For Ireland business-financed GERD as a percentage of modified GNI is estimated.

Source: own construction.

As seen in Figure 11, some countries have similar R&D tax incentive implementation rates along with sharp differences in business-financed GERD. Thus, for example, the tax incentive implementation rate in Hungary (0.46) is close to that estimated for Slovenia (0.48); however, there is a big gap in the level of business-financed R&D in GDP between the two countries. A similar conclusion can be drawn for Romania and the Czech Republic with a 0.31 and 0.39 tax incentive implementation rates respectively, and for Austria (0.59) and Iceland (0.58). Therefore, additional factors that affect business R&D investment decisions should be considered.

Direct financing of GERD is recognised as an important factor which has a significant impact on the R&D financing decisions of firms due to its contribution to the overall technological level of the country, quantity and quality of research personnel, and dissemination of knowledge. Since many studies are conducted at the firms' level, direct funding of BERD is used as one of the key independent variables to investigate the existence of a crowding-out effect of government grants on private R&D spending (OECD, 2020b; Cerulli and Póti, 2012; Marino et al., 2016; Hottenrott, Lopes-Bento, and Veugelers, 2017). From our point of view, government funding of GERD is a more comprehensive measure of the government impact on private R&D spending which can be assessed at countries' level. Therefore, we constructed the relative position of the countries considering the impact of the two factors: R&D tax incentive implementation rate and direct funding of GERD as a percentage of GDP (the percentage deviations from the sample mean are estimated and summarised). The results are presented in Figure 12.

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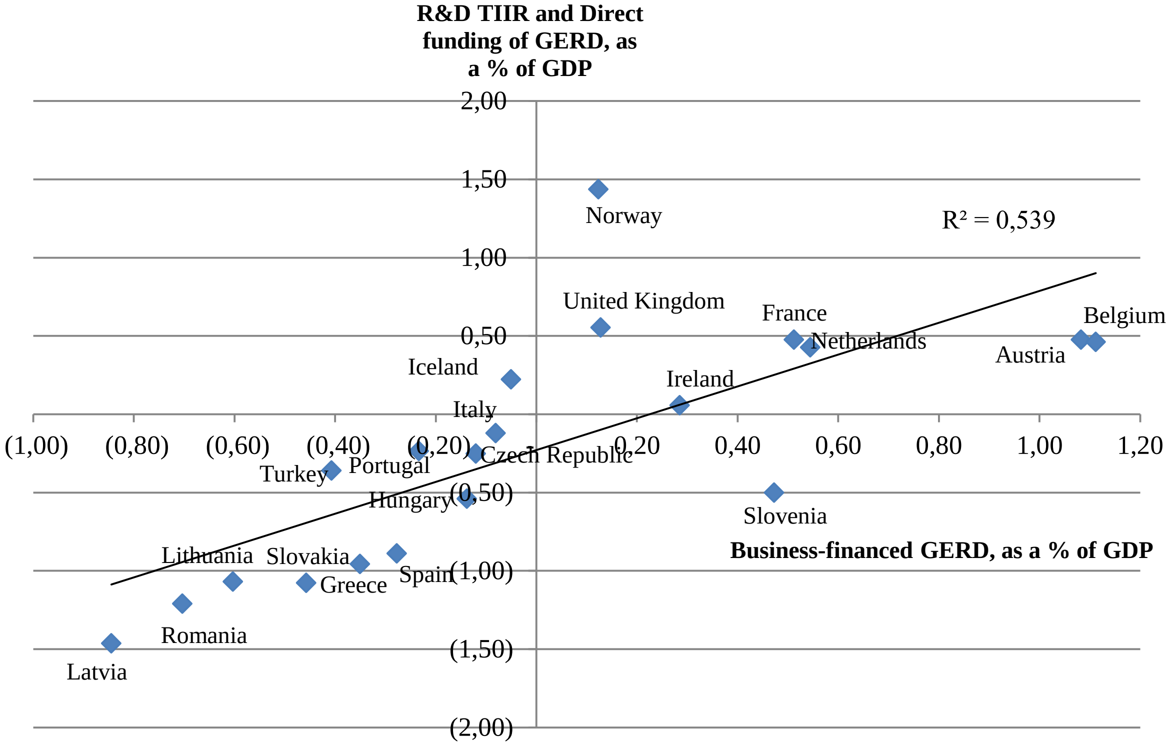

Figure 12 **– Countries' relative position based on the level of business-financed GERD, direct funding of GERD as a percentage of GDP, and R&D tax incentive implementation rate, 2017**

Notes: figures for the Netherlands are for 2018, for Romania for 2016. For Ireland business-financed GERD as a percentage of modified GNI is estimated.

Source: own construction.

The figure 12 shows strong association between analysed parameters (the correlation coefficient equals to 0.734). Countries which have relatively high business-financed GERD have also higher than average position based on the total effect of the two parameters: direct financing of GERD as a percentage of GDP and R&D tax incentive implementation rate.

The positions of Slovenia and Norway stand out from the rest of countries; indeed, these two countries experienced significant changes in the level of government-financed GERD as a percentage of GDP in recent years. Thus, for example, in Slovenia direct funding of GERD gradually decreased from 0.76 percentage of GDP in 2011 to 0.52 in 2014 and then to 0.43 in 2017; while in Norway, in contrast, direct funding increased from 0.72 percentage of GDP in 2011 to 0.87 in 2015 and then to 0.98 in 2017. Considering that direct funding of GERD plays a role in the long run, the average amount of government-financed GERD as a percentage of GDP from 2011 to 2017 can better reflect the effect of government impact on business R&D spending for these countries. After substituting these values with the averages for Slovenia and Norway, the correlation coefficient between variables increases to 0.784 (Appendix 4).

Therefore, the novel approach for analysing the attractiveness of tax incentives points out the necessity of introducing additional indicators. R&D tax incentive implementation (utilisation) rate can be a measure which reflects the behavioural responses of firms and the efficacy of delivering tax incentive policy by the government. The analysis showed that R&D tax incentive implementation rates are strongly correlated with the level of business-financed GERD. The indicator can be further used to assess the causal impact of such a relation.

2.3 Structural equation model for evaluating additionality of R&D tax incentives

A large number of studies make an attempt to analyse the effect of R&D tax incentives on the firms' R&D activity. Recent studies widely use the B-index as one of the determinants of private R&D investment. Westmore (2013) uses the B-index and the user cost of R&D capital[18] to estimate the short-run and long-run effects of these parameters on dynamics of R&D stock. The analysis is based on the panel data of 19 OECD countries over the period 1983–2008. Government financing of business R&D is included as a long-run independent variable, and is found to be sensitive to the time period (statistically significant in one out of two time periods).[19] The study further investigates the impact of R&D stock on the number of patents and multi-factor productivity, with the B-index as one of the estimating parameters which may have indirect effect on patenting activity and productivity gains.

Knoll et al. (2021) used the B-index measure to analyse the impact of R&D tax incentives on the R&D activity of multinational enterprises in Europe over the period 2000–2012.[20] A proxy of R&D activity is a quality-adjusted number of granted patents[21] that protect technologies, considering that the majority of technological inventors are located in the same country as the patent filing firm.[22] Those cases where the patent filing entity and the technology inventors are located in different countries are disregarded to avoid picking up effects related to strategic shifting of patent ownership to low-tax countries. Based on countries' B-indexes drawn from Bosenberg and Egger (2017), Knoll et al. computed average B-indexes for each MNE group at foreign locations to account for cross-border effects of R&D tax incentives. The asset weights for the host-country B-indexes were employed, considering that the cross-border tax effect is expected to be larger the larger the size of the foreign group location that experiences the tax shock.[23] Besides, a country's openness measured by FDI is included as one of the control variables.

Thomson (2017) used the B-index computed for 26 OECD countries at the industry level taking into account the share of current and capital expenditure for each industry[24] to estimate cross-country-industry variation in R&D financed by the business enterprise sector across 29 industries over the period 1987–2006. Since R&D tax incentives generally do not target a specific industry, the variation in the tax price of R&D across industries can be caused mostly by the differences in the distribution of current and capital expenditure, which gain significance if these types of expenditures are treated differently (capital expenditures are usually less covered by tax incentives). The study assumes that the representative firm has sufficient taxable income to claim the full amount of R&D tax incentives in the current year.

While the direction of the relationship between the B-index and R&D activity in the aforementioned studies can prove the positive impact of R&D tax incentives on the latter

[18] Real user cost of R&D is constructed based on the B-index, the long-term real interest rate and the depreciation rate on R&D capital, assumed to be 15 per cent per annum in all countries and time periods.

[19] Re-estimated model specification over the 1982–2001 period suggested that the direct government support variable had become statistically insignificant, which was confirmed by running the estimation over two sample periods, 1981–1994 and 1996–2008, with the variable only statistically significant in the latter.

[20] In total, the data comprise information on 1151 MNEs and 2900 multinational group locations hosted by 26 European countries.

[21] A value of patent is calculated based on the number of forward citations within a five-year period from the granting date of the patent, the patent's family size and the number of technology classes on the patent.

[22] Authors note that the number of patents is highly correlated with other measures of corporate R&D activity, referring to Hagedoorn and Cloodt (2003), Artz et al. (2010).

[23] Assets weight at foreign group location is defined as the average of total assets at foreign group location across sample years over the sum of this variable across all foreign R&D hosts of the MNE.

[24] The industry-specific tax price used in the analysis is the weighted average tax price of the two expenditure categories, where the weights are the lagged expenditure share mix for each industry.

indicator, the size of this impact may not be estimated precisely due to the actual use of tax benefits being neglected. Some single-country studies are facing a similar issue. For example, Dechezleprêtre et al. (2020), using regression discontinuity design, estimated elasticities of R&D expenditure to the user cost of R&D capital (where the B-index is a tax component of the user cost) for United Kingdom firms over the 2006–2011 period, which included the 2008 policy change that increased the generosity of tax incentives for medium-sized enterprises. They assumed that non-claiming firms have zero qualifying R&D expenditure, and loss-making large firms do not benefit from R&D tax incentive provisions (i.e. R&D tax credit carryovers are not incorporated in the computation of the B-index).[25] Since the study evaluates both intensive and extensive margin effects, the former assumption may lead to significant overestimation of the effect of tax incentives if non-claiming R&D performing large firms, becoming eligible for SME tax credit scheme under new rules, decide to use a tax incentive (for example, encouraged by the increased generosity of tax incentive scheme).[26] The latter assumption, which inflates the tax price of R&D for loss-making large firms, was also used in a recent study on the 2008 policy reform in the United Kingdom conducted by Guceri and Liu (2019) over the period 2002–2011 through the difference-in-difference design.[27] Therefore, while the aforementioned cross-country studies (Westmore, 2013; Knoll et al., 2020; Thomson, 2017) overstate the size of tax stimuli, the country-level studies of Dechezleprêtre (2017), Guceri and Liu (2019) underestimate the tax support of R&D (for loss-making large firms). As a result, this can bring lower elasticity estimates of R&D expenditure to its tax price[28]. Moreover, not counting for the actual use of R&D tax incentives (e.g. due to non-claiming firms or the existence of limitations in tax relief, such as ceilings or threshold depending tax credit rates) can further bias the results due to lower B-indexes assigned to countries or industries where firms do not fully benefit from tax incentives.

A recent study of the OECD (2020b) as the first phase of the microBeRD project (2016–2019) attempts to overcome this shortcoming. It estimates the elasticity of business R&D expenditure and R&D related outcomes to changes in the B-index based on pooled, non-disclosive micro-aggregated data for 20 OECD countries. For 10 OECD countries where administrative tax relief data have been available, the tax relief microdata are matched by national experts within countries to R&D survey data at the firm level using unique firm identifiers. This allowed the researchers to identify the corporate performers that make use of R&D tax incentive support and to exploit information on the uptake of R&D tax incentives in the analysis. Therefore, it is the first cross-country study that uses administrative tax data on the firm level to analyse the effect of tax incentives on R&D activity. However, it has its own limitation considering the profit-making scenario only,[29] which means that loss-making firms will be assigned with higher B-indexes, leading to overstating the size of tax stimuli.

Moreover, when assessing the impact of R&D tax incentives on R&D expenditure most of these studies introduce instrumental variables[30] to deal with the endogeneity problem which arises when the tax treatment (i.e. the tax credit rate) depends on the amount of R&D

[25] For firms making claims under the SMEs scheme, refundable tax credits were considered. The average user cost for profit- and loss-making SMEs was computed based on the share of firms in the sample with corporate tax liabilities in 2006 and 2007 (used as a proxy for probability of making a profit).

[26] Indeed, the study reports substantially higher than typical values of tax-price elasticity of R&D being at 4.

[27] There is no straightforward evidence in the study on the assumption concerning non-claiming firms.

[28] Since higher variation in the tax price will not lead to the adequate variation in R&D expenditure, i.e. loss-making firms which can carry-forward tax benefits but assigned with high B-indexes may still have appropriate level of R&D expenditures.

[29] The assumption is made because the information on micro-level profit/tax liability is currently not sufficiently available.

[30] Westmore (2013) includes the B-index into the model as a dynamic term.

expenditure, or the corporate income tax rate varies with the size of taxable profit[31]. Some studies employ current tax rules to lagged firm characteristics to generate an instrumental variable, or use it as a substitute for the original B-index measure (Guceri and Liu, 2019; Thomson, 2017; OECD, 2020b).[32] While generating an instrumental variable helps deal with the potential endogeneity issue in the model, it also may reduce the precision of the estimates. Besides, the use of the B-index constructed based on the previous year's firms' characteristics instead of the original B-index may lead to overstating or underestimating tax support for R&D (for example, if threshold tax credit rates are applied, and there is a significant difference in the amount of R&D below and above the threshold in current and previous years).

Therefore, despite significant development of assessment practices in recent years due to the growing availability of administrative data, there are still some potential methodological issues that should be addressed.

Our approach to assessing the effectiveness of R&D tax incentives takes into account both aspects: the generosity of existing tax incentives and actual use of tax support through the R&D tax incentive implementation rate. We consider that direct support to R&D should also be included in the assessment, as it represents a significant part of total government support to R&D in some countries. Moreover, we would like to separate the effects of direct support to all sectors (gross expenditure on R&D – GERD) and direct support of R&D expenditure, except those attributed to the business enterprise sector. Such effects have not been studied previously, since only government support of business enterprise R&D was commonly used as one of the regressors (for example, in the OECD microBeRD project (OECD, 2020b); by Westmore, (2013) and Knoll et al. (2021) as a control variable). In addition, introducing these variables into the equation will capture some uncontrolled heterogeneity among countries while reflecting other countries' specific characteristics. Thus, for example, direct government funding of GERD, being a complex measure of government support to R&D performed in all institutional sectors of the economy (such as higher education, government, private non-profit, and business enterprise sector), may have an overall effect on the level of R&D expertise, quality and quantity of R&D personnel, the development of R&D infrastructure, and therefore, can encourage business to invest in R&D.

Figure 13 highlights cross-country differences in the level and structure of direct support for R&D.

As can be seen from Figure 13, the level and composition of direct support varies significantly across countries. Thus, in Hungary the level of direct financing of GERD in GDP (0.42 per cent) is close to that of Slovenia (0.43 per cent); however, a significant part of its direct support is devoted to the business enterprise sector – 0.13 per cent – while in Slovenia this is only 0.07 per cent. Latvia, the Slovak Republic, Romania and Greece provide low direct support to the business enterprise sector (0.01–0.02 per cent of GDP), while Lithuania did not support the business sector through direct government funds in 2017. We suppose that such differences can cause heterogeneity in the responses of businesses in financing their R&D and should be treated separately.

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[31] This means that higher R&D expenditure will lead to lower taxable income, and consequently a lower corporate income tax rate could be applied.

[32] For example, Guceri and Liu (2019) construct an alternative user cost of capital measure based on the previous year's "before-R&D spending" profits; Thomson (2017) computes the industry-specific tax price based on the weighted average tax price of the two expenditure categories (current and capital) where the weights are the lagged expenditure share mix for each industry; in the OECD microBeRD project, the firm-level synthetic measure of the B-Index (in period t) is obtained by applying the R&D tax incentive design in year t to the R&D performance of firms in year t-2.

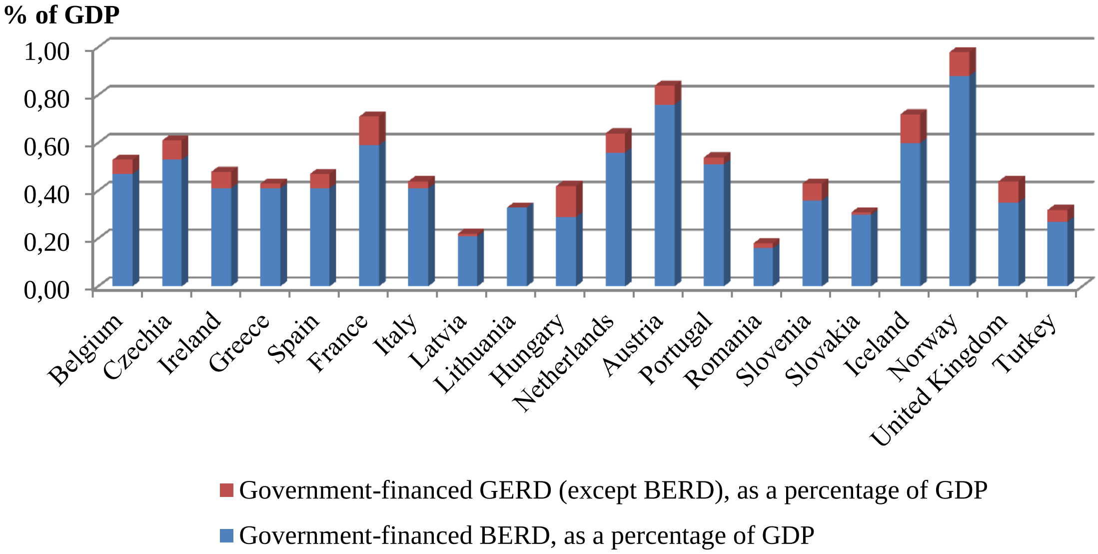

***Figure 13* – Direct support of business R&D and R&D of other sectors in 2017, as a percentage of GDP**

Notes: for Ireland government-financed GERD and government-financed BERD as a percentage of modified GNI is estimated.

Source: own construction based on Eurostat Science, Technology and Digital Society database (Eurostat, 2021a).

The path analysis was used to estimate the first- and second-order effects of R&D tax incentives. The first equation estimates the causal effect of tax treatment of R&D and direct funding on the level of business-financed R&D.[33] It enters the model in the two following forms:

$$BFRD_i = \beta_1 + \beta_2 ETT_i + \beta_3 DF_{R\&Di} + \varepsilon_i, \quad (9)$$

$$BFRD_i = \beta_1 + \beta_2 ETT_i + \beta_3 DF_{R\&D(excep\_of\_business)i} + \varepsilon_i\ , \quad (10)$$

where $BFRD_i$ is business-financed GERD in a country i as a percentage of GDP; $DF_{R\&Di}$ – direct funding of GERD in a country i as a percentage of GDP; $DF_{R\&D(excep\_of\_business)i}$ – direct funding of GERD except of BERD; ETT_i – the combined factor of efficiency of R&D tax treatment; ε_i – error term.

We introduce a general measure of tax treatment of R&D – the combined factor of efficiency of tax treatment of R&D (ETT_i), and compute it according to Formula (11):

$$ETT_i = (1 - \tau_i) * (1 - B - \text{index}_i) * TIIR_i, \quad (11)$$

where $TIIR_i$ is a R&D tax incentive implementation (utilisation) rate in a country i; τ_i is a corporate income tax rate in a country i.

There are two reasons behind the introduction of corporate income tax rate in the estimation. Firstly, the corporate income tax rate affects investment decisions of firms in general. Summers et al. (1981) distinguishes reductions in the corporate tax rate as one of the main categories of investment incentives, along with investment tax credit and accelerated depreciation (highlighting that they are more desirable than reductions in dividend taxes).

[33] Causal inference in research largely depends on design and causal assumptions; meanwhile statistical analysis by itself is rarely sufficient to establish causation (Kline, 2016).

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According to the firm-level analysis conducted by Millot et al. (2020) on a cross-country panel of MNE entities, MNE investment in a jurisdiction is negatively affected by effective corporate tax rate increases in that jurisdiction. Moreover, statutory corporate income tax rate is a key that affects investments in R&D-based industry (Stöwhase, 2002).

Secondly, the corporate income tax rate helps to correct the tax subsidy measure, since the latter strongly depends on the corporate income tax rate and shows only the discount in the price of R&D. For demonstrative purposes a simplified example on computation of the B-index is presented in Table 4.

Table 4 **– Computation of the B-index for different R&D tax incentive schemes and under different corporate income tax rates**

Country	A	B	C	D
Rate of - R&D tax allowance - R&D tax credit	 160% -	 130% -	 - 16%	 - 13%
Corporate income tax rate	20%	34%	20%	35%
B-index	0.85 $(1-0.2*1.6)/0.8$	0.85 $(1-0.34*1.3)/0.66$	0.80 $(1-0.2-0.16)/0.8$	0.80 $(1-0.2-0.16)/0.8$
Tax subsidy rate (1-B-index)	0.15	0.15	0.20	0.20

Note: for simplification it is assumed that all R&D expenditure can be deducted in the current year.
Source: own construction.

From the table it can be seen that in Country A the nominal value of the enhanced tax allowance is higher than in Country B; however, due to the lower corporate income tax rate B-indexes are equal in these countries. The same applies for Countries C and D: despite having a lower tax credit rate Country D taxes corporate profits at a higher rate, which leads to the same tax subsidy rate on R&D investment (Figure 14).

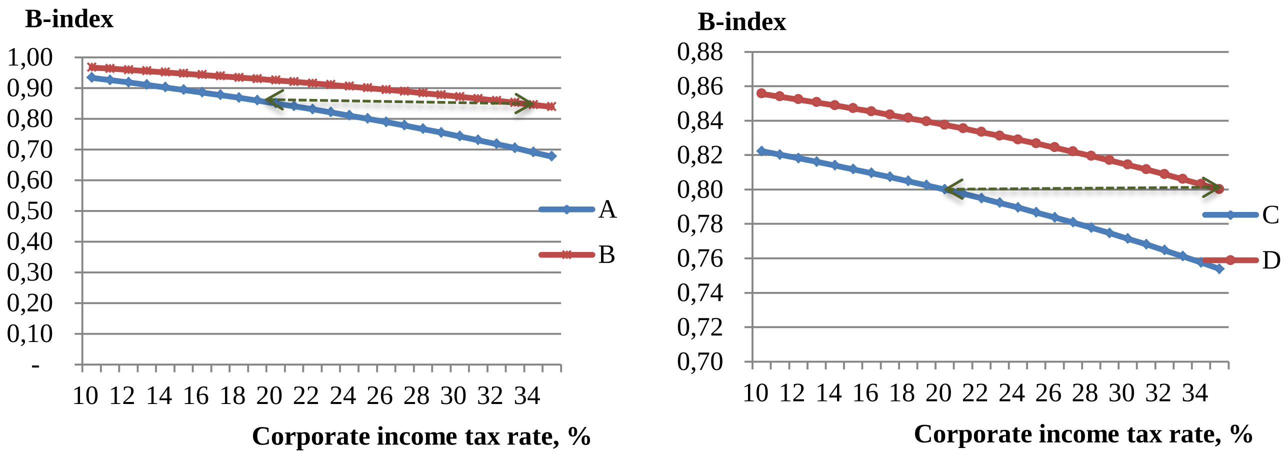

Figure 14 **– B-index measures for countries A, B, C, and D for different corporate income tax rates scenarios**

Source: own construction.

Figure 15 presents the variation of the B-index due to changes in the generosity of tax

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incentives while keeping the corporate income tax rate constant.

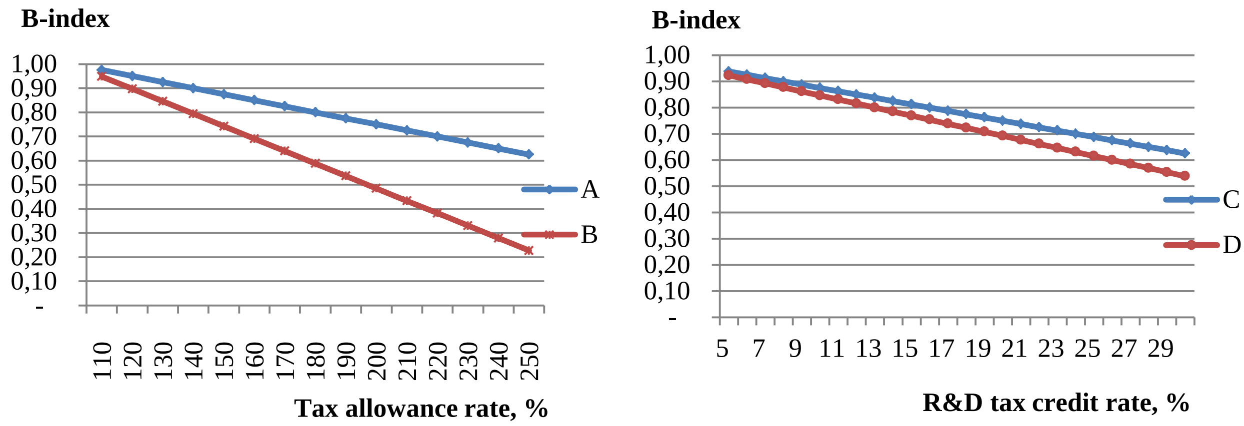

Figure 15 **– B-index measures for countries A, B, C, and D for various tax credit (or allowance) rates scenarios.**

Source: own construction.

As can be seen from Figure 15, the B-index is more responsive to the changes in R&D tax incentives in countries with higher corporate income tax rates (countries B and D).

When increasing the amount of tax savings, however, a higher corporate income tax rate can negatively affect the level of investment in general. The ETT_i will allow us to balance these two effects. The value $(1-\tau)$ in Formula (11) shows that generous tax incentive treatment will be more attractive in a country with a lower corporate income tax rate.

By simplification the following formula is derived:

$$ETT_i = (1-\tau_i) * Tax\ support_{norm,i}\ , \qquad (12)$$

where $Tax\ support_{norm,i}$ is a normalised amount of tax support for a country i, or the share of eligible business R&D (in terms of claimant) supported by tax incentives if multiplied by 100.

In the second equation of the structural model we intend to assess the effect of business-financed R&D on the amount of domestic patents (resident applications) (Formula 13).

$$Patents_i = \gamma_1 + \gamma_2 BFRD_i + \upsilon_i, \qquad (13)$$

where $Patents_i$ is the total amount of resident patent applications per million population in a country i in the following year[34]; υ_i – error term.

We do not expect the endogeneity caused by reverse causality to be a potential threat for the model estimation, since all countries in the data set apply flat corporate income tax rate and non-threshold dependent tax credit (allowance) rates are introduced by the majority of analysing countries. Moreover, estimating the share of R&D supported by tax incentives through the introduction of TIIR allows to account for the actual use of R&D tax incentives, while avoiding the endogeneity of R&D tax credit which may arise when absolute figures are estimated.

Reduced factorial design implied by the structural model comes at the expense of being able to fully disentangle all possible interaction effects, as many of them are assumed to be negligible and of no theoretical interest; however, this greatly reduces the number of participants required to achieve acceptable power.

[34] One-year lag is used to account for the time gap between R&D investment and patentable results.

Therefore, the structural equation model (SEM) will be estimated in the two following forms:

a) SEM_1:

$$\begin{cases} BFRD_i = \beta_1 + \beta_2 ETT_i + \beta_3 DF_{R\&Di} + \varepsilon_i \\ Patents_i = \gamma_1 + \gamma_2 BFRD_i + \upsilon_i \end{cases}, \quad (14)$$

b) SEM_2:

$$\begin{cases} BFRD_i = \beta_1 + \beta_2 ETT_i + \beta_3 DF_{R\&D(excep\_of\_business)i} + \varepsilon_i \\ Patents_i = \gamma_1 + \gamma_2 BFRD_i + \upsilon_i \end{cases}. \quad (15)$$

Estimated coefficients β_2 and γ_2 will allow us to derive additionality estimates (in business-financed R&D and the number of patent applications accordingly), based on which the second-order effect of R&D tax incentives can be assessed (i.e. the indirect effect of R&D tax incentives on patent applications).

The number of patent applications by a county's residents is used to estimate the second-order effects, since this indicator is easily comparable across countries as opposed to other innovation indicators used in single-country studies, such as the share of innovative products in total output or sales (for example, by Loshin and Mohnen (2008) for the Netherlands). The reason for limited cross-country comparability of the latter indicator lies in the fact that the definition of innovation involves some degree of subjectivity (OECD, 2019c). Thus, for example, according to the Community Innovation Survey 2018 (Eurostat, 2020) the share of turnover from new or significantly improved products that are new to the market[35] for product innovative enterprises is 7.5 per cent in the Slovak Republic, 10.4 per cent in Greece, and 6.9 per cent in Spain; while in more R&D intensive countries this indicator is lower – 5.4 per cent in Finland, 4.9 per cent in France, and 3.2 per cent in Norway (Appendix 5). Therefore, the number of patent applications is found to be a more suitable indicator of innovation. The data on patent applications is derived from WIPO Intellectual Property Statistics[36].

The structural equation model is estimated for 18 European countries[37] for 2015 and 2017. Prior to 2015 some of these countries did not offer R&D tax incentives, and therefore due to model specification cannot constitute a comparable sample set. The year 2017 is the latest year with comprehensive data on tax support, while for subsequent years some countries have not provided information on tax expenditures up to date, or have reported only provisional values. For a few countries data on direct support of GERD and government-financed GERD except for that performed by the business enterprise sector represents an average of the previous years due to higher vulnerability in these indicators. Until 2016, government R&D support through tax incentives in Austria was reported as a part of government funding. Therefore, to achieve consistency in reporting with other countries, the amount of government direct funding and business-financed GERD for this country were recalculated for 2015 by deducting from the former and adding to the latter indicator the amount of tax support provided to the business enterprise sector. For Romania, 2016 was used instead of 2017 due to the limited data. The amount of R&D tax incentive support for business R&D and direct support of GERD are derived from the Main Science and Technology Indicators (MSTI)

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[35] "New to the market" products have a higher level of novelty than products "new to the firm".

[36] Indicator 10 - Resident applications per million population (by origin), report type - total count by applicant's origin.

[37] Including Turkey

Database compiled by the OECD. More detailed statistics of government funding of R&D by sectors and BERD by source of funds are derived from the Science, Technology, Digital Society Database compiled by Eurostat.[38]

A few countries were excluded from the analysis. These are Slovenia, Belgium, and Sweden. In Slovenia the pattern of business-financed GERD significantly differs from all other countries (Figure 16).

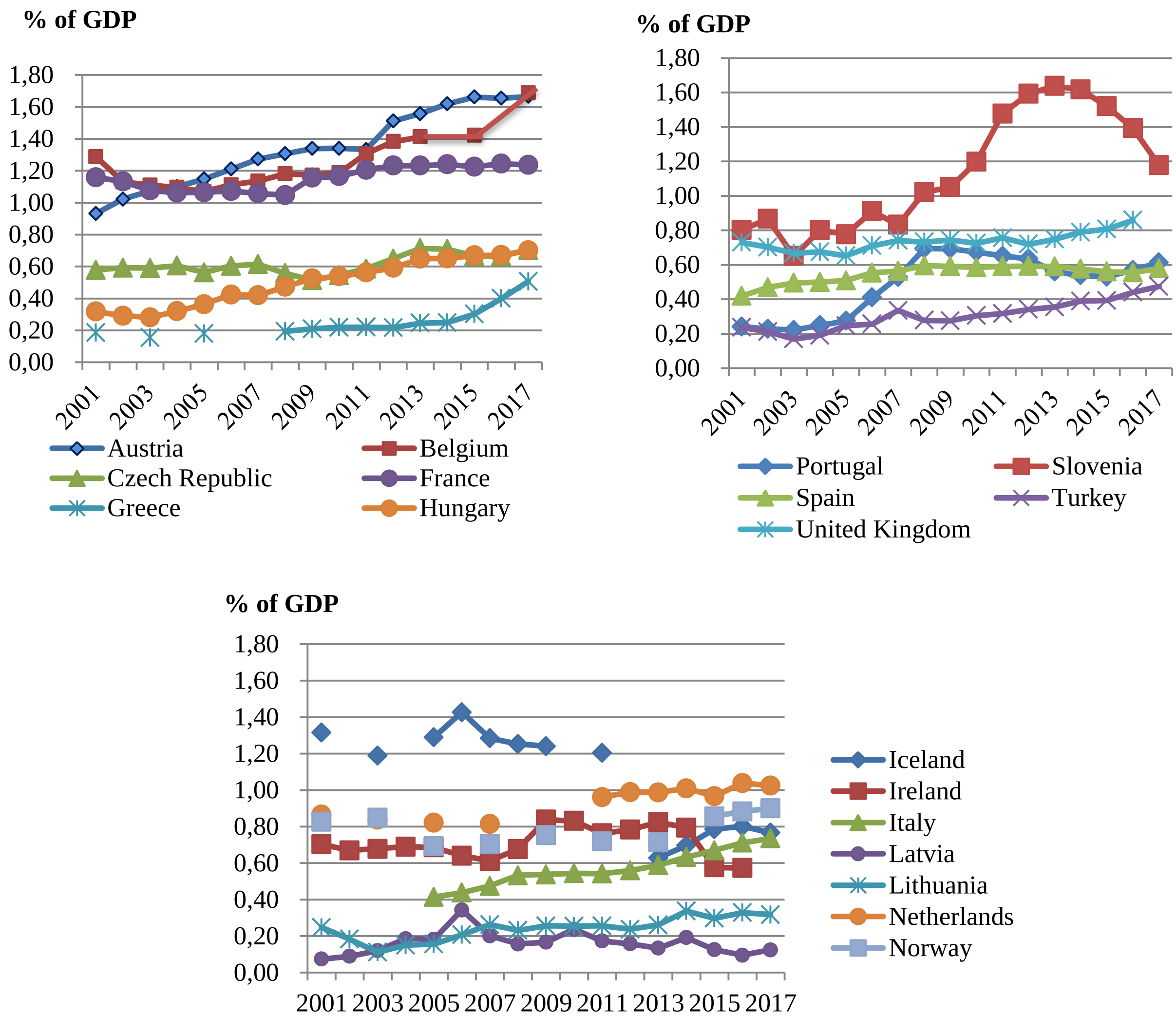

Figure 16 **– Business-financed GERD as a percentage of GDP in selected countries in 2001–2017**

Source: own construction based on the OECD Main Science and Technology Indicators Database (OECD, 201b).

In 2011, the sharp increase in business-financed R&D expenditure from 1.39 per cent to 1.78 per cent of GDP in this country is partly explained by the improvement of non-response analysis and the usage of new administrative sources to better identify R&D performers (OECD, 2021e). Additionally, business enterprise R&D was consistently increasing from 2009 to 2013 as a result of direct financing through structural funds co-financing of the Centers of Excellence (for the period 2009–2013 eight EU-co-financed Centres of Excellence have been set up) (Bučar, Jaklič, and Gonzalez Verdesoto, 2018; European Commission,

[38] GERD by sector of performance and source of funds (rd_e_gerdsc).

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2013), causing a subsequent increase in business-financed R&D, though with some lag (Figure 17). Therefore, due to the large variation in business and government funding of R&D, which can distort model estimates, Slovenia has been excluded from the analysis.[39]

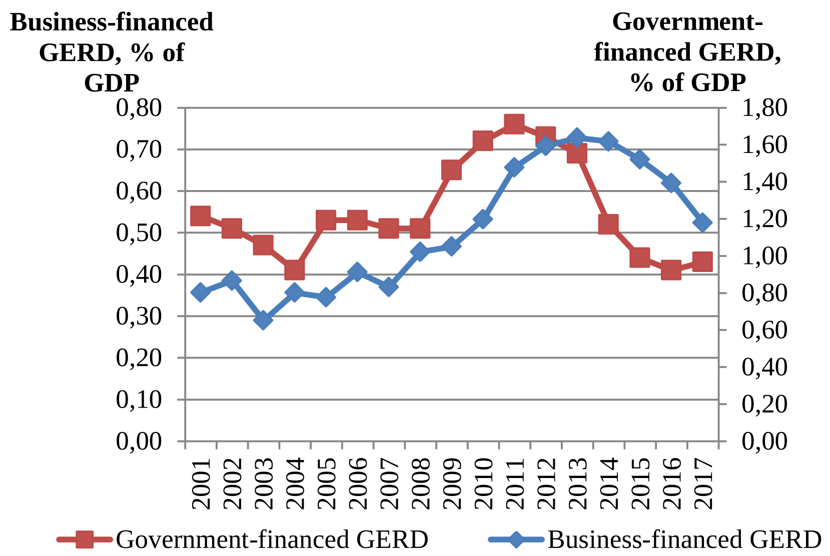

Figure 17 **– Government-financed and business-financed GERD as a percentage of GDP in Slovenia, 2001–2017**

Note: own construction based on OECD Main Science and Technology Database (OECD, 2021b).

From Figure 16, it can be seen that in Belgium and Greece business-financed R&D sharply increased in 2017 compared to 2015 (by 0.27 pp. and 0.22 pp. respectively). However, while in Greece the increase was accompanied by a growing amount of tax support and government funding of GERD, in Belgium government support of R&D through direct and indirect measures has decreased. Therefore, the high level of business-financed R&D in 2017 in Belgium could not be described only by these two measures, and the country consequently has been excluded from the analyses.[40] The exclusion of these two countries (Slovenia and Belgium) is justified since reducing the variance (besides that variance attributable to the intervention) can increase the statistical power of a small sample, meanwhile maintaining the sample representativeness.

The significance of tax incentives in Sweden is relatively low – the tax subsidy rate was at 0.05 for profit- and loss-making firms regardless of their size in 2017, while the EU mean for large profit- (loss-) making firms stood at 0.13 (0.11) (OECD, 2018b). Given that the country does not provide comprehensive data on the amount of direct government support, it cannot constitute a comparable case for the analysis.

The structural equation model is estimated based on the maximum likelihood estimator using the software package MPlus 8. Since the maximum likelihood fit function is based on a multivariate normality assumption, the distribution of each variable was analysed through normal Q-Q plots, skewness and kurtosis Z-values, Kolmogorov-Smirnov and Shapiro-Wilk tests (Appendix 6). The existence of outliers was tested through the computation of Mahalobinas distances to reveal the possible premises of deviations from normality.

[39] However, the model can be estimated with Slovenia in 2017 when trends in direct funding of GERD and business- financed GERD aligned.

[40] However, the model can be estimated with Belgium for 2015, when the level of business-financed R&D experienced a more gradual increase.

It was detected that the number of patent applications variable is positively skewed (the mean is twice as large as the median), which means more countries have a lower number of patent applications than the mean value. Since variance of the t-statistic depends on skewness (Yanagihara and Yyan, 2005), a robust estimator such as Satorra-Bentler rescaled test statistic leading to asymptotically correct confidence intervals is preferred. The Satorra-Bentler mean scaling statistic yields consistent results when data are of heavier tails (Cain, Zhang, and Yuan, 2017). It also performs better when sample size is small. Based on simulation results derived by Tong and Bentler (2013), the Satorra-Bentler scaled chi-square statistic outperformed classical goodness-of-fit method, namely maximum likelihood, and mean and variance adjusted statistics in terms of statistical power in small samples. The likelihood of a significance test detecting an effect when there actually is one was 0.62 for the Satorra-Bentler rescaled test statistic, 0.47 for the maximum likelihood method, and 0.16 for mean and variance adjusted statistics in a sample size of 50 for a multivariate normal distribution of variables; and 0.62, 0.46 and 0.13, respectively, when factors and errors are non-normally distributed and are independent. In a situation when factors and errors are non-normally distributed and they are dependent, the Satorra-Bentler rescaled test statistic outperforms other methods, while the maximum likelihood method tends to always reject a correct model (Type I error is 0.94) at small sample size. Since maximum likelihood is robust to moderate violations of normality assumption, many researchers opt to use maximum likelihood when data are moderately non-normal (Weston and Gore, 2006). Therefore, the structural equations models are estimated with both methods: Satorra-Bentler rescaled test statistic and maximum likelihood (the preferred models estimations results are given in detail in Appendix 7). The global fit measures for exact and approximate fit are presented in Table 5.

Table 5 **– Models fit information for 2017 datasets**

	SEM_1		SEM_2	
	ML	Satorra-Bentler mean rescaled statistic	ML	Satorra-Bentler mean rescaled statistic
χ^2 test:				
value	0.201	0.266	0.576	0.806
df	2	2	2	2
P-value	0.9044	0.8757	0.7497	0.6684
χ^2 test of model fit for baseline model:				
Value	51.559	92.438	47.954	75.777
df	5	5	5	5
P-value	0.000	0.000	0.000	0.000
RMSEA:				
Estimate	0.000	0.000	0.000	0.000
90 per cent CI	0.000 0.195	0.000 0.233	0.000 0.321	0.000 0.357
Probability RMSEA<0.05	0.908	0.881	0.759	0.680
CFI	1.000	1.000	1.000	1.000
TLI	1.000	1.000	1.000	1.000
SRMR	0.009	0.009	0.017	0.017
AIC	211.183	211.183	215.164	215.164
BIC	217.416	217.416	221.397	221.397

Source: own construction.

As can be seen from Table 5, the structural equation models are over-identified (df = 2), which indicates the existence of a unique solution for the structural parameters in the specified models.

The χ^2 goodness-of-fit statistic is not significant ($p > 0.05$), which indicates that the models have an exact fit. However, with smaller samples a null hypothesis is more likely to be retained, even with a large discrepancy between the sample covariance matrix and the model covariance matrix (Peugh and Feldon, 2020). As such, it is critical to evaluate the particulars of model-data correspondence in local fit testing. The root mean square of approximation (RMSEA) is a badness of fit index, declining with improving fit. The model closely fits the data, since the lower limit of the RMSEA is below 0.05 (the cutoff proposed by Browne and Cudeck (1993)). The Tucker-Lewis index (TLI) and the comparative fit index (CFI) are incremental indexes that measure improvement in fit from the baseline (independence) model to the proposed model. The value of 1 for both models (SEM_1 and SEM_2) is higher than the cutoff value of 0.95 proposed by Hu and Bentler (1999), indicating a good fit. The standardised root mean residual (SRMR) is a badness-of-fit index, and its minimum of 0 is for a perfectly fitting model. The values of SRMR for the proposed models are 0.009 and 0.017, indicating a good fit (less than 0.05 for a good fitting model is suggested by Hu and Bentler (1995)). The Akaike information criterion and the Bayesian information criterion suggest that SEM_1 which uses government-financed GERD (where all sectors of performance are included) as an independent variable better fits the data than SEM_2.

The estimated parameters for both models along with the computed additionality of R&D tax incentive policy based on derived estimates are presented in Table 6.

***Table 6* – Structural equation models results for 2017**

	SEM_1		SEM_2	
	Maximum likelihood	Satorra-Bentler mean rescaled statistic	Maximum likelihood	Satorra-Bentler mean rescaled statistic
R square:				
Business-financed GERD	0.742*** (0.105)	0.742*** (0.105)	0.678*** (0.125)	0.678*** (0.115)
Patents	0.776*** (0.093)	0.776*** (0.070)	0.776*** (0.093)	0.776*** (0.071)
Tolerance:				
ETT	0.915		0.920	
Government-financed GERD	0.915		-	
Government-financed GERD (except business R&D)	-		0.920	
ETT	1.528* (0.825)	1.528** (0.629)	1.661* (0.919)	1.661** (0.689)
Government-financed GERD	1.429*** (0.234)	1.429*** (0.338)	-	-
Government- financed GERD (except business R&D)	-	-	1.586*** (0.309)	1.586*** (0.429)
Patents	361.793*** (45.777)	361.793*** (48.064)	361.793*** (45.777)	361.793*** (48.335)
Total indirect	552.661* (306.674)	552.661** (234.894)	600.857* (341.216)	600.857** (258.980)
R&D additionality ratio	1.63	1.63	1.78	1.78
Additional patents: **-** on 0.10 % of GDP of tax support **-** as a percentage of	59	59	64	64

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total	32.3%	32.3%	35.1%	35.1%
Observations	18	18	18	18

*Notes: significance level p: * < 0.10, **< 0.05, ***< 0.01. The figures in parenthesis are standard errors.*
Source: own construction

As can be seen from Table 6, estimates of parameters are the same for both methods; however, Satorra-Bentler rescaled test statistic leads to improved significance of the estimates and lower standard errors. Consequently, we will refer to the Satorra-Bentler rescaled test statistic as our preference. The estimated models have high explanatory power: 74.2 per cent of the total variability in business-financed GERD is explained by ETT and government-financed GERD in SEM_1 and 67.8 per cent of the total variability in business-financed GERD by ETT and government-financed GERD except for R&D of the business enterprise sector in SEM_2. A significant proportion of the total variation in patent applications (77.6 per cent) is explained by business-financed GERD in both model specifications. Around 92 per cent of standardised variance in business-financed GERD is uniquely explained by each of the variables (ETT, government-financed GERD, and government-financed GERD except business sector R&D). All effects in the models are statistically significant.

The direct estimates of additionality were derived for government-financed GERD and government-financed GERD except business sector R&D. Based on the model results each euro of government direct support for R&D leads to 1.429 euro of additional business-financed R&D. The results are consistent with the recent OECD study (OECD, 2020b) that reported the effect of government funding of BERD on business R&D (net of direct funding and other external sources of R&D funding) as an additionality ratio of 1.373. The OECD analysis was conducted based on business R&D microdata for 17 OECD countries[41] for the period from 2016 to 2019. Up to this point, this is the only cross-country study, to our knowledge, that assesses the additionality of R&D tax incentive support, while most of cross-country studies focus solely on the elasticity of business R&D to the user cost of capital, which alone cannot be used to judge about deadweight loss (i.e. tax support provided to R&D that would happen anyway). The additionality of the government-financed R&D of other sectors (except the R&D of the business sector) estimated in SEM_2, 1.586, is higher than the additionality of government-financed GERD estimated in SEM_1. This may indicate that government funding of R&D of other sectors, such as higher education institutions, government organisations and non-profit institutions controlled by the government that perform or provide R&D services, has a significant effect on the intention of business enterprises to invest in R&D. Indeed, such type of funding may improve the quality of R&D personnel, lead to better infrastructure supporting R&D, and raise the level of R&D expertise.

The estimates of additionality of R&D tax support were derived from ETT coefficient based on the average business-financed R&D and average corporate income tax rate for countries analysed. The additional R&D induced by 1 euro of tax support is estimated at 1.63 euro. The result is comparable with the OECD additionality ratio (accounting for R&D tax support use), which was estimated at 1.409 based on the sample of 10 OECD countries[42] for the period 2016–2019. Overall the derived additionality of R&D tax incentives is higher than the additionality of direct funding of R&D. This may signal that tax incentives play an increasing role in incentivising business R&D in the countries analysed. The indirect effect of the efficiency of tax treatment on patents is found to be sizable and significant. The effect of

[41] The analysis covered the following countries: Australia, Austria, Belgium, Chile, the Czech Republic, France, Germany, Hungary, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Sweden, and the United Kingdom.

[42] These are Australia, Belgium, the Czech Republic, France, Hungary, Italy, the Netherlands, Norway, Portugal, and Sweden.

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R&D tax support was disentangled from the ETT variable, indicating that about 32.3 per cent of patents in the sample countries in 2017 were due to tax incentives. In other words, an additional tax support of 0.10 per cent of GDP induced 59 additional patents on average.

The effect of the corporate income tax rate is not of prime interest; however, based on the model results it can be assessed that a 1 percentage point reduction in corporate income tax rate leads to a 0.24 per cent increase in business-financed R&D. In comparison, the estimates for 18 OECD countries[43] (OECD, 2020b) suggest that a 1 percentage point reduction in the corporate income tax rate leads to an increase of business R&D investment by around 3.1 per cent. Conversely, the analysis in Appelt et al. (2019) conducted for 18 OECD countries[44] through the 2000–2016 period found that corporate income tax rate has no significant effect on business-funded BERD. Therefore, the effect of corporate income tax rate on business R&D appears to be heterogeneous, while the main drivers of business R&D activity are direct government funding and tax incentive support measures.

In order to investigate if the positive effect of tax incentives on business R&D activity persists through the years, the model was tested for 2015 for the same set of countries. The normality of the data was similarly explored (Appendix 6). A variety of tests, such as the skeweness and kurtosis z-scores, Q-Q plot, Kolmogorov-Smirnov and Shapiro-Wilk tests, demonstrate that the effectiveness of tax treatment variable is not normally distributed. The reason is the presence of the extreme value of ETT for Ireland. However, the test for multivariate outliers has not detected Ireland's case as significant. Therefore, it has been decided to leave the case in the sample in order to achieve comparability of the estimates between 2015 and 2017. Since the Satorra-Bentler rescaled test statistic may lead to biased results in the presence of outliers, a more robust estimator proposed by Yuang and Bentler (1998) was used. The results of the model fit are presented in Table 7.

Table 7 **– Models fit information for 2015 datasets**

	SEM_1		SEM_2	
	Maximum likelihood	Yuang-Bentler rescaled test statistic	Maximum likelihood	Yuang-Bentler rescaled test statistic
χ^2 test:				
Value	3.648	3.135	3.415	3.648
Df	2	2	2	2
P-value	0.1614	0.2085	0.1813	0.1614
χ^2 test of model fit for baseline model:				
Value	62.056	55.240	54.433	51.348
Df	5	5	5	5
P-value	0.000	0.000	0.000	0.000
RMSEA:				
Estimate	0.214	0.178	0.198	0.206
90 per cent CI	0.000 0.559	0.000 0.534	0.000 0.548	0.000 0.553
Probability RMSEA<0.05	0.175	0.223	0.195	0.185
CFI	0.971	0.977	0.971	0.967
TLI	0.928	0.944	0.928	0.918
SRMR	0.061	0.061	0.062	0.062

[43] The analysis covers Australia, Austria, Belgium, Canada, Chile, the Czech Republic, France, Germany, Hungary, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Sweden, and the United Kingdom.

[44] The analysis covers Australia, Belgium, Canada, the Czech Republic, Denmark, France, Hungary, Ireland, Italy, Japan, Korea, Mexico, Norway, Portugal, Slovenia, Spain, the United Kingdom, and the United States.

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AIC	204.405	204.405	211.794	211.794
BIC	210.637	210.637	218.027	218.027

Source: own construction.

As can be seen from Table 7, the χ^2 value is not significant, suggesting that the model has an exact fit. This argument can be supported by the χ^2 test of model fit for baseline model: the low p-value (< 0.05) of this test suggests that the proposed model significantly differs from the baseline model, where there are no covariances between variables. By jointly considering the point estimate for the RMSEA and its associated confidence interval, we cannot reject the null hypothesis of the exact fit since the lower bound of the confidence interval is 0. As noted by Chen et al. (2008), the sample RMSEA values and confidence intervals appear to be unbiased estimates of the corresponding population values when the sample size is reasonably large. Furthermore, Hu and Bentler (1998) reported that for a correctly specified model with small degrees of freedom and small sample size, RMSEA values can be quite large. Therefore, they recommended not computing RMSEA for small degrees of freedom, especially with small sample sizes. Similarly, at small sample size, the range of TLI tends to be large (Bentler, 1990); therefore, a cautious interpretation of model acceptability based on this fit index is recommended when sample size is small (Bentler, 1998). For smaller sample size (less than 250 observations) Hu and Bentler (1999) recommend combination rules based on CFI and SRMR, since combination rules based on RMSEA or TLI with SRMR tend to reject more true population models under the nonrobustness condition. Therefore, we refer to CFI and SRMR fit indexes, which suggest that both models have an acceptable fit (with CFI > 0.95 and SRMR < 0.08). The AIC and BIC criterions show that the model with government-financed GERD (SEM_1) instead of government-financed GERD excluding R&D of the business sector (SEM_2) as an independent variable can be preferred as better reflecting reality.

The estimated parameters for both models along with the computed additionality of tax support measures are presented in Table 8.

Table 8 **– Structural equation models results for 2015**

	SEM_1		SEM_2	
	Maximum likelihood	Yuang-Bentler rescaled test statistic	Maximum likelihood	Yuang-Bentler rescaled test statistic
R square:				
Business-financed GERD	0.824*** (0.075)	0.824*** (0.060)	0.735*** (0.107)	0.735*** (0.082)
Patents	0.779*** (0.092)	0.779*** (0.061)	0.779*** (0.092)	0.779*** (0.064)
Tolerance:				
ETT	0.965		0.981	
Government-financed GERD	0.965		-	
Government-financed GERD (except business R&D)	-		0.981	
ETT	0.945** (0.455)	0.945*** (0.251)	1.170** (0.554)	1.170*** (0.324)
Government-financed GERD	1.671*** (0.199)	1.671*** (0.280)	-	-
Government-financed GERD (except	-	-	1.832*** (0.287)	1.832*** (0.382)

business R&D)				
Patents	344.408*** (43.294)	344.408*** (43.111)	344.408*** (43.294)	344.408*** (43.110)
Total indirect	325.450** (191.903)	325.450*** (104.056)	402.805** (197.394)	402.805*** (135.189)
R&D additionality ratio	1.08	1.08	1.34	1.34
Additional patents: **-** on 0.10 % of GDP of tax support **-** as a percentage of total	37 20.5%	37 20.5%	46 25.2%	46 25.2%
Observations	18	18	18	18

*Notes: significance level p: * < 0.10, **< 0.05, ***< 0.01. The figures in parenthesis are standard errors.*
Source: own construction

As can be seen from Table 8, both estimation methods provide statistically significant estimates of parameters at a level less than 5 per cent. However, the Yuang-Bentler rescaled test statistic is preferred since it is corrected for non-normality of data. Most of the variability in business-financed R&D is explained by the model (82.4 per cent for SEM_1 and 73.5 per cent for SEM_2). Similarly, a significant proportion of the total variation in patent applications (77.9 per cent) is explained by business-financed R&D. Around 97 per cent of the standardised variance in business-financed GERD is uniquely explained by government-financed GERD and ETT in SEM_1 and around 98 per cent – by government-financed GERD of other sectors (excluding business R&D) and ETT in SEM_2. The additionality of government-funded GERD excluding R&D of the business sector is higher than the additionality of total government-funded GERD, similarly to that for 2017. This finding supports the previous conclusion that direct support of private R&D leads to less additional R&D than the direct funding of R&D of other sectors. In general, the additionality of direct government funding of GERD in 2015 is higher than in 2017, while additionality of indirect support through R&D tax incentives for 2015 is lower. This could be explained by it being a post-crisis period when businesses (especially in developing countries) facing difficulties in financing their R&D activities more often used tax incentives as substitutes for their private R&D expenditure, while government funding has a more restrictive nature and often should be complemented by partial financing of R&D projects through the enterprise's own funds. The number of patent applications indirectly induced by R&D tax incentives in 2015 is lower (at average 37 against 59 in 2017 on 0.10 per cent of GDP of tax support). Meanwhile, the effect of R&D tax incentives on patent applications is still sizable (20.5 per cent of additional applications induced by R&D tax incentives).

Therefore, the positive effect of R&D tax incentives on business-financed R&D is robust across the years; however, it may vary in size due to other meaningful macroeconomic factors.

2.4 Industry-specific correlation analysis of R&D intensity and productivity

Productivity is a measure of efficiency of utilisation of production inputs, such as capital and labour. It is considered as a key source of economic growth and competitiveness. As a third-order effect of R&D tax incentives, it is estimated to significantly less extent in the literature, and most commonly at a single country's level only. Considering that the firm's productivity is affected by various factors along with R&D investment, we cannot measure the effect of R&D expenditure on productivity in a functional form due to the limited data set. However, the strength of association between R&D intensity and productivity for different industries on a cross-country level may provide evidence of potential positive impact of R&D tax incentive policy on productivity based on the estimated additionality in R&D spending due to tax incentives.

The R&D intensity was computed for high-, medium-high-, medium-low-, and low-technology manufacturing industries classified based on NACE Rev. 2 at the two-digit level. Some industries were excluded due to limited data. From the service sector, only high tech knowledge-intensive services were included in the analysis, which are defined as such by Eurostat (Eurostat, 2021b) with the exception of audiovisual and broadcasting activities. The last two are referred to as low R&D intensive industries by the OECD (DSTI, 2015). The scientific research and development industry is excluded since R&D constitutes the main type of this sector's activity. The results are presented in Table 9.

Table 9 **- The strength of association between productivity and R&D intensity in selected business industries based on cross-country data, 2017**

Business industries	Pearson correlation
1.Manufacturing industry	
1.1 High-technology:	
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.427**
Manufacture of computer, electronic and optical products	0.648***
1.2 Medium-high-technology:	
Manufacture of chemicals and chemical products	0.681***
Manufacture of electrical equipment	0.728***
Manufacture of machinery and equipment n.e.c.	0.894***
Manufacture of motor vehicles, trailers and semi-trailers	0.755***
Manufacture of other transport equipment	0.293
1.3 Medium-low-technology	0.658***
1.4 Low-technology	0.506**
2. High-tech knowledge-intensive services:	
Telecommunications	0.272
Computer programming, consultancy and related activities	0.284
Information service activities	0.443**

Note: significance level p: * < 0.10, **< 0.05, ***< 0.01.
Source: own construction based on Appendix 8.

According to the data in Table 9, there is a strong statistically significant positive correlation between R&D intensity and productivity in industries, such as "Manufacture of machinery and equipment", "Manufacture of motor vehicles, trailers and semi-trailers", and "Manufacture of electrical equipment"; a medium-strong statistically significant positive correlation in "Manufacture of basic pharmaceutical products and pharmaceutical preparations", "Manufacture of computer, electronic and optical products“, "Manufacture of chemicals and chemical products", "Information service activities", and in medium-low technology and low-technology manufacturing industries. A lower than anticipated correlation between the two variables in the pharmaceutical sector can be explained by the fact that in some countries, such as the United Kingdom, Sweden, Norway, Denmark and France, businesses prefer to contract out a significant part of their R&D to research organisations. As contract research may be considered as a part of intermediate consumption on national accounts, it can distort to some extent business R&D intensity indicators of those countries (since R&D expenditures by the main type of activity of the enterprise in terms of turnover are used in computation of productivity). The correlation coefficient for "Information service activities" is affected by outliers. Portugal is found to have a low productivity estimate related to R&D intensity of the information service activities sector (Table 8.12 in Appendix 8). A lower value is also found for Iceland, while for Belgium and the United Kingdom the productivity is significantly higher in comparison with R&D efforts of the sector. When excluding these countries the correlation coefficient increases to 0.746. The correlation coefficient is low and not significant for “Manufacture of other transport equipment”, “Computer programming, consultancy and related activities”, and “Telecommunications”. Therefore, R&D tax incentives in support of these industries may bring lower value in terms of productivity growth if the causal relationship presents. The results are in line with some counties’ evaluations. Thus, for example, the fourth official evaluation of the Netherland’s WBSO scheme (de Boer et al., 2019b) reveals the positive correlation between the R&D wage bill (which is found to be positively affected by the WBSO scheme – largely through an increase in R&D hours), and additional value per worker. The conducted survey indicates the existence of such third-order effects.

Regarding the heterogeneity in the association between R&D intensity and productivity in manufacturing industries with different R&D intensity levels, we should note that the strength of association is lower for low-technology manufacturing industries. This outcome is supported by the study of Ortega-Argiles, Potters, and Vivarelli (2011), who conclude that high-tech sectors are far ahead in terms of the impact on productivity of their R&D investments as regards top European R&D investors.

Therefore, considering that most European countries do not differentiate R&D tax incentives by industrial sectors, the third-order effects of R&D tax incentives in the form of productivity growth may be expected primarily from sectors which have a strong positive association between R&D expenditure and productivity.

CHAPTER 3. INVESTIGATING HETEROGENEITY IN THE IMPLEMENTATION OF R&D TAX INCENTIVES

3.1 Cluster analysis of European countries for differing efficiency of implementation of R&D tax incentives

Application of an R&D tax incentive implementation rate may provide a government with additional information about the efficiency of implementation of its R&D tax incentive policy relative to that of other countries. Investigating the causes of these differences is important in order to correct policy actions and improve the means of policy delivery. Institutional factors are often important drivers of effectiveness of government policies. Strong institutions nurture confidence, and confidence influences the decisions of foreign and domestic R&D investors. Therefore, to reveal the existence of the connection between tax incentive implementation rate and institutional factors, we analysed the strength of association between TIIR and the set of indicators evaluated in the Global Competitiveness report published by the World Economic Forum. The institutional factors which may potentially have an impact on the implementation of R&D tax incentive policy are presented in Table 10.

Table 10 **– Strength of institutions indicators**

Institutional indicators	Evaluating questionnaire
Illegal diversion of public funds	In your country, how common is illegal diversion of public funds to companies, individuals, or groups? [1 = very commonly occurs; 7 = never occurs]
Irregular payments and bribes	Average score across the five components of the following Executive Opinion Survey question: In your country, how common is it for firms to make undocumented extra payments or bribes in connection with (1) imports and exports; (2) public utilities; (3) annual tax payments; (4) awarding of public contracts and licenses; (5) obtaining favourable judicial decisions? In each case, the answer ranges from 1 [very common] to 7 [never occurs]
Judicial independence	In your country, how independent is the judicial system from influences of the government, individuals, or companies? [1 = not independent at all; 7 = entirely independent]
Favouritism in decisions of government officials	In your country, to what extent do government officials show favouritism to well-connected firms and individuals when deciding upon policies and contracts? [1 = show favouritism to a great extent; 7 = do not show favouritism at all]
Burden of government regulation	In your country, how burdensome is it for companies to comply with public administration’s requirements (e.g., permits, regulations, reporting)? [1 = extremely burdensome; 7 = not burdensome at all]
Efficiency of legal framework in settling disputes	In your country, how efficient are the legal and judicial systems for companies in settling disputes? [1 = extremely inefficient; 7 = extremely efficient]
Transparency of government policymaking	In your country, how easy is it for companies to obtain information about changes in government policies and regulations affecting their activities? [1 = extremely difficult; 7 = extremely easy]
Strength of auditing and accounting standards	In your country, how strong are financial auditing and reporting standards? [1 = extremely weak; 7 = extremely strong]

Source: own construction based on the Global Competitiveness Report 2016-2017.

The reported indicators are derived from the World Economic Forum’s Executive Opinion Survey, and are reflected in the Global Competitiveness Report 2016–2017 with the exception of Romania, for which the indicators from the Global Competitiveness Report 2015–2016 were used in the analysis.

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The institutional indicators along with TIIR and generosity of R&D tax incentives are presented in Appendix 9. Turkey and Italy were excluded from the analysis due to their extraordinary high TIIRs, which can be caused partly by the low generosity of their R&D tax incentives. The graphical representation of the association between countries' TIIRs and institutional indicators is reflected in Figure 18.

The correlation analysis shows a strong positive association between TIIR and all presented institutional indicators except "strength of auditing and accounting standards", for which a medium-strong association with TIIR is identified (Table 11). The strength of association of this institutional indicator with TIIR is weakened by such countries as Romania and the Slovak Republic, for which the strength of auditing and reporting standards score is higher than the average (5.8 and 5.5 respectively, with the average being 5.2 for the country set analysed), while TIIR in these countries is significantly lower than the average – 0.21 for Romania and 0.23 for the Slovak Republic, with the average being 0.56.[45] Therefore, in these two countries changes in TIIR and auditing and accounting standards indicator are less associated with each other.

***Table 11* – The strength of association between TIIR and institutional factors**

	Illegal diversion of public funds	Irregular payments and bribes	Independence of judicial system	Favouritism in decisions of government officials	Burden of government regulation	Efficiency of legal framework in settling disputes	Transparency of government policy-making	Strength of auditing and reporting standards
Pearson Correlation	0.855***	0.788***	0.843***	0.816***	0.709***	0.805***	0.793***	0.662***
Number of countries	18	18	18	18	18	18	18	18

*Note: *** significant at < 0.01.*
Source: own construction.

To identify homogenous groups of countries based on the three following characteristics, specifically, generosity of R&D tax incentives, R&D tax incentive implementation rate, and institutional characteristics of the countries cluster analysis was applied. All institutional indicators are strongly correlated with each other, which enabled us to group them into one factor. "The strength of auditing and reporting standards" is less related to the rest of institutional indicators; therefore, it was excluded from the factor analysis (Table 10.2, Appendix 10). After its exclusion the Kaiser-Meyer-Olkin measure of sampling adequacy increased from 0.801 to 0.929, signalling that around 93 per cent of variance in institutional indicators might be a common variance (Tables 10.2 and 10.4, Appendix 10).

[45] When excluding Romania and the Slovak Republic from the correlation analysis the strength of association increases to 0.808, meaning that the tax incentive implementation rate is strongly associated with strong auditing and reporting standards for the rest of the countries studied.

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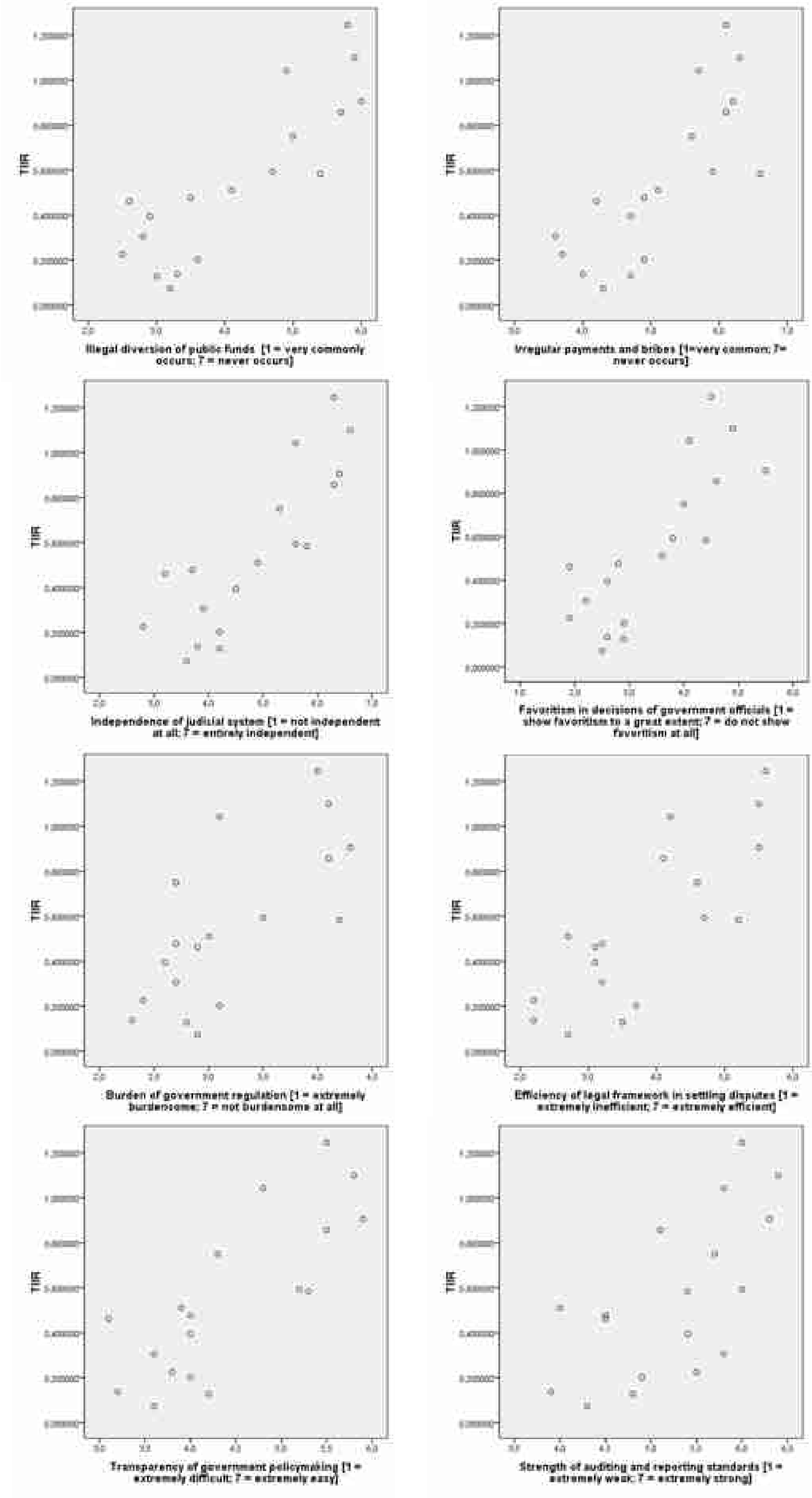

Figure 18 **– The correlation between tax incentive implementation rate and institutional factors, 2017**

Source: own construction.

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Based on between-group linkages three clusters were identified (Figure 19).

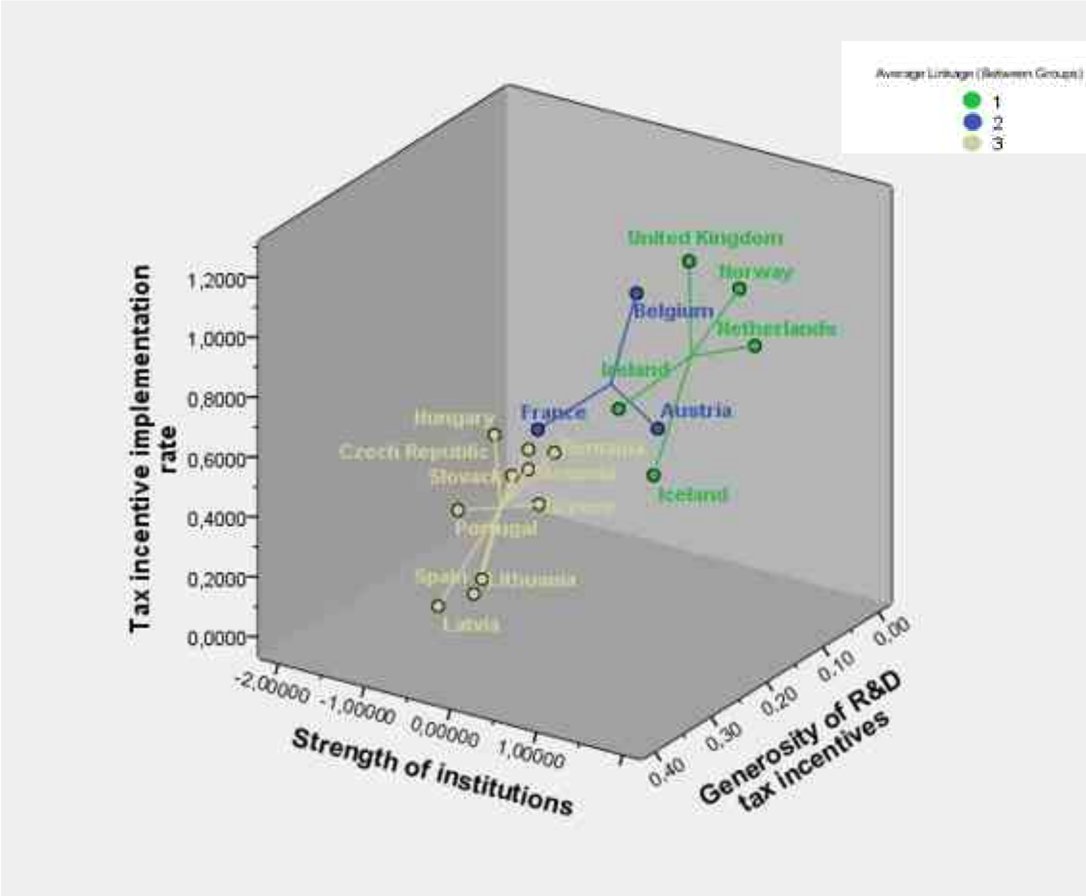

Figure 19 **– Clusters of counties based on institutional factors, generosity of R&D tax incentives, and tax incentive implementation rate**

Source: own construction

The analysis of variance shows that there are significant differences among the clusters in terms of tax incentive implementation rate and strength of institutions; however, not in terms of the generosity of R&D tax incentives (Table 11.3, Appendix 11). This can mean that not the generosity of R&D tax incentives is the main driver of the policy effectiveness, but the fact of how these tax incentives are implemented and used along with the institutional framework of a country. In other words, even generous R&D tax incentives may gain low popularity among businesses due to the weak institutional framework in a country, which would lead to a less efficient implementation of tax incentive policy, and therefore the low effect of the tax incentive policy on firms' R&D activity can be expected.

The classification characteristics of countries related to specific clusters are presented in Table 12. The first cluster mainly consists of the British Isles and Scandinavian countries. These countries have the highest tax incentive implementation rates. The lower values for Ireland and Iceland can be caused by overestimated tax subsidy rates that do not take into account limitations in the usage of tax incentives. Thus, for example, in Iceland there is a ceiling for eligible intramural R&D per project and per firm, as well as a ceiling for purchased R&D and R&D collaboration, which are assumed not to be binding in the computation of the B-index. In Ireland a ceiling is set up for subcontracted R&D expenditure. On the other hand, for Norway and the Netherlands the weighted tax subsidy rates were used in the computations, and for the United Kingdom the average tax subsidy rate is computed based on the actual amount of tax support provided by the type of the scheme, therefore giving more precise estimates of TIIR.

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Table 12 **– The classification characteristics of countries by clusters**

	TIIR	Generosity of R&D tax incentives	Institutional indicators							
			Illegal diversion of public funds [1 = very commonly occurs; 7 = never occurs]	Irregular payments and bribes [1 =very common; 7 = never occurs]	Independence of judicial system [1 = not independent at all; 7 = entirely independent]	Favouritism in decisions of government officials [1 = show favouritism to a great extent; 7 = do not show favouritism at all]	Burden of government regulation [1 = extremely burdensome; 7 = not burdensome at all]	Efficiency of legal framework in settling disputes [1 = extremely inefficient; 7 = extremely efficient]	Transparency of government policymaking [1 = extremely difficult; 7 = extremely easy]	Strengths of institutions average score (rows 3-9)
Cluster 1										
Iceland	0.58	0.24	5.4	6.6	5.8	4.4	4.2	5.2	5.3	5.3
Ireland	0.86	0.29	5.7	6.1	6.3	4.6	4.1	4.1	5.5	5.2
Netherlands	0.91	0.12	6.0	6.2	6.4	5.5	4.3	5.5	5.9	5.8
Norway	1.10	0.13	5.9	6.3	6.6	4.9	4.1	5.5	5.8	5.7
United Kingdom	1.25	0.19	5.8	6.1	6.3	4.5	4.0	5.6	5.5	5.5
Mean	*0.94*	*0.19*	*5.8*	*6.26*	*6.3*	*4.8*	*4.1*	*5.2*	*5.6*	*5.5*
Std. dev.	*0.25*	*0.07*	*0.2*	*0.21*	*0.3*	*0.4*	*0.1*	*0.6*	*0.2*	*0.3*
Cluster 2										
Austria	0.59	0.15	4.7	5.9	5.6	3.8	3.5	4.7	5.2	4.9
France	0.75	0.31	5.0	5.6	5.3	4.0	2.7	4.6	4.3	4.7
Belgium	1.04	0.16	4.9	5.7	5.6	4.1	3.1	4.2	4.8	4.8
Mean	*0.80*	*0.21*	*4.9*	*5.73*	*5.5*	*4.0*	*3.1*	*4.5*	*4.8*	*4.7*
Std. dev.	*0.23*	*0.09*	*0.2*	*0.15*	*0.2*	*0.2*	*0.4*	*0.3*	*0.5*	*0.1*
Cluster 3										
Hungary	0.46	0.17	2.6	4.2	3.2	1.9	2.9	3.1	3.1	3.2
Slovenia	0.48	0.19	3.5	4.9	3.7	2.8	2.7	3.2	4.0	3.7
Portugal	0.51	0.37	4.1	5.1	4.9	3.6	3.0	2.7	3.9	3.9
Czech Republic	0.39	0.18	2.9	4.7	4.5	2.6	2.6	3.1	4.0	3.7
Spain	0.13	0.30	3.0	4.7	4.2	2.9	2.8	3.5	4.2	3.8
Greece	0.14	0.09	3.3	4.0	3.8	2.6	2.3	2.2	3.2	3.2
Lithuania	0.20	0.31	3.6	4.9	4.2	2.9	3.1	3.7	4.0	3.9
Latvia	0.07	0.31	3.2	4.3	3.6	2.5	2.9	2.7	3.6	3.4
Slovak Republic	0.23	0.10	2.5	3.7	2.8	1.9	2.4	2.2	3.8	3.1
Romania	0.31	0.08	2.8	3.6	3.9	2.2	2.7	3.2	3.6	3.5
Mean	*0.29*	*0.21*	*3.5*	*4.41*	*3.9*	*2.6*	*2.7*	*3.0*	*3.7*	*3.5*
Std. dev.	*0.16*	*0.11*	*0.5*	*0.53*	*0.6*	*0.5*	*0.3*	*0.5*	*0.4*	*0.3*

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The strongest positions in the institutional factors in the first cluster are taken by the Netherlands and Norway, while Iceland and Ireland have less strong institutions. The highest variability in institutional factors within the group is observed in "efficiency of legal framework in settling disputes" where the United Kingdom has the most efficient legal framework, while Ireland has the lowest score in the group.

The second cluster consists of Western European countries. The average TIIR is equal to 0.80 with a standard deviation of 0.23. However, the real gap among countries is lower, since Austria and France have ceilings on subcontracted R&D which are assumed not to be binding in the computation of their tax subsidy rates. Considering that in 2017 around 11.3 per cent of total business-financed GERD in France was performed by scientific R&D organisations, and around 9.6 per cent in Austria (Eurostat, 2021a), the TIIRs of these countries can be underestimated. On the opposite, in Belgium TIIR may be slightly overestimated due to the fact that tax support for this country is reported on the gross-of-tax basis; however, payroll withholding tax exemption is effectively taxable, reducing the amount of expenditure deductible from taxable income. The average score for the institutional factors in the group is 4.7 which is lower than in the previous group (5.5). In general, France has a slightly lower position in institutional factors mostly due to lower transparency of government policymaking and burdensome government regulation.

The third cluster has the lowest average TIIR being at 0.29 and the lowest average score for institutions (3.5). It consists mainly of Central and Eastern European countries. The strongest positions in the group belong to Portugal and Slovenia, with TTIRs at 0.51 and 0.48 and the average scores for institutions 3.9 and 3.7, respectively. The lowest positions in the group are held by Latvia, Greece, and the Slovak Republic. This cluster of countries is characterised by the highest favouritism in decisions of government officials; this can lead to some degree of subjectivity in obtaining tax support when government officials are involved in decision-making process on recipients of tax support and approvals of qualifying R&D. Thus, for example, with the minimum score of 1 meaning favouritism in decisions to a great extent, the average score for this indicator in the group is 2.6, while in the first cluster it is equal to 4.8, and in the second cluster it is 4.0. Other significant differences in the institutional scores of the third cluster relative to the other two arise from "Transparency of government policymaking" and "Illegal diversion of public funds". This means that in the third group of countries it is more difficult for companies to obtain information about changes in government policies and regulations affecting their activities, which can be crucial when a firm decides whether to use tax incentives. Furthermore, if businesses believe that illegal diversion of public funds takes place in the country, they may not be encouraged to apply for R&D tax incentives, expecting that the decisions on tax support are not objective and transparent.

Such institutional indicators as burden of government regulation and making undocumented extra payments still differ among the three groups of countries but to a lesser extent, which means that they may have lower potential impact on the usage of R&D tax incentives by firms.

Therefore, the institutional framework of a country should be taken into account while implementing R&D tax incentives. Tax incentive policy supported by strong institutions can encourage firms to use tax incentives, leading to higher tax incentives take-ups by firms, which can further lead to higher additionality of the policy in terms of business R&D investment growth.

3.2 Application of R&D tax incentives implementation rate in policy analysis

The tax incentive utilisation (implementation) rate can be applied by policymakers when analysing the changes in tax incentives take-ups in a country.[46] Thus, for example, if the generosity of R&D tax incentives has increased, the TIUR may show how quickly firms react to policy reform, and the relative attractiveness of the introduced changes in the tax scheme compared with the old one can be evaluated.

The changes in TIUR were analysed for the set of European countries based on the R&D tax incentives effective in each country from 2001 to 2019 for the years where sufficient data is available (Table 13). Country notes on the computation of TIUR are presented in Appendix 13.

Computed tax incentive utilisation rates helped to identify some common trends in the usage of R&D tax incentives. Thus, as shown in Table 13, in the crisis year 2009 in some countries (such as Austria, Belgium, the Netherlands, Turkey, and the Czech Republic) the TIUR increased, which can reflect increased demand from businesses for supporting their R&D activities. In Slovenia and Italy a decrease in TIUR is observed, which can signal that due to the lack of profits, firms could not benefit from the tax scheme. The tax incentive scheme in Italy was non-refundable, with no carry-over, while in Slovenia unused benefits could be carried forward only for five years.

In some cases a low tax incentive utilisation rate accompanied by high generosity can signal the existence of limitations, such as ceilings and floors, in the usage of R&D tax incentives. For example, in Spain the generosity of R&D is one of the highest among the countries; however, the TIURs are relatively low for the observed period. The reason is the existence of ceilings for R&D tax credit (as a percentage of gross tax due) and payroll withholding tax credit (as a percentage of the annual wage bill for qualified research staff) that are assumed to be non-binding in the computation of the B-index. Moreover, the ceiling exists on a refund received at a 20 per cent discount (optional to carry-forward provision), which is also not modelled in the B-index indicator. For some countries, an observed increase in TIUR is caused by lowering limitations in the usage of tax incentives in the form of increased ceilings or removed thresholds. For example, in France the gradual increase of TIUR from 0.36 to 0.50 in 2006–2008 reflects the changes introduced to the scheme in the form of increased ceiling for R&D tax credit from 10 million euro in 2006 to 16 million euro in 2007; furthermore, from 2008 the ceiling was removed and the scheme became fully volume-based. In Norway TIUR increased from 0.30 in 2013 to 0.47 in 2015 while the threshold for R&D tax credit was increased for intramural R&D to 15 million Norwegian kroner (5.5 million in 2013), for purchased R&D to 33 million Norwegian kroner (11 million in 2013), and for total R&D to 33 million Norwegian kroner (11 million in 2013). In Iceland, the ceiling for R&D expenditure per project and per firm increased from 100 million to 300 million Icelandic krona in 2017, and for purchased R&D or a collaboration agreement from 150 million to 450 million Icelandic krona; these changes were followed by an increase in TIUR from 0.30 in 2015 to 0.58 in 2017.

Some changes to the R&D tax scheme can make it more attractive for firms, and therefore lead to increased TIURs. Thus, for example, in the United Kingdom in 2014 the payable tax credit was introduced for large companies which before could benefit only from non-refundable super deduction for their R&D expenditures. After the introduction of the scheme the TIUR increased from 0.55 in 2013 to 0.96 in 2014, and the number of claims from large firms increased by 2.2. In Ireland TIUR increased from 1.32 in 2014 to 1.51 in 2015 when the R&D tax credit became entirely volume-based (from 2012 to 2014 a hybrid tax credit was

[46] The term “tax incentive utilisation rate” is better suited for the purpose of such analysis.

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Table 13 – **R&D tax incentive utilisation rates for European countries, 2001-2019**

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria																			
Tax subsidy rate	0.10	0.03	0.06	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.12	0.12	0.12	0.12	0.12	0.15	0.15	0.17	0.17
TIUR	-	2.99	-	0.65		0.60	0.75	-	0.86	-	0.58	-	0.58	-	0.69	-	0.59	-	0.61
Belgium																			
Tax subsidy rate	-	-	-	-	0.10	0.09	0.10	0.13	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16
TIUR	-	-	-	-	0.01	0.23	0.43	0.53	0.84	0.92	0.91	0.90	0.95	-	1.30	-	1.04	-	-
Czech Republic																			
Tax subsidy rate	-	-	-	-	0.26	0.23	0.23	0.20	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
TIUR	-	-	-	-	0.19	0.22	0.23	0.24	0.30	0.36	0.46	0.45	0.47	0.41	0.46	0.42	0.39	0.35	0.36
France																			
Tax subsidy rate	0.08	0.08	0.08	0.15	0.15	0.21	0.21	0.43	0.43	0.43	0.44	0.44	0.45	0.45	0.45	0.43	0.43	0.43	0.43
TIUR	0.35	0.32	0.29	0.31	0.35	0.36	0.44	0.50	0.52	0.55	0.50	0.51	0.50	0.50	0.51	0.53	0.54	0.54	0.53
Greece																			
Tax subsidy rate	-	-	-	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.07	0.09	0.09	0.09	0.09	0.07
TIUR	-	-	-	-	-	-	-	-	-	1.27	1.07	1.82	0.21	0.23	0.21	0.23	0.14	0.17	0.21
Hungary																			
Tax subsidy rate	0.21	0.2	0.21	0.18	0.18	0.18	0.24	0.24	0.24	0.21	0.21	0.21	0.35	0.34	0.34	0.34	0.22	0.21	0.20
TIUR	-	-	-	-	-	-	-	-	1.25	1.33	1.32	0.82	0.50	0.59	0.56	0.33	0.36	0.30	0.29
Iceland																			
Tax subsidy rate	-	-	-	-	-	-	-	-	-	-	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
TIUR	-	-	-	-	-	-	-	-	-	-	0.12	-	0.37	0.36	0.30	0.33	0.58	0.55	0.54
Ireland																			
Tax subsidy rate	-	-	-	0.21	0.21	0.21	0.21	0.21	0.26	0.26	0.25	0.27	0.26	0.27	0.29	0.29	0.29	0.29	0.29
TIUR	-	-	-	0.31	0.27	0.30	0.65	0.55	0.58	0.62	0.80	0.76	1.09	1.32	1.51	1.48	0.77	0.64	0.76
Italy																			
Tax subsidy rate	-	-	-	-	-	-	0.12	0.12	0.12	-	-	-	-	-	0.04	0.04	0.09	0.09	0.07
TIUR	-	-	-	-	-	-	0.29	0.47	0.37	-	-	-	-	-	1.75	2.76	2.46	2.60	2.57
Latvia																			
Tax subsidy rate	-	-	-	-	-	-	-	-	-	-	-	-	-	0.31	0.31	0.31	0.31	-	-
TIUR	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.05	0.09	0.08	-	-
Lithuania																			
Tax subsidy rate	-	-	-	-	-	-	-	0.31	0.45	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
TIUR	-	-	-	-	-	-	-	0.08	0.17	0.17	0.15	0.17	0.14	0.14	0.23	0.30	0.23	0.20	0.25
Netherlands																			
Tax subsidy rate	0.17	0.17	0.17	0.06	0.18	-	0.19	-	0.23	-	0.24	0.24	0.23	0.23	0.23	0.25	0.25	0.25	0.25
TIUR	0.44	-	0.41	-	0.42	-	0.40	-	0.66	-	0.58	0.53	0.49	0.51	0.46	0.53	0.48	0.43	0.44

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Norway																			
Tax subsidy rate	-	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.22	0.22
TIUR	-	-	0.38	-	0.33	-	0.25	-	0.27	-	0.27	-	0.30	-	0.47	0.59	0.62	0.61	0.55
Portugal																			
Tax subsidy rate	0.30	0.30	0.30	-	-	0.28	0.28	0.28	0.41	0.41	0.41	0.41	0.41	0.40	0.39	0.39	0.39	0.39	0.39
TIUR	0.31	0.41	0.46	-	-	0.48	0.56	0.43	0.34	0.33	0.38	0.34	0.39	0.46	0.53	0.51	0.51	0.68	-
Romania																			
Tax subsidy rate	-	-	-	-	-	-	-	-	-	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
TIUR	-	-	-	-	-	-	-	-	-	-	-	-	-	0.52	0.37	0.31	-	-	-
Slovak Republic																			
Tax subsidy rate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.11	0.10	0.28	0.41
TIUR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.11	0.23	0.24	0.17
Slovenia																			
Tax subsidy rate	-	-	-	-	-	0.05	0.04	0.04	0.04	0.08	0.08	0.18	0.17	0.17	0.17	0.17	0.19	0.19	0.19
TIUR	-	-	-	-	-	1.18	1.37	1.02	0.76	0.57	0.49	0.32	0.34	0.38	0.46	0.48	0.48	0.43	0.41
Spain																			
Tax subsidy rate	0.39	0.39	0.40	0.40	0.40	0.40	0.35	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30
TIUR	-	0.15	0.16	0.18	0.19	0.14	0.15	0.16	0.17	0.15	0.12	0.14	0.15	0.18	0.17	0.17	0.16	0.15	-
Turkey																			
Tax subsidy rate	-	-	-	-	-	-	-	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
TIUR	-	-	-	-	-	-	-	1.28	2.94	2.70	2.48	2.49	1.86	2.06	2.23	2.35	2.50	3.03	3.34
United Kingdom																			
Tax subsidy rate	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.13	0.13	0.13	0.13	0.16	0.18	0.17	0.18	0.18	0.19	0.20	0.20
TIUR	-	-	-	-	-	0.49	0.52	0.50	0.53	0.56	0.58	0.55	0.55	0.96	1.15	1.20	1.25	1.36	-

Note: tax subsidy rates and TIURs calculated in line with the developed methodological approach.
Source: own construction.

available). In contrast, in Italy, an incremental R&D tax credit introduced in 2015 appeared to be more attractive to firms than the volume-based tax credit widely available from 2007 to 2009. While the average TIUR for the old scheme was at 0.38, for the new tax credit it is at 2.4. In Portugal an increase in the period for which the tax credit can be carried forward – from six years in 2013 to eight years in 2014 – was accompanied by the increase in TIUR from 0.39 to 0.46.

Sometimes countries which increase the generosity of their R&D tax incentives may experience a decrease in the TIUR due to lower activity of firms in take-ups of R&D tax incentive. For example, in 2013 Hungary introduced an additional R&D tax incentive – an SSC exemption for researchers. This change is reflected in the increased tax subsidy rate from 0.21 to 0.35; however, the TIUR decreased from 0.82 in 2012 to 0.50 in 2013. The reason behind that may be lower availability of the new tax incentive due to limitations in its usage (up to a monthly gross wage of 500 thousand Hungarian forint). In some cases increased generosity of R&D tax incentives accompanied by lowering TIUR (computed based on cash estimates for tax support) can signal low profitability of firms, which does not allow them to fully benefit from tax incentives through corporate income taxation. As an example, in Slovenia R&D tax allowance rates were raised from 20 per cent in 2009 to 40 per cent in 2010, to 100 per cent in 2012; at the same time TIUR decreased from 0.76 in 2009 to 0.57 in 2010 to 0.32 in 2012. Therefore, cash-based tax support did not increase proportionally, which suggests the existence of some obstacles to utilisation of the R&D tax incentive. In Portugal, an increase in volume-based rate for R&D expenditure from 20 per cent in 2008 to 32.5 per cent in 2009 did not cause a corresponding increase in TIUR. On the contrary, it decreased from 0.43 to 0.34, which can indicate growing uncertainty of firms in conducting R&D in times of crises (a refund in case of losses was not provided).

In some cases when tax parameters of the scheme remain constant, the increase in TIUR may reflect purely behavioural effects of the firms. Thus, for example, in Belgium TIUR significantly increased from 0.95 in 2013 to 1.30 in 2015. Since the estimates of tax support are provided on an accrual basis, the increase may reflect higher tax incentives uptakes. According to the third evaluation of R&D tax incentives in Belgium (Dumont, 2019), the number of firms benefitting from partial exemption from withholding tax for wages paid to employees with master's degrees increased by about 11 per cent from 2013 to 2015; additionally, the number of firms which used tax deduction increased by about 60 per cent. This demonstrates the growing attractiveness of R&D tax schemes among R&D performing firms.

Despite the high generosity and potential availability of tax incentives, they may not attract potential users. This case can be attributable to Latvia, where R&D tax incentives were abolished due to low applicability.

Therefore, the R&D tax incentive utilisation rate can be used by policymakers as an additional measure which reflects the availability of existing tax incentives, as well as their attractiveness for potential users.

Modelling of tax support based on headline tax incentive implementation rates is another way of applying TIIR in policy analysis.[47] Modelling of the amount of tax support can be based on benchmark TIIRs for countries with similar institutional characteristics. It is assumed that such countries are more likely to be able to achieve the level of frontier country in implementation of R&D tax incentives. For countries where weighted and non-weighted B-indexes differ and where figures for the former are not available, the original TIIRs were used (based on the non-weighted B-index).

The group of countries with similar institutional framework is presented in Figure 20.

[47] The term "tax incentive implementation rate" is better suited for the purpose of such analysis.

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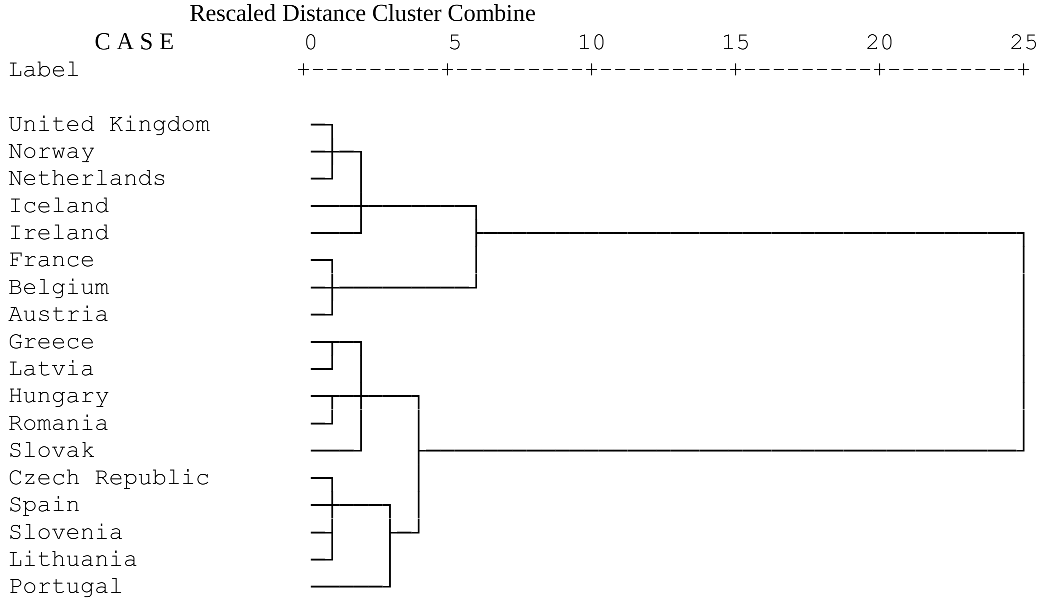

Figure 20 **– Hierarchical clusters of countries with similar institutional characteristics**

Note: *dendrogram using Average Linkage (Between Groups).*
Source: constructed by the author with the use of SPPS Statistics.

Based on the hierarchical clusters of countries presented in Figure 19, groups of countries were formed to which the benchmark TIIR can be applied (Table 14).

Table 14 **– Benchmark and baseline countries for TIIRs modelling**

Benchmark country	Hungary	Portugal	United Kingdom
Baseline countries	Latvia Romania Slovak Republic Greece	Czech Republic Lithuania	Norway Netherlands

Source: own construction.

For France, Belgium, and Austria no benchmark has been chosen. In Austria TIIR can be underestimated since R&D expenditures subcontracted to related parties are not eligible for R&D tax credit, while in France they are counted for tax credit purposes, although with a limit (2 million euro). In Austria subcontractor fees that qualify for the R&D tax credit cannot exceed 1 million euro annually, while in France the subcontracted R&D fees may not exceed 12 million euro. Since the share of subcontracted R&D for firms that use tax incentives is not known, more precise TIIR for these countries cannot be computed. Furthermore, in Belgium the estimates of TIIR can be overstated to some extent since the gross-of-tax figures for tax support are used. For Iceland and Ireland lower TIIRs reflect limitations in usage of R&D tax incentives, and therefore they were not adjusted to the benchmark.

The differences in TIIRs in countries with a similar institutional framework may arise from better awareness of R&D tax incentives, more simplified application procedure, and other factors that could be learned and adopted to countries' current practice. It is expected these changes may have a positive impact, albeit to a limited extent. The more laborious way will be improving the institutional framework, which can take considerable time and effort by governmental officials.

The modelling was performed through the application of the headline TIIR for each group of countries given in Table 14, and the average increases in tax support and business-financed R&D were computed (Table 15). The weighted average B-index was used based on its availability for some countries to eliminate the effect of limitations in the use of R&D tax incentives on computed TIIRs.

Table 15 **– Results of modelling 1**

	Baseline	New	Difference (p.p.)
The average tax support, as a % of GDP	0.105	0.115	0.010
Business-financed GERD, as a % of GDP	0.730	0.746	0.016

Source: own construction.

From Table 15 it can be seen that if R&D tax incentive implementation rates in baseline countries increase to the level of those in benchmark due to better delivery of tax incentive policy, the average tax support as a percentage of GDP increases by 0.01 p.p. and the average business-financed R&D increases by around 0.02 p.p. Moreover, the expected growth in these indicators can be computed for different conditions, such as if some countries will weaken their limitations on the usage of R&D tax incentives. Thus, for example, if Austria were to apply similar contracting rules as in France, assuming that taxpayers have similar behavioural patterns, the average tax support would further increase up to 0.117 per cent of GDP, and average business-financed R&D would increase to 0.750 per cent of GDP (Table 16).

Table 16 **– Results of modelling 2**

	Baseline	New	Difference (p.p.)
The average tax support, as a % of GDP	0.105	0.117	0.013
Business-financed GERD, as a % of GDP	0.730	0.750	0.020

Source: own construction.

Therefore, investigating the practice of implementation of R&D tax incentives in countries that have similar institutional frameworks may provide a better understanding of the behavioural patterns of taxpayers and thus help identify ways of better delivering the policy to increase its overall efficiency.

3.3 Benchmarking R&D tax incentives and improving cross-study comparability of their efficiency

Numerous evaluations have been conducted in order to assess the responsiveness of firms to R&D tax incentives. Most commonly authors measure the elasticity of R&D expenditure to changes in the tax component of user cost of R&D capital. However, the results of these studies are often not comparable due to differences in the methodologies used. Many current studies use a difference-in-difference methodological framework or regression discontinuity design to estimate the effect of changes in existing tax incentive schemes. These results cannot be used to identify countries with the best practices, since they do not estimate the overall impact of R&D tax incentives. Some studies compare tax incentive schemes based on selected criteria to identify best practices. For example, the European Commission (2014a) benchmarked tax incentives based on three main categories of features: scope of the policy (including the type of R&D tax incentive and costs covered), targeting and organisation.

In terms of scope the French tax credit scheme ("Jeunes Enterprises Innovantes", "JEI") tops the list (Table 17). It supports only R&D wages, which is considered by the European Commission as the best practice due to low administration and compliance cost (i.e. 'it may be more straightforward to distinguish R&D and non-R&D labour than R&D and non-R&D expenditures' (European Commission, 2014b, page 76)) and stronger externalities of these types of expenditures. Moreover, the scheme has a strict novelty requirement ("new to the world") which supports R&D with potentially the largest social returns. The JEI scheme is in the form of a tax credit (i.e. the amount of tax benefit does not vary with the tax rate) and supports the volume of R&D expenditure (i.e. it is easier to administer and it does not distort the investment planning of the firm).

Table 17 **– Ranking of R&D tax incentives as best practices by the European Commission**

Name of the scheme	Scheme description	Overall rank (score)	Scope rank (score)	Targeting rank (score)	Organisation rank (score)
"Jeunes Enterprises Innovantes" (France)	Payroll withholding tax credit for young innovative firms	1 (0.78)	1 (1.00)	16 (0.67)	3 (0.60)
"SkatteFUNN" (Norway)	R&D tax credit	2 (0.73)	23 (0.40)	61 (0.39)	1 (0.80)
"WBSO" (Netherlands)	Payroll withholding tax credit/social security contributions reduction	5 (0.65)	9 (0.60)	48 (0.50)	3 (0.60)
R&D tax credit (Ireland)	R&D tax credit	6 (0.61)	47 (0.27)	5 (0.78)	3 (0.60)
"Corporate tax credit for R&D" (United Kingdom)	R&D tax allowance	8 (0.60)	9 (0.60)	36 (0.61)	15 (0.50)
"Skattekreditordningen" (Denmark)	R&D tax credit for deficit-related R&D expenses	9 (0.59)	23 (0.40)	50 (0.44)	3 (0.60)
Credit for R&D personnel (Spain)	Social security contributions exemption	11 (0.57)	9 (0.60)	1 (0.89)	16 (0.40)

Notes: scores range from 1 as for the best practice to -1 as for non-recommendable practice. Only top tax schemes of European countries are selected. Accelerated amortization schemes are not reflected.

Source: own construction based on European Commission (2014b).

Organisational rank is tightly connected to the practical implementation of tax incentive policy. In terms of organisation the highest rank is determined for the Norwegian scheme "ScatteFUNN". The application procedure of "ScatteFUNN" is based on self-declaration and can be carried out online, a one-stop agency is available and guidance throughout the application can be received from relevant authorities. The high score is also driven by the presence of regular official evaluations of the tax credit, which is less common for other R&D tax incentive schemes. R&D tax schemes in France ("JEI"), the Netherlands ("WBSO") and Denmark ("Skattekreditordningen") lag slightly behind in terms of organisation. Thus, for example, in Denmark the application procedure of "Skattekreditordningen" in general presents a good administration practice; however, the refund period is long and can take up to two years. The lower score for the Netherlands' WBSO scheme is caused by the absence of public consultations, while for the French "JEI" no electronic application procedure is available.

In terms of targeting, the tax credit for R&D personnel in Spain has the highest score. The scheme does not differentiate in terms of region, legal form or firm size. It has no minimum requirements for R&D expenditures, no brackets, and it is immediately refundable.

The relatively low score on targeting for the Norwegian “SkatteFUNN” is partly caused by targeting SMEs, which is considered by the European Commission as a neutral practice; the further decrease in its score is associated with neutrality of “SkatteFUNN’ to young firms, the existence of ceilings and the non-availability of carry-forwards. However, we consider that the refundability of the scheme should outweigh the latter criteria, since it is a more beneficial practice for firms.

In general, the European Commission (2014a) considers targeting SMEs as a neutral practice, referring to the fact that there is not enough evidence that small firms respond more strongly to R&D tax incentives than large firms. Moreover, addressing the study of Bloom et al. (2013) the Commission argues that knowledge spillovers are not stronger for small firms, as the gap between social and private returns to R&D is more profound for large firms. Instead it emphasises that more generous support and a refund option for young firms is a better practice. From our point of view, tax support of SMEs in the form of refunds is justified due to the limited financing capabilities of such firms. For example, under the United Kingdoms’ R&D tax allowance scheme only SMEs could benefit from a cash refund, even though from 2013 such benefits were offered for large firms under the RDEC scheme. As good practices of refund options for large companies, we consider R&D tax credit in Belgium and French R&D tax credit (“Crédit d'Impôt Recherche”), which are refundable after five and three years, respectively (for the part which is not used). Such a design will incentivise large companies to conduct profitable activity, at the same time providing some certainty in the recovery of their R&D expenditures. A good practice for counties with constrained budgets may be the Spanish R&D tax credit scheme, which can be refunded at the discount. Tax scheme rules may also offer the possibility to choose between carry-over and discounted refund options, which will provide large companies with more flexibility in managing their finances.

Targeting of R&D tax incentives on regions is non-recommendable practice by the European Commission since it might trigger firms to move their activities, which works against economy of scale. Moreover, it is considered that offering a higher tax rate of support in a region with not satisfactory framework conditions is unlikely to have an effect on innovation. Despite this fact, the R&D tax incentive scheme in Italy modified in 2020 offered enhanced tax credit rates for Southern regions. Such a design feature is rather an exception for European countries and provides a base for further evaluations of the practice.

Although tax incentives with the strict novelty requirement “new to the world” are considered by the European Commission as best practice, they may be less available for firms and may not sufficiently cover potentially innovative companies. In such a case the novelty requirement “new to the firm” (“new to the country”) may be good practice in countries which lag behind in terms of innovation. At the same time, introducing a patent box regime in such a country will incentivise the creation of high-quality patented inventions. Since currently the benefit due to the scheme is restricted by the actual R&D activities performed in a given country (see Action 5 of the OECD’s Base Erosion and Profit Shifting Plan), firms have limited possibilities to shift their income and oversubsidising is less likely to take place.

Some additional features of R&D tax incentives should be added to the assessment of good practices (Table 18).

Taxability of tax relief may be an additional criterion to benchmark tax schemes, since non-taxable tax schemes can be better understood by the firms and are easier to comply with. However, this criterion should not disregard tax schemes that are essentially taxable, such as social security contributions tax credits.

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***Table 18* – Additional design features for benchmarking R&D tax incentive schemes**

Design features	Content	Best practice
Taxability of tax relief	Taxable versus non-taxable	Non-taxable
Expenditures covered	Treatment of costs of R&D audits	Covered for SMEs
	Eligibility of qualified prototype and pilot model expenses	Eligible for SMEs
Applicability of tax relief based on timing of R&D expenditures incurred	Applicability to retroactive, current or future investment	Applicable to retroactive, current and future investment
Availability of advance approval for future R&D projects	Available versus not available	Available
Refundability	Cash refunds versus redemption against other taxes	Redemption against other taxes; cash refunds if the full amount was not redeemable through other taxes

Source: own construction.

R&D audits are essential requirements in some countries and provide firms with supporting documentation to justify their expenditures. However, most often such audits are not requested by tax authorities as a prerequisite for applying for R&D tax incentives. The cost of audits is generally high and can be burdensome for SMEs. Embedding such costs in the qualifying expenditures will increase the attractiveness of tax scheme for SMEs and improve their financial compliance. Construction of prototypes and pilot models are part of the innovation process used for the validation of new products, processes and services; however, they are often not considered as a part of R&D expenditures and, therefore, do not benefit from R&D tax incentives. Including these innovation costs at a full or lower R&D tax credit rates for SMEs will further improve small firms' financing capabilities in carrying out R&D activities.

The applicability of tax relief for retroactive, current and future investment increases the flexibility of firms in utilising R&D tax incentives. Since awareness about the scheme may not be widespread, especially at the time of introduction of new R&D tax incentives, it can be beneficial for firms to be able to apply it retroactively. Such a design will increase scheme's attractiveness and may lead to higher take-up rates. Availability of advance approval for future R&D projects will increase legal certainty of firms at an earlier stage. Such an approval can be obligatory if a country is planning to implement refund provisions. This will increase the quality of applications and may prevent the misuse of the scheme.

Refundability of R&D tax relief can be realised in different ways. Some counties – instead of a cash refund – allow firms to offset tax credit against different types of tax liability. For example, in Italy R&D tax credit can be offset against income tax liability, regional taxes and social security contributions. This practice can be considered as more beneficial for firms since it may reduce the time needed for obtaining a refund. Additionally, such refunds may involve lower administrative costs.

An additional design feature of tax schemes that might be desirable for implementation in countries with a lack of highly qualified R&D personnel is the offering enhanced tax credit rates for researchers with doctoral degrees. Such an incentive will stimulate firms to hire more qualified R&D personnel and potentially may lead to higher innovation output. At the other end of the spectrum, if these countries have less competitive wages, it may allow firms to raise salaries for such employees, which may have a positive impact on retaining highly qualified staff in the county. As an example, the modified tax scheme in Italy offers an enhancement rate (150 per cent of the actual expenditure) for costs related to highly qualified employees under 35 years of age with a PhD in their first job and employed with a fixed-term contract (OECD,

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2022). Such a design can be considered as a good practice since it supports young researchers – who are usually highly mobile – and assists in retaining them in the country.

Increasing the comparability of methodologies used to evaluate the effectiveness of R&D tax incentives will allow best practices to be identified from the practical point of view. From our observations there are following discrepancies among studies that affect their comparability:

1. Treatment of carry-forward provisions in modelling the B-index and the user cost of R&D capital. Numerous studies (e.g. Guceri and Liu, 2019; Agrawal, Rosell, and Simcoe, 2020; Dechezlepretre et al. 2020) do not account for the possibility of loss-making firms to benefit from tax incentives through carry-forward provisions; therefore, overstating the user cost of R&D for such firms. However, since the study of Agrawal, Rosell, and Simcoe (2020) is conducted based a sample consisting predominantly of firms with fully refundable tax credits, this assumption will not significantly distort elasticity estimates. The other two aforementioned studies estimate the effect of differential changes in the user cost of R&D for newly classified SMEs with payable tax credits compared to companies that remained as large (under a new definition of company size for the purpose of R&D tax credit) for which only the carry-forward option for negative tax liability was available. Therefore, the distortive effects in these studies may be more pronounced, resulting in the underestimated elasticities of R&D investment to its tax price.

The official evaluation of research and development tax credit in the United Kingdom (Fowkes, Sousa, and Duncan, 2015) takes a different approach. It considers only the profit-making scenario, as it better reflects the grounds for the relevant economic decisions. The profit-making scenario for firms with negative tax liability is used in the recent OECD MicroBeRD project (OECD, 2020b) due to difficulties in obtaining and linking tax liability micro-data to firms' R&D data, and in the study of Holt, Skali and Thomson (2021). From our point of view, despite this approach better reflecting the value of tax stimuli for loss-making firms, it underestimates to some extent the tax price of R&D for such firms, thereafter affecting the elasticity estimates.

A more sophisticated method of computation of the user cost for loss-making firms was used by Rao (2016). She discounts carry-forward tax credits and R&D expensing provision based on the following formula:

$$\rho_{it} = (r_t + \delta - \pi_t^K) \times p_t^K \times \frac{\left(1 - \tau_{it+l_{it}}(1 + r_t)^{-l_{it}} - c_{it}(1 + r_t)^{-m_{it}}\right)}{\left(1 - \tau_{it+l_{it}}(1 + r_t)^{-l_{it}}\right)}, \tag{16}$$

where ρ_{it} – relevant user cost of a firm i at time t; τ_{it} – marginal tax rate; l_{it} – years of tax losses; c_{it} – marginal tax credit rate; m_{it} – years of carry-forwards for R&D tax credit; r_t – real interest rate; δ – depreciation rate; π_t^K – science and tech wage inflation; p_t^K – purchase price of R&D.

The third multiplier reflects the tax price of one monetary unit of R&D. Where the relevant data on the firm level are available the tax price computed according to the above formula may better reflect the value of future tax benefits and lead to more precise elasticity estimates.

While conducting analysis on the aggregate level we suggest considering the average time period of returning to profit, the average size of losses for loss-making firms, and the average taxable income for profit-making firms. These data will allow estimating the average number of years required for recovering the tax credit through carry-forward provisions. The tax price of R&D may be computed with the following formula:

$$R\&D^{tax\ price}{}_i = p_t^K \times \frac{1 - \tau_i(1 + r_i)^{-l_i} - \lambda_{mi} \sum_{m=n}^{k} c_i(1 + r_i)^{-m_i}}{1 - \tau_i(1 + r_i)^{-l_i}}, \tag{17}$$

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where $R\&D^{tax\,price}{}_i$ is the tax price of R&D in a country i; τ_i –corporate income tax rate; r_i – real interest rate; c_i – tax credit rate; l_i – average period of returning to profit; $m = [n : k]$ – consecutive years from n to k of recovering tax credits through carry-forward provisions; λ_{mi} – constant probability of recovering tax credits in years m.

The constant probability of recovering tax credits in years m may be computed based on the average number of years required for their recovery. The following formula may be applied:

$$\overline{T_{c_i}} = \frac{\overline{TC_i}}{\overline{P_{before\,tax_i}} \times (1-\tau_i)} \quad , \tag{18}$$

where $\overline{T_{c_i}}$ – the average period of recovering tax credits in a country i; $\overline{TC_i}$ – the average size of tax credits; $\overline{P_{before\,tax_i}}$ – the average profit before income tax.

The data required for computations may be derived from tax filings of firms benefitting from R&D tax incentives.

For illustrative purposes we computed the tax price of R&D according to different methodologies applied in the literature as well as according to the suggested formula. The following input data were used for computations: τ_i equal to 25 per cent; c_i equal to 20 per cent; r_i equal to 5 per cent; years of tax losses or the average period returning to profit (l_i) equal to 3 years; m_{it} equal to 4 years; and $\overline{T_{c_i}}$ equal to 2 years[48]. The results are reflected in Table 19.

Table 19 **– Treatment of carry-forward tax credit and its effect on the tax price of R&D**

Methodology	Computation	Tax price of R&D
Modelled as a current benefit (profit-making scenario)	$\frac{1-0.25-0.20}{1-0.25}$	0.73
Not modelled as a current or future benefit	$\frac{1-0.25}{1-0.25}$	1.00
Discounting according to Rao (2016)	$\frac{1-\frac{0.25}{(1+0.05)^3}-\frac{0.20}{(1+0.05)^4}}{1-\frac{0.25}{(1+0.05)^3}}$	0.79
Discounting based on the average period of recovering tax credits	$\frac{1-\frac{0.25}{(1+0.05)^3}-0.05\frac{0.20}{(1+0.05)^4}-0.05\frac{0.20}{(1+0.05)^5}}{1-\frac{0.25}{(1+0.05)^3}}$	0.80

Note: for simplification all R&D expenditures are treated as current.
Source: own construction.

As can be seen from the table, there is a significant variation in the tax price of R&D due to the different methodologies used. Discounted values of tax benefits give more moderate estimates. The differences may be more pronounced based on the time periods of returning to profit and recovering the tax credits, the applied discount rate, and the share of loss-making firms which use carry-forwards in the sample.

2. The other source of differences is the method of computation of refundable provisions in the tax price of R&D. Most studies (for example, Agrawal, Rosell, and Simcoe, 2020; Scott and Gliner, 2020; Dechezlepretre et al., 2020; Holt, Skali, and Thomson, 2021) do not consider the carry-forward option of general losses and recovering R&D investment in the future periods.

[48] Therefore, the constant probability of recovering tax credits λ_{mi} can be computed as $\frac{1}{\overline{T_{c_i}}}$, and is equal to 0.5.

They take into account only immediately refundable tax credits. The OECD (2020b) in its MicroBeRD project applies a profit-making scenario for firms entitled to cash refunds of R&D tax credits. From our point of view, the approach to the computation of tax price of R&D for firms with cash refunds should also take into account carry-over possibilities of general losses and the discounting option of cash refunds, since some countries have introduced limits on the amount refundable (e.g. Spain, Norway) or have determined a certain period within which the equal portions of tax credits are reimbursed (e.g. Ireland).

Applying similar preconditions as for Table 19, the tax price of R&D was estimated based on different methodologies of accounting for refundable provisions in computations. The results are reflected in Table 20.

***Table 20* – Treatment of refundable tax credit and its effect on the tax price of R&D**

Methodology	Computation	Tax price of R&D
Only immediately refundable tax credit is modelled	$1-0.20$	0.80
Immediate deductability of R&D expenses and cash refund are modelled	$\frac{1-0.25-0.20}{1-0.25}$	0.73
Modelling carry-forwards for deductible R&D expenses and cash refunds (immediate/non-immediate):		
- 3 years of carry-forward losses and immediate refund of tax credit	$\frac{1-\frac{0.25}{(1+0.05)^3}-0.20}{1-\frac{0.25}{(1+0.05)^3}}$	0.74
- 3 years of carry-forward losses and non-immediate refund of tax credit (3 instalments)	$\frac{1-\frac{0.25}{(1+0.05)^3}-\sum_{n=1}^{3}\alpha\frac{0.20}{(1+0.05)^n}}{1-\frac{0.25}{(1+0.05)^3}}$	0.77

Notes: α is a share of annually reimbursed tax credit $\left(\alpha=\frac{1}{n}\right)$; n – years of carry-forward of non-immediate refund ($n=3$).

Source: own construction.

As can be seen from the table, accounting for the future possibility to deduct R&D expenses from taxable profits lowers the tax price of R&D, thereby leading to more precise estimates which are close to the profit-making scenario. If a refund has limits, then the tax price of R&D investment is higher and more comparable with accounting for only an immediate refund. Therefore, modelling refunds for specific countries should be adapted to tax rules applied in those countries. Since carry-forward options of tax losses are commonly available in European countries, we recommend accounting for them in the computations.

3. Evaluating the effect of R&D tax incentives on qualifying versus total amount of R&D expenditures. There is some evidence that qualified R&D can be more responsive to tax treatment than total R&D spending (Rao, 2016). Therefore, while comparing elasticities from different studies this feature should be taken into account. Estimating elasticities of total amount of R&D expenditure on the micro level is more demanding and requires linking administrative tax data to firms' business survey data. While some studies (e.g. Rao, 2016) make both estimates, others (e.g. Liu and Guceri, 2019) estimate only elasticity of qualified R&D expenditure, conducting additional tests to investigate if the relabelling or substitution of R&D expenditures might take place. We consider that both practices are acceptable and should be utilised in the research.

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4. Evaluating extensive versus intensive margin effects of R&D tax incentives. While most research focuses on the intensive margin, which is the additional R&D expenditure among businesses already claiming the relief, some studies (e.g. Dechezlepretre et al., 2020) capture both intensive and extensive effects of the tax policy. Since the former is not a complete measure of the relief's effectiveness there might be some differences in the elasticities, as was observed by Dechezlepretre et al. (2020) – firms already engaged in innovation activities had the strongest responses to a policy change.

5. Evaluating the effect of policy change versus the overall effect of R&D tax incentives. We consider that these estimations should not be compared since there could be decreasing returns to scale regarding the generosity of the scheme, as well as low responses to changes to less generous schemes that do not incentivise enough companies, since the compliance costs incurred by firms may outweigh the benefits.

Additionality ratios associated with the derived elasiticies based on different evaluation methods should also be compared with caution. The gross additionality includes the increase in private R&D spending due to the amount of tax subsidy itself and additional business R&D over the amount of tax subsidy. Most studies report the gross estimates, while, for example, the official third evaluation of R&D tax incentives in Belgium conducted by Dumont (Dumont, 2019) reports BFTB in net terms. Thus, for example, the BFTB of 0.14 in net terms implies that one euro of R&D tax credit results in 0.14 euro additional R&D, in addition to the one euro received in tax support.

The conclusion about more or less effective policies should not be based only on simple comparisons of additionality ratios, since R&D tax incentive policy may play different roles in the policy mix. If a country relies on tax incentives as an additional tool to stimulate private R&D, it may expect additionality higher than one to conclude that the policy is effective. However, if the government introduced tax incentives as a substitute for direct support measures, it may find that a BFTB value around one is still a desirable policy result. Moreover, spillover effects that are not reflected in the additionality ratio should be assessed separately.

There are some ways that may be considered by policymakers to improve the comparability of the introduced measure of TIIR:

1. Calculating the weighted tax subsidy rates for the rest of the European countries, especially those which impose limitations on the use of R&D tax incentives. For this purpose the data on the distribution of eligible R&D spending should be made available. Currently, such data are provided to the OECD by France, Hungary, the Netherlands, Norway, Portugal, and Sweden. The use of the weighted tax subsidy rates in the calculation of TIIR will allow disentangling purely behavioural effects of firms in tax incentive take-up based on its perceived attractiveness.

2. Estimating R&D tax expenditures on an accrual basis. Ideally the data on both the accrual and cash basis should be collected; however, accrual estimates allow disregarding the differences in TIIR due to the better economic conditions of firms affecting their profitability status. While use of the weighted average B-index for profitable and loss-making firms in the formula only partly solves this problem, the accrual estimates coupled with the profit-making scenario B-index will better reflect the intention of firms to use tax incentives. To improve estimates of TIIR computed based on cash-basis tax expenditures, the distribution of eligible R&D among profit- and loss-making firms should be available, and the B-index for the loss-making scenario should be computed based on the suggested formula (B-index component in Formula (17)).

3. Reporting of R&D expenditure on net of tax basis. Some countries which offer wage related tax incentives (for example, payroll withholding tax exemption in Belgium, SSC exemptions in Hungary, Spain and Turkey, payroll withholding tax credit in the Netherlands) report tax expenditures on gross-of-tax basis. Since this relief is taxable (i.e. it decreases the

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amount of deductible cost for corporate income tax purposes) the amount of tax support may be overstated, which may lead to higher TIIRs. Therefore, reflecting tax expenditure on net of tax basis will better reflect the size of tax stimuli and will lead to more precise estimates of TIIRs.

4. Aligning tax incentives accountable in the computation of the B-index and in the estimation of the amount of tax support of business R&D. While most commonly these two measures are aligned, there may be a case when the B-index does not incorporate all existing R&D tax incentives due to complexities in their modelling or the limited scope of taxpayers that may utilise the tax incentive (for example, the R&D tax allowance for grant recipients in the Slovak Republic). Therefore, tax incentives that are not modelled in the B-index should be excluded from the amount of tax support for the purpose of calculating TIIRs.

Improving methodological aspects of estimating effectiveness of R&D tax incentives will allow policymakers to make more informed and justified policy decisions.

Conclusions and recommendations

When introducing tax incentives governments should clearly identify the aims and possible results of such a policy. The policy effectiveness will depend on the design of the incentives themselves, its administrative mechanism, and the timely and reliable assessment of the effects that will lead to appropriate conclusions and to further improvements. The accumulated international experience should be considered.

By combining different R&D tax incentives schemes, countries may achieve several policy objectives such as growth of business R&D investment, providing additional support to small and medium-sized enterprises; stimulating cooperation between industry and public research institutions and universities; and encouraging patenting activity. This will provide diversity in available tax incentives and ensure the tax competitiveness of the country.

The results of the overview of major practices in tax incentive schemes applied by European countries suggest that in terms of tax incentive design, the preference should be given to volume-based tax schemes and carry-over provisions. The former will be easier to administer for both firms and tax authorities, while the possibility of carrying over provisions will provide firms with more flexibility in their investment decisions, allowing them to invest in high-risk R&D activity with high innovative potential. As justified in Chapter 3, the refundable provisions should be considered as favourable treatment first of all for SMEs and young innovative firms. For large firms, which have more flexibility in financing their R&D, a cash refund after a specific time may be the preferred practice. Otherwise, immediate refunds may be provided by tax incentive schemes to support R&D with high novelty requirement ("new to the world"). Stimulating cooperation between industry and research institutions is widely recognised as a good practice which will support knowledge dissemination.

When implementing R&D tax incentives, potential sources of their financing should be considered. Analysis of historical experience in Chapter 1 showed that decisions on introducing of R&D tax incentives and selecting their generosity should take into account the state of the government budget and the given country's involvement in international tax competition for R&D capital. Based on some case examples, it was suggested that even generous tax incentives may not always lead to additional R&D investment if the elasticity of foreign R&D is low due to the prevalence of low and medium-low technological industries in the economy. Therefore, the elasticity of foreign and domestic business investment should be taken into account to avoid unwarranted tax giveaways.

Policymakers should also consider that the lower the corporate tax rate of a country, the higher the tax support provided in the form of tax allowances should be (due to less tax savings) in order to raise their significance.

While introducing R&D tax incentives it should be defined which data are needed for evaluating their effectiveness and how to collect that data. This will allow timely and thorough policy evaluations. As suggested in Chapter 3, the conclusions about policy effectiveness should be based on the perceived objectives and should not be constrained by generally acceptable canon of BFTB higher than one, since some substitutional effects on private financing are allowable while decreasing the role of direct financing in the policy mix. Moreover, spillover effects generated by the tax policy are acknowledged as additional benefits that cannot be easily assessed.

Applying a novel indicator developed in Chapter 2, namely tax incentive implementation rate, in the policy analysis will allow conclusions to be drawn about efficacy of introduced policy, and may provide valuable information for decision-makers on the perceived attractiveness of changes in the tax schemes to business investors. If such data are publicly available, it may also guide policy decisions on better shaping the policy based on the benchmark TIIRs of countries that are comparable in all other aspects. The cluster analysis coupled with factor analysis of institutional characteristics of European countries, presented in Chapter 3, showed that countries with stronger institutions have higher TIIRs. Therefore, strong institutions may facilitate better delivery of R&D tax incentive policy.

Collecting and providing more thorough data on the distribution of tax support among eligible R&D and the extensive data on the amount of R&D tax expenditure will allow increasing cross-country comparability of the efficiency of implementation of R&D tax policy, and will form a basis for conducting more reliable analysis of tax incentive attractiveness. Based on the suggested improvements in methodological approaches, further research may provide additional insight on firms' responses to tax stimuli and would allow identification of the best practices grounded on empirical results.

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5. Marmilava, K. (2023). R&D tax incentive implementation rate: a novel approach to analysing attractiveness of tax incentives. *Theory, Methodology, Practice*: Club of Economics in Miskolc. Forthcoming.
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Workshops and conference presentations:

1. "Heterogeneity in implementation of R&D tax incentive policy: The role of institutional factors". 3rd RICE PhD Seminar Sustainable Business and Economy, University of Public service, September 2022, Budapest, Hungary.
2. "R&D tax expenditures in the EU countries: On the way to achieving consistency in public administration". The Conference "Critical Rethinking of Public Administration" organised by Doctorates' Council of the Ludovika – University of Public Service and Public Administration Department of the Association of Hungarian PhD and DLA Candidates, Ludovika – University of Public Service, 8 April 2022, Budapest, Hungary.
3. "R&D tax incentive implementation rate: a novel approach for analyzing attractiveness of R&D tax treatment". 2nd RICE PhD Seminar "European business and economy", National University of Public Service, 24 September 2021, Budapest, Hungary.
4. "Reshaping R&D tax incentive policy in terms of international tax competition". 1st RICE PhD Seminar "Economic challenges of 2020", National University of Public Service, 4 September 2020, Budapest, Hungary.
5. "Methodological issues of analyzing attractiveness of R&D tax incentives in cross-country comparisons". International Scientific Conference "The Challenges of Analyzing Social and Economic Processes in the 21st Century", 7-9 November 2019, University of Szeged, Szeged, Hungary.

6. "Reporting on R&D tax expenditures in OECD countries". XI Nemzetközi Tudományos Konferencia 'Mérleg és Kihívások', 17-18 October 2019, Lillafüred, University of Miskolc, Hungary.
7. "R&D tax incentives in terms of international tax competition". Academic conference "Intelligent specialization to enchance innovation and competitiveness", Széchenyi 2020 program framework (EFOP-3.6.1-16-2016-00013) under the European Union project, 27 November 2018, Székesfehérvár, Corvinus University, Hungary.
8. "Tax incentives for encouraging R&D activities". Challenges in National and International Economic Policies workshop supported by the European Association for Comparative Economic Studies", 23-24 March 2017, University of Szeged, Hungary.

Summer schools:

1. "Quantitative Methods for Public Policy Evaluation", Barcelona Graduate School of Economics (on-line course), 2021.
2. "Introduction to Structural Equation Modeling: Confirmatory Factor Analysis with Mplus", The 8th GESIS Summer School in Survey Methodology, 2019, Cologne, Germany.
3. "Introductory Econometrics", SIdE Italian Econometric Association, 2019, Bertinoro, Italy.
4. "PhD Summer School in Circular Economy", EIT Raw Materials, 2018, Diest, Belgium.

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Appendices

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Appendix 1. Computation of share of tax support provided by scheme types based on HM Revenue and Customs Research and Development Tax Credits Statistics 2020

Table 1 - Cost of support claimed for the R&D tax credit for all schemes by financial year on an accounting period basis, 2017-18 (RD2)

R&D tax scheme	Amount, £ million	Share, %
SME deductions and payable credits	2 760	53.64
LC and RDEC	2 385	46.36
Total cost for all schemes	5 145	100.00

Source: own computation based on HM Revenue and Customs Research and Development Tax Credits Statistics 2020

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Appendix 2. **Countries' features of R&D tax incentive schemes for determining B-index scenario used for computation of TIIR**

Country (type of R&D tax incentive)[49]	**Refundability**	**Carry-over**	**Estimates of GTARD (accrual/ cash basis)**	**B-index scenario used for computations**
Austria: R&D tax credit ("Research premium")	Refundable	-	Cash	B-index for profit-making firm
Belgium: R&D tax allowance (converted to R&D tax credit if not utilised after 5 years) Payroll withholding tax credit	After 5 years Immediately refundable[50]	4 years (carry-forward) -	Accrual	B-index for profit-making firm
Czech Republic: R&D tax allowance	Non-refundable	3 years (carry-forward)	Cash	Profit/Loss making scenarios (50%/50%)
France: R&D tax credit ("Crédit d'Impôt Recherche", CIR) SSC reduction	After 3 years Immediately refundable	3 years (carry-forward) -	Accrual	B-index for profit-making firm
Greece: R&D tax allowance	-	5 years (carry-forward)	Cash (tax benefits earned and claimed in the current year only)	Profit/Loss making scenarios (50%/50%)
Hungary:[51] R&D tax allowance SSC and vocational training contribution reductions	- Immediately refundable	5 years (carry-forward) -	Accrual	B-index for profit-making firm
Iceland: R&D tax credit	Refundable	-	Cash	B-index for profit-making firm
Ireland: R&D tax credit	Over 3 years in 3 instalments	Carry-forward indefinite Carry-back 1 year	Cash	Profit/Loss making scenarios (50%/50%) (a refund in three annual instalments is modelled)
Italy: R&D tax credit	Refundable	Indefinite (carry-forward)	Cash	B-index for profit-making firm (a refund is modelled)

[49] Type of tax incentive which is modelled in the B-index is reflected.
[50] Tax relief provisions related to wage taxes are immediately refundable due to the nature of tax incentives, i.e. tax benefits are provided in the form of decreased tax rates or tax exemptions.
[51] The B-index model does not account for the innovation contribution related R&D tax allowance, local business tax related R&D tax incentive and the development tax incentive for acquisition of intangible assets, machinery and equipment and buildings used for R&D purposes.

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Latvia: R&D tax allowance	-	Indefinite (carry-forward)	Accrual	B-index for profit-making firm
Lithuania: R&D tax allowance	-	Indefinite (carry-forward)	Accrual	B-index for profit-making firm
Netherlands: Payroll withholding tax credit/SSC reduction ("WBSO")	Immediately refundable	-	Budget-based estimates	B-index for profit-making firm
Norway: R&D tax credit ("SkatteFUNN")	Refundable	-	Cash	B-index for profit-making firm
Portugal: R&D tax credit ("SIFIDE-II")	-	8 years (carry-forward)	Accrual	B-index for profit-making firm
Romania: R&D tax allowance	-	7 years (carry-forward)	Accrual	B-index for profit-making firm
Slovak Republic: R&D allowance	-	4 years (carry-forward)	Accrual	B-index for profit-making firm
Slovenia: R&D tax allowance	-	5 years (carry-forward)	Cash	Profit/Loss scenarios (50%/50%)
Spain:[52] R&D tax credit	Refundable at a 20% discount	18 years (carry-forward)	Cash	Profit/Loss scenarios (50%/50%) (18 years carry-forward provision is modelled)
Turkey: R&D tax allowance	-	Indefinite (carry-forward)	Cash	Profit/Loss scenarios (50%/50%)
The United Kingdom: R&D tax credit ("RDEC") R&D tax allowance	Refundable (only for large firms) Refundable (only for SMEs)	Indefinite (carry-forward) Indefinite (carry-forward)	Accrual	B-index for profit-making firm

Notes: *accelerated depreciation provision for R&D capital offered in some countries (Belgium, France, Ireland, Lithuania, Romania, Spain, the United Kingdom) is not modelled in the B-index.*
Source*: constructed by the author.*

[52] The B-index model does not account for the 40% of exemption of employer SSC for qualified R&D staff which is only fully compatible with the R&D tax credit in the case of innovative SME.

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Appendix 3. Eligibility criteria for R&D tax relief based on subcontracting rules and the choice of relevant indicator of R&D expenditure for computation of TIIR

Country	Eligibility criteria (subcontracting rules)	R&D indicator(s) (or their sum) used in computation of TIIR
Austria	The purchaser or contracting party providing the R&D service can claim tax benefits (no double tax relief). Qualifying EU/EEC institution must be unrelated to the principal. Research conducted by a member of the same group of company is not eligible.	1. Business-financed GERD 2. BERD financed from foreign business enterprise sector by unrelated parties
Belgium	Expenditures of an R&D centre acting on behalf of another party are eligible for the R&D tax credit (investment deduction).	1.Business-financed BERD; 2.BERD financed by foreign business sector.
Czech Republic	Expenditure on external services for R&D provided by public R&D institutions (e.g. universities and research institutes) qualifies for relief.	Business-financed GERD
France	The sums received by the subcontractors (in the context of public or private subcontracting) from which or from whom the R&D operations have been commissioned are deducted from the base for calculating their own tax credit.	Business-financed GERD
Greece	Firms that subcontract R&D to research laboratories of the public sector qualify for the R&D tax allowance. The public research laboratories as subcontractors are not entitled to R&D tax relief for the R&D they have been commissioned by companies.	Business-financed GERD
Hungary	The tax relief may be claimed by the firm carrying out R&D activities using the taxpayer's own assets and workers at the taxpayer's risk and benefit. This includes R&D activities carried out by the taxpayer's workers using the taxpayer's own assets on behalf of others, as well as (joint) research and development activities carried out under research and development agreements.	1. Business-financed BERD; 2. BERD financed by foreign business sector.
Iceland	The company that owns the R&D projects will be eligible to claim the tax credit. In collaboration between two or more parties, the tax deduction is prorated between the participating companies.	Business-financed GERD
Ireland	If an Irish company performs research for other unrelated companies for a fee, the company performing the research is permitted to claim the credit, as long as the company providing the funding is not claiming the credit.	1. Business-financed GERD; 2. BERD financed from foreign business sector by unrelated parties
Italy	Eligible expenditures include costs of research contracts with universities, research institutions and establishments, and other entities, including innovative start-ups; R&D contracted to firms from other EU member states or from the European Economic Area.	1.Business-financed GERD; 2. BERD financed by foreign business sector.
Latvia	The paying company will be able to claim the tax benefit for payments made to registered Scientific Institutions for qualifying R&D activities; payments made to accredited institutions for performing certification, calibration and testing services are	Business-financed GERD

	qualified research expenses. The R&D performer cannot claim the tax allowance.	
Lithuania	Subcontracting costs are eligible only if the outsourced R&D work was carried out in the European Economic Area or in a state which is outside the European Economic Area, but with which the Republic of Lithuania has concluded and applies a double taxation agreement.	Business-financed GERD
Netherlands	The costs of outsourced R&D do not qualify for the WBSO scheme. WBSO support is provided only for R&D that is carried out in the firm that claims WBSO support. If R&D is contracted out by a firm, the contractor may be able to apply for WBSO support for this R&D.	1.Business-financed BERD 2.BERD financed from foreign business sector
Norway	A company can claim tax relief for R&D subcontracted to approved R&D institutions or other entities.	Business-financed GERD
Portugal	R&D contracts with external S&T entities (public entities and (or) entities recognised as possessing R&D capabilities). Excludes the deductibility of all expenses incurred by taxable persons carrying out R&D projects or providing services of R&D for a fee, not acquiring any rights to the results of this R&D activity.	Business-financed GERD
Romania	Tax incentives are granted to the part taking the risk irrespective of the costs incurred. This is typically the performer of the R&D activity (assuming all other conditions are fulfilled). R&D tax incentives are also granted to taxpayers who perform R&D activities for the benefit of group companies, provided they also receive the full right to use the results of those R&D activities. Where a third-party contractor performs part of the R&D activities, the party paying for the research can treat the amount paid as a qualified research expense. The contractor also may benefit from the incentive for the related expenses as long as the party paying for the research does not use the incentive.	1. Business-financed GERD; 2. BERD financed by foreign business sector.
Slovak Republic	Fees paid for subcontracting R&D are qualifying expenses if work is subcontracted to public universities or public research institutes. Fees paid to certified private R&D organisations are also eligible as long as the organisation does not claim the super deduction for the costs it incurred in providing the qualified services.	Business-financed GERD
Slovenia	The contracting company (principal company) can claim the costs of contracts with external experts and researchers performing the R&D work and the costs of contracts with R&D organisations and other parties that are registered for performing R&D activities.	Business-financed GERD
Spain	R&D expenditure if paid for by a third-party does not qualify for the R&I tax credit, i.e. the sums paid to companies from whom R&D operations have been commissioned (R&D subcontractors) are deducted from the base for calculating their own tax credits	Business-financed GERD
Turkey	Companies ordering contracted R&D and innovation/design activities will benefit from R&D deduction, as well as the parties carrying out contracted	Business-financed GERD

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	R&D activities, sharing the total R&D incentive amount 50 – 50%.	
United Kingdom	Large companies can only claim subcontracting costs if they are paid to a university, health authority, charity, scientific research organisation, individual, or a partnership of individuals. Large companies can claim the relief on costs associated with work that is contracted for them as long as it was contracted by another Large Company or any person not subject to UK tax. SMEs cannot claim small company relief on costs that are subsidised or related to activities that were contracted to them, although they may be able to make a claim under the less generous Large Company relief.	1. Business-financed GERD; 2. BERD financed by foreign business sector.

Note: constructed by the author

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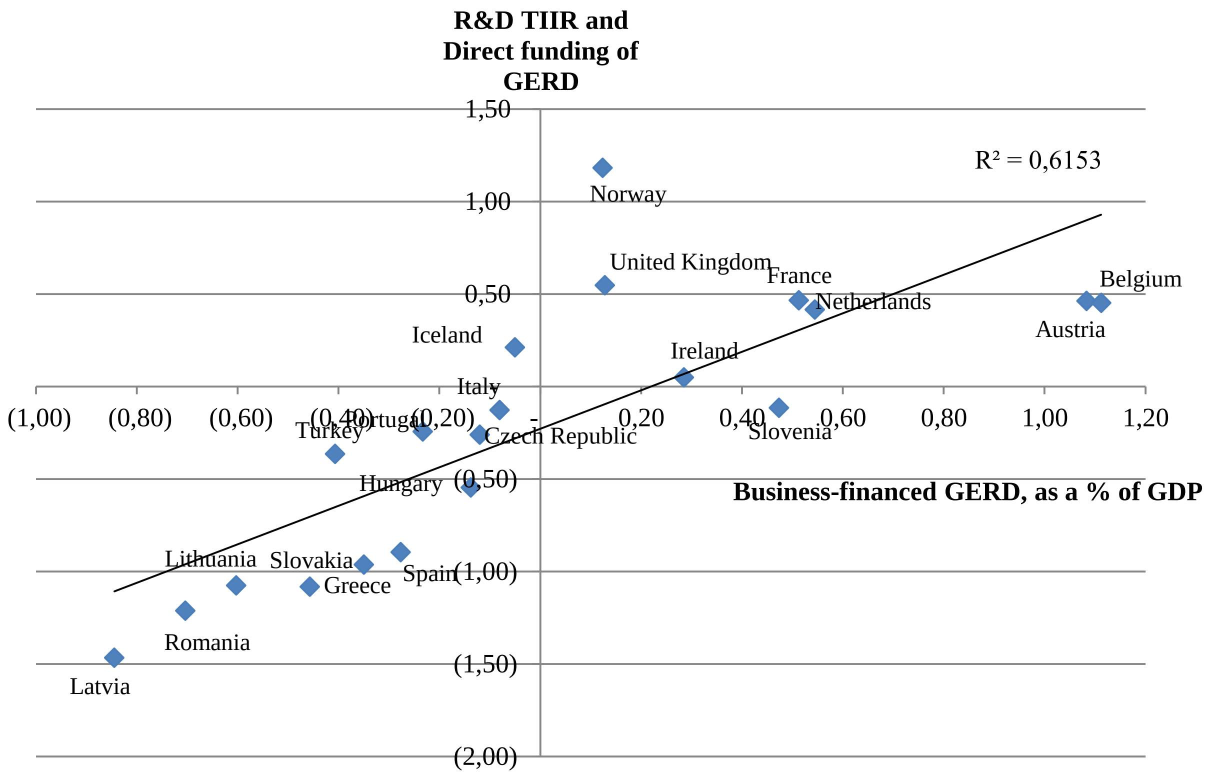
Appendix 4. The strength of association between business-financed GERD and the dual factor of government-funded GERD as a percentage of GDP, and the R&D TIIR, 2017



Notes: government-financed R&D as a percentage of GDP for Norway and Slovenia are the averages from 2011 to 2017; figures for the Netherlands are for 2018, for Romania for 2016. For Ireland business-financed GERD as a percentage of modified GNI is estimated. To estimate the relative position of each country based on two factors (TIIR and government-funded R&D as a percentage of GDP), the percentage deviations from the sample mean are estimated and summarised.

Source: own construction.

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Appendix 5. Turnover of enterprises from new or significantly improved products in 2018

Table 5.1 - Turnover of enterprises from new or significantly improved products in 2018, as a percentage of total

Country	New or significantly improved products	New or significantly improved products that were new to the firm	New or significantly improved products that were new to the market
Belgium	15.7	11.5	4.1
Czech Republic	12.8	6.4	6.4
Denmark	10.5	7.5	3.1
Germany	14.8	11.3	3.5
Ireland	10.5	3.6	6.9
Greece	23.8	13.4	10.4
Spain	16.1	9.3	6.9
France	8.8	3.9	4.9
Italy	16.9	10.5	6.3
Latvia	8.4	5.2	3.2
Lithuania	9.5	5.9	3.6
Hungary	8.8	4.7	4.1
Netherlands	8.2	3.4	4.8
Austria	14.9	8.6	6.3
Poland	6.4	4.2	2.2
Portugal	12.2	7.4	4.8
Romania	8.8	6.6	2.2
Slovenia	12.3	9.7	2.6
Slovakia	11.2	3.7	7.5
Finland	14.3	8.9	5.4
Sweden	13.7	8.3	5.4
Iceland	5.6	2.3	3.2
Norway	8.0	4.8	3.2
Switzerland	15.2	14.4	0.8
Turkey	10.0	:	:

Note: : data not available;
Source: own construction based on Eurostat CIS2018 [inn_cis11_prodt].

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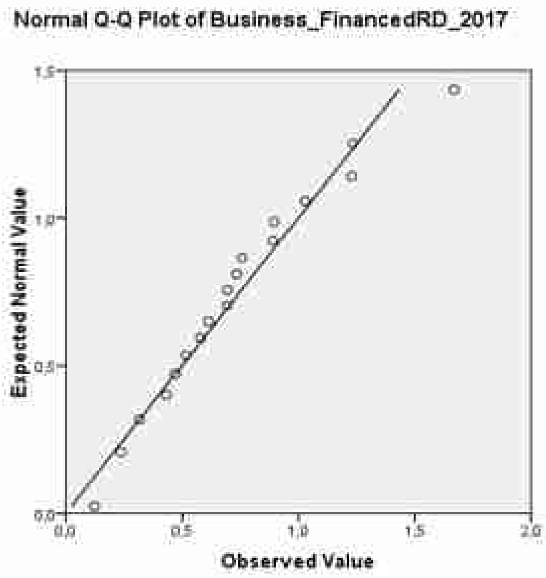
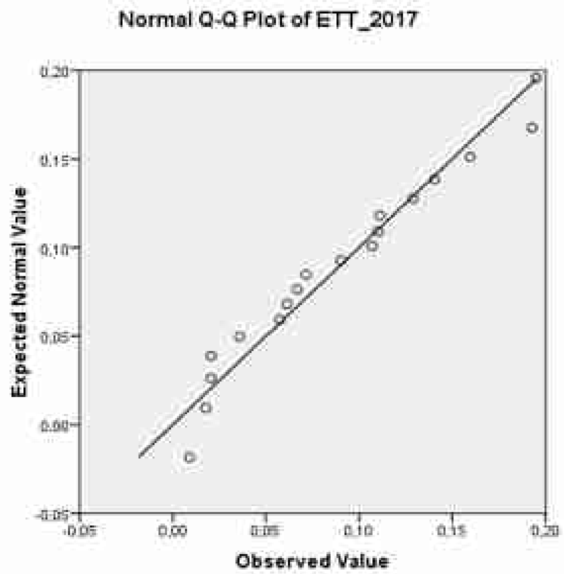
Appendix 6. Testing normality, univariate and multivariate outliers

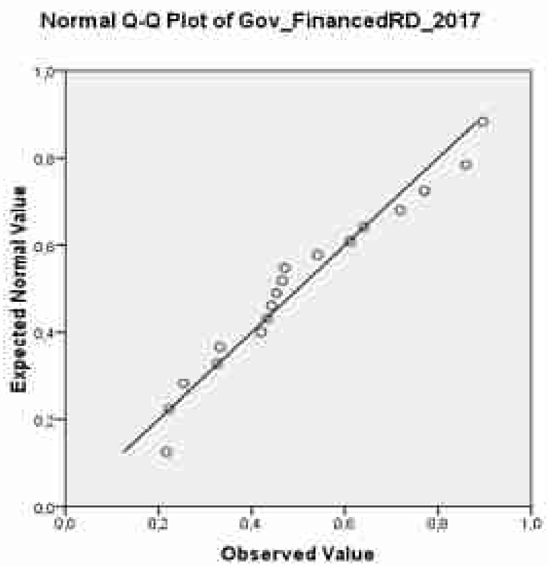
Table 6.1 – Skewness and kurtosis Z-values

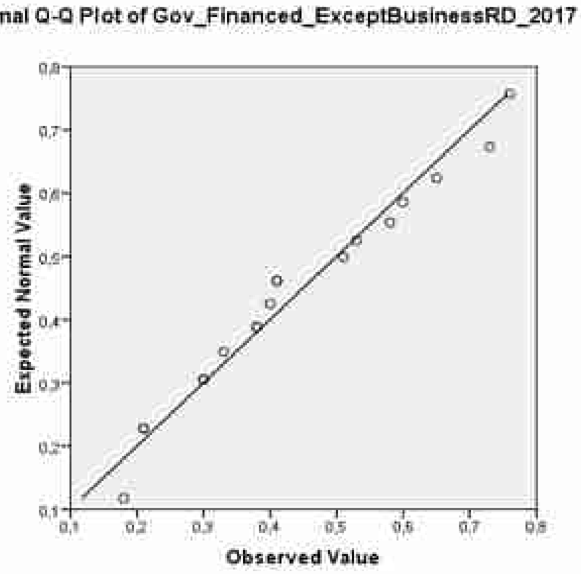
	Skewness			Kurtosis		
	Statistic	Std. Error	z-value	Statistic	Std. Error	z-value
Business_FinancedRD_2017	0.742	0.536	1.384	0.680	1.038	0.655
ETT_2017	0.396	0.536	0.739	-0.806	1.038	-0.776
Gov_FinancedRD_2017	0.449	0.536	0.838	-0.648	1.038	-0.642
Gov_Financed_ExceptBusinessRD_2017	0.332	0.536	0.619	-0.774	1.038	-0.746
Patents_2017	1.077	0.536	**2.010**	0.090	1.038	0.087
Business_FinancedRD_2015	0.842	0.536	1.571	0.755	1.038	0.727
ETT_2015	2.288	0.536	**4.269**	6.727	1.038	**6.481**
Gov_FinancedRD_2015	0.213	0.536	0.397	-0.635	1.038	-0.612
Gov_Financed_ExceptBusinessRD_2015	0.088	0.536	0.164	-0.829	1.038	-0.799
Patents_2015	1.118	0.536	**2.086**	0.134	1.038	0.129

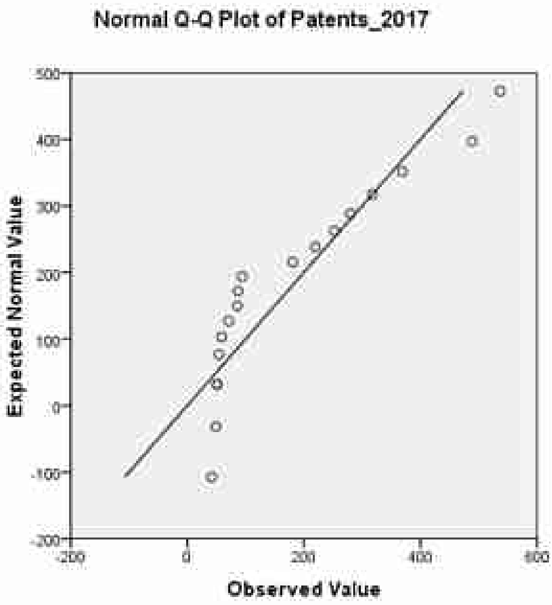
*For samples with N < 50 acceptable range for z-values is between -1.96 and +1.96.
Note: notations “Patents _2017” and “Patents_2015” reflect the dataset to which the data belong. The next year for “the number of patent applications” variable was used in the analysis.

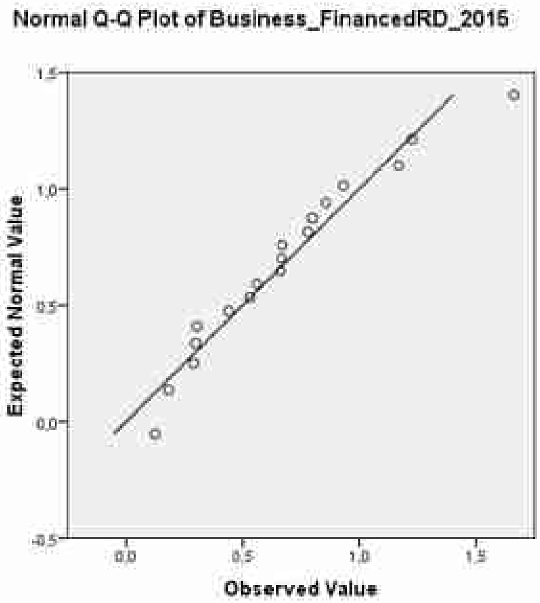


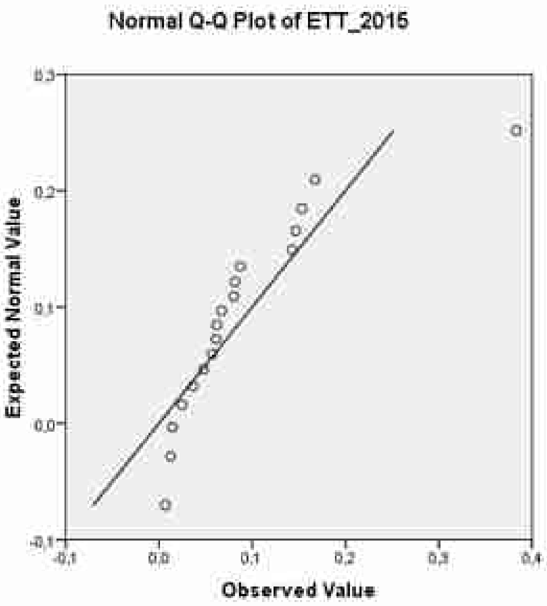


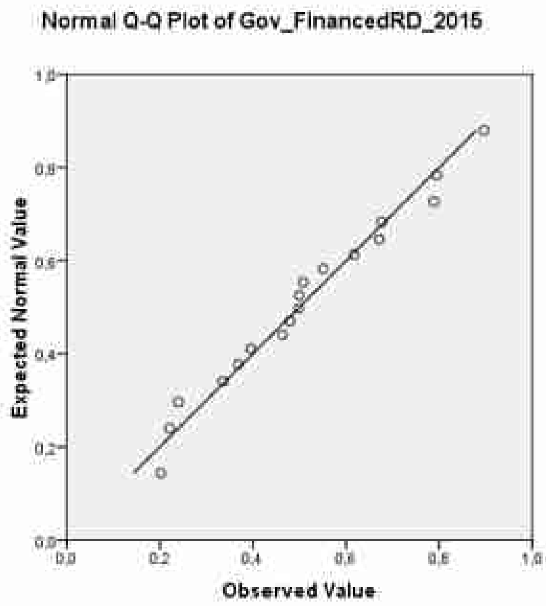


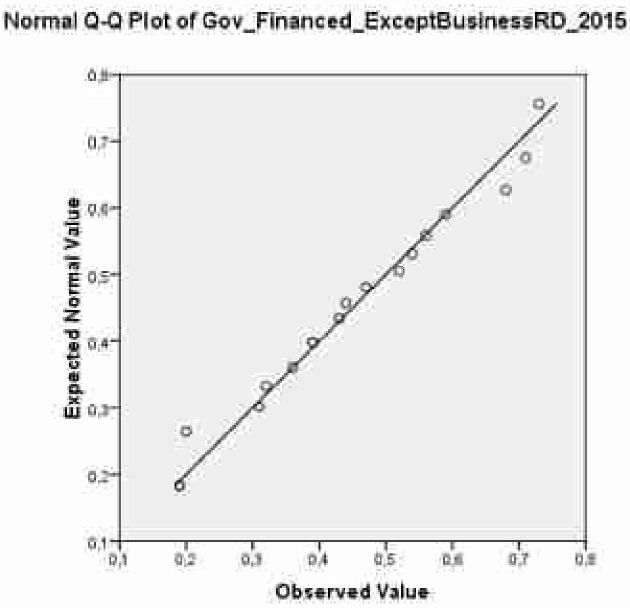



Normal Q-Q Plot of Patents_2017
Expected Normal Value
500
400
300
200
100
0
-100
-200
-200
0
200
400
600
Observed Value


Normal Q-Q Plot of Business_FinancedRD_2015
Expected Normal Value
1,5
1,0
0,5
0,0
-0,5
0,0
0,5
1,0
1,5
Observed Value


Normal Q-Q Plot of ETT_2015
Expected Normal Value
0,3
0,2
0,1
0,0
-0,1
-0,1
0,0
0,1
0,2
0,3
0,4
Observed Value


Normal Q-Q Plot of Gov_FinancedRD_2015
Expected Normal Value
1,0
0,8
0,6
0,4
0,2
0,0
0,0
0,2
0,4
0,6
0,8
1,0
Observed Value


Normal Q-Q Plot of Gov_Financed_ExceptBusinessRD_2015
Expected Normal Value
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
Observed Value

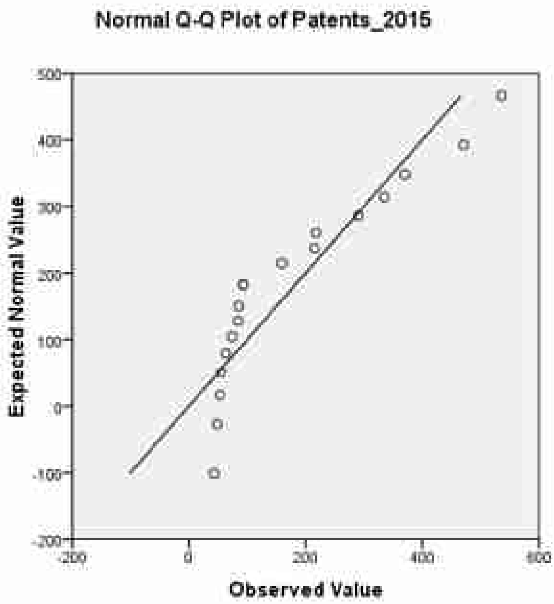

Normal Q-Q Plot of Patents_2015
Expected Normal Value
500
400
300
200
100
0
-100
-200
-200
0
200
400
600
Observed Value

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Table 6.2 – Tests of Normality for data 2017

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Patents_2017	0.267	18	**0.001**	0.826	18	**0.004**
Business_FinancedRD_2017	0.136	18	0.200*	0.962	18	0.644
ETT_2017	0.115	18	0.200*	0.942	18	0.313
Gov_FinancedRD_2017	0.175	18	0.153	0.944	18	0.334
Gov_Financed_ExceptBusinessRD_2017	0.173	18	0.164	0.953	18	0.469

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Table 6.3 – Tests of Normality for data 2015

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Business_FinancedRD_2015	0,117	18	0,200*	0,945	18	0,352
ETT_2015	0,238	18	**0,008**	0,766	18	**0,001**
Gov_FinancedRD_2015	0,118	18	0,200*	0,966	18	0,719
Gov_Financed_ExceptBusinessRD_2015	0,092	18	0,200*	0,956	18	0,521
Patents_2015	0,273	18	**0,001**	0,826	18	**0,004**

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Table 6.4 – Identification of univariate outliers for 2017 dataset*

	ZBusiness_Financed RD_2017	ZETT_2017	ZGov_FinancedRD _2017	ZGov_Financed_Except Business RD_2017	ZPatents_2017
Austria	2.43	- 0.37	1.88	1.66	1.92
Czech Republic	- 0.09	- 0.53	0.51	0.52	- 0.60
France	1.30	0.69	1.27	1.21	1.17
Greece	- 0.55	- 1.36	- 0.34	- 0.21	- 0.83
Hungary	- 0.09	- 0.29	- 0.41	- 0.79	- 0.81
Iceland	0.08	0.38	1.03	0.92	0.43
Ireland	0.78	1.81	- 0.13	- 0.16	- 0.01
Italy	0.01	1.21	- 0.30	- 0.16	0.23
Latvia	- 1.56	- 1.16	- 1.36	- 1.31	- 0.83
Lithuania	- 1.06	- 0.47	- 0.86	- 0.61	- 0.88
Netherlands	1.29	0.03	0.65	0.81	2.22
Norway	0.44	0.31	1.70	1.83	0.85
Portugal	- 0.30	0.88	0.17	0.41	- 0.61
Romania	- 1.27	- 1.16	- 1.39	- 1.48	- 0.78
Slovak Republic	- 0.76	- 1.21	- 0.84	- 0.79	- 0.84
Spain	- 0.39	- 0.90	- 0.17	- 0.16	- 0.70
Turkey	- 0.67	0.37	- 1.20	- 1.29	- 0.56
United Kingdom	0.42	1.77	- 0.19	- 0.34	0.61

*|z| > 3.0 indicates an outlier

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Table 6.5 – Identification of univariate outliers for 2015 dataset*

	ZBusiness_FinancedRD_2015	ZETT_2015	ZGov_FinancedRD_2015	ZGov_Financed_ExceptBusiness RD_2015	ZPatents_2015
Austria	2.47	- 0.32	1.91	1.67	1.85
Czech Republic	- 0.03	- 0.27	0.52	0.55	- 0.57
France	1.38	0.59	1.37	1.38	1.20
Greece	- 0.93	- 0.88	- 0.58	- 0.33	- 0.77
Hungary	- 0.02	0.71	- 0.24	- 0.74	- 0.70
Iceland	0.26	- 0.38	0.79	0.67	0.23
Ireland	0.64	**3.31**	- 0.06	- 0.09	- 0.15
Italy	- 0.01	- 0.48	- 0.02	0.14	0.21
Latvia	- 1.38	- 0.86	- 1.53	- 1.44	- 0.82
Lithuania	- 0.94	- 0.33	- 0.71	- 0.50	- 0.90
Netherlands	1.23	- 0.12	0.82	0.85	2.27
Norway	0.45	- 0.10	1.40	1.55	0.98
Portugal	- 0.36	0.63	0.19	0.44	- 0.63
Romania	- 1.23	- 0.75	- 1.44	- 1.50	- 0.83
Slovack	- 0.96	- 0.95	- 0.87	- 0.80	- 0.86
Spain	- 0.29	- 0.61	- 0.06	- 0.03	- 0.57
Turkey	- 0.59	- 0.04	- 1.35	- 1.50	- 0.63
United Kingdom	0.31	0.87	- 0.16	- 0.33	0.69

*|z| > 3.0 indicates an outlier

Table 6.6 – Identification of multivariate outliers for 2017 dataset

	Regression 1		Regression 2		Regression3	
	D_M^2	p-value	D_M^2	p-value	D_M^2	p-value
Austria	4.459	0.108	3.535	0.171	5.884	0.015
Czech Republic	0.762	0.683	0.771	0.680	0.008	0.929
France	1.732	0.421	1.582	0.453	1.701	0.192
Greece	1.842	0.398	1.868	0.393	0.304	0.581
Hungary	0.202	0.904	0.634	0.728	0.009	0.926
Iceland	1.063	0.588	0.862	0.650	0.006	0.940
Ireland	3.737	0.154	3.770	0.152	0.615	0.433
Italy	1.929	0.381	1.737	0.420	0.000	0.988
Latvia	2.486	0.288	2.382	0.304	2.445	0.118
Lithuania	0.798	0.671	0.478	0.788	1.130	0.288
Netherlands	0.451	0.798	0.693	0.707	1.657	0.198
Norway	2.942	0.230	3.410	0.182	0.190	0.663
Portugal	0.783	0.676	0.802	0.670	0.090	0.765
Romania	2.555	0.279	2.783	0.249	1.610	0.204
Slovakia	1.712	0.425	1.676	0.433	0.578	0.447
Spain	0.819	0.664	0.818	0.664	0.152	0.696
Turkey	2.036	0.361	2.297	0.317	0.445	0.505
United Kingdom	3.691	0.158	3.904	0.142	0.174	0.676

Note: p-value < 0.001 indicates an outlier; D_M^2 – Mahalanobis distance
Regression1: business-financed GERD regressed on ETT and government-financed GERD; regression 2: business-financed GERD regressed on ETT and government-financed GERD except of business enterprise sector; regression 3: number of patents regressed on business-financed GERD.

Table 6.7 – Identification of multivariate outliers for 2015 dataset

	Regression 1		Regression 2		Regression3	
	D_M^2	p-value	D_M^2	p-value	D_M^2	p-value
Austria	4.109	0.128	3.101	0.212	6.121	0.013
Czech Republic	0.413	0.813	0.429	0.807	0.001	0.974
France	2.001	0.368	2.055	0.358	1.899	0.168
Greece	0.956	0.620	0.822	0.663	0.866	0.352
Hungary	0.646	0.724	1.215	0.545	0.001	0.982
Iceland	0.920	0.631	0.681	0.711	0.070	0.792
Ireland	11.423	0.003	11.249	0.004	0.411	0.521
Italy	0.239	0.887	0.279	0.870	0.000	0.988
Latvia	2.689	0.261	2.526	0.283	1.903	0.168
Lithuania	0.544	0.762	0.324	0.851	0.893	0.345
Netherlands	0.746	0.689	0.775	0.679	1.524	0.217
Norway	2.102	0.350	2.512	0.285	0.206	0.650
Portugal	0.407	0.816	0.525	0.769	0.131	0.717
Romania	2.308	0.315	2.547	0.280	1.523	0.217
Slovak	1.398	0.497	1.347	0.510	0.925	0.336
Spain	0.378	0.828	0.377	0.828	0.082	0.774
Turkey	1.859	0.395	2.278	0.320	0.346	0.556
United Kingdom	0.861	0.650	0.957	0.620	0.098	0.754

Note: p-value < 0.001 indicates an outlier; D_M^2 – Mahalanobis distance.
Regression1: business-financed GERD regressed on ETT and government-financed GERD; regression 2: business-financed GERD regressed on ETT and government-financed GERD except of business enterprise sector; regression 3: number of patents regressed on business-financed GERD.

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Appendix 7. Results of SEM for preferred models for 2017 and 2015.

```
Mplus VERSION 8.6 DEMO
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INPUT INSTRUCTIONS

  TITLE: Path analysis 2017;
  DATA: FILE IS SEM_2017.dat;
  VARIABLE: NAMES ARE busfinrd ETT govfinrd patents;
  MODEL:
  patents on busfinrd;
  busfinrd on ETT govfinrd;
  MODEL INDIRECT: patents IND ETT;
  ANALYSIS: Estimator=MLM;
  OUTPUT: CINTERVAL Sampstat Standardized residual;

INPUT READING TERMINATED NORMALLY

Path analysis 2017;

SUMMARY OF ANALYSIS

Number of groups                                                 1
Number of observations                                          18

Number of dependent variables                                    2
Number of independent variables                                  2
Number of continuous latent variables                            0

Observed dependent variables

  Continuous
   BUSFINRD    PATENTS

Observed independent variables
   ETT         GOVFINRD
Estimator                                                      MLM
Information matrix                                        EXPECTED
Maximum number of iterations                                  1000
Convergence criterion                                    0.500D-04
Maximum number of steepest descent iterations                   20

Input data file(s)
  SEM_MLM_2017.dat

Input data format  FREE

     SAMPLE STATISTICS

           Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                0.730       182.778         0.089         0.506

           Covariances
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       0.142
 PATENTS       51.390     23950.395
 ETT            0.010         3.521         0.003
 GOVFINRD       0.063        23.769         0.003         0.041
```

```
           Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       1.000
 PATENTS        0.881         1.000
 ETT            0.454         0.398         1.000
 GOVFINRD       0.833         0.761         0.291         1.000


UNIVARIATE SAMPLE STATISTICS
     UNIVARIATE HIGHER-ORDER MOMENT DESCRIPTIVE STATISTICS

         Variable/         Mean/     Skewness/   Minimum/ % with                Percentiles
        Sample Size      Variance    Kurtosis    Maximum  Min/Max      20%/60%    40%/80%    Median

     BUSFINRD                0.730       0.678       0.123    5.56%       0.435      0.578      0.695
              18.000         0.142       0.190       1.671    5.56%       0.736      0.899
     PATENTS               182.778       0.985      42.000    5.56%      51.000     71.000     90.500
              18.000     23950.395      -0.249     537.000    5.56%     181.000    280.000
     ETT                     0.089       0.362       0.009    5.56%       0.021      0.061      0.081
              18.000         0.003      -0.915       0.195    5.56%       0.107      0.129
     GOVFINRD                0.506       0.410       0.217    5.56%       0.326      0.434      0.468
              18.000         0.041      -0.797       0.896    5.56%       0.479      0.641

THE MODEL ESTIMATION TERMINATED NORMALLY

MODEL FIT INFORMATION
Number of Free Parameters                        7
Loglikelihood
          H0 Value                         -98.592
          H1 Value                         -98.491
Information Criteria
          Akaike (AIC)                     211.183
          Bayesian (BIC)                   217.416
          Sample-Size Adjusted BIC         195.907
            (n* = (n + 2) / 24)

Chi-Square Test of Model Fit
          Value                              0.266*
          Degrees of Freedom                     2
          P-Value                           0.8757
          Scaling Correction Factor         0.7564
            for MLM
*   The chi-square value for MLM, MLMV, MLR, ULSMV, WLSM and WLSMV cannot be used
    for chi-square difference testing in the regular way.  MLM, MLR and WLSM
    chi-square difference testing is described on the Mplus website.  MLMV, WLSMV,
    and ULSMV difference testing is done using the DIFFTEST option.

RMSEA (Root Mean Square Error Of Approximation)
          Estimate                           0.000
          90 Percent C.I.                    0.000  0.233
          Probability RMSEA <= .05           0.881
CFI/TLI
          CFI                                1.000
          TLI                                1.000
Chi-Square Test of Model Fit for the Baseline Model
          Value                             92.438
          Degrees of Freedom                     5
          P-Value                           0.0000
SRMR (Standardized Root Mean Square Residual)
          Value                              0.009
MODEL RESULTS
                                                           Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value

 PATENTS  ON
    BUSFINRD         361.793     48.064      7.527      0.000
 BUSFINRD ON
    ETT                1.528      0.629      2.427      0.015
    GOVFINRD           1.429      0.338      4.225      0.000
 Intercepts
    BUSFINRD          -0.128      0.111     -1.158      0.247
    PATENTS          -81.243     34.097     -2.383      0.017
```

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```
Residual Variances
   BUSFINRD           0.037      0.012      3.016      0.003
   PATENTS         5357.871   1817.416      2.948      0.003

QUALITY OF NUMERICAL RESULTS
     Condition Number for the Information Matrix              0.164E-03
       (ratio of smallest to largest eigenvalue)

R-SQUARE

    Observed                                        Two-Tailed
    Variable        Estimate       S.E.  Est./S.E.    P-Value

    BUSFINRD           0.742      0.105      7.044      0.000
    PATENTS            0.776      0.070     11.128      0.000


TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

                                                    Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value

Effects from ETT to PATENTS
  Total              552.661    234.894      2.353      0.019
  Total indirect     552.661    234.894      2.353      0.019
  Specific indirect 1
    PATENTS
    BUSFINRD
    ETT              552.661    234.894      2.353      0.019
```

```
CONFIDENCE INTERVALS OF MODEL RESULTS

                  Lower .5%  Lower 2.5%    Lower 5%    Estimate    Upper 5%  Upper 2.5%   Upper .5%

 PATENTS   ON
    BUSFINRD       237.989     267.587     282.727     361.793     440.858     455.998     485.596

 BUSFINRD ON
    ETT             -0.093       0.294       0.492       1.528       2.563       2.761       3.148
    GOVFINRD         0.558       0.766       0.873       1.429       1.985       2.092       2.300

 Intercepts
    BUSFINRD        -0.413      -0.345      -0.310      -0.128       0.054       0.089       0.157
    PATENTS       -169.072    -148.074    -137.334     -81.243     -25.153     -14.412       6.585

 Residual Variances
    BUSFINRD         0.005       0.013       0.017       0.037       0.057       0.060       0.068
    PATENTS        676.571    1795.735    2368.221    5357.871    8347.520    8920.006   10039.170

CONFIDENCE INTERVALS OF TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

                  Lower .5%  Lower 2.5%    Lower 5%    Estimate    Upper 5%  Upper 2.5%   Upper .5%

Effects from ETT to PATENTS

  Total            -52.379      92.269     166.260     552.661     939.061    1013.053    1157.700
  Total indirect   -52.379      92.269     166.260     552.661     939.061    1013.053    1157.700

  Specific indirect 1
    PATENTS
    BUSFINRD
    ETT            -52.379      92.269     166.260     552.661     939.061    1013.053    1157.700
RESIDUAL OUTPUT

     ESTIMATED MODEL AND RESIDUALS (OBSERVED - ESTIMATED)

           Model Estimated Means/Intercepts/Thresholds
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                0.730       182.777         0.089         0.506
```

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```
           Residuals for Means/Intercepts/Thresholds
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                0.000         0.000         0.000         0.000


           Model Estimated Covariances/Correlations/Residual Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       0.142
 PATENTS       51.390     23950.416
 ETT            0.010         3.538         0.003
 GOVFINRD       0.063        22.915         0.003         0.041


           Model Estimated Correlations/Residual Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       1.000
 PATENTS        0.881         1.000
 ETT            0.454         0.400         1.000
 GOVFINRD       0.833         0.734         0.291         1.000


           Residuals for Covariances/Correlations/Residual Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000        -0.021
 ETT            0.000        -0.017         0.000
 GOVFINRD       0.000         0.854         0.000         0.000


           Residuals for Correlations/Residual Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000         0.000
 ETT            0.000        -0.002         0.000
 GOVFINRD       0.000         0.027         0.000         0.000

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Mplus VERSION 8.6 DEMO
MUTHEN & MUTHEN

INPUT INSTRUCTIONS

  TITLE: path analysis 2015;
  DATA: FILE IS SEM_MLR_2015.dat;
  VARIABLE: NAMES ARE busfinrd ETT govfinrd patents;
  MODEL:
  patents on busfinrd;
  busfinrd on ETT govfinrd;
  MODEL INDIRECT: patents IND ETT;
  ANALYSIS: Estimator=MLR;
  OUTPUT: CINTERVAL Sampstat Standardized residual;

INPUT READING TERMINATED NORMALLY

path analysis 2015;
SUMMARY OF ANALYSIS

Number of groups                                                 1
Number of observations                                          18
```

```
Number of dependent variables                                    2
Number of independent variables                                  2
Number of continuous latent variables                            0

Observed dependent variables

  Continuous
   BUSFINRD    PATENTS

Observed independent variables
   ETT         GOVFINRD

Estimator                                                      MLR
Information matrix                                        OBSERVED
Maximum number of iterations                                  1000
Convergence criterion                                    0.500D-04
Maximum number of steepest descent iterations                   20

Input data file(s)
  SEM_MLR_2015.dat

Input data format  FREE

     SAMPLE STATISTICS

           Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                0.675       182.500         0.091         0.512

           Covariances
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       0.151
 PATENTS       51.854     22938.361
 ETT            0.012         1.847         0.007
 GOVFINRD       0.067        23.409         0.003         0.039

           Correlations
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD       1.000
 PATENTS        0.882         1.000
 ETT            0.367         0.142         1.000
 GOVFINRD       0.884         0.788         0.187         1.000

UNIVARIATE SAMPLE STATISTICS

     UNIVARIATE HIGHER-ORDER MOMENT DESCRIPTIVE STATISTICS

         Variable/         Mean/     Skewness/   Minimum/ % with                Percentiles
        Sample Size      Variance    Kurtosis    Maximum  Min/Max      20%/60%    40%/80%    Median

     BUSFINRD               0.675       0.770       0.124    5.56%       0.298      0.530      0.664
              18.000        0.151       0.245       1.663    5.56%       0.669      0.856
     PATENTS              182.500       1.023      43.000    5.56%      55.000     84.000     93.000
              18.000    22938.361      -0.216     536.000    5.56%     159.000    290.000
     ETT                    0.091       2.092       0.007    5.56%       0.025      0.057      0.064
              18.000        0.007       4.683       0.383    5.56%       0.080      0.143
     GOVFINRD               0.512       0.195       0.203    5.56%       0.336      0.464      0.500
              18.000        0.039      -0.788       0.897    5.56%       0.508      0.672

THE MODEL ESTIMATION TERMINATED NORMALLY

MODEL FIT INFORMATION
Number of Free Parameters                        7
Loglikelihood
          H0 Value                         -95.202
          H0 Scaling Correction Factor      1.0435
            for MLR
```

```
          H1 Value                           -93.378
          H1 Scaling Correction Factor        1.0701
            for MLR
Information Criteria
          Akaike (AIC)                       204.405
          Bayesian (BIC)                     210.637
          Sample-Size Adjusted BIC           189.128
            (n* = (n + 2) / 24)
Chi-Square Test of Model Fit
          Value                                3.135*
          Degrees of Freedom                       2
          P-Value                             0.2085
          Scaling Correction Factor           1.1636
            for MLR
*   The chi-square value for MLM, MLMV, MLR, ULSMV, WLSM and WLSMV cannot be used
    for chi-square difference testing in the regular way.  MLM, MLR and WLSM
    chi-square difference testing is described on the Mplus website.  MLMV, WLSMV,
    and ULSMV difference testing is done using the DIFFTEST option.

RMSEA (Root Mean Square Error Of Approximation)
          Estimate                             0.178
          90 Percent C.I.                      0.000  0.534
          Probability RMSEA <= .05             0.223
CFI/TLI
          CFI                                  0.977
          TLI                                  0.944
Chi-Square Test of Model Fit for the Baseline Model
          Value                               55.240
          Degrees of Freedom                       5
          P-Value                             0.0000
SRMR (Standardized Root Mean Square Residual)
          Value                                0.061

MODEL RESULTS
                                                          Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value
 PATENTS  ON
    BUSFINRD         344.408     43.111      7.989      0.000
 BUSFINRD ON
    ETT                0.945      0.251      3.763      0.000
    GOVFINRD           1.671      0.280      5.963      0.000
 Intercepts
    BUSFINRD          -0.266      0.109     -2.445      0.014
    PATENTS          -49.949     23.649     -2.112      0.035
 Residual Variances
    BUSFINRD           0.026      0.009      3.064      0.002
    PATENTS         5079.563   1865.156      2.723      0.006

QUALITY OF NUMERICAL RESULTS
     Condition Number for the Information Matrix              0.417E-04
       (ratio of smallest to largest eigenvalue)

R-SQUARE
    Observed                                                   Two-Tailed
    Variable        Estimate       S.E.  Est./S.E.    P-Value

    BUSFINRD           0.824      0.060     13.675      0.000
    PATENTS            0.779      0.061     12.828      0.000

TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS
```

DOI: 10.14750/ME.2024.027

```
                                                   Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value

Effects from ETT to PATENTS
  Total              325.450    104.056      3.128      0.002
  Total indirect     325.450    104.056      3.128      0.002

  Specific indirect 1
    PATENTS
    BUSFINRD
    ETT              325.450    104.056      3.128      0.002


CONFIDENCE INTERVALS OF MODEL RESULTS
                  Lower .5%  Lower 2.5%    Lower 5%    Estimate    Upper 5%  Upper 2.5%   Upper .5%
 PATENTS  ON
    BUSFINRD       233.364     259.911     273.491     344.408     415.325     428.905     455.452
 BUSFINRD ON
    ETT              0.298       0.453       0.532       0.945       1.358       1.437       1.592
    GOVFINRD         0.949       1.122       1.210       1.671       2.132       2.220       2.393
 Intercepts
    BUSFINRD        -0.546      -0.479      -0.445      -0.266      -0.087      -0.053       0.014
    PATENTS       -110.863     -96.300     -88.851     -49.949     -11.047      -3.598      10.965
 Residual Variances
    BUSFINRD         0.004       0.010       0.012       0.026       0.041       0.043       0.049
    PATENTS        275.295    1423.858    2011.382    5079.563    8147.745    8735.270    9883.832

CONFIDENCE INTERVALS OF TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS
                  Lower .5%  Lower 2.5%    Lower 5%    Estimate    Upper 5%  Upper 2.5%   Upper .5%
Effects from ETT to PATENTS

  Total             57.424     121.501     154.279     325.450     496.622     529.399     593.476
  Total indirect    57.424     121.501     154.279     325.450     496.622     529.399     593.476

  Specific indirect 1
    PATENTS
    BUSFINRD
    ETT             57.424     121.501     154.279     325.450     496.622     529.399     593.476

RESIDUAL OUTPUT

     ESTIMATED MODEL AND RESIDUALS (OBSERVED - ESTIMATED)

           Model Estimated Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                 0.675       182.499         0.091         0.512

           Residuals for Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                 0.000         0.001         0.000         0.000

           Standardized Residuals (z-scores) for Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                 0.000       999.000         0.000         0.000

           Normalized Residuals for Means
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
                 0.000         0.000         0.000         0.000

           Model Estimated Covariances
              BUSFINRD      PATENTS       ETT           GOVFINRD
              ________      ________      ________      ________
 BUSFINRD        0.151
 PATENTS        51.854     22938.340
 ETT             0.012         4.213         0.007
 GOVFINRD        0.067        23.187         0.003         0.039
```

```
          Model Estimated Correlations
             BUSFINRD      PATENTS       ETT           GOVFINRD
             ________      ________      ________      ________
 BUSFINRD       1.000
 PATENTS        0.882         1.000
 ETT            0.367         0.324         1.000
 GOVFINRD       0.884         0.780         0.187         1.000

          Residuals for Covariances
             BUSFINRD      PATENTS       ETT           GOVFINRD
             ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000         0.022
 ETT            0.000        -2.367         0.000
 GOVFINRD       0.000         0.221         0.000         0.000

          Residuals for Correlations
             BUSFINRD      PATENTS       ETT           GOVFINRD
             ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000         0.000
 ETT            0.000        -0.182         0.000
 GOVFINRD       0.000         0.007         0.000         0.000

          Standardized Residuals (z-scores) for Covariances
             BUSFINRD      PATENTS       ETT           GOVFINRD
             ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000       999.000
 ETT            0.000       999.000         0.000
 GOVFINRD       0.000       999.000         0.000         0.000

          Normalized Residuals for Covariances
             BUSFINRD      PATENTS       ETT           GOVFINRD
             ________      ________      ________      ________
 BUSFINRD       0.000
 PATENTS        0.000         0.000
 ETT            0.000        -1.567         0.000
 GOVFINRD       0.000         0.032         0.000         0.000

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Fax: (310) 391-8971
Web: www.StatModel.com
Support: Support@StatModel.com

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Input files

SEM_1 for 2017

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France	1.235650880,0.12891505401328,0.770305543,369
Hungary	0.693694467,0.07146829268293 0.4199824359,54
Austria	1.670530583,0.06676380688711,0.896083254,489
Norway	0.898994411,0.10677263265385,0.85947408,318
Netherlands	1.229025152,0.09028195488722,0.640523690,537
Iceland	0.758955643,0.11110003697542,0.718985309,252
Portugal	0.613646298,0.14039194939342,0.541434093,86
Czech Republic	0.695418164,0.05742300398124,0.61111275,87
Spain	0.578410618,0.03578772476822,0.470893708,71
Italy	0.735550096,0.15961815308180,0.442233666,220
Greece	0.515846559,0.00894645883213,0.433524785,51

Turkey	0.471104091,0.11020918941670,0.25375,94
Lithuania	0.317461577,0.06131450673163,0.325875275,42
Latvia	0.123404483,0.02066375500000,0.222721004,51
Slovak Republic	0.434875373,0.0178028016316,0.331651785,49
Romania	0.237605586,0.02050456844058,0.21688432,59
Ireland	1.033772316,0.19497414354375,0.479460905,181
United Kingdom	0.891684544,0.19282638392277,0.465458961,280

SEM_2 for 2017

Country	Busfinrd ETT govfinrd exceptBERD patents
France	1.235650880,0.12891505401328,0.65,369
Hungary	0.693694467,0.07146829268293,0.30,54
Austria	1.670530583,0.06676380688711,0.73,489
Norway	0.898994411,0.10677263265385,0.76,318
Netherlands	1.229025152,0.09028195488722,0.58,537
Iceland	0.758955643,0.11110003697542,0.60,252
Portugal	0.613646298,0.14039194939342,0.51,86
Czech Republic	0.695418164,0.05742300398124,0.53,87
Spain	0.578410618,0.03578772476822,0.41,71
Italy	0.735550096,0.15961815308180,0.41,220
Greece	0.515846559,0.00894645883213,0.40,51
Turkey	0.471104091,0.11020918941670,0.21,94
Lithuania	0.317461577,0.06131450673163,0.33,42
Latvia	0.123404483,0.02066375500000,0.21,51
Slovak Republic	0.434875373,0.0178028016316,0.30,49
Romania	0.237605586,0.02050456844058,0.18,59
Ireland	1.033772316,0.19497414354375,0.41,181
United Kingdom	0.891684544,0.19282638392277,0.38,280

Input files

SEM_1 for 2015

Country	busfinrd ETT govfinrd patents
France	1.225080876,0.14271710825400,0.789165642,370
Ireland	0.930906184,0.38295110341843,0.499123643,159
Hungary	0.665808480,0.15338076923077,0.463685915,74
Austria	1.662700886,0.06203548251918,0.896502774,471
United Kingdom	0.800108722,0.16740999882664,0.479748269,290
Norway	0.856061132,0.08143694111789,0.794731400,335
Netherlands	1.167812547,0.08028,0.677093599,536
Iceland	0.780289386,0.05690196585604,0.671874629,218
Portugal	0.530301178,0.14663648361724,0.550758779,85
Czech Republic	0.661816850,0.06694752483259,0.617517141,93
Spain	0.560417227,0.03661557677277,0.500283039,93
Italy	0.669161600,0.04795685896057,0.508356214,215
Greece	0.303341503,0.01263922002786,0.395289126,63
Turkey	0.44,0.08727272727273,0.24,84
Lithuania	0.297696937,0.06110240899119,0.368794818,43
Latvia	0.124124384,0.01438073602041,0.202668666,55
Slovak Republic	0.290842896,0.00697283663411,0.335681341,48
Romania	0.182124532,0.02455161574617,0.221279873,53

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SEM_2 for 2015

Country	Busfinrd	ETT	govfinrd exceptBERD	patents
France	1.225080876	0.14271710825400	0.68	370
Ireland	0.930906184	0.38295110341843	0.43	159
Hungary	0.665808480	0.15338076923077	0.32	74
Austria	1.662700886	0.06203548251918	0.73	471
United Kingdom	0.800108722	0.16740999882664	0.39	290
Norway	0.856061132	0.08143694111789	0.71	335
Netherlands	1.167812547	0.08028	0.59	536
Iceland	0.780289386	0.05690196585604	0.56	218
Portugal	0.530301178	0.14663648361724	0.52	85
Czech Republic	0.661816850	0.06694752483259	0.54	93
Spain	0.560417227	0.03661557677277	0.44	93
Italy	0.669161600	0.04795685896057	0.47	215
Greece	0.303341503	0.01263922002786	0.39	63
Turkey	0.44	0.08727272727273	0.19	84
Lithuania	0.297696937	0.06110240899119	0.36	43
Latvia	0.124124384	0.01438073602041	0.20	55
Slovak Republic	0.290842896	0.00697283663411	0.31	48
Romania	0.182124532	0.02455161574617	0.19	53

DOI: 10.14750/ME.2024.027

Appendix 8. Industry-specific correlation coefficients for R&D intensity and productivity

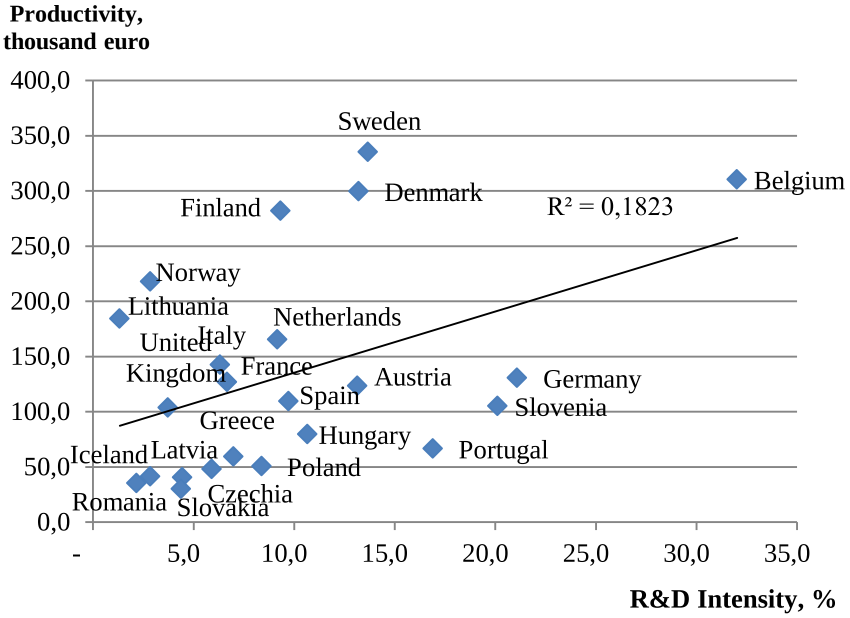

Figure 8.1 – The strength of association between R&D intensity and productivity in "Manufacture of basic pharmaceutical products and pharmaceutical preparations", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for Lithuania are for 2015, for Slovenia 2011, for Iceland 2016, for Norway and Sweden 2013. For Sweden data on BERD are reported based on industry orientation classification criteria.

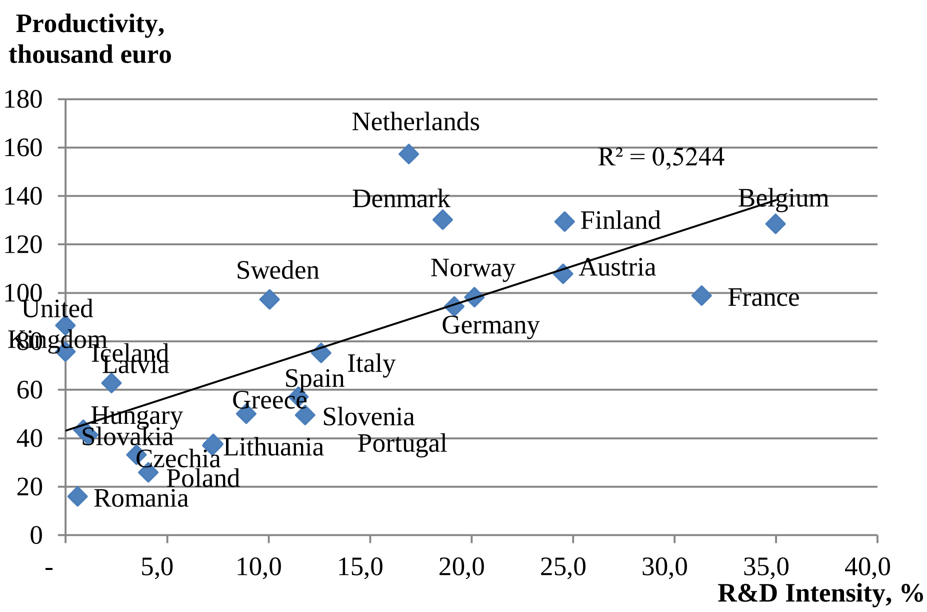

Figure 8.2 – The strength of association between R&D intensity and productivity in "Manufacture of computer, electronic and optical products", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The *figures for Latvia are for 2015, for Norway 2016. For Sweden data on BERD are reported based on industry orientation classification criteria.*

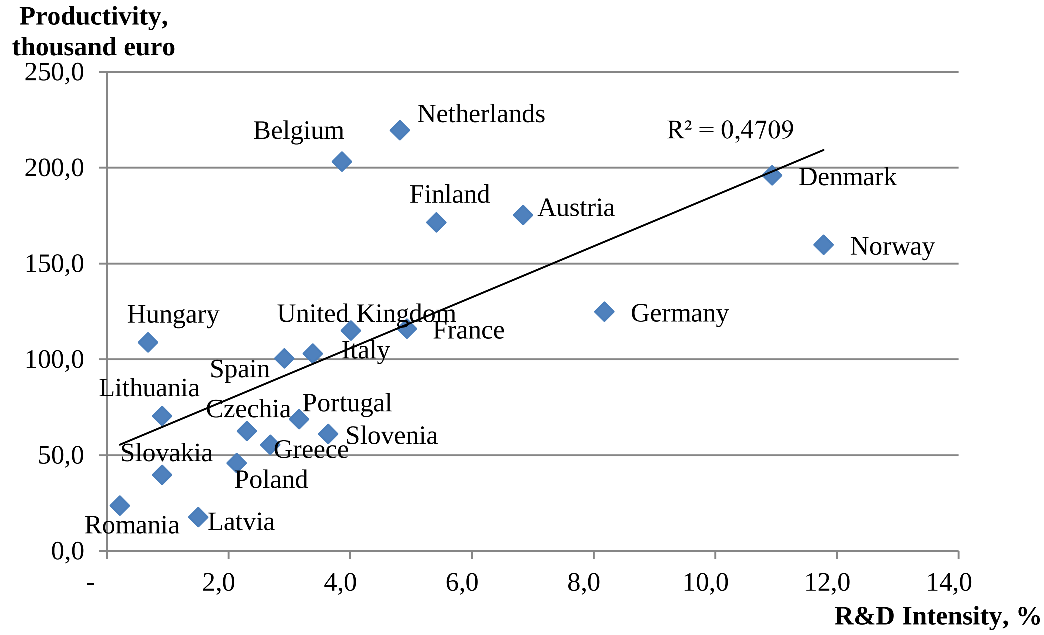

Figure 8.3 – The strength of association between R&D intensity and productivity in "Manufacture of chemicals and chemical products", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for the United Kingdom are for 2018, for Norway 2016.

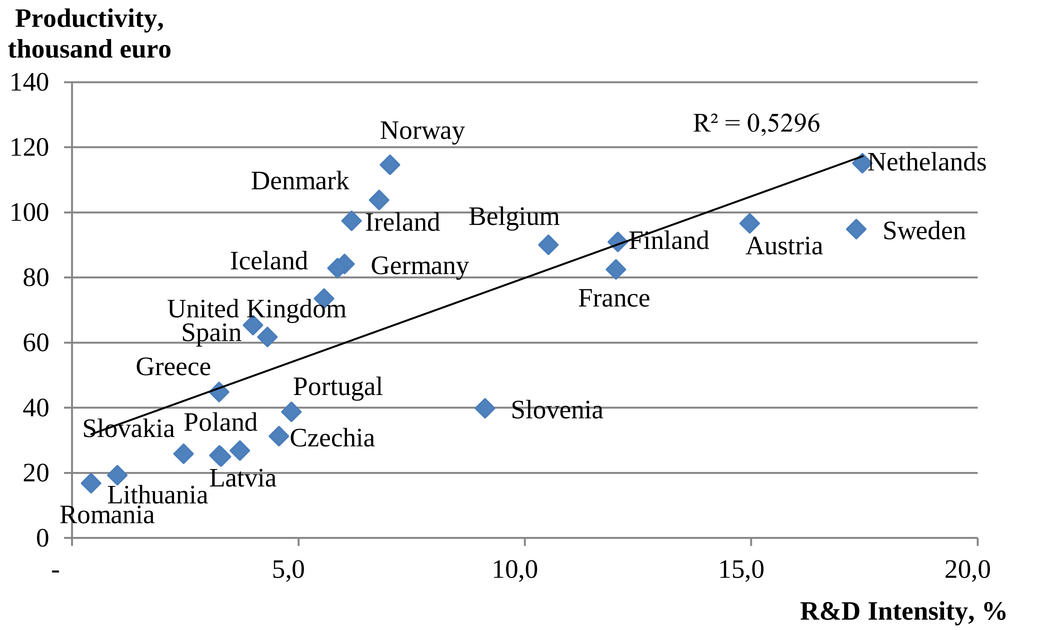

Figure 8.4 – The strength of association between R&D intensity and productivity in "Manufacture of electrical equipment", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and

Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). For Sweden data on BERD are reported based on industry orientation classification criteria.

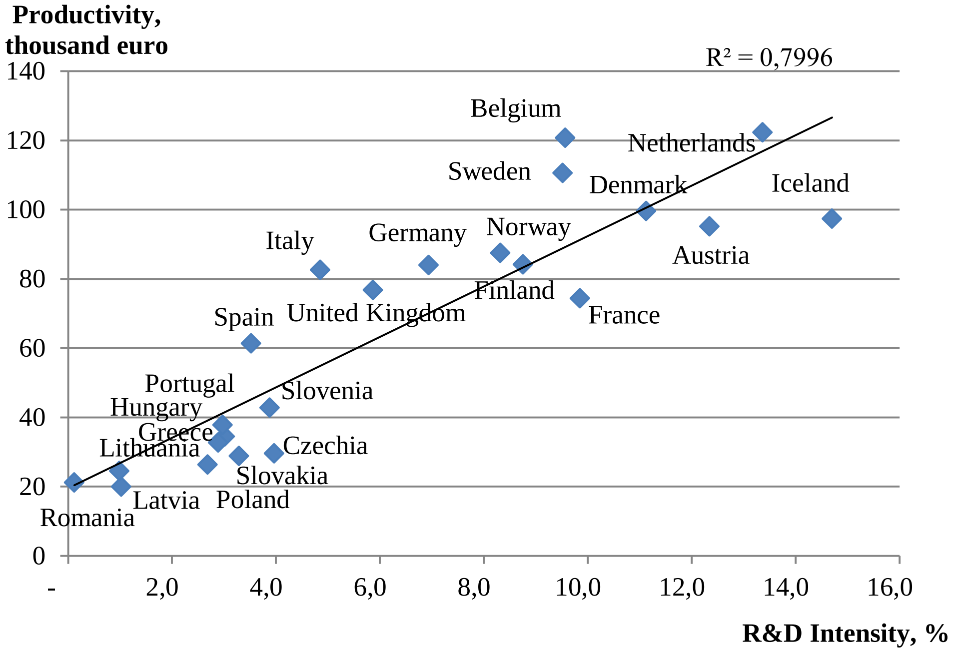

Figure 8.5 – The strength of association between R&D intensity and productivity in "Manufacture of machinery and equipment n.e.c.", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for the United Kingdom are for 2015. For Sweden data on BERD are reported based on industry orientation classification criteria.

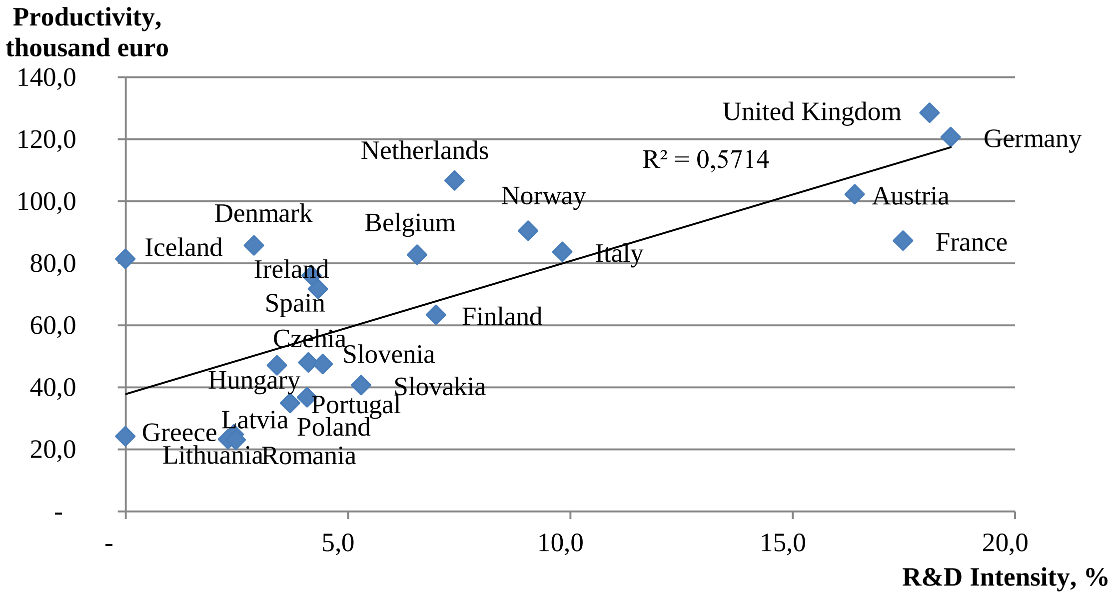

Figure 8.6 – The strength of association between R&D intensity and productivity in "Manufacture of motor vehicles, trailers and semi-trailers", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and

Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for Greece and Latvia are for 2015.

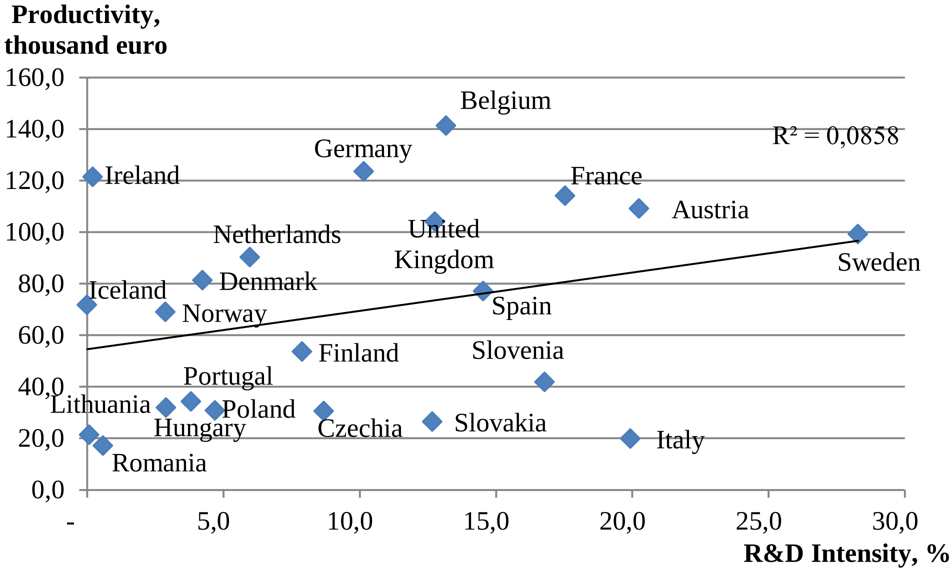

Figure 8.7 – The strength of association between R&D intensity and productivity in "Manufacture of other transport equipment", 2017

Note: R&D intensity computed as a ratio of BERD (by main type of activity) to value added based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for Norway are for 2018. For Sweden data on BERD are reported based on industry orientation classification criteria.

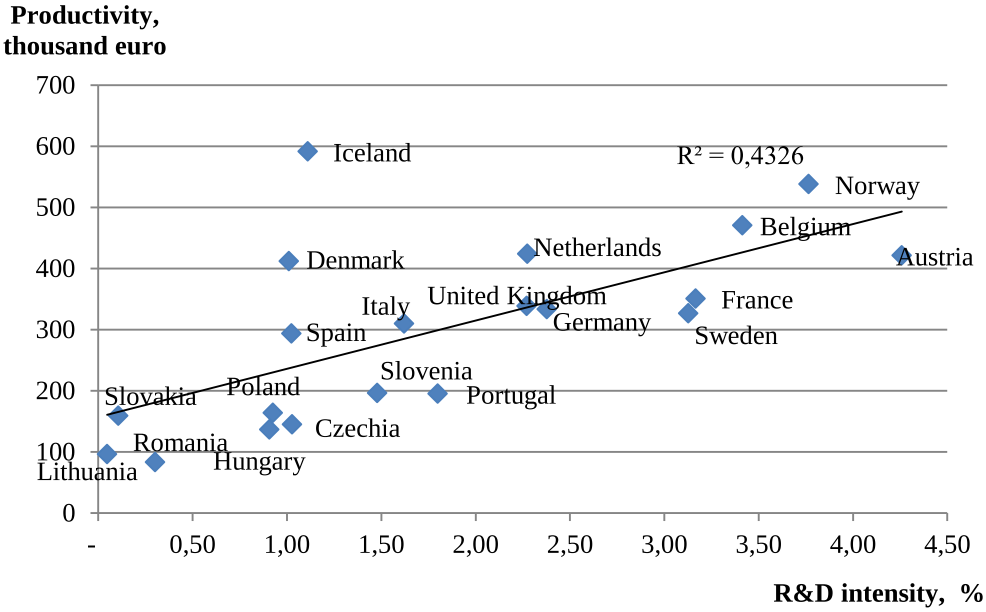

Figure 8.8 – The strength of association between R&D intensity and productivity in medium-low-technology industries, 2017

Note: the medium-low technology industries for which comprehensive data are available have been included in the analysis. These are: Manufacture of rubber and plastic products (22); Manufacture of other non-metallic mineral products (23), Manufacture of basic metals (24); Manufacture of fabricated metal products, except machinery and equipment (25); Repair and installation of machinery and equipment (33). R&D intensity computed as a ratio of

BERD (by main type of activity) of selected industries to value added based in those industries based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per person employed derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The data for Hungary and the Slovak Republic are for 2018, for Slovenia for 2016, for Sweden for 2013. For Sweden data on BERD are reported based on industry orientation classification criteria.

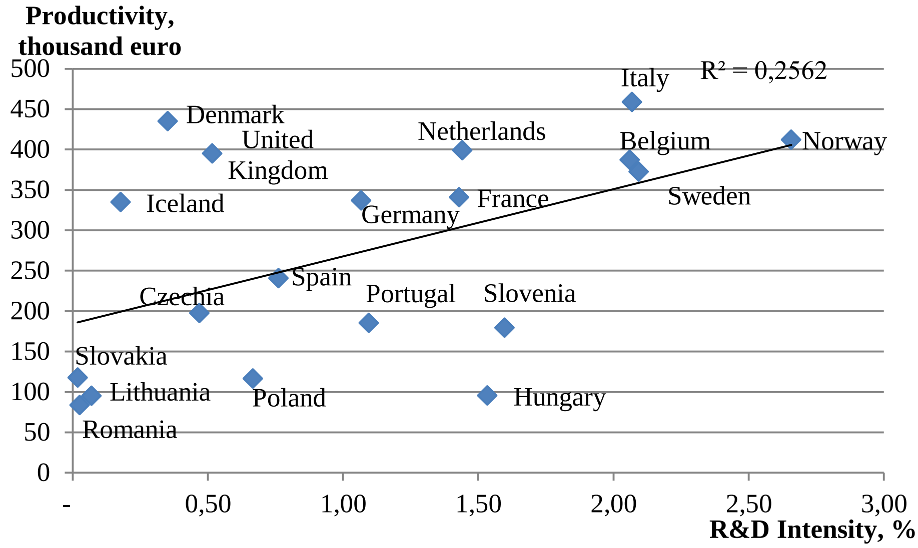

Figure 8.9 – The strength of association between R&D intensity and productivity in low-technology industries, 2017

Note: the low-technology industries for which comprehensive data are available have been included in the analysis. These are: Manufacture of textiles (13); Manufacture of wearing apparel (14); Manufacture of leather and related products (15); Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (16); Manufacture of paper and paper products (17); Printing and reproduction of recorded media (18). R&D intensity computed as a ratio of BERD (by main type of activity) of selected industries to value added based in those industries based on OECD Research and Development Statistics (Business enterprise research and development by industry, ISIC Rev. 4) and Table 6A. Value added and its components by activity, ISIC Rev. 4 (National Accounts, Detailed Tables and Simplified Accounts). Productivity is determined by gross value added per person employed derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The data for Slovenia for Manufacture of textiles (13); Manufacture of wearing apparel (14); Manufacture of leather and related products (15) are for 2018.

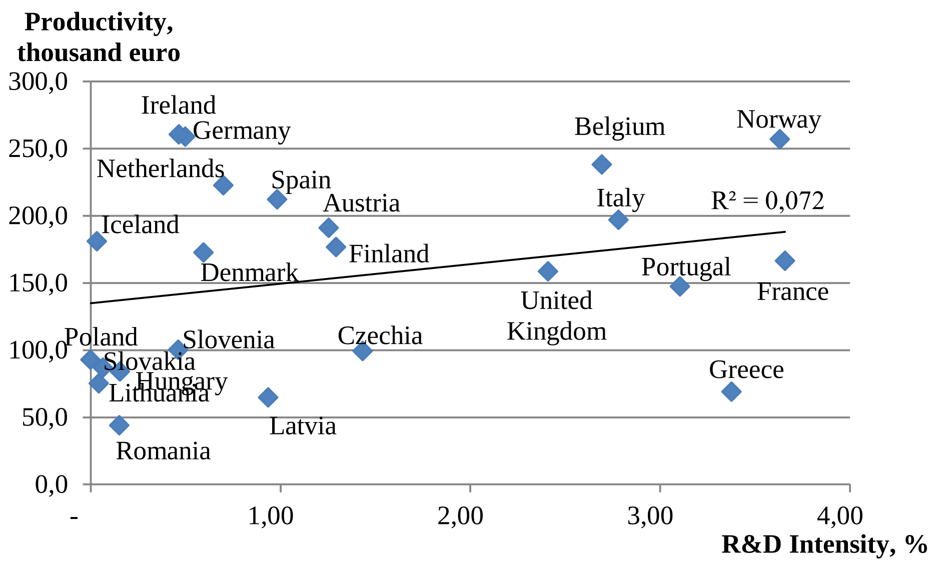

Figure 8.10 – The strength of association between R&D intensity and productivity in "Telecommunications", 2017

DOI: 10.14750/ME.2024.027

Note: R&D intensity computed as a ratio of BERD to value added at factor cost based on Eurostat Science, Technology and Digital Society Database (BERD by NACE Rev. 2 activity [rd_e_berdindr2]) and Industry, Trade and Services Database (Annual detailed enterprise statistics for services (NACE Rev. 2 H-N and S95) [sbs_na_1a_se_r2]). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r2]). The figures for Slovakia are for 2016, for Lithuania for 2018.

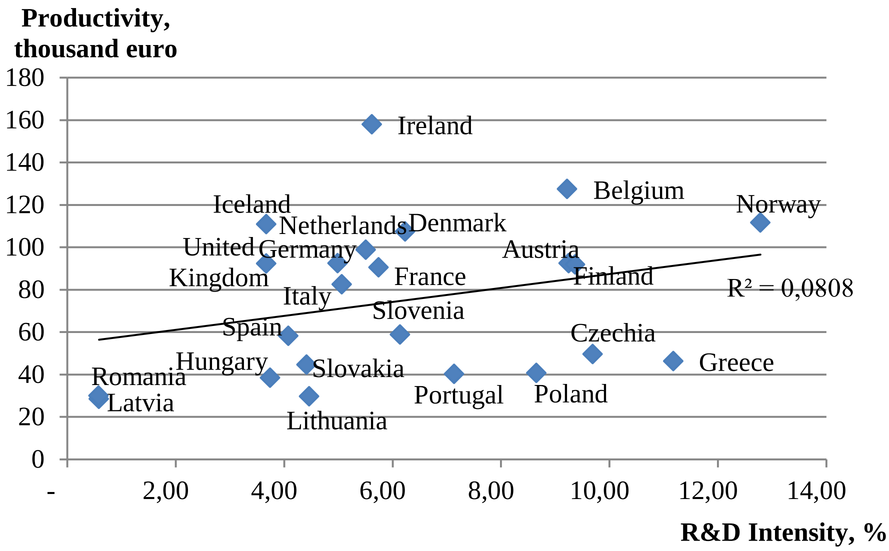

Figure 8.11 – The strength of association between R&D intensity and productivity in "Computer programming, consultancy and related activities", 2017

Note: R&D intensity computed as a ratio of BERD to value added at factor cost based on Eurostat Science, Technology and Digital Society Database (BERD by NACE Rev. 2 activity [rd_e_berdindr2]) and Industry, Trade and Services Database (Annual detailed enterprise statistics for services (NACE Rev. 2 H-N and S95) [sbs_na_1a_se_r2]). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r2]).

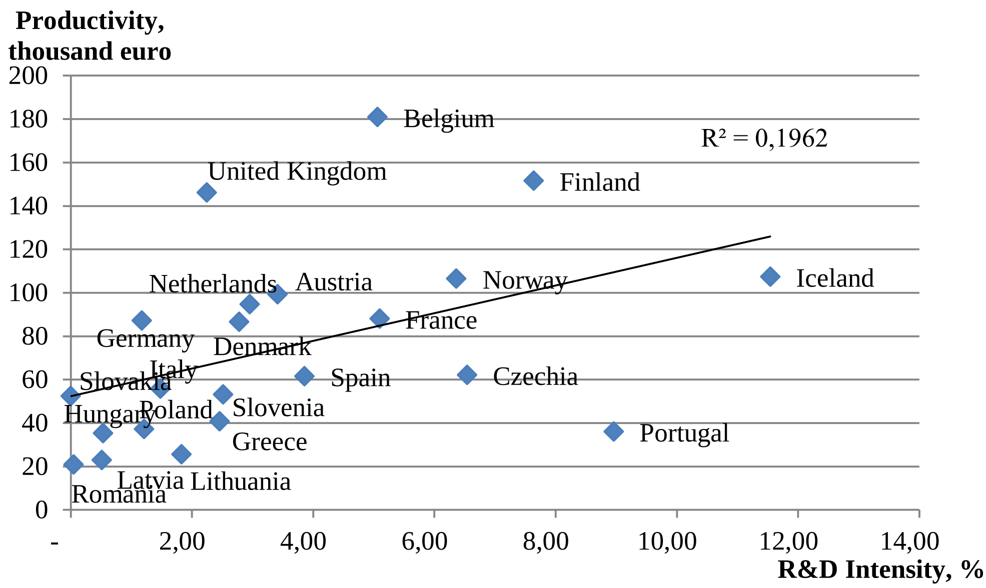

Figure 8.12 – The strength of association between R&D intensity and productivity in "Information service activities", 2017

Note: R&D intensity computed as a ratio of BERD to value added at factor cost based on Eurostat Science, Technology and Digital Society Database (BERD by NACE Rev. 2 activity [rd_e_berdindr2]) and Industry, Trade and Services Database (Annual detailed enterprise statistics for services (NACE Rev. 2 H-N and S95)

DOI: 10.14750/ME.2024.027

[sbs_na_1a_se_r2]). Productivity is determined by gross value added per employee derived from Eurostat Industry, Trade and Services Database (Annual enterprise statistics for special aggregates of activities [sbs_na_sca_r]). The figures for Poland are for 2016, for Greece for 2016.

DOI: 10.14750/ME.2024.027

Appendix 9. Generosity of R&D tax incentives, tax incentive implementation rate and the strength of institutions in selected countries, 2017

Country	TIIR	Generosity of R&D tax incentives	Institutional indicators							
			Illegal diversion of public funds [1 = very commonly occurs; 7 = never occurs]	Irregular payments and bribes 1 [very common] to 7 [never occurs]	Independence of judicial system [1 = not independent at all; 7 = entirely independent]	Favouritism in decisions of government officials [1 = show favouritism to a great extent; 7 = do not show favouritism at all]	Burden of government regulation [1 = extremely burdensome; 7 = not burdensome at all]	Efficiency of legal framework in settling disputes [1 = extremely inefficient; 7 = extremely efficient]	Transparency of government policymaking [1 = extremely difficult; 7 = extremely easy]	Strength of auditing and accounting standards [1 = extremely weak; 7 = extremely strong]
Austria	0.59	0.15	4.7	5.9	5.6	3.8	3.5	4.7	5.2	6.0
Belgium	1.04	0.16	4.9	5.7	5.6	4.1	3.1	4.2	4.8	5.8
Czech Republic	0.39	0.18	2.9	4.7	4.5	2.6	2.6	3.1	4.0	5.4
France	0.75	0.31	5.0	5.6	5.3	4.0	2.7	4.6	4.3	5.7
Greece	0.14	0.09	3.3	4.0	3.8	2.6	2.3	2.2	3.2	3.9
Hungary	0.46	0.17	2.6	4.2	3.2	1.9	2.9	3.1	3.1	4.5
Iceland	0.58	0.24	5.4	6.6	5.8	4.4	4.2	5.2	5.3	5.4
Ireland	0.86	0.29	5.7	6.1	6.3	4.6	4.1	4.1	5.5	5.1
Italy	**2.39**	**0.09**	3.3	4.3	4.0	2.2	2.0	2.1	3.1	4.3
Latvia	0.07	0.31	3.2	4.3	3.6	2.5	2.9	2.7	3.6	4.3
Lithuania	0.20	0.31	3.6	4.9	4.2	2.9	3.1	3.7	4.0	4.9
Netherlands	0.91	0.12	6.0	6.2	6.4	5.5	4.3	5.5	5.9	6.3
Norway	1.10	0.13	5.9	6.3	6.6	4.9	4.1	5.5	5.8	6.4
Portugal	0.51	0.37	4.1	5.1	4.9	3.6	3.0	2.7	3.9	4.0
Romania	0.31	0.08	2.8	3.6	3.9	2.2	2.7	3.2	3.6	5.8
Slovak Republic	0.23	0.10	2.5	3.7	2.8	1.9	2.4	2.2	3.8	5.5
Slovenia	0.48	0.19	3.5	4.9	3.7	2.8	2.7	3.2	4.0	4.5
Spain	0.13	0.30	3.0	4.7	4.2	2.9	2.8	3.5	4.2	4.8
Turkey	**2.51**	**0.06**	4.3	4.3	3.1	2.9	3.4	3.1	4.5	4.3
United Kingdom	1.25	0.19	5.8	6.1	6.3	4.5	4.0	5.6	5.5	6.0

Notes: for Romania TIIR and generosity of R&D tax incentives are for 2016, for the Netherlands for 2018; for Romania institutions scores are based on the Global Competitiveness Report 2016-2017, for the rest countries on the Global Competitiveness Report 2017-2018. Own construction.

DOI: 10.14750/ME.2024.027

Appendix 10. The strength of institutions: factor analysis

Table 10.1 – KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**,801**
Bartlett's Test of Sphericity	Approx. Chi-Square	218,529
	df	28
	Sig.	**,000**

Table 10.2 – Anti-image Matrices

		Illegal diversion of public funds	Irregular payments and bribes	Independence of judicial system	Favoritism in decisions of government officials	Burden of government regulation	Efficiency of legal framework in settling disputes	Transparency of government policymaking	Strength of auditing and reporting standards
Anti-image Correlation	Illegal diversion of public funds	**,906**[a]	-,186	-,142	-,668	-,173	-,048	,165	-,066
	Irregular payments and bribes	-,186	**,793**[a]	-,241	,124	,333	-,638	-,545	,671
	Independence of judicial system	-,142	-,241	**,946**[a]	-,400	-,078	,099	,057	-,236
	Favoritism in decisions of government officials	-,668	,124	-,400	**,853**[a]	,242	-,110	-,394	,296
	Burden of government regulation	-,173	,333	-,078	,242	**,787**[a]	-,526	-,682	,595
	Efficiency of legal framework in settling disputes	-,048	-,638	,099	-,110	-,526	**,772**[a]	,476	-,779
	Transparency of government policymaking	,165	-,545	,057	-,394	-,682	,476	**,759**[a]	-,762
	Strength of auditing and reporting standards	-,066	,671	-,236	,296	,595	-,779	-,762	**,559**[a]

a. Measures of Sampling Adequacy(MSA)

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Table 10.3 – KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**,929**
Bartlett's Test of Sphericity	Approx. Chi-Square	193,759
	df	21
	Sig.	**,000**

Table 10.4 – Anti-image Matrices

		Illegal diversion of public funds	Irregular payments and bribes	Independence of judicial system	Favoritism in decisions of government officials	Burden of government regulation	Efficiency of legal framework in settling disputes	Transparency of government policymaking
Anti-image Correlation	Illegal diversion of public funds	**,894**[a]	-,191	-,162	-,680	-,166	-,160	,177
	Irregular payments and bribes	-,191	**,973**[a]	-,115	-,106	-,112	-,249	-,070
	Independence of judicial system	-,162	-,115	**,957**[a]	-,355	,080	-,139	-,195
	Favoritism in decisions of government officials	-,680	-,106	-,355	**,876**[a]	,086	,201	-,272
	Burden of government regulation	-,166	-,112	,080	,086	**,945**[a]	-,124	-,440
	Efficiency of legal framework in settling disputes	-,160	-,249	-,139	,201	-,124	**,950**[a]	-,289
	Transparency of government policymaking	,177	-,070	-,195	-,272	-,440	-,289	**,922**[a]

a. Measures of Sampling Adequacy(MSA)

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Table 10.5 – Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6,433	91,907	91,907	6,433	91,907	91,907
2	,209	2,989	94,896			
3	,146	2,091	96,987			
4	,084	1,196	98,183			
5	,068	,971	99,154			
6	,041	,592	99,746			
7	,018	,254	100,000			

Extraction Method: Principal Component Analysis.

Table 10.6 – Component Matrix[a]

	Component
	1
Illegal diversion of public funds	,975
Favoritism in decisions of government officials	,974
Independence of judicial system	,972
Irregular payments and bribes	,965
Transparency of government policymaking	,965
Efficiency of legal framework in settling disputes	,934
Burden of government regulation	,924

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

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Appendix 11. Cluster analysis

Table 11.1 – Average Linkage (Between Groups)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	3	16,7	16,7	16,7
	2	5	27,8	27,8	44,4
	3	10	55,6	55,6	100,0
	Total	18	100,0	100,0	

Table 11.2 – Descriptive statistics for cluster analysis

Clusters		**Tax incentive implementation rate**	**Generosity of R&D tax incentives**	**Strength of institutions** *(Factor score)*	Illegal diversion of public	Irregular payments and bribes	Independence of judicial system	Favouritism in decisions of government officials	Burden of government regulation	Efficiency of legal framework in settling disputes	Transparency of government policymaking
1	Mean	,796	,207	,461	4,867	5,733	5,500	3,967	3,100	4,500	4,767
	N	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	,228	,090	,178	,153	,153	,173	,153	,400	,265	,451
2	Mean	,938	,194	1,312	5,760	6,260	6,280	4,780	4,140	5,180	5,600
	N	5	5	5	5	5	5	5	5	5	5
	Std. Deviation	,252	,072	,198	,230	,207	,295	,444	,114	,622	,245
3	Mean	,291	,210	-,794	3,150	4,410	3,880	2,590	2,740	2,960	3,740
	N	10	10	10	10	10	10	10	10	10	10
	Std. Deviation	,161	,105	,369	,493	,528	,613	,513	,255	,504	,363
Total	Mean	,555	,205	,000	4,161	5,144	4,817	3,428	3,189	3,833	4,428
	N	18	18	18	18	18	18	18	18	18	18
	Std. Deviation	,359	,090	1,000	1,259	,951	1,205	1,091	,665	1,138	,900

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Table 11.3 – ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
TIIR * Average Linkage (Between Groups)	Between Groups	(Combined)	1,603	2	,802	20,327	,000
	Within Groups		,592	15	,039		
	Total		2,195	17			
Generosity of tax incentives * Average Linkage (Between Groups)	Between Groups	(Combined)	,001	2	,000	,047	,954
	Within Groups		,137	15	,009		
	Total		,138	17			
REGR factor score* Average Linkage (Between Groups)	Between Groups	(Combined)	15,556	2	7,778	80,787	,000
	Within Groups		1,444	15	,096		
	Total		17,000	17			

Table 11.4 – Measures of Association

	Eta	Eta Squared
TIIR * Average Linkage (Between Groups)	,855	,730
Generosity of tax incentives * Average Linkage (Between Groups)	,079	,006
REGR factor score * Average Linkage (Between Groups)	,957	,915

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Appendix 12. Country notes on the computation of TIUR 2001-2019

Austria. The following subcontracting rules were applied: research conducted by a member of the same group of company is not eligible. From 2001 to 2015 business-financed gross expenditure on R&D were computed by adding tax support through R&D tax incentives which was reported as a part of government direct funding up to 2016. Provisional value for business-financed GERD was used for 2019.

Belgium. The amount of tax support reported on an accrual basis was used in the computation of TIIRs.

Czech Republic. Since R&D services provided by public universities and public research institutions from 2014 are qualified research expenses, the amount of business-financed GERD was used in the computation (from 2015 to 2019 2% out of 3% of business-financed R&D out of business enterprise sector was attributable to higher education sector, and 1% to the government sector according to Eurostat Science, Technology and Digital society database). From 2005 to 2013 only the amount of business-financed business enterprise R&D was used in the computation (the share of contracted certified R&D which is eligible for tax allowance is not known; however, since the amount of R&D financed by business and performed out of the business enterprise sector is not sizable, its exclusion will not affect our estimates to a significant extent). The average tax subsidy rates for 2005–2019 are computed based on tax subsidy rates for profit-making and loss-making firms.

France. From 2001 to 2004 the amount of business-financed BERD was used in the computation of TIUR since R&D under the contract were not eligible for the R&D tax credit. Some ambiguity existed prior to 2007 in relation to the eligibility of foreign contract R&D; however, firms conducting R&D under foreign contracts did claim the credit (Thomson, 2012 with the reference to Deloitte Touche Tohmatsu, 2008). Therefore, additionally BERD financed from foreign business enterprise sector is included in computations from 2001 to 2006. From 2007 to 2019 only the amount of business-financed GERD is considered. In 2016–2017 provisional value of tax support is provided. The estimates of TIIRs are based on non-weighted B-index.

Hungary. In Hungary from 2010 to 2019 the average B-index was computed based on the share of SMEs in total tax incentive support for R&D. The share of SMEs for 2017 was at 9% (OECD, 2019d), and extrapolated from 2010 to 2016 due to lack of the data for these years. For 2018 and 2019 the shares are equal to 10% and 12% accordingly based on R&D tax incentives country profile published annually by the OECD (https://www.oecd.org/sti/rd-tax-stats-hungary.pdf). From 2010 to 2016 the differences in tax subsidy rates for large firms and SMEs are caused by the different corporate income tax rates applied to the taxable income based on its size. Therefore, SMEs benefitting from the smaller corporate income tax rate received a lower amount of R&D tax incentives due to lower tax liability. Since a firm performing R&D activities can claim tax relief, the amount of BERD financed by the foreign business enterprise sector can be eligible for tax support. From 2001 to 2008 such data are not reported by Eurostat and therefore TIUR is not computed for these years. The estimates of TIIRs are based on non-weighted B-index.

Ireland. In Ireland R&D contracted from unrelated parties only can be eligible for a tax credit. The data on R&D financed by foreign unrelated business parties is available only for selected years (2015, 2017, and 2019). For the rest of years TIUR is less precise and computed without consideration of foreign business enterprise sector (unrelated firms).

Italy. In Italy from 2007–2009 the tax subsidy rate is specified based on volume-based R&D tax credit (10%), and from 2008 to 2019 based on the incremental R&D tax credit (25%). From 2009 to 2011 the R&D tax credit (Law 296/2006) was only available to firms that had incurred R&D expenditure in 2007–2009 and not yet received tax support, and therefore is not modelled in the B-index. R&D tax credits (fixed amount on qualified researchers and 60% for R&D collaboration) applicable in 2001–2014 are not specified. R&D contracted to firms from the foreign business enterprise sector are eligible for R&D tax incentives, and are therefore included in the computation.

Netherlands. For the Netherlands the share of small firms in tax support in 2002 was used for the computation of the average tax subsidy rate in 2001 due to the lack of availability of relevant data. Based on subcontracting rules the amount of business-financed BERD and BERD financed from the foreign business enterprise sector was used in the computation. For 2005, 2007, and 2009 the amount of business R&D financed from foreign business enterprise sector is extrapolated from the previous years (being equal to 0.12% of GDP from 2001 to 2003); therefore, the TIUR may be less precise for these years.

Norway. The share of SMEs in total tax support for 2018 and 2019 is equal to 70% according to the OECD R&D country profile (https://www.oecd.org/sti/rd-tax-stats-norway.pdf). For 2017 their share constituted 82% (OECD, 2019e). For 2015 the share of SMEs (72%) is extrapolated on the rest of years due to limited data. Considering that the difference between tax subsidy rates for large firms and SMEs is negligible (about 0.02-0.03) this assumption will not affect TIUR estimates. TIUR is computed based on non-weighted B-index since such data are currently available from 2017 only. For the years where data on business-financed GERD is not available, TIUR is not computed.

Portugal. For Portugal the value of tax support for 2018 is provisional. For 2001 the average tax subsidy rate is computed based on the share of business-financed BERD performed by SMEs of the total business-financed BERD, which constituted 27.8% according to OECD R&D Statistics. According to the OECD time-series estimates of government tax relief for business R&D (OECD, 2019b) the share of tax support provided to SMEs (52%) is close to the share of SMEs in BERD (48%). Moreover, considering that the difference in tax subsidy rates for large firms and SMEs in 2001 does not differ significantly (0.31 and 0.26 respectively), the average tax subsidy rate is a reliable estimate.

The Slovak Republic. TIUR in computed for the R&D tax allowance introduced in 2015. R&D tax allowance for incentive recipients is not modelled in the B-index.

Turkey. Estimates of tax support may include the cost of standard deductions for current R&D expenditures and may therefore overstate its amount in relation to other countries.

The United Kingdom. The data on BERD financed by the foreign business enterprise sector from 2001 to 2005 is not available. Since this amount relative to business-financed GERD is significant (around 30%), it can have a sizable effect on the TIUR. Therefore, TIUR for these years is not computed. The value of tax support for R&D in 2018 is provisional.

Romania. Tax support figures are available only from 2014 to 2016. The values of tax support for R&D in 2015 and 2016 are provisional. The TIUR is for R&D tax allowance and accelerated depreciation for R&D capital assets.