Taxation and Innovation

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Abstract[*]

This paper reviews the empirical evidence on the effects of tax incentives on R&D, innovation, and productivity and on the effects of the tax burden on the relocation of R&D facilities. It discusses the various costs and benefits that have to be taken into account in the computation of the effectiveness of tax incentives on innovation. The paper ends with 10 policy lessons that can be drawn from the evidence reported in the literature.

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1. Introduction

Many studies have shown that research and development (R&D) and innovation are key drivers of economic growth. The problem from a policy perspective is the presence of market failures related to R&D and innovation. There are at least four kinds of market failures. First, the R&D performed by one firm or in one sector may have repercussions on productivity in other firms or sectors. There could be pecuniary spillovers (market stealing in case of substitute products or market creating in case of complementary products) or knowledge spillovers (standing on the shoulders of giants). The empirical literature suggests that positive spillovers dominate. Individual firms do not take spillovers into consideration when deciding on their optimal amount of R&D; therefore, the amount of R&D performed is below the social optimum. Second, there is a problem of asymmetric information between innovator and fund provider. Because of the public nature of knowledge, firms are reluctant to give out too much information about their new ideas, but banks or other financial institutions need sufficient information to warrant lending money to the innovator. Firms may therefore be financially constrained when the external cost of capital exceeds the private cost of capital. They will refrain from doing the optimal amount of R&D that they would do in the absence of financial constraints. Third, the risk and the money required for certain R&D projects may be too high to bear for a particular firm. Fourth, there might be coordination failures between various R&D performers, like duplication of effort, competition for the same kinds of scientists, or insufficient exchange of ideas.

For all these reasons, the market by itself will not produce an efficient allocation of resources to R&D and innovation. Therefore, government has a role to play in promoting R&D and innovation. One of the ways of doing this is through R&D tax incentives. By giving tax incentives to the private sector, government encourages some firms to start doing R&D (extensive margin) and others that were already R&D-active to increase their R&D expenditure (intensive margin). In addition, R&D tax credits can attract R&D labs of multinational firms and prevent domestic R&D firms to move to foreign countries. Even though multinational firms operate on a global scale, it is always attractive to have some R&D labs located in one's own country, because of the highly educated labor they can hire or bring along with them, and because of the spillovers they generate on the local economy.

This report is organized as follows. Section 2 reviews the various modalities of R&D tax incentives that have been introduced. Section 3 reviews the empirical evidence that exists on the effect that tax incentives have had on R&D and innovation in the countries where they were introduced. It also reviews some of the work of some component that indirectly enter and attenuate the effects of the tax incentives, namely the personal and corporate income taxes. Section 4 reviews the literature on taxes and the (re)location of IP rights and R&D facilities. Section 5 gives some estimates of the costs associated with tax incentives. Section 6 concludes by discussing the policy implications from the evidence gathered in the literature.

2. Public Programs that Promote R&D and Innovation through Tax Incentives

In 2018, 30 out of 36 Organisation for Economic Co-operation and Development (OECD) countries provided some kind of tax support for business R&D expenditure. In the European Union (EU), 20 out of the 28 member countries provided such support (Appelt, Galindo-Rueda, and González Cabral, 2019). In Latin America and the Caribbean (LAC), half of the countries have implemented R&D tax incentives in their national innovation system.[1]

The typology of R&D tax incentives includes tax credits based on R&D + innovation (RDI) expenditure and tax measures that are not based on RDI expenditure (see Box 1). R&D is generally defined as in the Frascati Manual (OECD, 2015).[2] In countries such as Argentina and Spain, some innovation expenditures benefit from fiscal incentives. Innovation expenditure, as defined in the Oslo Manual (OECD and Eurostat, 2005), includes acquisition of capital goods for innovation, training for innovation, design, acquisition of rights to use patents, and other intellectual property rights.

The main distinguishing characteristic among incentives based on R&D expenditure is whether they are volume-based or incremental. The latter, restricted to R&D increments with respect to a base, are in principle more efficient in terms of output per unit of tax expenditure. There can be limits, restrictions, and possibilities of refundability. Although in principle R&D tax credits are neutral, that is, they do not favor particular types of research, it is possible to focus on specific types of R&D or agents. Countries can have different combinations of measures, ceilings, and special provisions. Moreover, in addition to country-level tax incentives, there can be regional tax incentives.

In 2007, the Netherlands and Luxembourg introduced the patent box. In 2019, according to the Tax Foundation, 14 out of 28 EU member states (including the United Kingdom) had some sort of patent box in place, and outside the EU, Switzerland, Lichtenstein, South Korea, Israel, and Turkey had them.[3] Patent box regimes differ according to the type of intellectual property (e.g., patents, software, copyrights) that is eligible, the rate of the tax reduction, existing or newly granted patents, whether the property right is acquired or self-developed or there is at least a local development requirement, the definition of IP-related income (royalties, notional royalties, income from innovation, etc.), whether current IP-related expenses and past R&D expenses can be deducted at the income tax rate for IP or non-IP income (see Evers, Miller, and Spengel, 2015; Guenther, 2017; and Alstadsæter et al., 2018 for a detailed account of the differences among OECD countries).

[1] For an account of the R&D tax incentives in place in various LAC countries in 2014, see https://assets.kpmg/content/dam/kpmg/pdf/2015/03/americas-rd-incentives-and-services-guide.pdf. See also figure 48 in Inter-American Development Bank (2010).

[2] According to the Frascati Manual (OECD, 2015), "Research and experimental development (R&D) comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications."

[3] See https://taxfoundation.org/patent-box-regimes-europe-2019/ and Guenther (2017).

Box 1: Typology of R&D Tax Incentives

1) Tax incentives in relation to R&D (or RDI)

- Immediate write-off (expensing) of current R&D costs and accelerated depreciation of capital R&D costs
- Tax credits or tax allowance proportional to the level of R&D. With tax allowances a multiple of the R&D expenses can be deducted from the taxable income.
- In proportion to the increase in R&D expenses with respect to a fixed base (e.g., a particular year), but most often with respect to a variable base (e.g., the average R&D expenditure over the last three years)
- The tax credits can be deducted from the income taxes to be paid or directly from the employer's social security contributions/payroll tax.
- Measures can be put in place for the use of tax incentives in the absence of income taxes to be paid
    - Refundability of unused tax credits
    - Carry-back and carry-forward of unused tax credits
- Focus can be put on specific types of R&D or agents
    - research on environment, health, defense, agriculture, information technology
    - R&D in university, small and medium enterprises (SME), R&D conducted in peripheral regions, R&D done in cooperation with universities or government labs, R&D done intramurally or extramurally, R&D for foreign-owned firms
- There can be certain limits to R&D tax credits: ceilings on the amount of R&D supported, maximum of R&D tax credits. There can also be nonlinear, differential rates varying with the amount of R&D. The tax credit can be based on labor expenses only.

2) Tax incentives not based on R&D expenditure:

- Reduced corporate income taxes for start-up firms
- Reduced taxes on dividends from venture capital funding
- Reduced taxes for high-skilled immigrants
- Patent boxes or innovation boxes, i.e., reduced corporate income tax on revenues from patents or from recognized innovation

3. Effect of Tax Burden and Tax Incentives on R&D and Innovation

3.1 Evidence on the Effects of R&D Tax Incentives on R&D

The literature on the empirical evidence on the effects of R&D tax incentives on R&D and innovation has been surveyed by Hall and Van Reenen (2000), Parsons and Phillips (2007), Ientile and Mairesse (2009), European Commission (2014), Becker (2015), Laredo, Köhler and Rammer (2016), Appelt et al. (2019), and recently Hall (2019) and partially in many other studies addressing this issue. Castellaci and Lie (2015) and Blandinières, Steinbrenner and Weiss (2020) perform meta-regression analyses. Gaessler, Hall, and Harhoff (2019) survey the literature on the evidence regarding the patent box.

Some of the first studies on this topic surveyed firms, asking them about the extent to which they invested more in R&D because of the introduction of R&D tax incentives. Mansfield and Switzer (1985) reported an additionality of only 0.4 in Canadian firms. A subsequent study by Finance Canada and Revenue Canada (1997) came up with an additionality factor greater than one (1.38), pointing to a crowding-in effect in the sense that firms would spend more than just the amount of money they would receive in terms of tax incentives from the government. Ljunggren et al. (2006) conducted a survey of users of the R&D tax incentive in Norway and reported that roughly 20 percent of the respondents stated that they would have done the R&D even without tax support, and roughly two-thirds answered that they would have executed their R&D projects but on a smaller scale. Haegeland and Møen (2007b) report on other surveys in Norway that arrived at the same conclusion.

The amount of money that firms are willing to spend on R&D can be modeled as deriving from the first-order condition of profit maximization, which stipulates that the net-of-corporate-tax return from a marginal dollar spent on R&D should be equal to the price of R&D times the opportunity cost of that marginal investment—that is, the depreciation rate plus the interest rate minus the expected rate of inflation in the price of R&D—multiplied by the net-of-fiscal-incentives cost of that marginal dollar of R&D. In other words, the gross of tax marginal return to R&D has to equal the so-called user cost of R&D, which contains the various tax parameters. As a consequence of this equality, the higher the corporate income tax rate, the lower the optimal amount of R&D, and the higher the R&D tax incentives, the higher the optimal amount of R&D. The extent of these reactions to the tax parameters will depend on the elasticities which may be firm specific and vary with the institutional environment in which firms operate.

Table 1 presents a comprehensive but by no means exhaustive list of empirical studies that have estimated a price elasticity of R&D from such optimal demand for R&D equations, most of them using instrumental variables to control for the endogeneity of the user cost of R&D. The studies are listed in the chronological order of their publication date. For the studies that estimate a dynamic demand for R&D equation, only the long-run elasticities are reported in column 3, that is, those that correspond to the changes between steady states after an initial shock in R&D tax support. Only the estimates that pertain to the full sample are reported. Column 4 contains the computed factors of additionality, that is, how much R&D is generated by the tax incentive per dollar of R&D expenditure.

Table 1. Evidence on Long-run Price Elasticities of R&D and the additionality of R&D Tax Incentives

Study	country	Long-run price elasticity of R&D	Additionality
Bloom, Griffith, Van Reenen (2002)	9 OECD countries 1979–1997	-1.0	
Parisi-Sembenelli (2003)	Italy 1992–1997	-1.5 to -1.8	
Koga (2003)	Japan 1989–1998	-0.7	
Dagenais, Mohnen, Therrien (2004)	Canada 1975–1992	-1.09	0.98
Mairesse-Mulkay (2004)	France 1980–1997	-2.7	2.0 - 3.6
Bernstein-Mamuneas (2005)	USA Canada	-0.8 -0.14	
Corchuelo (2006)	Spain 1990–1998	-1.2	
Harris, Lee, Trainor (2009)	Northern Ireland 1998–2003	-1.36	
Baghana-Mohnen (2009)	Quebec 1997–2003	-0.14	
Lokshin-Mohnen (2012)	Netherlands 1996–2004	-0.56	0.31 - 0.75
Westmore (2013)	19 countries, 1983–2008	-1.0	
Mulkay-Mairesse (2013)	France 2000–2007	-0.4	0.7
Rao (2016)	U.S. 1981–1991	-1.98	
Thomson (2017)	26 OECD ind./country data 1987–2006	-4.0	5.3 approx.
Appelt et al. (2020)	20 OECD ind./country data 2000–2017	-0.6	1
Labeaga, Martínez-Ros, Mohnen (2020)	Spain 2001–2008	-1.83*	

Source: Authors' elaboration.

*Weighted average of long-run elasticities for small and for large firms, and based on administrative data of tax expenditure instead of statutory rates.

Table 1 shows that R&D expenditure is responsive to changes in the price of R&D. That is, it responds positively to increases in the R&D allowances, tax credits, and R&D cost deductions, or to reductions in the corporate income tax rate. It is less clear-cut whether these elasticities are greater or less than 1. A few studies indicate that even if the point estimates are less than 1, the confidence intervals often include the value 1. Some studies that report high values also call for caution because the long-run elasticities are based on a high coefficient for the lagged dependent variable—indicating persistence in R&D expenditure or R&D stock—which may overly inflate the computed long-run elasticity.

What may be more informative for policymakers is not so much the price elasticities of R&D as the additionality ratio. Is there (partial) crowding out, that is, do firms replace some of their expenditure with tax money, or is there additionality, that is, do firms spend more on R&D than the tax expenditure by government? The factor of additionality can be computed from the price elasticity and the B-index.[4] Some studies (e.g., Baghana and Mohnen, 2009; Bozio et al., 2014 ; Dechezleprêtre et al., 2016; Labeaga et al., 2020) have also been able to access administrative data, which allows an even better computation of the actual money received in the form of tax incentives for R&D—accounting for possible delays in the payments to firms. Except for the results reported in Mairesse and Mulkay (2004) and Thomson (2017), both of which indicate the sensitivity to the coefficient of the lagged dependent variable, most studies find a ratio equal to 1 or even below 1, in other words showing hardly any sign of additionality.

During the period examined in Mairesse and Mulkay (2004) France had only an incremental R&D tax credit, by construction limited to cases of additionality, whereas the study by Mulkay and Mairesse (2013) was an ex-ante evaluation of the post-reform 2008 system, which was entirely based on volume-based tax incentives. Incremental R&D tax credit is by construction more efficient in terms of bang for the buck (i.e., increase in R&D per dollar of tax expenditure) because it applies only to marginal R&D and does not subsidize inframarginal R&D. It is not surprising then, that the additionality is much higher in their first study. The additionality can increase if second-order effects are taken into account: more R&D leads to unit cost reductions, which can stimulate demand, and then indirectly R&D through the output elasticity. In this way, Bernstein (1986) computed an additionality effect between 1.05 and 1.70—depending on the price elasticity of demand—when output is treated as endogenous, against an additionality of 0.8 when output is considered as exogenous (based on an estimated long-run price elasticity of R&D of -0.32 for Canada). From the standpoint of a general equilibrium framework, the bang for the buck is only the tip of the iceberg.

Some other studies (Table 2) have conducted quasi-experiments to evaluate the change in R&D that is attributable to the introduction of some tax reforms, rather than estimating directly the price elasticities of R&D. The inference is based on propensity score matchings, difference-in-differences, or regression discontinuity designs. Exogenous changes in the tax system can be used to infer their effect on R&D, innovation, or other firm performance measures under certain assumptions and controls for confounding factors. The various studies point to a positive and significant effect of R&D tax incentives on the amount spent on R&D, but not necessarily on patents and productivity, with an additionality that varies across studies. This may be due to the data, the particular environment, or the estimation technique.

[4] Thomson (2017) provides a formula for the computation of the additionality: $\eta/(\eta(1-B)-B)$, where η is the elasticity of R&D to its user cost and B is the B-index.

Table 2. Evidence on Additionality from Studies Using Treatment Evaluation Methods

Study	Country	Method	Effects
Cornet and Vroomen (2005)	Netherlands 2000–2001	Difference in differences*	Additionality: 0.50-0.80
Duguet (2012)	France 1993–2003	Kernel propensity score matching	Additionality: 1.00 to 3.30
Czarnitzki, Hanel and Rosa (2011)	Canada cross section of firms 1997–1999	Propensity score matching	Positive effect on R&D, innovation output (number and sales of new products) but no significant effect on productivity, profitability, or market shares.
Haegeland and Møen (2007b)	Norway 1993–2005	Difference in differences**	Positive increase in R&D, additionality: 2.0, higher probability to start and to continue doing R&D
Corchuelo-Martínez-Ros (2010)	Spain 1998–2002	Kernel Propensity score matching	Significant positive effect on R&D
Bozio, Irac and Py (2014)	France 2004–2010	Difference in differences with propensity score matching	Significant effect of 2008 R&D tax credit reform on R&D, but not on the number of patents
Dechezleprêtre, Einiö, Martin, Nguyen and van Reenen (2016)	UK 2001–2012	Regression discontinuity design****	R&D user cost elasticity: -2.6
Acconcia & Cantabene (2017)	Italy 2008–2009	Quasi-random assignment ***	Firms with cash holdings increased R&D, liquidity constrained firms did not; for high-tech firms no total effect on R&D but a shift toward outsourcing to the detriment of employment of skilled labor; only temporary effect on economic performance

Guceri and Liu (2019)	UK 2002–2011	Difference in differences****	R&D user cost elasticity: -1.6 Bang for the buck: 1
Nilsen, Raknerud and Iancu (2020)	Norway 2002–2013	Dose response model	Significant positive dose responses only for R&D starters and only for output and employment, not for labor productivity

Source: Authors' elaboration.
* Reform for startup firms introduced in the R&D tax credit system in the Netherlands in 2001.
** Introduction of SkatteFUNN in Norway in 2002.
*** Introduction of R&D tax credit in Italy 2009.
**** Reform introduced in the UK in 2008.

3.2 Extensive Margin

Corchuelo (2006) for Spain finds that a modification in the R&D tax credits in Spain in 1995 had more of an effect on the decision to engage in R&D than on the intensity of R&D expenditure for firms already doing R&D. Bozio, Irac, and Py (2016) find that firms that applied for an R&D tax credit at the time of the French reform of 2008, which switched from an incremental to a volume-based tax credit, spent more on R&D compared to those that did not apply for tax credits then, and more at the extensive margin, that is, for firms that did not apply for tax credits before the reform, than at the intensive margin, that is, for firms that had applied for R&D tax credits before the reform. Nilsen, Raknerud, and Iancu (2020) report that in Norway tax incentives have their greatest effect at the extensive margin, and even more for incumbents than for start-ups. Hægeland and Møen (2007b), Dechezleprêtre, Einiö, Martin, Nguyen, and Van Reenen (2016), Labeaga et al. (2020), and Appelt, Bajgar, Criscuolo, and Galindo-Rueda (2020) also report a positive effect on the extensive margin.

3.3 Heterogeneity

Small firms are more likely than large firms to be financially constrained and should therefore be more in need of government support because of the market failure argument of asymmetric information. Most studies that have looked into this issue find higher elasticities for small than for large firms, including Labeaga et al. (2020), Lokshin and Mohnen (2012), Koga (2003), Corchuelo (2006), Hægeland and Møen (2007b), Baghana and Mohnen (2009), Appelt et al. (2020). Hægeland and Møen (2007b) also report higher additionality for low-tech firms and firms with low-skill intensity. Castellacci and Lie (2015) have performed a meta-analysis from the results of various studies on the effectiveness of R&D tax credits. They report higher degrees of additionality in SMEs. Rao (2016) estimates that multinational firms react to R&D tax changes in the short run, but she finds no significant effect in the long run. She also finds that small, young, and low-asset firms react positively to beneficial tax changes in the short run but negatively in the long run.

Regarding heterogeneity across industries, in Appelt et al. (2020) the elasticity of R&D to its user cost is higher for firms that do below average R&D. The authors suspect that this factor may partially explain the sensitivity of the price elasticity of R&D to size. They also find that the elasticity is lower in high R&D-intensive sectors than in other sectors. Castellacci and Lie (2015) in their meta-analysis also conclude that the additionality is higher in low-tech firms and in services. In contrast, Freitas, Castellacci, Fontana, Malerba, and Vezzulli (2017) estimate higher additionality effects in terms of R&D intensity (input additionality) and in terms of share of innovative sales (output additionality) in firms where R&D is the most important strategy, specifically, science-based and specialized suppliers in the Pavitt classification.[5] Lee (2012) concludes that R&D tax credits are more effective in increasing R&D intensity in firms with low technological competence, non-clustered firms, firms operating in industries with high technological opportunities and in high competitive markets, firms whose past growth was moderate at best, and firms experienced in collaborative R&D.

There may also be heterogeneity with respect to the type of tax incentive. Agrawal, Rosell, and Simcoe (2014) estimate a higher elasticity of R&D to its user cost for contract research than for the R&D wage bill. As already stated, the incremental R&D tax credit is more efficient in terms of bang for the buck than the volume-based tax credit. Freitas et al. (2017) also report a higher additionality in Norway and Italy than in France (possibly due to the incremental R&D incentive scheme in France compared to the level-based system in Norway and Italy). When decomposing the user cost into its constituents, Mairesse and Mulkay (2004) report that the highest effect comes from the R&D tax credit, followed by the R&D deductibility, and that the other components are not statistically significant. In a computable general equilibrium model, Russo (2004) reaches the same conclusion: the R&D tax credit has a higher bang for the buck in promoting R&D than the personal income tax, the corporate income tax, and the investment tax credit for upstream or downstream users. Akcigit, Dinlersoz, Greenwood, and Penciakova (2019) argue that venture capital (VC)-backed firms are more innovative and should therefore be taxed less than non VC-backed firms.

Finally, there may be heterogeneity with respect to the phase of the business cycle. Parisi and Sembenelli (2003) find the R&D price elasticity to be larger in recessions than in expansions, as expected, given that the financial constraints are more acute in periods of recession.

3.4 Effect on Innovation and Economic Performance

Do R&D tax incentives affect more than just R&D? Do they affect down-the-line innovation and economic performance, like productivity or profitability? Besides input additionality, are there also output additionality and behavioral additionality? The evidence is mixed. Czarnitzki, Hanel, and Rosa (2011) report that Canadian firms that benefited from tax credits were more innovative—in terms of number of new products, share of sales due to new products, and the probability of coming up with products new to the market and not just new to the firm—than similar firms that did not receive R&D tax incentives. However, Bozio et al. (2016) find no effect of the French reform of 2008, when France switched from a hybrid to an entirely volume-based R&D tax credit, on the number of patents two years after the reform. Perhaps the reference period is too short to notice an effect after just two years. Over a longer period (1996–2010), Bösenberg and Egger (2017) find a significant negative correlation between average effective tax rates and the B-index for patent filings in a panel dataset of 106 countries. Hægeland and Møen (2007b) report that

[5] Additionality in terms of increases in R&D or innovation is not to be confused with additionality in terms of efficiency, i.e., bang for the buck.

R&D tax incentives in Norway increased the probability of engaging in R&D but had no strong effect on cooperation with universities. Cappelen, Raknerud, and Rybalka (2012) estimate that the R&D tax incentive system in Norway increased process innovation and, at a 10 percent significance level, the probability of introducing a product new to the firm, but it had no significant impact on patenting and the introduction of a new product on the market. Wu (2008) finds that the introduction of R&D tax credits by U.S. states increased the share of high-tech establishments by 1.35 percent.[6]

3.5 What is the effect of the patent box on R&D?

Bradley, Dauchy, and Robinson (2015) conclude from their cross-country analysis that a 1 percentage point decrease in the tax rate on patent income increases new patent applications by 3 percent. Bösenberg and Egger (2017) obtain a negative effect of having a patent box on patent filings. As pointed out by Bradley et al. (2015), the result they obtain applies only to patent applications (only a third of which are granted), and it may concern patenting of previously unpatented intellectual property in contrast to new patents. Therefore, it might be more interesting to look at the effect on R&D. Gaessler et al. (2019) find no impact of the patent box on R&D at the country level. Alstadsæter et al. (2015) also find no effect on research activity unless there is a local development requirement. This result, however, contrasts with the one reported by Schwab and Todtenhaupt (2018), according to whom a patent box introduced in the country of a foreign affiliate of a German firm increases the total R&D of that multinational firm if there is no nexus requirement. If the patent box is accompanied by a nexus requirement, a cross-border effect on total R&D depends on the relocation costs of R&D and the R&D agglomeration externalities. Mohnen, Vankan, and Verspagen (2018) on Dutch firm data find that the patent (later generalized to innovation) box in the Netherlands, which requires a local development, increases R&D man-hours, but that only part of the tax advantage is used for extra investment in R&D.

3.6 Evidence of the Effects of Corporate and Personal Income Tax Rates

Another strand of the literature focuses on whether the tax burden has any effect on innovation, following many studies that had examined the link between tax burden and growth. The question is whether taxes increase innovation by allowing government to spend on infrastructure and on research projects that increase the return to R&D, or whether they dampen innovation efforts of private firms because they encourage tax evasion and leave less financial capital over to fund private research or to serve as collateral for outside funding.

Akcigit, Grigsby, Nicholas, and Stantcheva (2018) examine the effect of corporate and personal federal and state taxes, in terms of marginal and average rates, on the number of patents and their quality (as measured by the number of forward citations received), at the macro and micro level, as well as the location choices of inventors and firms, allowing for spillover and agglomeration effects. They find strong evidence that taxes negatively affect the inventive activity

[6] The numbers are slightly higher when the share of high-tech establishments is measured by the share among all establishments rather than by the number of high-tech establishments per 1000 population.

along the intensive and extensive margins as well as the location of these activities, and more so for corporate than for non-corporate firms.

A few other studies confirm these results. Mukherjee, Singh, and Žaldokas (2017) find on U.S. data that a rise in corporate taxes decreases R&D expenditure, new product announcements, patent grants, and the quality of granted patents. Firms with high marginal tax rates and little ability to avoid taxes are hurt more than others by the tax increase. Atanassov and Liu (2020) show on U.S. firm data that higher corporate income taxes discourage innovation, the more so as firms are financially constrained, have a weak governance, few tangible assets and a small patent stock. The reason is that in a principal-agent model, higher taxes increase the need for a higher collateral and lower the incentive for firms to seek financing for risky investments in innovation. Lower taxes increase R&D, the number of patents as a proxy for the quantity of innovation, and the quality of innovation measured by the number of citations. The effect is even larger on the quality than on the quantity of patents. Contrary to Mukherjee et al. (2017), they find a symmetric directional effect of tax rises and tax cuts in terms of patents and patent citations three to four years later.

The structure of taxation is also important. Lapatinas, Kyriakou, and Garas (2019) argue that a lower tax burden on capital relative to labor exerted indirectly a positive effect on economic growth in 17 OECD countries between 1970 and 2001 through the production of more sophisticated exported products. Taxation on capital decreases economic sophistication, more so in more developed countries.

3.7 Evidence from Developing and Emerging Countries

As rightly pointed out by Crespi, Giuliodori, Giuliodori, and Rodriguez (2016), the evidence on the effectiveness of R&D tax incentives from developed countries might not hold for developing countries because they are further away from the technology frontier, they operate in less R&D-intensive industries, their scientific capacities and financial means are more constrained, and their national system of innovation is less developed.

Crespi et al. (2016) find for Argentina over the period 1998–2004 that firms are more responsive to tax incentives for capital goods than for R&D expenditure (with respective long-run price elasticities of -2.33 and -0.86), while market failure is more severe for R&D than for capital equipment. Consequently, given that low-tech sectors spend relatively more on capital goods for innovation than on R&D, firms in low-tech sectors are more responsive in R&D+i to tax credits than firms in high-tech sectors. The long-run elasticities are relatively similar in small and large firms.

Ivus, Jose, and Sharma (2021) examine the effect of the Tax Reform Act of 2010–11 in India on R&D expenditure, R&D intensity, the number of patent applications at the European Patent Office (EPO) and the number of patent applications at the U.S. Patent and Trademark Office (USPTO). They use a difference-in-differences approach comparing firms that registered with the Department of Industrial and Scientific Research—a condition for applying for R&D tax credits—and those that did not apply. They find a positive effect on R&D expenditure, hardly any effect on R&D intensity (R&D/sales), and a small but positive effect on patent applications. In a previous study on India, Mani (2010) concluded that the elasticity of R&D with respect to R&D tax remit was lower than 1 and significant only in the chemical industry. The reason suspected is the low cost reduction provided by the R&D tax credits.

Yang, Huang, and Hou (2012) find on the basis of a propensity score matching analysis that essentially large Taiwanese firms listed on the Taiwan stock exchange between 2001 and 2005 respond moderately to R&D tax credits, slightly more so in electronics. They estimate an elasticity of R&D to the R&D tax remit of 0.30 for all the firms in their sample and of 0.37 for the electronics firms and a bang for the buck of only 0.12.

Chen, Liu, Suárez Serrato, and Xu (2018) examine the Chinese InnoCom programme of 2008, which changed the R&D intensity notch above which Chinese firms benefit from a lower income tax rate. They estimate an increase in R&D of 29 percent for large firms, 17 percent for medium, and 10 percent for small firms. However, they document a substantial amount of R&D relabeling (around 25 percent of the declared R&D increase). They show that in the presence of relabeling it is more efficient to resort to such a notch-based incentive system compared to a regular R&D tax credit because of the lower monitoring costs and the possibility of offering tax credits to more productive firms.

A few studies have also been conducted on the effect of the tax burden on innovation. In 2006, China decreased the corporate income tax for domestic firms by increasing the wage deductions from gross income and the R&D allowance for domestic firms. Using a difference-in-differences approach, Shao and Xiao (2019) show that this lower corporate income tax burden increased design, invention, and utility patent filings in China two years after the reform went into effect. According to their analysis of heterogeneity, the effect was higher for larger firms and for firms in the eastern provinces. There was also a consequent increase in patent scope, measured by the number of patent classes defined in the patent, for invention patents (but not for utility patents). The authors find that the financial constraint was loosened, allowing for an increase in R&D, capital expenditures, but also the purchase of technology. An increase in productivity was not yet visible in the period they examined.

In a quasi-experimental study, Howell (2016) performed a difference-in-differences analysis following a VAT tax reform in China implemented in 2014. He found that this reform increased the firms' liquidity and their share of sales due to new products and processes, but not the R&D expenditure of privately-owned firms. The innovation might have been caused by more physical capita investment and purchase of outside technologies. In 2002, China introduced another tax reform, which transferred tax collection from the local to the state tax bureau, thereby effectively decreasing corporate income taxes by 10 percent for firms that could benefit from it, namely those not incorporated before 2002. Cai, Chen, and Wang (2018) conclude from a regression discontinuity design that, following this decrease in the effective tax rate, R&D expenditure, the number of patents as well as the quality of patents increased for the firms affected by this tax reform.

Wang and Kesan (2018) examine the effects of corporate tax and value-added tax reductions in SMEs in the software and integrated circuit (IC) sectors in China on R&D per employee and the number of patent applications per employee. They cover 140 publicly listed SMEs in the two largest science parks in China (Zongguancun in Beijing and Zhangjiang in Shanghai). They examine the effects of the tax reform in 2011 using a difference-in-differences approach. They find that corporate tax reductions (which are firm-specific) encourage R&D and patent applications in the beneficiary firms compared to the non-beneficiaries, but that value-added tax reductions (which are product-specific) increase R&D and patent applications not in the sectors producing but in those consuming software and integrated circuits.

In conclusion, even in developing countries, tax relief in various forms favor innovation, although the effects of R&D-specific tax incentives appear to be more muted than in developed countries. This is consistent with the results reporting that tax incentives are more efficient in R&D-intensive sectors.

4. Taxes and (Re)location of R&D Facilities

A large literature has found evidence of a link between taxation and the location of multinational firms, their level of investment, financial decisions such as profit shifting, dividend repatriation, the use of debt or transfer pricing (see Hines, (1999, and Devereux, 2006 for a review). For instance, Devereux and Griffith (1998) find a significant negative correlation between the choice of location and the average effective tax rate, measured as the difference between the net present value of an investment before and after different kinds of taxes, tax credits, and allowances relative to the net present value before tax. Hines (1999) reports that U.S. firms adjusted their R&D activities depending on whether they were affected or not by a tax change in the United States concerning foreign tax credits.

The possibility that firms can relocate their activities, and in particular their R&D activities, is also visible when incorporating cross-state or cross-country R&D tax incentives in an R&D demand equation. Bloom, Griffith and Van Reenen (2002) and Wilson (2009) report significant cross-border elasticities of R&D. Wilson (2009) estimates an elasticity of R&D with respect to the out-of-state user cost of R&D of 2.5, cancelling out the effect of an equivalent increase in the in-state user cost of R&D.

Multinational firms can separate the location of their R&D facilities and the location of the intellectual property rights through licensing, contract R&D, and transfer of IP. Griffith, Miller, and O'Connell (2014) find that statutory corporate tax rates influence the country choice of legal ownership of patents, often more so for high-quality patents. Their study confirms prior results on the influence of taxes on multinational firms' patent locations by Dischinger and Riedel (2011), Karkinsky and Riedel (2012), and Ernst and Spengel (2011).[7]

In the last 20 years, patent boxes were introduced in various European countries, offering reduced income tax rates on income streams coming from intellectual property rights. Using their estimates of cross-elasticities of patent locations and corporate income tax rates, Griffith et al. (2014) find

[7] To give an order of magnitude, Karkinsky and Riedel (2012) find that a one percentage point increase in the corporate tax rate decreases the number of patent applications by 3.8 percent, and Dischinger and Riedel (2011) find that a reduction of one percentage point tax difference to other affiliates increases on average a subsidiary's intangible property investment by 1.7 percent.

through simulations that patent boxes attract patent locations but not enough to overcome the decrease in tax revenues. Alstadsæter et al. (2018) also confirm that patents get located in countries with R&D patent boxes. Gaessler et al. (2019) find that the patent box mainly prevents patents from being transferred and that the presence of a local development (or nexus, i.e., physical presence) requirement reduces the probability of a patent transfer. Bradley et al. (2015) do not find that patent boxes encourage firms to relocate their patent ownerships, but that patent development and ownership are co-located. Schwab and Todtenhaupt (2018) find the transfer effect to be larger for granted patents than for patents that are still in the examination phase. The probability of a patent transfer increases with the value of the patent (also found by Alstadsæter et al., 2018), the tax rate in the selling country (also found by Ciaramella, 2017), and is higher in multinational companies.

Akcigit, Baslandze, and Stantcheva (2015) study the effect of top tax rates on the mobility of top inventors. Domestic inventors will not be much affected by changes in the domestic top tax rates, but foreign inventors do respond to changes in these domestic tax rates. Inventors with many research projects in a particular country move less in response to tax changes, whereas researchers working in multinational firms are more mobile. Moretti and Wilson (2017) estimate that the long-run elasticity of mobility of star scientists (i.e., with patents in the upper 5 percent of the distribution) to taxes is 1.8 for personal income taxes, 1.9 for state corporate income tax, and —1.7 for the investment tax credit.

5. The Costs Associated with R&D Tax Incentives

5.1 Marginal Excess Burden of Taxation

A dollar of tax expenditure spent on R&D tax incentives has a social cost higher than one dollar because of the marginal burden of taxation. Optimizing agents do not equate the actual marginal benefit to the actual marginal cost in their decisions to consume, supply labor, or invest, but the artificial marginal benefit and marginal cost including the tax rates. Consequently, they work less than they would otherwise do because of the penalizing personal income tax. This inefficiency connected to taxation, called the marginal excess burden of taxation (MEB), has been estimated in various places and for various taxes. Parsons and Philipps (2007) use a weighted average of the estimated MEB of various taxes existing in Canada in 2004 amounting to 0.27.

5.2 Administrative Costs

In order to run the R&D tax credit system, a team has to be set up to administer the program (information officers, accountants who receive and handle the applications, inspectors who verify whether the amount declared is real R&D, and so on). The Canada Revenue Agency evaluated the total operating costs of running the program at 1.7 percent of the R&D tax credits paid out (Parsons and Phillips, 2007). In its evaluation of the R&D tax incentives in the Netherlands, Dialogic (2019) reports the administrative costs related to its two programs (WBSO for R&D labor costs and RDA for R&D-related costs other than labor) in 2017 to be 1.5 percent of the R&D tax credits paid out. For the innovation box, Dialogic (2015) calculates an administrative cost 0.43 percent of the related tax expenditure. Tassey (2007, p. 607) for the United States writes that "According to one source, a quarter of the audit resources of the IRS' small and midsize business division are allocated to examining claims for the R&E credit." Guenther (2017) raises a number of options that would make the administration and compliance of patent boxes complicated and costly, such as narrowly targeting mixes of IP, conditioning on the existence of spillovers, or determining the proportion of revenues due to patents or innovations.

5.3 Compliance Costs

There are also compliance costs for firms applying for R&D tax credits (collecting information, understanding the regulations, filling out the applications, responding to requests by inspectors, etc.). These costs are higher for first-time applicants than for regular applicants and higher for small firms than for large firms. Parsons and Phillips (2007) report a study released by Finance Canada and Revenue Canada in 1997, which evaluated these costs at 15 percent for claims below 100,000 CAD, at 10 percent for claims between 100,000 and 500,000 CAD and at 5.5 percent for claims above 500,000 CAD. On the basis of the claims made in 2004, Parsons and Phillips (2017) calculated a weighted average compliance cost of 7.9 percent.

Based on surveys conducted with beneficiaries of those measures, the Dutch evaluation of the R&D tax incentives (Dialogic, 2019) evaluates that the costs related to the use of intermediates in the application of those tax incentives in 2017 were on the order of 3.8 percent of the received tax credits, and the own compliance costs were 4.4 to 7.2 percent of the money received, with the proviso that part of those costs could also have been incurred when applying for the innovation box (reduced income taxes on approved revenues from innovation). In the evaluation of the innovation box in the Netherlands (Dialogic, 2015), the compliance costs for the application of the innovation box were determined to be 2.6 percent of the money received.

Taking into account the marginal excess burden of taxation, the administration and compliance costs on the one hand, and the R&D externalities (estimated on the basis of a pretty broad literature survey at 0.57) on the other, Parsons and Phillips (2007) arrive at a 10.9 percent net welfare effect of the tax incentives in Canada. However, they also warn that for small changes in these various estimates, the net welfare effect could well become negative.

5.4 Cost and Benefit Analysis of R&D Tax Incentives

In a computable general equilibrium (CGE) setting, all direct and indirect costs and benefits are taken into account. For example, attention should be paid to the effect of R&D tax incentives on the wages of R&D workers, the positive externalities of R&D in terms of consumer surplus, the negative externalities due to market stealing, the dynamic externalities due to sequential innovation, congestion externalities (fishing in the same pond), the effects of tax competition, the indirect effects of R&D on innovation, productivity, competitiveness, and the indirect effects due to various macroeconomic constraints such as a balanced budget and the balance of payments. Personal or corporate income taxes need to be raised to finance R&D tax expenditures with repercussions on other public expenditure such as infrastructure, health, education. Higher personal income taxes can also dampen personal consumption expenditure and thereby decrease the incentives to innovate through a demand effect or lower long-term savings and thereby increase the interest rate, which discourages innovation. In these general equilibrium models, the movements of labor from the production to the research sector or vice versa can play an important role on the effects of tax measures on R&D.

In Russo (2004), for example, an investment tax credit in the research sector increases productivity in the research/capital goods-producing sector and the final goods sector. As a result, the relative wage in the two sectors hardly changes. But an investment tax credit in the final goods-producing sector increases productivity in the upstream capital goods-producing sector without affecting the final goods sector, and thereby increases wages in the upstream sector, attracting workers to that sector and increasing R&D. With the QUEST III model used by the European Commission, McMorrow and Röger (2009) simulate the effect on GDP of a 5 percentage point increase in the R&D tax credit to bring the EU tax credit to the level in force in the United States, given reasonable calibrations of the parameters of the model. Given the supposed declining rate of return on R&D and the limited availability of qualified personnel in the short run, the multiplier effect is found to be minimal: it would after 20 years increase the share of R&D in GDP by 11 percent, GDP by 0.08 percent and TFP by 0.11 percent. Von Brasch, Cappelen, Hungnes, and Skjerpen (2020) calculate the long-term effect of tax incentives in Norway within a macro-based model with R&D spillovers and a balanced budget.[8] Because of the additional R&D generated by the R&D tax incentives, productivity increases within and across sectors, so that output, wages, consumption, and exports increase in the long run (after 40 years) by one percentage point.

6. Conclusions and Policy Discussions

From the evidence gathered so far, we can conclude that higher taxes dampen the readiness to invest in R&D and the intensity of investments in R&D, and they indirectly reduce innovation output, be it patents, new products, the quality of patents, or the novelty of new products. The evidence holds for countries close to the technological frontier as well as for middle-income countries that are on the way to catching up with the technology leaders, although the effect seems to be more pronounced for high-income countries. There may be differences across sectors (high-tech vs. low-tech), types of firms (size, age, multinationals) and kinds of taxes (capital, labor), but the general picture is that tax burdens stand in the way of innovation. From the reverse perspective, decreases in taxes stimulate R&D and innovation, although not all studies have found as much of an effect with tax reductions as with tax increases.

Special provisions have been introduced in many countries to stimulate R&D and innovation, which more than other investments suffer from various sorts of market failure. The idea is to specifically support R&D-performing firms or projects, if possible those which have the highest social repercussions, and open the door for more technological advances in the future. Here also, the evidence shows that R&D tax incentives lead to more R&D and indirectly to more innovation, although often the effect on productivity is hard to discern. As Westmore (2013) shows, tax incentives can have a positive effect on R&D and possibly on innovation output (patents or sales of new products) but not on total factor productivity (TFP). The reasons could be that the period is too short to see an effect or that productivity is hard to measure, but also that new patents or products may have a low return, or that social costs (compliance, administration, tax-related

[8] Tax incentives are counteracted by a reduction in household transfers.

inefficiencies, monopoly situations, support for intendants discouraging new entrants, etc.) are too high compared to the social benefits.

The R&D tax incentive is often found to have more of an effect on the extensive than the intensive margin. Most studies find higher elasticities of R&D to tax incentives for small than for large firms. The R&D tax credits are often found to be more effective in increasing R&D intensity in firms with low technological competence and in firms operating in industries with high technological opportunities. Among the various tax rates that can influence R&D, the rate of the R&D tax credit is the most influential. Although it has been largely found that R&D and even innovation output respond positively to tax incentives, the bang for the buck is not always found to be greater than 1, especially not for volume-based tax incentives and if application costs, compliance costs and the indirect burden of taxation are taken into account. The net social benefit of tax incentives very much depends on the extent of R&D spillovers.

There is little doubt that taxes and tax incentives can influence the location of R&D facilities, intellectual property, and inventors. The possibility of tax competition in relation to R&D and innovation cannot be discounted. Most studies find that the patent box leads to more R&D only if there is a local nexus requirement. Even in developing countries, tax relief in various forms favors innovation, although the effects of R&D-specific tax incentives are more muted than in developed countries.

The following ten policy lessons can be drawn from the evidence reported in the literature.

1) Changes in the R&D tax credit rate seem to be more efficient in stimulating R&D than changes in the income tax rate, in part because they make it possible to limit R&D support to R&D-performing firms.

2) Incremental R&D tax credits are more efficient than level-based R&D tax credits. Indeed, an increase in the volume-based R&D tax credit rate will automatically apply to the R&D that was already planned. Incremental R&D tax credit, on the contrary, applies only to marginal R&D (for a further discussion on this point see Russo, 2004; Atkinson, 2007; Lokshin and Mohnen, 2012; and Hall, 2019). Volume-based R&D tax credits thus carry a deadweight loss. However, the deadweight loss also applies to increases in R&D that were already planned before the introduction of the tax credit. Dagenais, Mohnen and Therrien (2004) estimate the deadweight loss to be 80 percent of the tax expenditure; the Australian Bureau of Industry Economics (1993) and Lokshin and Mohnen (2012) report similar percentages. Nevertheless, governments are increasingly shifting to a level-based tax incentive system because it is easier to manage, it does not lead to a see-saw behavior to capture the most of the R&D tax support, and it provides continuous support even in the absence of acceleration of R&D investment. Blandinières et al. (2020) conclude that hybrid systems, that is, those with both types of R&D tax credits, are not very effective, probably due to the complexity of such a system.

3) The patent box, to the extent that it is accompanied by a domestic development requirement, can stimulate R&D and attract R&D labs, thereby generating intellectual property income, and make sure that the revenues from innovation are collected in the home country. Many downsides of the patent box have been mentioned. It is an ex-post and not an ex-ante support; hence, it may

support innovations that are not based on R&D. It does not provide financing at the R&D stage, but finances successful innovations, and it may lead to tax competition to attract R&D firms.

4) As Tassey (2007) argues, the R&D tax credit may mainly affect development projects and incremental improvements because of its low effect on the cost of R&D. Only marginal projects would be affected by a decrease in the user cost due to R&D tax incentives; projects with high return would be done anyway.

5) In some countries, many firms do not take advantage of existing R&D tax credits because they are uninformed or find the application costs too expensive and complicated. Corchuelo and Martínez-Ros (2010) report that in 2002, less than 50 percent of R&D-performing firms in their sample of Spanish manufacturers benefited from R&D tax credits. Receiving direct government support, having financial stability, and firm size were positively correlated with claiming tax support. Gokhberg, Kitova, and Roud (2014) report for Russia that one out of nine firms refused to apply for accelerated depreciation for innovation equipment because of the high transaction costs.

6) Tax competition may completely eliminate any domestic incentive effect, as in a prisoner's dilemma game. The solution would be for countries to coordinate their tax systems.

7) Most studies in the literature have evaluated the effectiveness of R&D tax incentives without controlling for the influence of direct R&D support in the form of grants and subsidies. If the other means of funding R&D—direct grants and subsidies—are also significant, ignoring their effect could over- or under-estimate the effect of tax support depending on the effectiveness of the other channel and the interaction between the two types of support. Hægeland and Møen (2007a), Czarnitzki and Lopes-Bento (2014), Guerzoni and Raiteri (2015), and Appelt et al. (2020) find that direct R&D support and R&D tax incentives are complements. That is, they reinforce each other in increasing R&D. Guellec and van Pottelsberghe de La Potterie (2003), Marino, Lhuillery, Parrotta, and Sala (2017), and Dumont (2017) find the opposite. Nilsen et al. (2020) examine both direct and indirect R&D support but report few cases where firms receive multiple types of support. In this regard, the result reported by Huergo and Moreno (2017) that complementarity holds for SMEs but not for large firms is interesting. It could well be that the total R&D support exceeds the amount that would be optimal to correct for possible market failures, in which case there may be crowding out and deadweight loss. It could also be that there are optimal amounts of support for separate sources of market failure and excess support for each because of a partial overlap of different support measures or a lack of coordination in the support programs. This could be due to the existence of different decision makers, such as regional, national, or supranational authorities.

8) Some countries, such as Canada, put more emphasis on indirect R&D support whereas others, like Germany, have almost no indirect R&D support. How do they compare? One advantage of the indirect R&D support is that it leaves the choice of R&D projects up to the private sector instead of letting the government pick a winner, although some types of R&D tax support can be conditioned on particular types of research in terms of content (e.g., health, environment, etc.) or in terms of the way that R&D is conducted (e.g., collaboration with universities). On the other hand, direct support can be directed toward projects that are a priori more rewarding for society

at large, such as basic research, which may have more externalities since many other research projects follow. Busom, Corchuelo, and Martínez-Ros (2014) advocate for both measures because different kinds of firms prefer different types of support. Coad, Mathew, and Pugliese (2020) show that firms are rational when choosing whether to do R&D. Firms that choose not to do R&D would grow less if they did engage in R&D. Hence, the goal should not be to maximize the number of R&D performers but to channel the funds to firms that want to invest in R&D but may not have the means to do so.

9) Besides the possible complementarity between direct and indirect R&D support, it is reasonable to assume complementarity between fiscal support for R&D and macroeconomic stability and good governance. As illustrated in the case of China by Chen et al. (2018) and Böing and Peters (2021), R&D support can be inefficient if firms use relabeling and fund misappropriation. This inefficacy of R&D support through tax incentives can be more acute in developing countries that have not yet established a sound macroeconomic policy with checks and balances. Another prior condition for success of tax-related R&D support is the availability of human capital. Otherwise, tax incentives lead to higher wages for R&D workers with no increase in actual R&D. This point was forcefully made by Cirera and Maloney (2017).

10) As indicated by Akcigit and Stantcheva (2020), a gain in efficiency of tax incentives can be achieved by giving higher tax incentives to small firms and venture capital-funded firms. Political connections favoring established incumbents over newcomers should be avoided.

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