THEMA Working Paper n°2021-14
CY Cergy Paris Université, France

R&D Tax Credits across the European Union: Divergences and convergence

Laurence Jacquet, Stéphane Robin

April 2023 version

R&D Tax Credits across the European Union: Nonsense or Common Sense?[*]

Laurence JACQUET[†] Stéphane ROBIN[‡]

April 12, 2023

Abstract

We examine the R&D, innovation and productivity effects of R&D tax credits (R&DTC) in 8 EU countries in the context of a proposed EU-wide "super deduction" on R&D expenditures. Estimating CDM-type econometric models on industry-level panel data, we find that past R&D systematically feeds current R&D. The estimate of our proxy measure of input additionality during an R&DTC phase is generally close to 1, but rarely larger than 1. R&D intensity affects patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, but this relationship is R&DTC-related only in Belgium, France and Spain. Only in France and the UK do we observe a full R&D - innovation - productivity relationship. In the UK, this relationship is not affected by the R&DTC scheme. In France, a 1% increase in R&D conducted under the second to fourth phases of R&DTC (1999-2017) entails a cumulated 0.36% increase in patenting intensity, which translates to a 0.16% increase in productivity. The main policy implication of our results is that R&DTC may help the EU reach its "R&D at 3% of GDP" objective, but should not be the only instrument implemented to spur innovation and productivity in the EU.

Keywords: R&D Tax Credits, Public Support to R&D, CDM model, Science and Technology Policy, European Policy

JEL codes: O38, H25, H54

---

[*] The authors thank participants to various conferences and seminars, and in particular Marcel Gérard, Bertrand Koebel and Phu Nguyen-Van, for their very helpful comments on prior versions of this paper. The usual disclaimers apply.

[†] CY Cergy Paris Université, CNRS, THEMA, F-95000, Cergy, France. Email: laurence.jacquet@cyu.fr. Webpage https://sites.google.com/site/econlaurencejacquet

[‡] Corresponding author, Université Paris 1 Panthéon-Sorbonne, PRISM-Sorbonne, Paris, France and BETA, University of Strasbourg. Email: stephane.robin@univ-paris1.fr. Webpage: https://www.pantheonsorbonne.fr/page-perso/strobin

I Introduction

To make the EU "*the most competitive and dynamic knowledge-based economy in the world*",[1] the 2000 Lisbon Agenda involved increasing investments in R&D up to 3% of the EU Gross Domestic Product (GDP). This objective was not met by 2010, when the Lisbon Agenda gave way to the Europe 2020 strategy, and remains to be attained in the current Horizon Europe program, which has superseded Europe 2020. In the words of research commissioner Mariya Gabriel, the 3% of GDP figure remains a "guiding light" for Horizon Europe.[2] The main policy tools to foster an increase in R&D spending are R&D tax incentives and, more specifically, R&D tax credits (R&DTC).

So far, R&D tax incentives have been the prerogative of EU Member States, resulting in a great diversity of instruments (and eligibility conditions) across the EU. Things have begun to change with the 2016 Common Consolidated Corporate Tax Base (CCCTB) proposal, which would be subsumed and extended by the Business in Europe: Framework for Income Taxation (BEFIT). The latter aims at establishing a single corporate tax rulebook in the EU, based on apportionment and a common tax base. Indeed, the proposal suggests to implement a "super-deduction" that would allow EU-based firms to deduce more than 100% of their R&D expenditures from their tax base. This super deduction may co-exist with national schemes, should Member States wish to go on with their current R&D tax incentives. The proposal of a super-deduction of R&D expenditures at the EU level is grounded in the aforementioned beliefs that economic growth in Europe can only be knowledge-based, and that the current level of R&D investment in the EU is too low to generate the required knowledge. R&D tax incentives, and the proposed super-deduction in particular, are seen as the obvious solution to boost R&D investment throughout the EU, hoping that this increased investment will have positive returns in terms of innovation and, ultimately, growth.

In this paper, we examine whether these expectations have strong foundations by estimating the effect of R&D tax incentives on R&D expenditures, innovation outcome and economic growth in several EU countries. We thus address two oft-mentioned challenges in the literature: the dearth of cross-country comparisons on the one hand, and the fact that most studies limit themselves to the effect of tax incentives on R&D expenditures on the other. Our selected countries include Austria, Belgium, Czech Republic, France, the Netherlands, Italy, Spain and the UK.[3] In each country, we estimate two econometric models on industry-level panels that cover a period starting in the late 1970s / early 1980s (depending on the country) and ending in 2017. The first model is an adaptation of Mairesse and Mohnen (2002)'s "accounting framework" for innovativeness and the second an adaptation of the CDM model (Crépon et al., 1998, Lööf et al., 2017). The former explicitly applies

---

[1] In the words of the EU Parliament (2000): http://www.europarl.europa.eu/summits/lis1_en.htm, Part I, Point 5.

[2] See for instance: https://sciencebusiness.net/framework-programmes/news/member-states-asked-sign-pact-higher-rd-investment.

[3] While the UK is not part of the EU anymore, it was a fully-fledged EU Member State over the period which we study. We will discuss the implications of Brexit further on in the text.

to various levels of analysis (from firm to country) and the latter, while primarily applied to firm-level data, has also proven worthy with industry-level data (Bourlès et al., 2013, Amable et al., 2016, Bartelsman et al., 2017).

Overall, we find that past R&D feeds current R&D, whether it is conducted when an R&DTC is available or not. For R&D conducted under an R&DTC, we find an estimate of our proxy measure of input additionality that is generally close to 1, which is consistent with the literature. It suggests that R&DTC help industries maintain their level of R&D intensity across the years, but are not conducive to higher levels of R&D intensity. Identifying a relationship between R&DTC and innovation output is more difficult. While R&D intensity does affect patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, this relationship is R&DTC-related only in Belgium, France and Spain. Only in France and the UK do we observe a full R&D-innovation-productivity relationship. In both cases, the relationship depends on which definition of R&D intensity is retained. In the UK, the R&D-innovation-productivity relationship is not affected by the R&DTC scheme. In France, we find that a 1% increase in R&D conducted during three successive periods of R&DTC (from 1999 to 2017) entails a cumulated 0.36% increase in patenting intensity and a 0.16% increase in productivity. The main policy implication we derive from these results is that a "super-deduction" on R&D of the type proposed in BEFIT may help the EU reach its 3% of GDP objective, but only time will tell whether the remarkably generous character of the said deduction will also spur innovation and productivity.

The paper is organized as follows: In Section II, we present some economic justifications for the existence of R&DTC schemes as well as the rationale for the super-deduction proposed at the EU level. In Section III, we illustrate, using the selected EU countries, the complexity and sheer diversity of R&DTCs schemes. In Section IV, after briefly replacing our study within the related literature, we present our data and econometric analysis. We summarize our findings and discuss their policy implications in a Section V. We conclude in Section VI, the final section.

II R&DTC schemes in the EU

II.1 Economic justification for the existence of R&DTC

R&D tax incentives and related R&D policies are rooted in the belief that, in modern economies, innovation is the main source of growth, a belief largely grounded in endogenous growth theory (e.g., Romer (1990)). This belief has led to the widespread conviction, in EU policy circles, that innovation may be the only option to get the EU economy out of stagnation and back on the path of growth. The rationale is that innovation-induced economic growth will result in increased wealth, employment and well-being. EU policy makers are therefore searching for the conditions that are more likely to make firms increase their innovation effort. A widespread recommendation consists in creating the conditions of increased competition between firms (or in “letting the market decide"), as the increased competitive pressure would supposedly lead firms to innovate in order to survive or to gain advantages over their competitors.

A potential problem with this recommendation is that markets left to their own devices are likely to generate less R&D,[4] and therefore less innovation, than it would be desirable for the society as a whole (Arrow, 1962). Among economists, this is known as a "market failure". As far as investment in R&D is concerned, there are at least two reasons for such a failure.

One reason is that knowledge created through R&D, just like any type of knowledge, is largely immaterial and presents some characteristics of a "public good": It cannot be completely appropriated by its creators, and the related ideas can be - more or less rapidly, depending on their complexity - copied and used by other firms. Intellectual property rights (e.g., patents) may alleviate this problem, but do not completely solve it (e.g., a patent is effective only for a limited period of time and/or over specific geographical areas).

A second reason is that innovation is a very risky and uncertain endeavour, and that investment in R&D is not a safe investment. Firms may therefore face serious difficulties in finding financial support for their R&D projects, as banks and investors may be unwilling to lend money to projects that they cannot easily monitor (or the outcomes of which they cannot clearly see). This may result in the abandonment of projects that firms would be eager to pursue had they the required funds. If the assumption that innovation is conducive to economic growth and to social well-being is correct, then the two above-mentioned reasons call for public intervention in order to spur firms' R&D effort. This type of public intervention will generally take the form of R&D subsidies or of R&D tax incentives such as R&DTCs.

II.2 Towards a "super-deduction" on R&D in the EU?

So far, we have examined justification for the existence of R&DTCs in general. In practice, tax credits can take a multiplicity of forms, and may vary hugely across EU Member States. At one end of the spectrum, there are States where no tax credit exists (e.g., Germany) and, at the other, States where R&DTCs have been implemented for a long time (e.g., France), possibly experiencing changes along the way. The question of whether this variety should be harmonized at the EU level seems to have finally found, in EU policy circles at least, a positive answer with the proposal, in October 2016, of a revamped CCCTB (actually the re-launch of a 2011 proposal). This initiative, now enclosed within the broader BEFIT proposal, suggested the implementation of a "super-deduction" on R&D expenditures:[5]

"To support innovation in the economy, this re-launch initiative will introduce a super-deduction for R&D

---

[4] Although alternative innovation channels do exist (see, e.g., Bozeman and Link (1983) for a thorough examination of these issues), R&D is generally considered as the primary input to the innovation process.

[5] The 2011 proposal already included a specific regime for R&D-conducting firms. The R&D regime in the 2016 proposal is more generous and constitutes a somewhat more radical proposal.

costs into the already generous R&D regime of the proposal of 2011. The baseline rule of that proposal on the deduction of R&D costs will thus continue to apply; so, R&D costs will be fully expensed in the year incurred (with the exception of immovable property). In addition, taxpayers will be entitled, for R&D expenditure up to EUR 20000000*, to a yearly extra super-deduction of 50%. To the extent that R&D expenditure reaches beyond EUR* 20000000*, taxpayers may deduct 25% of the exceeding amount.*" (European Commission (2016), pp. 9-10)

This super-deduction is, in effect, a very generous R&DTC scheme, as was clearly stated in the associated press release:[6] *"The CCCTB will support innovation in Europe by allowing the costs of R&D investment to be tax deductible. All companies that invest in R&D will be allowed to deduct the full cost of this investment plus an additional percentage of the costs, depending on how much they spend. The full cost of R&D will be 100% deductible, while an additional 50% deduction will be offered for R&D expenses of up to EUR* 20 *million. An additional 25% deduction will be allowed for R&D spending over EUR* 20 *million*".

The press release illustrated this scheme with the following example. An EU-based company that spends EUR 30 million on R&D in a given fiscal year will be allowed to deduct: (i) the full amount of its R&D expenditures (i.e., EUR 30 million) from its taxable income, plus (ii) an additional 50% of the first EUR 20 million (i.e., EUR 10 million) plus (iii) an additional 25% of the remaining R&D expenditures above the EUR 20 million threshold (i.e., EUR 2.5 million as 25% of the remaining EUR 10 million). In total, this hypothetical company will be able to deduct EUR 42.5 million from its CCCTB, which only goes to show that "super-deduction" is a rather appropriate term for this R&DTC scheme.[7]

The "super-deduction" seems to have been added to the 2016 CCCTB proposal to serve multiple objectives. The first was probably to make the proposal more appealing to reluctant Member States, as it offers them a channel through which they may maintain their international attractiveness– more specifically towards high-technology and innovative firms. Second, the variety of R&DTC regimes that currently prevails throughout the EU may result in a specific form of tax competition, geared towards R&D: high-tech and R&D intensive firms may be willing to settle down in countries/regions where the tax regime favors R&D more. This in turn could cause uneven increases in R&D investments across EU regions (with R&D expenditures rising in some States and stagnating in others), which plays against the "3% of GDP" objective for R&D investment in Europe. By introducing a certain degree of harmonization in R&DTCs, a "super-deduction" would lessen this threat.[8] Finally, the "super-deduction" could also be a way - insofar as tax credits are effective science and technology

---

[6] http://europa.eu/rapid/press-release_MEMO-16-3488_en.htmtext

[7] The scheme is even more generous for "small starting companies" (i.e., start-ups, primarily), which will be allowed to deduct a further 100% of their R&D expenditures, within the limit of EUR 20 million. Thus, a start-up that invests EUR 5 million in R&D will be allowed to deduct EUR 10 million from its CCCTB.

[8] The super deduction would not totally rule out national R&D tax incentives, though. The principles stated in the 2011 CCCTB proposal still prevailed in the 2016 proposal: "A company which does not qualify or does not opt for the system provided for by the CCCTB Directive remains subject to the national corporate tax rules, which may include specific tax incentive schemes in favour of Research & Development." (European Commission (2011), p. 6)

policy instruments - to foster higher investment in R&D despite post-pandemic budget cuts in the Horizon Europe programme.

The EU ECON committee adopted the report on the 2016 CCCTB proposal on February, 28th, 2018 (with some amendments), followed by the Parliament on March 15th, of the same year. The CCCTB, and its associated super deduction on R&D, was then submitted to the Council of the European Union for validation. On May 18th 2021, while the CCCTB was still waiting for validation, the EC adopted a new communication on business taxation in which it proposes a new framework dubbed BEFIT. The BEFIT framework, currently under discussion, is destined to replace and extend the 2016 CCCTB proposal. At such, it is likely to incorporate a (possibly updated) super-deduction on R&D.

Whatever the outcome of this long legislative process, the implementation of the super-deduction would not make a clean slate - at least in the short run - of all the R&DTCs that currently exist within EU Member States. This specific EU context therefore makes our projected empirical analysis on EU Member States, with harmonized industry-level data, particularly relevant. Before detailing the precise aims, scope and methodology of our empirical analysis, though, we need to further sketch and illustrate the sheer variety of R&D tax incentives that exist throughout Europe - variety to which we have only hinted at in the present section.

III The complexity of R&DTCs illustrated for selected EU Member States

We now turn to the examination of R&DTC schemes in eight EU Member States: Austria, Belgium, Czech Republic, France, Italy, The Netherlands, Spain and the United Kingdom. This selection was partly imposed by data constraints[9] (see Section IV) but nevertheless gives a fair representation of the EU, as it includes: (1) four members of the Inner Six (Belgium, France, Italy and the Netherlands), i.e. the founding members of the European Economic Community (EEC) in 1957, (2) two western European States that joined the European Community (EC, successor to the EEC) in the 1970s (the United Kingdom, UK) and 1980s (Spain), (3) a western European State that joined the EU (successor to the EC) in the 1990s (Austria) and (4) a former Communist State of Eastern Europe that joined the EU in 2004 (Czech Republic). The situation of the UK is unique among these countries: the UK was an EU Member State over the observation period (late 1970's to late 2010's) but has officially left the EU in January 2021, at the end of the 4-year process known as Brexit. The possible implications of Brexit for the R&DTC-innovation-productivity relationship are discussed in Appendix A.

In the present section, we highlight how the R&DTC schemes that exist in these countries may differ along multiples dimensions. We do not detail the specifics of each scheme, which would be beyond the scope of our study,[10] but focus instead on some key dimensions that we illustrate with

---

[9] These countries are those for which we were able to gather complete industry-level panel datasets, spanning a time period that goes from the mid-1970s/early 1980s to the late 2010s, and containing information on R&D, innovation and productivity.

[10] For exhaustive comparisons, see Straathof et al. (2014), Deloitte (2014), Ernst&Young (2014). OECD (2010) also pro-

some aspects of the above-mentioned schemes.

III.1 R&D expenditures

FIGURE 1 ABOUT HERE

Before comparing R&DTCs per se, it is useful to have a look at the state of investment in R&D in the EU. Figure 1 displays gross R&D expenditures as a percentage of GDP for each of our selected countries over the period 1981-2019. For the sake of comparison, Figure 1 also displays, as a benchmark, R&D expenditures in Germany (the only EU country that reached the 3% of GDP objective at the national level without implementing any R&DTC over the period) as well as the OECD average and the EU 27 average (the latter being available only from 1995 onwards). A first striking feature is that, across the whole period, R&D expenditures in Germany remain consistently above both the OECD average and the EU 27 average. They are also higher than in any of our selected countries for most of the period, being caught up by the Austrian ones from 2012 onwards. By 2017, both countries had reached the afore-mentioned “3% of GDP" objective, and even gone beyond this symbolic threshold, which was approached (but not attained) by Belgium in 2019. At that date, the remaining countries were all neatly below, and the EU27 average had only reached 2% of GDP. This may explain why Germany never felt the need to introduce an R&DTC. The question of whether Austria (and, to a lesser extent, Belgium) would have caught up with Germany in the absence of tax credit remains open, though. At the other end of the spectrum, R&D expenditures have remained consistently low (below 1.5% of GDP) throughout the period in Italy and Spain, both countries being far below the OECD average and the EU 27 average. Interestingly, Czech Republic (which is observed from 1995 onwards) started with a level of R&D expenditures akin to that of Italy and Spain, but managed to get close to the EU 27 average by the end of the period.

In the remaining countries, R&D expenditures more or less follow the OECD slowly ascending trend, while remaining below the OECD average throughout. Overall, they oscillate between the EU 27 average (which reached 2% of GDP in 2019) and the OECD average (which is higher than the EU average and around 2.5% of GDP in 2019). Among these countries, France is the one where R&D expenditures are the highest, going above the OECD average in the 1990s and remaining close in the 2000’s and 2010’s. Overall, Figure 1 suggests that our selected countries all have an interest (in the light of the Lisbon Agenda and subsequent Europe 2020 and Horizon Europe objectives) in raising their R&D expenditures. This may explain the reliance on R&DTCs as policy instruments to achieve this objective. Nevertheless, while all these countries have implemented R&DTC schemes, these differ widely in their timeline, tax rate and tax base. We will now provide a broad picture of these divergences, relying on factual information gathered by crossing the references mentioned in

---

vides, for the year 2009, a useful comparative table that encompasses our selected countries.

Footnote 10 : Deloitte (2014), Ernst&Young (2014), OECD (2010) and, last but not least, Straathof et al. (2014).

III.2 Differences in R&DTC schemes

Regarding **timeline**, France was first, among the selected countries, in introducing an R&DTC.[11] This was done in 1983. The credit was incremental, based on the yearly variation (increase) in R&D expenditures, and remained so until 1998, with various changes in rates and ceiling across the period, as well as a brief attempt at a co-existing volume-based tax credit from 1987 to 1990. In 1999, the R&DTC was renewed for a final period of five years, and it was made permanent in 2004, with a volume-based component introduced in parallel to the main incremental component. A major reform made the R&DTC completely volume-based in 2008. Compared to France, the remaining countries are latecomers: Spain introduced its first “real" R&DTC in 1995, Belgium and the Netherlands introduced theirs in 1998, Italy and the UK did so in 2000 and Czech Republic in 2005. Perhaps for this reason, these countries experimented less with their R&DTCs, and did not go through several phases with radical changes in their tax credit schemes. That said, in Italy, the R&DTC was introduced regionally at first, with a tax rebate varying across regions, and only became a harmonized national scheme in 2006. Last but not least, the case of Austria is rather specific, as an R&DTC co-existed with an “R&D tax allowance" (focusing on the outcome of R&D activities) from 1988 to 2010. In order to make the Austrian tax scheme simpler and more consistent, the tax allowance was suppressed in 2010, effectively leaving the tax credit as the sole instrument.

As mentioned earlier, eligibility conditions for an R&DTC may vary widely across countries, which results in tax bases (or, in the case of tax credit, the base for a tax rebate) varying along multiple dimensions. First, tax credits can be **incremental** (i.e., based on the yearly variation in R&D expenditures) or **volume-based** (i.e., based on the yearly volume of R&D expenditures, possibly with respect to a year of reference). The latter form of tax credit makes it easier for firms to obtain tax rebates, but whether it gives them a strong incentive to increase R&D expenditures remains doubtful. Nonetheless, R&DTCs are currently volume-based (or primarily volume-based) in all selected countries except in Italy, where an incremental tax credit prevails. The French R&DTC that existed between 1983 and 1999 was also primarily incremental[12] (it coexisted with a volume-based tax credit between 1987 and 1990). In the Czech Republic, a small incremental component may be added to the main R&DTC, which is volume-based. Overall, the current prevalence of volume-based tax credits would likely facilitate a possible harmonization, and indeed the super-deduction conceived in the 2016 CCCTB proposal is volume-based.

---

[11] Giraud et al. (2014) present a detailed timeline of the French R&DTC in their report to the French Ministry of Higher Education and Research.

[12] For instance, from 1985 onwards, the tax rebate was equal to 50% of the variation of a firm’s R&D expenditures between year t and $t-1$.

The tax base can also vary with **firm size** and with the **industry** in which a firm operates. Thus, the rate of the R&DTC in Italy during 2000-2014 was of 20 to 30% for SMEs (depending on regions), versus 15 to 25% for medium-sized firms and 10 to 20% for large ones. In the UK,[13] the R&DTC introduced in 2000 was originally available to SMEs only and a different regime for larger companies was introduced in parallel in 2002. The former could deduce 50% of their R&D personnel expenses from their taxable profit, whereas the latter could deduce 25%. In 2008, these amounts could be as high as 75% of R&D personnel expenses for SMEs and 30% for large firms. In the Netherlands, the amount of the 1998 tax credit was of 40% of "knowledge workers" wages in SMEs versus 17% in large firms. In 2004, it was raised to 42% for SMEs and reduced to 14% for large firms.

By contrast, in France, the current R&DTC does not formally distinguish between SMEs and large firms,[14] but the amount of the tax credit varies with respect to the investment in R&D. It is equal to 30% for investments lower than EUR 100 million and 5% for investments above this threshold. In effect, since SMEs typically invest lower amounts in R&D, they will benefit from the higher tax credit - but this scheme also let large firms benefit from the same rate (provided their investment remains below the threshold), which is not the case in the UK or in the Netherlands. Not only may this feature of the French tax credit give large firms an incentive to under-invest, it may also make harmonization more difficult.

R&DTC regimes may also be industry-specific, either targeting certain industries or excluding some industries. For instance, prior to 1992, agricultural and textile firms could not benefit from the French R&DTC. In the UK, since 2008, pharmaceutical firms doing vaccine research can deduce about 40 to 50% of their R&D personnel expenses from their taxable profit. This is, in effect, a specific regime, distinct from both the SME regime and the large company regime. In the super-deduction proposed with the 2016 CCCTB (and presumably with its successor), a specific regime for newly-created small firms would apply, as stated in Footnote 7.

Another dimension in which tax bases vary is the existence of a ceiling to the R&DTC. Most countries impose a ceiling, and among our selection all have, at some stage, imposed one, except for Czech Republic. In France, the tax credit introduced in 1983 had a ceiling of FF 3 million (approximately 900000 EUR[15]), which was raised up to 5 million (about EUR 1.3 million) in 1985 and 10 million (about EUR 2.5 million) in 1987. A ceiling still existed in the early 2000's, but was finally suppressed in 2008, probably because it kept on rising (from EUR 8 million in 2004 to EUR 10 million in 2006 and EUR 16 million in 2007). The super-deduction included in the 2016 CCCTB proposal does not impose a ceiling: R&D expenditures are fully deductible from the consolidated corporate tax. A threshold of

---

[13] See for instance https://forrestbrown.co.uk/rd-tax-credits-explained/ for a business-oriented presentation of the British R&DTC scheme

[14] In the sense that the applied rates and threshold are the same for SMEs and large firms. The main difference is that refund is immediate for SMEs, whereas it occurs after 3 years for large firms.

[15] We did all conversions of French francs to euros using the online tool of the French National Statistical Institute (INSEE) which takes long-term inflation into account.

EUR 20 million exists, however, for additional deductions: an additional 50% deduction is available under the threshold, whereas the additional deduction is of “only" 25% beyond the threshold.

Last but not least, the contents of R&D expenditures that entitle firms to a tax rebate vary hugely across countries. In the Netherlands, the expense base for the R&DTC is restricted to R&D wages (and social contributions). In Belgium, it primarily consisted in R&D wages as well, but has been extended to include capital assets. Investments in R&D are eligible to the tax credit provided they have no harmful effect on the environment (a condition which does not exist in the other four countries). In the remainder of our selected countries, the expense base includes all R&D expenditures (reported as such in a firm's accounts). Of all these countries, France may be the one where the definition of R&D expenditures is the broadest. For instance, they include external R&D conducted in any European Economic Area (EEA) country. The expense base may also include items that are beyond the actual expenses. Thus, 200% of the wages (and overheads) of young Ph.D. graduates are tax deductible, provided that the graduates are hired on a long-term contract. In the 2016 CCCTB proposal, the super-deduction is supposed to bear on all R&D costs incurred in a given year, with the exception of immovable property.

IV Empirical analysis

There exists a large literature on the evaluation of R&DTCs, the bulk of which uses micro-data to estimate the effect of specific tax credit schemes on R&D expenditures within countries. These studies rely primarily on structural approaches in IV settings and more rarely on quasi-experimental methods like differences-in-differences (DID). A detailed review of this literature would go far beyond the scope of the present paper. The interested reader will find a very thorough one in the 122 pages-long report on R&D tax incentives addressed by Straathof et al. (2014) to the EC and a less systematic but more recent one in Bloom et al. (2019). When we discuss our results in Section V, we will naturally refer for comparison to the relevant key references mentioned in these reviews.

Our study finds its own place in this already abundant literature, as we exploit a panel of 11 industries observed for 20 to 35 years across our 8 selected EU countries to address two challenges highlighted in the above-mentioned reviews. The first is the dearth of cross-country comparisons on the effectiveness of R&D tax incentives. There are good reasons for this. On the one hand, harmonized innovation survey micro-data does not necessarily provide precise information on tax incentives, and cross-country comparisons that use this type of data ideally require an international team of researchers. These constraints explain why a comparative study like Czarnitzki and Lopes-Bento (2012) had to focus on a broad measure of public R&D subsidies (and not on tax incentives) and on an ad-hoc selection of countries (the Flanders region of Belgium, Germany, Luxembourg and South-Africa). On the other hand, macro-econometric studies like Bloom et al. (2002) generally rely on country-level data (a panel of 9 countries observed over 18 years, in the case of these authors), and can only estimate an averaged effect of R&DTCs across all countries.

Since our primary interest lies in comparing EU countries, we address this first challenge head-on. Industry-level panel data is particularly well suited to international comparisons, especially when the number of industries and/or years is large enough to allow for within-country estimations, as is the case with our panel, which we present in detail in Sub-Section IV.1.

The second challenge is that most studies focus on the impact of R&DTCs on R&D expenditures, and not on innovation, let alone productivity. Again, we are able to tackle this challenge head-on, because our panel provides us with a good proxy for innovation output (patenting intensity) and with a rigorously-constructed measure of productivity (an index of Total Factor Productivity growth).

An obvious shortcoming of industry-level data, compared for instance to firm-level data, is that it does not provide precise information on the specifics of a given tax credit scheme. However, we have collected precise information on the *timeline* of R&DTCs in each selected country, and we can use this information for econometric identification and statistical inference. Exploiting the rich time-series dimension of our panel, what we measure is thus the impact of doing R&D *when tax incentives are available*, compared to doing R&D in periods when such schemes are not available. This is similar in spirit to measuring the effect of a time-varying event from a certain date onwards in purely time-series data. Our methodology is detailed in Sub-Section IV.2. The above-mentioned shortcoming is, in our opinion, more than offset by what our panel allows us to do, i.e., capture the long-run dynamics of R&D, innovation and productivity across a relevant selection of EU countries, with and without R&D tax incentives, prior to a planned harmonization of these incentives.

IV.1 Data and variables

Our primary data source was the EU-KLEMS database (Stehrer et al., 2019), originally compiled by the Groningen Growth and Development Centre (GGDC) and currently run by the Vienna Institute for International Economic Studies (WIIW). The latest release covers the years 1995 to 2017,[16] while previous releases[17] allow researchers to cover a period ranging from the late 1970s to 1995. We completed this data with information from linked OECD and EUROSTAT databases. This data compilation yielded, for every country covered in this study, a panel of 11 industries, the time dimension of which can vary from one country to the other. Within a given country, some variables are available over a longer period of time than others. However, constructing appropriate panels for the econometric analysis imposes a consistent time window, so our econometric models are de facto estimated over strongly balanced panels. We explain this balancing further at the end of this sub-section.

Our key variables are R&D intensity, patenting intensity and Total Factor Productivity (TFP), which is sometimes called Multi-Factor Productivity (MFP) in the literature. We use two alternative

---

[16] 2019 release, available at https://euklems.eu/

[17] Previous releases are available at http://euklems.net

measures of R&D intensity, which correspond to the two definitions that are generally found in the literature: (1) the ratio of R&D capital stock[18] to the number of hours worked each year in each industry and (2) the ratio of R&D capital stock to the Value Added (VA) measured each year in each industry.

Patenting intensity is simply defined as the number of patents divided by the number of hours worked. The number of patents is the number of patent applications to the European Patent Office (EPO) by sector of economic activity (EUROSTAT, Sciences & Technology database). A concordance matrix between the International Patent Classification (IPC) and the NACE industry classification then allows patent applications to be distributed across industries for a given country (Schmoch et al., 2003). The division by hours worked yields a continuous aggregate indicator of innovation intensity. We use patenting intensity as a proxy for innovation broadly speaking. We are well aware that patents are not the only output of the innovation process, and that much innovation can occur without patenting. Our rationale for using patenting as a proxy for innovation is that we are conducting an industry-level (not a firm-level) analysis, and more innovative industries are likely to produce more patents on average. Thus, the intensity of patenting in an industry reflects the intensity of innovation, broadly defined, that occurs within this industry.

Finally, our measure of TFP is the TFP growth index computed at the industry level by the EU-KLEMS team on the basis of VA and expressed in base 100 for the year 2010. As explained earlier, we will measure the effect of R&DTCs by comparing periods without tax credits to periods that saw the implementation of an R&DTC. We therefore add to our main variables dummy variables that indicate whether an R&DTC is implemented in year t in the country to which industry i belongs.

Since our panels of industries all have a long time dimension, our variables of interest may display a behavior that is more typical of time series than of panel data. In particular, we need to check their stationarity, since non-stationary variables would lead to invalid econometric inference. To do so, we conduct unit root tests (adapted for panel data) on the natural logarithm of our raw variables, prior to the construction of the balanced panels. In the raw data, some variables are observed over a longer period of time than others, whereas the building of the estimation panels imposes a common time frame to all variables in a given country. In this context, it is generally wiser to perform unit root tests on the raw variables than after building the panels, because doing so lets the econometrician exploits the full time dimension of each variable to estimate the autoregressive models that yield the test statistic. We perform Im-Pesaran-Shin (IPS) tests (Im et al., 2003), the test statistic of which is built as the average of the usual Augmented Dickey-Fuller (ADF) test statistic computed for each time series in each xit variable (i.e., for each x_{1t}, x_{1t}, ..., x_{nt} in each x_{it} variable). We compute the ADF test statistics using Autoregressive Distributed Lags (ADL) models with drift and trend. We implement a version of the IPS test that allows the errors of the underlying ADL models to be serially correlated. The

---

[18] This ratio is provided by the EU-KLEMS linked database, derived from OECD ANBERD.

results of the IPS tests are displayed in Table 1. The tests shows that all our variables are stationary in all countries, except for the log-R&D intensities in the UK and, to a lesser extent, in Austria. We will address this non-stationarity issue by using the first-differenced variables[19] in our econometric modeling. This only requires minimal modifications in the modeling for these two countries because the baseline econometric models already include lagged variables, as will be seen in Sub-Section IV.2.

TABLE 1 ABOUT HERE

We further describe, in Appendix C, the construction and balancing of the panels that we will use for our econometric estimations. We first present the list of industries in Appendix C, Table A.1. We initially gathered information on 13 industries, namely 11 industries covering the whole of the manufacturing sector, plus the energy industry (E-D, "Electricity, Gas and Water Supply") and the construction industry (F, "Construction"). Unfortunately, the number of patents applications is not available in the latter two industries. Since the patenting intensity variable is required in our econometric analysis (see Sub-Section IV.2), this reduces the individual dimension of our panels to the remaining 11 manufacturing industries. In addition, to ensure a consistent time windows for our econometric models, we have to define the starting year of a given panel as the first year in which all relevant variables are observed. In some countries, this may be as early as the late 1970's/early 1980's, whereas in other the starting year is in the mid-1990's. Furthermore, at the time of this writing, the number of patents applications is not available in the source dataset after 2014, which means that all panels have to end in that specific year, even if some variables (such as VA or TFP) are observed up to 2017. Taken together, these constraints make for a strongly balanced panel of 11 manufacturing industries, observed over 20 years for Austria, Belgium and Czech Republic and over 35 years for the remaining countries. We summarize the structure of these balanced panels in Appendix C, Table A.2, which also contains information about the timeline of R&DTC's in each selected country. We can notice that, once an R&DTC has been triggered in a given country, it lasts until the end of our observation period.

Last but not least, Table A.3 in Appendix C provides summary statistics (averaged over industries and time) for our four key variables. This table displays a sharp contrast, in terms of innovation effort and output, between Belgium, France, Netherlands (all members of the Inner Six) and the UK on the one hand, and Austria, Italy, Spain and Czech Republic on the other. The former have both a high R&D intensity (with, e.g., an average R&D/VA ratio ranging from 0.30 to 0.50) and a high patenting intensity. While Austria is a close second to this group of innovative countries, Spain and Czech Republic are lagging behind (with an R&D/VA ratio barely above 0.10 and a low or very low patenting intensity). Although also a member of Inner Six, Italy occupies, as far as innovation is concerned, a sort of middle ground between Austria and the two laggards.

---

[19] The first-differenced variables are stationary. Their IPS test statistics are featured under Table 1.

The high patenting intensity in the most innovative countries conceals a certain heterogeneity, though, as evidenced by the high dispersion (the standard deviation of the variable is much larger than its average value). Thus, innovation output in these countries is likely to be driven by a few innovative industries, with little patenting among the remaining industries. Conversely, the very low patenting intensity in a country like Czech Republic retraces the catching-up process associated with its transition from a former Communist State to an independent democratic country in 1993 and a new EU Member State in 2004. It may not reflect the situation of all industries in the country in 2022.

In order to get a better grasp of the dynamics and heterogeneity of innovation within each of our selected countries, we also present our innovation variables (R&D intensities and patenting intensity) by industry for each selected country in Figures A.1 to A.3 in Appendix C. In all countries except Czech Republic, we observe an increasing trend in R&D intensity defined with respect to hours worked. At the end of the period, this measure of R&D intensity is the highest in Belgium, France, and the Netherlands closely followed by the UK. It is at its lowest in Czech Republic. Although the increasing trend concerns most industries, we notice that, in each selected country, a couple of industries are more R&D-intensive than the rest. These are primarily “Chemicals and Chemical products" and “Electric, Electronic and Optical Equipment", with some country-specific R&D champions like “Transport equipment" in France and Italy and “Coke, Petroleum and Nuclear fuel" in France, Spain and the UK.

Things are much more contrasted with the second measure of R&D intensity, defined with respect to VA. Although an increasing trend can still be observed in countries like Austria or France, a certain stagnation prevails in many other countries, like the Netherlands, sometimes accompanied by a decrease in certain industries, like in Czech Republic, Italy and the UK. In Belgium, overall stagnation is accompanied by an increasing trend in the “Electric, Electronic and Optical Equipment" industry. In Spain, R&D intensity slightly increases in some “traditional" industries but decreases in supposedly more innovative ones like the “Chemicals and Chemical products", “Electric, Electronic and Optical Equipment" and “Transport equipment" industries.

Rather reassuringly for the R&D-innovation relationship, we observe that patenting intensity follows the same increasing trend as our first measure of R&D intensity, although a slight decline may be observed in two UK industries (“Chemicals and Chemical products" and “Transport equipment"). At the end of the period, patenting intensity is at its highest in Belgium, the Netherlands and France, like R&D intensity was. We also notice that, in each country, the most R&D-intensive industries (such as the “Electric, Electronic and Optical Equipment" industry) are also the most patent-intensive ones, which, again, is reassuring for the R&D-innovation relationship that is at the heart of the Horizon Europe strategy.

IV.2 Methodology

IV.2.a IV regressions for countries with a single phase of R&DTC

The first analyses we conduct on our panel of industries consist in estimating, within each selected country, a structural econometric model that relates (log-)patenting intensity to past (log-)R&D intensity, and past (log-)R&D intensity to its own lag.[20] Assuming that the lag has a direct effect on R&D but not on patenting, the model can be specified as an IV model. Based on the literature initiated by Hall et al. (1986), this assumption is reasonable provided one controls for industry-specific and time-specific effects. We introduce R&D both as a single regressor and in interaction with indicators of the time period in which the R&DTC was implemented. Formally, using i and t as the respective indices of industry and year, this model[21] can be written as:

$$\begin{aligned}
\ln PI_{it} &= \beta_{11} \ln RD_{it-1} + \beta_{12} \ln RD_{it-1} \times TC_{t-1} + u_{i1} + v_{1t} + w_{1it} \\
\ln RD_{it-1} &= \beta_{21} \ln RD_{it-2} + \beta_{22} \ln RD_{it-2} \times TC_{t-2} + u_{2i} + v_{2t} + w_{2it} \\
\ln RD_{it-1} \times TC_{t-1} &= \beta_{31} \ln RD_{it-2} + \beta_{32} \ln RD_{it-2} \times TC_{t-2} + u_{3i} + v_{3t} + w_{3it}
\end{aligned} \tag{1}$$

where PI denotes patenting intensity, RD denotes R&D intensity and TC_t is a dummy variable equal to 1 if an R&DTC exists in year t and to 0 otherwise. This dummy variable, in interaction with the log-R&D intensity, captures the effect of doing R&D when an R&DTC is available. Each equation $j (j = 1, 2, 3)$ includes an industry fixed effect u_{ji}, a time fixed effect v_{jt} and a random error w_{jit}. Model (1) can be interpreted as an empirical representation of the so-called “innovation production function". As explained in Mairesse and Mohnen (2002), it provides both an econometric and an interpretative (or “accounting") framework that can be applied to various spatial units (firms, industries, countries) and makes sense at each level of analysis. As explained in the beginning of this section, we apply it at the industry level in eight European countries.

All these countries except France have known a single phase of R&DTC that was still ongoing at the end of the observation period. Therefore, estimating Model (1) in these countries is equivalent to splitting the sample into two periods (before the introduction of the R&DTC, and after its introduction) and estimating a simpler model, without interaction term, in each sub-sample. France never stopped relying on an R&DTC, from 1983 to the end of our observation period, but the R&DTC scheme went through several well-distinct phases (see Sub-Section III.2). To take this into account, we apply, in France, a different specification of our model, presented in Subsection IV.2.b.

---

[20] Since the introduction of the tax credit in these countries is comparatively recent, and since the sample size in some countries is comparatively small, we prefer keeping to one-year lags between patenting and R&D on the one hand and between current and past R&D on the other.

[21] Equation (1) is actually the benchmark specification of our model. We experimented with more elaborated specifications including additional regressors such as the export share of production (to control for innovation driven by international demand). Besides consuming precious degrees of freedom, these additional controls were overall insignificant and did not change the results of our benchmark specification.

Econometrically speaking, Model (1) is an IV model with two endogenous variables in the second-stage equation (the $\ln P_{iit}$, or patenting intensity, equation) and, therefore, two first-stage equations (the $\ln RD_{it-1}$ and $\ln RD_{it-1} xTC_{t-1}$, or R&D intensities, equations). We estimate Model (1) using fixed-effect two-stages least squares (FE-2SLS) with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors, using the ivreg2 and xtivreg2 software components developed by Baum et al. (2002) and Schaffer (2005).

In Model (1), some coefficients of specific interest are β_{11}, β_{12}, β_{31} and β_{32}. Coefficient β_{12} measures the effect on patenting intensity of past R&D conducted in the presence of a tax credit, while β_{11} measures the baseline effect of R&D on patenting intensity. The estimate of β_{11} + β_{12} provides a measure of the elasticity of patenting with respect to R&D intensity, with β_{12} measuring the contribution of R&D conducted during a phase of R&DTC to this elasticity. Given our "innovation production function" interpretative framework, we expect elasticity $\beta_{11} + \beta_{12}$ to be positive. The larger this elasticity, the higher the degree of "innovativeness" or "innovativity" in the country of interest (Mairesse and Mohnen, 2002, Mohnen et al., 2006).

Coefficient β_{32} measures the effect on current R&D intensity of past R&D conducted when an R&DTC is available while β_{31} measures the baseline effect on the same current R&D intensity of past R&D conducted in the absence of R&DTC. The estimate of β_{32} therefore provides a proxy measure of the share of current R&D expenditures that can be attributed to the R&DTC. This measure corresponds in our framework to what is known in the literature as *input additionality* or *bang for the buck* (BFTB). Comparing the estimate of β_{32} to the estimate of β_{31} will give some appreciation as regards the effectiveness of R&DTCs. Our econometric modeling makes our estimate of input additionality fall within what Straathof et al. (2014) call the "direct approach", because it does not rely on the intermediate economic decision variable known in the literature as the user cost of R&D.

After estimating Model (1), we try to push things further by estimating a variant of Crépon et al. (1998)'s structural model (generally referred to as CDM) of the R&D-innovation-productivity relationship. Again, just like the "accounting" framework proposed by Mairesse and Mohnen (2002), the CDM model makes sense at various levels of analysis. While most often applied to firm-level data, it has also been successfully applied to industry-level data (e.g., Bourlès et al. (2013); Amable et al. (2016)). In the present paper, our version of this model is specified as:

$$\begin{aligned}
\ln TFPG_{it} &= \alpha_1 \ln \widehat{PI}_{it-1} + v_i + \nu_t + \omega_{1it} \\
\ln PI_{it-1} &= \beta_{11} \ln RD_{it-2} + \beta_{12} \ln RD_{it-2} \times TC_{t-2} + u_{1i} + v_{1t} + w_{1it} \\
\ln RD_{it-2} &= \beta_{21} \ln RD_{it-3} + \beta_{22} \ln RD_{it-3} \times TC_{t-3} + u_{2i} + v_{2t} + w_{2it} \\
\ln RD_{it-2} \times TC_{t-2} &= \beta_{31} \ln RD_{it-3} + \beta_{32} \ln RD_{it-3} \times TC_{t-3} + u_{3i} + v_{3t} + w_{3it}
\end{aligned} \tag{2}$$

where $TFPG$ is the TFP growth index provided by EU-KLEMS and where the hat symbol on the lnP_{iit} variable in the first equation (i.e., the TFP equation) indicates that this variable is the predicted value from the previous equation (i.e. the patenting intensity equation). The TFP equation includes more implicit controls than meet the eye. In the EU-KLEMS data, TFP is calculated following a classic growth accounting approach, using a VA-based measure of aggregate output and controlling the capital and labour aggregate inputs.[22] This approach ensures that our measure of productivity growth is net of the effect of the usual capital, materials and labour inputs (the influence of materials being taken into account through the use of a VA-based measure of output).

Model (2) can be seen as an extension of Model (1) with a third stage dedicated to TFP, α_1 measuring the effect of innovation on TFP growth. If productivity growth is driven by innovation, as expected in the literature (which sometimes calls TFP "Solow's residual"), then one should expect α_1 to be positive. If innovation is indeed fed by R&D, as the "innovation production function" framework suggests, then R&D may have an indirect effect on growth, mediated by innovation. And if R&DTCs do spur R&D, then they in turn may have an effect on growth. Model (2) allows us to examine the empirical relevance of this supposed relationship. We estimate it by FE-2SLS with HAC standard errors, using the same procedure and software components as for Model (1). In addition, we bootstrap the standard errors in the productivity equation to account for predicted regressor bias.

IV.2.b "L'exception française"

France has experimented with different phases of R&DTC which set the country apart in our selection of EU member States. In all countries, there can be changes in R&DTC schemes, but these changes correspond to comparatively minor adjustments (typically, a change in the share of R&D expenditures that can be claimed back by R&D-doing firms). In France, the different phases correspond to deeper changes that can radically alter the design of the tax credit scheme. The French R&DTC was originally introduced in 1983 as an experiment. It was an incremental scheme (see Sub-Section III.2) set for a fixed period of time (five years), at the end of which its relevance was examined, and the decision to proceed or not with the scheme was taken. This lasted from 1983 to 1998, and the 1999-2003 period was the final five-year renewal period of the original R&DTC. In 2004, a new R&DTC scheme was introduced, on a permanent basis. This new scheme remained primarily incremental (as the original scheme had been), but now comprised a volume-based component. Finally, a major reform made the R&DTC completely volume-based in 2008.

To account for this relatively tumultuous history, we have to distinguish at least four periods of implementation in our empirical analysis. These periods correspond to major changes in the tax credit scheme: (i) 1983-1998 is the period of the original incremental tax credit; (ii) 1999-2003 is its final five-year renewal period, with uncertainty regarding the existence of a tax credit in the future; (iii) 2004-2007 is the period in which the tax credit, now primarily incremental with a volume-based component, was made permanent; (iv) 2008 to 2017 (final year in the 2019 EU-KLEMS database) is

---

[22] See https://euklems.eu/ and, e.g., Adarov and Stehrer (2019), for details of the calculation.

the period in which the tax credit has become wholly volume-based. This leads us to adapt Model (1) as follows:

$$\begin{aligned}
\ln PI_{it} &= \beta_{11}\ln RD_{it-3} + \beta_{12}\ln RD_{it-3}\times TC1_{t-3} + \beta_{13}\ln RD_{it-3}\times TC2_{t-3} \\
&\quad +\beta_{14}\ln RD_{it-3}\times TC3_{t-3} + \beta_{15}\ln RD_{it-3}\times TC4_{t-3} + u_{i1} + v_{1t} + w_{1it} \\
\ln RD_{it-3} &= \beta_{21}\ln RD_{it-4} + u_{2i} + v_{2t} + w_{2it} \qquad (3) \\
\ln RD_{it-3}\times TC1_{t-3} &= \beta_{31}\ln RD_{it-4}\times TC_{t-4} + u_{3i} + v_{3t} + w_{3it} \\
\ln RD_{it-3}\times TC2_{t-3} &= \beta_{41}\ln RD_{it-4}\times TC2_{t-4} + \beta_{42}\ln RD_{it-4}\times TC1_{t-4} + u_{3i} + v_{3t} + w_{3it} \\
\ln RD_{it-3}\times TC3_{t-3} &= \beta_{51}\ln RD_{it-4}\times TC3_{t-4} + \beta_{52}\ln RD_{it-4}\times TC2_{t-4} + u_{3i} + v_{3t} + w_{3it} \\
\ln RD_{it-3}\times TC4_{t-3} &= \beta_{61}\ln RD_{it-4}\times TC4_{t-4} + \beta_{62}\ln RD_{it-4}\times TC3_{t-4} + u_{3i} + v_{3t} + w_{3it}
\end{aligned}$$

where $TC_{jt} = 1$ if France was in phase j of its R&DTC at time t, and $TC_{jt} = 0$ otherwise (the period of reference is 1980-1982, when no R&DTC existed). The other variables and parameters are defined as in Model (1).

Although both are empirical representations of the "innovation production function", Model (3) and Model (1) present some noticeable differences. First, due to the comparatively longer history of R&DTC in France, we are able to experiment with longer lags in the patenting equation. Doing so is relevant because later contributions in the vein of Hall et al. (1986) (such as van Ophem et al. (2002) and Gurmu and Pérez-Sebastian (2008)) have found stronger lagged effects in some countries in the more recent period. Based on this literature, we assume a 3-year lag between patenting intensity and our various measures of R&D intensity. As a sensitivity analysis, and to increase comparability with Model (1), we also experimented with one-year lags in Model (3). Doing this did not qualitatively affect our results - it simply made some estimated parameters slightly less significant. The output of this sensitivity analysis is presented in Table A.4 in Appendix C. In Model (3), in order to capture the dynamics of knowledge accumulation and the possible effect of transitions from one phase of R&DTC to the next, each interacted R&D intensity variable is instrumented with its own lag plus the lag of the interacted variable that corresponds to the previous phase of R&DTC. Baseline R&D is instrumented with its own lag only.[23]

While Model (3) is technically an IV model, its specification is less straightforward than that of Model (1), which is closer to textbook standard. The software components on which we relied in Sub-Section IV.2.a to estimate Model (1) do not accommodate the estimation of as convoluted a model as Model (3). We therefore estimate Model (3) by 2-Stages Least Squares with industry-level fixed effects (FE-2SLS) using the reg3 Stata command instead. Since this command does not offer heteroskedasticity- and autocorrelation-consistent formulas for the standard errors of the estimated

---

[23] Because of the succession of four distinct phases of R&DTC, instrumenting the baseline R&D intensity with the interacted R&D intensities makes less sense here than in Model (1). When we did so as a sensitivity analysis, we found that these other “instruments" were actually non significant and thus useless for statistical inference.

parameters, we perform post-estimation tests for heteroskedasticity and for the autocorrelation of the random errors. We correct the standard errors of the estimates whenever necessary. As was already the case in the other selected countries, the model can readily be extended to a CDM-type model by adding a productivity equation:

$$
\begin{aligned}
\ln TFPG_{it} &= \alpha_1 \ln PI_{it-1} + v_i + \nu_t + \omega_{it} \\
\ln PI_{it-1} &= \beta_{11} \ln RD_{it-4} + \beta_{12} \ln RD_{it-4} \times TC1_{t-4} + \beta_{13} \ln RD_{it-4} \times TC2_{t-4} \\
&\quad + \beta_{14} \ln RD_{it-4} \times TC3_{t-4} + \beta_{15} \ln RD_{it-4} \times TC4_{t-4} + u_{i1} + v_{1t} + w_{1it} \\
\ln RD_{it-4} &= \beta_{21} \ln RD_{it-5} + u_{2i} + v_{2t} + w_{2it} \\
\ln RD_{it-4} \times TC1_{t-4} &= \beta_{31} \ln RD_{it-5} \times TC1_{t-5} + u_{3i} + v_{3t} + w_{3it} \qquad (4) \\
\ln RD_{it-4} \times TC2_{t-4} &= \beta_{41} \ln RD_{it-5} \times TC2_{t-5} + \beta_{42} \ln RD_{it-5} \times TC1_{t-5} + u_{3i} + v_{3t} + w_{3it} \\
\ln RD_{it-4} \times TC3_{t-4} &= \beta_{51} \ln RD_{it-5} \times TC3_{t-5} + \beta_{52} \ln RD_{it-5} \times TC2_{t-5} + u_{3i} + v_{3t} + w_{3it} \\
\ln RD_{it-4} \times TC4_{t-4} &= \beta_{61} \ln RD_{it-5} \times TC4_{t-5} + \beta_{62} \ln RD_{it-5} \times TC3_{t-5} + u_{3i} + v_{3t} + w_{3it}
\end{aligned}
$$

As we did with Model (3), we estimate Model (4) by FE-2SLS and perform post-estimation tests for heteroskedasticity and for the autocorrelation of the random errors. We do not need to bootstrap the standard errors in the productivity stage equation because the standard deviation formulas in the reg3 command already account for possible predicted regressor biases. Again, as a sensitivity analysis, we estimated an alternative specification of Model (4) with one-year lags. This alternative specification is identical, in its R&D and patenting stages, to the one presented in Table A.4 in Appendix C, with the added productivity stage being presented in Column (1) of Table A.6 (also in Appendix C). Again, the estimates of this added stage are quite similar, qualitatively, with those that we obtain in the original model and comment on in the next section.

V Findings and discussion

V.1 Countries with a single phase of R&DTC

We display in Table 2 the results we obtained for the seven selected countries with a single phase of R&DTC. The left-hand side panel of Table 2 features the results obtained when R&D intensity is defined with respect to employment (number of hours worked), while the right-hand side panel features those obtained when R&D intensity is defined with respect to VA. The first striking result is that, no matter what measure we use, past R&D feeds current R&D in all countries except Austria.[24] More specifically, baseline R&D correlates with its lag (Table 2, upper section) and the interacted term indicating R&D conducted during a phase of tax credit correlates with its own (Table 2, mid-section).

---

[24] This exception is likely due to the fact that in Austria (1) the R&D variables are used in first-difference to ensure stationarity and (2) the period of observation is comparatively small.

The latter result confirms that doing R&D when an R&DTC is available is conducive to more R&D. The associated coefficient, β_{32}, can be interpreted as a proxy measure of input additionality or BFTB (see Sub-Section IV.2.a). A glance at the middle section of Table 2 reveals that this coefficient is close to 1 in all countries except Belgium, where it is closer to 0.75.[25]

A BFTB close to 1 in a given country means that the R&D intensity accumulated in a year when an R&DTC is available leads to an equivalent level of R&D intensity the next year. This macro finding is consistent with the micro empirical literature, where a BFTB close to 1 means that firms spend on R&D every euro they save on taxes. For instance, in Italy, Caiumi (2011) finds, using firm-level data, that a tax cut of EUR 1 leads to an additional investment in R&D of EUR 0.86. In the Netherlands, Lokshin and Mohnen (2012), using simulations on firm-level data, find an estimate of input additionality roughly equal to 1 in the short run (i.e., in the first four years of the tax credit), which goes down to 0.5 in the long run (i.e., after fifteen years). In Belgium, Dumont (2012), using a panel of firms, finds estimates equal to 0.79 for an R&DTC targeting young innovative companies and to 0.82 for an R&DTC granted to firms that hire R&D personnel with a Master's degree. Overall, it seems that results obtained using firm-level data are persistent at our more aggregated industry-level of analysis (which makes sense since all the econometric analyses at hand aim at estimating *average* effects). While there is a large empirical consensus on the value of 1, Antonelli (2020) questions the policy relevance of this value and brings forwards theoretical arguments in favor of targeting R&DTC towards firms or industries where additionality is *larger* than 1. We will come back to this when we discuss the policy implications of our findings in Sub-Section V.3.

TABLE 2 ABOUT HERE

The relationship between innovation (as measured by patenting intensity) and R&D is much more difficult to identify than the dynamics of R&D described in the above paragraphs. In the lower section of Table 2 (dedicated to the patenting equation), Belgium, the Czech Republic and Spain are the only countries where we observe a positive association between innovation and R&D. In Belgium and Spain, this association holds for both measures of R&D intensity, whereas in the Czech Republic it is only valid with the first measure (R&D stock per hours worked) and only holds for baseline R&D intensity. In Belgium and Spain, the estimated elasticity of patenting to R&D conducted when an R&DTC is available is equal to about 0.20 overall, no matter which definition of R&D intensity we retain. In Spain, this elasticity comes in addition to an estimated elasticity of patenting to baseline R&D of about 0.30 to 0.40 (depending on which definition of R&D intensity is used). In Belgium, it stands alone-which could be due to the existence, for a number of years, of patent boxes in parallel to the R&DTC. By contrast, the Spanish result could be driven by the generosity of the tax credit (one of the most generous in Europe, according to Straathof et al. (2014)).

---

[25] In Belgium, when R&D intensity is defined with respect to hours worked, a small effect of baseline R&D (estimated at 0.17) can be added to the 0.75 estimate to reach a value of 0.92, similar to what is observed elsewhere.

This second finding is somewhat less optimistic than those reviewed in Straathof et al. (2014), who consider that “[o]verall, studies on the effectiveness of R&D tax incentives tend to find a positive impact on innovation." (p.38). Indeed, Ernst and Spengel (2011) find that R&D tax incentives have a positive effect on patenting in Europe. However, this study does not use cross-country comparisons per se, but relies on a database pooling patents applied for at the EPO, from various European countries. Similarly, Westmore (2013), using a panel of OECD countries (with the country as the relevant unit of analysis) finds that R&D incentives are positively associated with patenting at the OECD level. But, again, the nature of the data is such that the author can only derive a global estimate and cannot conduct cross-country comparisons. Compared to these studies, the relationship between innovation and R&D is likely to be more tenuous and difficult to identify at the industry level, especially after controlling for unobserved heterogeneity with fixed effects and accounting for endogeneity, heteroskedasticity and autocorrelation of the error terms as we do here. Unobserved heterogeneity, in particular, may explain an important part of our results, as the industry fixed effect is extremely significant (at a level lower than 1%) in the patenting equation in all countries and with both measures of R&D intensity. Industries that are noticeably more innovative than the rest in Figure A.3 tend to display a "patenting premium". This is especially the case of the "Electrical, electronic and optical equipment" industry, where the estimated individual component to the fixed effect is always significantly positive at the 1% level.[26] This suggests that the specificity and high-tech character of this industry is a primary driver of patenting, before the economic context and the availability or non-availability of a tax credit.

TABLE 3 ABOUT HERE

As can be seen in Table 3, the results pertaining to TFP are even more tenuous. We find that patenting intensity is associated with a higher TFP growth in three countries only: Italy, the UK and, to a lesser extent, the Netherlands. These countries are not those where we observed a relationship between patenting and the R&D conducted under an R&DTC. The supposedly virtuous circle leading from R&D to growth through innovation is thus even more difficult to identify at our level of analysis than the relationship between R&D and innovation.

V.2 Effects of the French R&DTCs

We now turn to the estimates of Model (3), dedicated to France, which we present in Table 4. A first striking feature, observable with both measures of R&D intensity, is that, as we already observed in the other countries of our selection, past R&D feeds current R&D. Past baseline R&D investments are associated with higher investments in baseline R&D and past R&D conducted during a phase

---

[26] For the sake of concision, these estimates are not displayed in Table 2 but remain available upon request from the authors.

of R&DTC is associated with more R&D in that phase (and/or in the next one). Thus the different phases of R&DTC in France seem to have contributed to the dynamics of R&D investment.

TABLE 4 ABOUT HERE

Whatever the measure of R&D intensity we consider, our proxy measure of input additionality[27] is close to 1 in the first three phases of the French R&DTC (which goes hand in hand with what we observed in the other countries of our selection) and slightly above one in the fourth and final one, when the tax credit became volume-based.[28] When R&D intensity is defined with respect to hours worked, our estimates are equal to 0.87 in the first phase, $(0.80 + 0.06 =)0.86$ in the second phase, $(0.20 + 0.75 =)0.95$ in the third phase and $(0.24 + 1 =)1.24$ in the final phase. When R&D intensity is defined with respect to VA, these estimates become 0.87, $(0.79 + 0.05 =)$ 0.84, $(0.75 + 0.20 =)0.95$ and $(0.99 + 0.24 =)1.23$ respectively, which is overall very close. The interpretation of these figures is the same as in Sub-Section V.1: when input additionality is close to 1, the R&D intensity accumulated in a year when an R&DTC is available leads to an equivalent level of R&D intensity the next year. When input additionality is larger than 1, i.e. around 1.23 or 1.24, the R&D intensity accumulated in a year when an R&DTC is available leads to a level of R&D intensity that is 23% to 24% higher the next year.

Finding an estimate of input additionality close to 1 in the first three phases of the French R&DTC is consistent with the micro-econometric literature on the French tax credit. Duguet (2012), using Propensity Score Matching on firm-level data, finds an estimate of input additionality equal to 1 prior to 2003, an observation period which corresponds to our first two phases. Over 2000-2007, which roughly corresponds to our second and third phases, Mulkay and Mairesse (2013), using a more structural approach, find an input additionality[29] of about 0.7. Relying on simulations to assess long-run additionality after the 2008 reform which made the tax credit fully volume-based, they conclude that additionality should gradually rise above 1 in the five years following the reform, and then slowly decrease to 0.7 by 2020.

Our estimate of 1.23 or 1.24 in the fourth phase is in line with these previsions, although we cannot observe the expected long-run decline. It is also, among all our results, the only estimate that is in line with Antonelli (2020)'s recommendation of targeting R&DTC towards firms or industries where additionality is larger than 1. We will not claim, though, that the post-2007, volume-based French R&DTC is the only one that can be justified from a policy standpoint. This would be presumptuous, if not preposterous, all the more since our proxy measure of additionality does not exactly correspond to the measure proposed in Antonelli (2020). We come back to this point in the next sub-section.

---

[27] As in model (1), input additionality or BFTB is measured here by the coefficient (or sum of coefficients) associated with the lag(s) of the $R\&D \times TC$ interaction term(s) in the R&D equations.

[28] This is probably not a coincidence, as we will discuss in the next paragraph.

[29] Formally defined, in their model, as the elasticity of R&D capital with respect to its user cost, it is equal, using their preferred estimates, to $1 - 0.08/0.24 \sim 0.67$.

Our second important result concerns the patenting equation, which allows us to identify a significant relationship between patenting intensity and R&D intensity. Among the other selected countries, we observed such a relationship only in Czech Republic, Belgium, Spain and the UK. It was an overall tenuous relationship, except in Spain where it was well identified. In France, the R&D-to-patents relationship is strongly identified with both measures of R&D intensity and concerns baseline R&D as well as R&D conducted during an R&DTC phase. A 1% increase in baseline R&D intensity entails a 0.25% to 0.7% increase in patenting intensity, depending on whether R&D intensity is defined with respect to VA or to hours worked. With the latter (former) definition, R&D performed under the third and fourth (second, third and fourth) phases of the tax credit leads to an additional 0.15% (0.36%) increase in patenting over 2004-2017 (1999-2017), which corresponds to an additional 0.005% (0.01%) per year.

Overall, the R&D-to-patents relationship identified in France is quite similar to the one observed in Spain. The reasons for which these two countries are the only ones in our selection where we observe such a strong and clear-cut relationship may have to do with the characteristics of the tax credit schemes that prevail in these countries. Indeed, in both countries, the R&DTC scheme is long-running and comparatively generous (according to Straathof et al. (2014), the Spanish and French schemes are among the three most generous in all OECD countries).

TABLE 5 ABOUT HERE

Finally, when we add a productivity equation to our econometric model, extending it to a CDM-type framework, we find that patenting intensity may have a positive effect on TFP, depending on which measure of R&D intensity we use in the model. As can be seen in Table 5, a 1% increase in patenting intensity entails a 0.44% increase in the TFP growth index when R&D intensity is defined with respect to VA, but has no effect on TFP when R&D intensity is defined with respect to hours worked. Since a 1% increase in R&D performed under the second, third or fourth phase of the French R&DTC scheme entails a 0.37% (cumulated) increase in patenting intensity over 1999-2017, this same 1% entails a $(0.36x0.44 \sim)0.16$ increase in TFP, through the effect of patenting. Despite the caveat that it is valid only with our second measure of R&D intensity, this result makes France the only country in our selection where the R&D-innovation-productivity relationship is not only fully identified, but also strengthened by an R&DTC scheme. This finding is robust to the use of shorter lags in the model, as can be seen in Table A.4 and in Column (1) of Table A.6 in Appendix C. It is also in line with recent macroeconomic findings. Le Gall et al. (2021) assess the lagged impact of 2008 reform of the French R&DTC (which made it volume-based, as explained in Sub-Section IV.2.b) on the French economy. Relying on simulations, they predict that the reform is likely to increase French GDP by 0.02 to 0.05 percentage points by 2023. All in all, empirical researchers looking for trickle down effects of R&DTC on patents and productivity could therefore make their own Val Waxman's punchline in *Hollywood Ending*: "Thank God the French exist."

We nevertheless wanted to submit this optimistic conclusion to an extreme robustness check of sorts. To do so, we estimated alternative specifications of Model (3) and Model (4) in which we simply treated the four well-distinct phases of the French R&DTC as a single long phase of R&DTC beginning in 1983. To make the robustness test even more stringent, we restrained all lagged variables to one-year lags. This alternative specification is neither credible nor realistic from a policy perspective because (1) one compares an extremely long R&DTC period (1983-2014) to a ridiculously small non-R&DTC period (1980 to 1982) and (2) within the long R&DTC period, one treats four very different policy instruments as a single unified policy. We only implement this specification to check whether going to such extremes actually "kills" the effect of R&DTC on patenting and productivity growth.

The findings, presented in Appendix C, in Table A.5 (for the innovation production function) and in Column (2) of Table A.6 (for the productivity equation), are interesting. The effect of patenting on productivity disappears, which was to be expected in such an extreme specification. The effect of R&D on patenting, though, does not disappear completely. When R&D intensity is measured as the ratio of R&D expenditures to hours worked, we find a strongly significant positive effect of R&D intensity on patenting intensity. The interacted term (indicating that R&D is performed when a tax credit is available) is not significant per se, but this is most certainly due to the fact that, in that extreme specification, R&DTC are available almost all the time (from 1983 to 2014, i.e. 32 years out of 35 years). Our robustness check thus suggests that in France, the relationship between R&DTC, R&D, patenting and productivity is extremely strong, since it does not totally disappear even in an econometric specification that was specifically designed to annihilate it.

V.3 Policy implications

To sum up our findings, we can safely conclude that, in spite of their differences, the various national R&DTC schemes that exist throughout the EU all seem to spur further investment in R&D. Their effect on innovation output is more tenuous, though, and it is extremely difficult to identify any effect on productivity at all (even in France, the identification of the latter effect depends on how R&D intensity is defined).

Regarding the effect on R&D, we observe that input additionality (or BFTB) is always close to 1, which means that the level of R&D intensity observed under an R&DTC - in addition to baseline R&D intensity - in any given year is conducive to the equivalent level the next year. This effectiveness of R&DTC in pushing an industry towards more investment in R&D is probably associated to the fact that all the R&DTC schemes we have considered are volume-based, which makes the tax deduction easier to claim and more generous than in an incremental scheme. France is a case in point: there, we observe that switching to a fully volume-based scheme after 2008 boosts the BFTB from about

1 to roughly 1.20. Overall, this result is good news for the aforementioned EU objective of having an amount of R&D expenditures equivalent to 3% of GDP. In addition, since the "super deduction" associated with the BEFIT proposal is a very generous volume-based scheme, it is likely to work towards the 3% objective as well.

It is also interesting to examine this result in the light of Antonelli (2020)'s policy prescriptions. This author provides theoretical arguments that justify the targeting of R&DTC towards firms or industries where additionality is larger than 1. His proposed measure of additionality, though, is more sophisticated than the direct estimate of our proxy measure: it is defined as the ratio of the flow of new R&D activities carried out by recipients of public funding to the size of this funding itself.[30] While conceptually attractive, this measure of additionality is difficult to implement empirically, especially with aggregated data such as ours. One needs a measure of new R&D activities (which are not easily disentangled from R&D expenditures as a whole) and a measure of the amount of the funding. Applying our own estimates of BFTB to OECD country-level data, we were able to derive a rough estimate of Antonelli (2020)'s measure for our selected countries. This yearly estimate, which has to be taken with extreme caution, is plotted in Figure 2 from 2000 onwards. The details of its calculation are given in Appendix B. Overall, Figure 2 shows a measure of additionality that, at best, remains in the 0.8 to 1 range and rarely, if ever, goes above 1. In Antonelli (2020)'s framework, this calls for a better targeting of R&DTC schemes, in order not simply to maintain R&D activities but also to generate new ones.

FIGURE 2 ABOUT HERE

As regards the elusive effect of R&DTCs on innovation output, we can note that France and Spain, the only countries where we identify a significantly positive effect, both have a long-running and extremely generous tax credit. This observation suggests that, in order to have an effect on innovation output, tax credits had better be generous - a conclusion which corroborates the opinion of Straathof et al. (2014), based on a review of the R&DTC literature. Again, since the EC has made the “super deduction" associated with the BEFIT proposal extremely generous, as highlighted in Sub-Section II.2, chances are that such a policy may have a positive impact on innovation output. This remark on generosity extends to the supposedly positive effect of R&DTCs on productivity, which we observe only in France, one of the three OECD countries with the most generous R&DTC scheme. Since any “super deduction" in the vein of the one mentioned above would be extremely generous, it could be expected to have a productivity effect.

Nevertheless, it might then be effective but too generous to be efficient, as suggested by our empirical exercise on existing R&DTC schemes based on Antonelli (2020). This is another issue,

---

[30] Since, in our data, we cannot observe the size of the funding, but only its availability, one could say that our additionality estimates measure the *effectiveness* of R&DTC, whereas Antonelli (2020)'s concept of additionality is designed as a measure of their *efficiency*.

which goes beyond the scope of the present paper, and on which but few studies exist. Akcigit et al. (2022) constitute a welcome exception. Their theoretical reasoning complemented by empirical estimations lead them to conclude that there is indeed room for improvement in R&DTC policies. They suggest for instance conditioning R&D tax incentives on innovation performance. This is in line with Antonelli (2020)'s recommendation of aiming R&DTC at firms or industries where additionality is larger than 1.

Our final remark is for the UK. This country was an EU Member State during the whole of our observation period (1980-2017) but left the EU in 2021, which places it in a rather unique situation. Interestingly, our results for the UK allow us to identify an R&D-innovation-productivity relationship, but this relationship is not influenced by the UK's R&DTC scheme. Rather, past baseline R&D intensity (when defined with respect to hours worked) feeds current baseline R&D, which feeds future patenting intensity, which in turn feeds TFP growth.

This lack of effectiveness of R&DTCs suggest that the UK should not rely too much on this instrument for the future of its science and technology policy. It should rather, as suggested in the sources reviewed in Appendix A, try to create new cooperations in research with the EU. But the lack of effectiveness of R&DTC also has a potentially brighter side for the UK's post-Brexit science policy. Indeed, if the R&D - innovation - productivity relationship holds without the need of an R&DTC, then UK firms do not need any "super deduction" on R&D expenditures to generate knowledge and diffuse it throughout the economy. Our estimates suggest that this relationship is fragile, though, and the UK may never see this brighter side. At the micro level, as was said earlier, any UK firm that performs R&D (or has an R&D-performing subsidiary) on EU territory will be eligible to the super-deduction associated with the yet-to-come BEFIT proposal. But the perspective is of course quite different at the national science policy level.

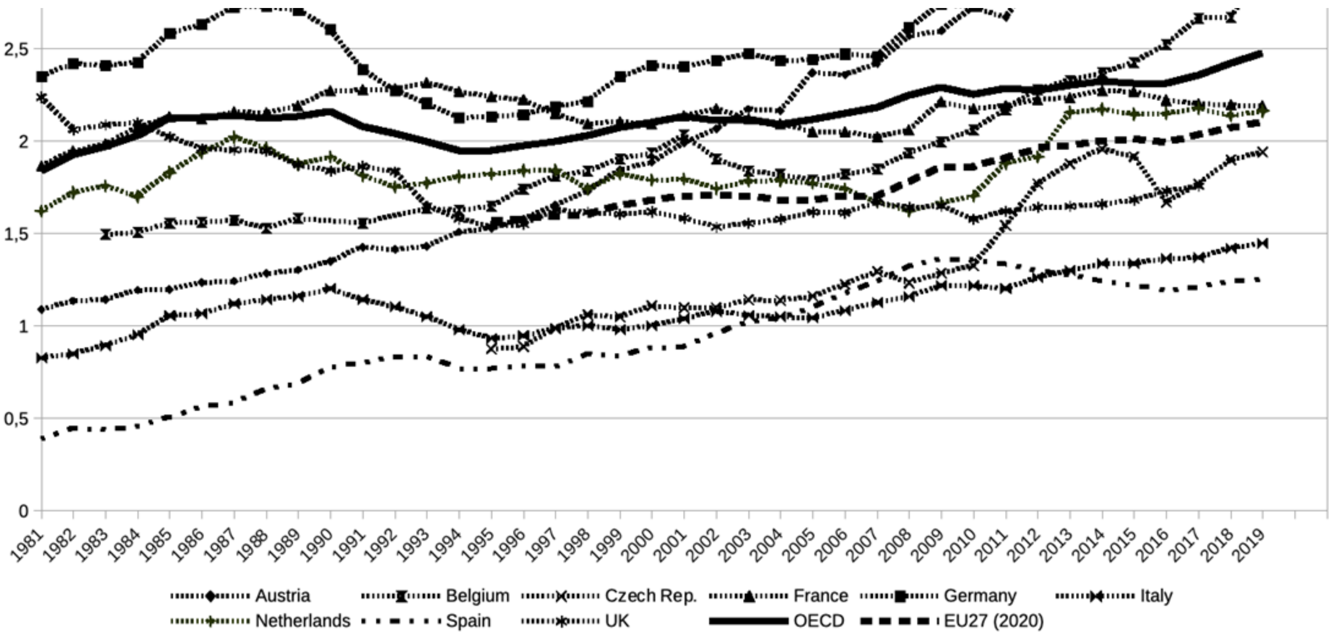
VI Conclusion

Using industry-level panel data, we have examined the R&D, innovation and productivity effects of R&DTC schemes implemented in 8 EU countries, in the context of a proposed EU-wide "super deduction" on R&D. The data covers a period ranging from the late 1970s/early 1980s to 2017 and concerns Austria, Belgium, Czech Republic, France, Italy, the Netherlands, Spain and the UK. Our econometric analysis shows that, overall, past R&D feeds current R&D, whether R&D is conducted during an R&DTC phase or not. For R&D conducted during an R&DTC phase, our estimate of "input additionality" (or BFTB) is generally close to 1, which is consistent with the literature and tend to indicate that all savings induced in an industry by the tax credit are reinvested in future R&D. This finding suggests that existing R&DTC schemes may be effective, but not necessarily efficient, as additionality is generally not larger than 1. The indirect R&D subsidies created by R&DTC schemes are thus reinvested in R&D to maintain existing R&D activities, but not necessarily to generate new ones. This is confirmed by a country-level empirical exercise with a measure of additionality that relates a proxy for new R&D activities to the amount of tax credit received.

Identifying a relationship between R&DTC and innovation output is even more difficult. While R&D intensity does affect patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, this relationship is R&DTC-related only in Belgium, France and Spain. In Spain, a 1% increase in baseline R&D translates to a 0.26% to 0.44% increase in patenting intensity (our measure of innovation output), to which R&D conducted in a period of R&DTC adds an extra 0.20%. In France, a 1% increase in baseline R&D entails a 0.25% to 0.70% increase in patenting intensity, to which R&D conducted in a recent phase of R&DTC adds an extra 0.15% (cumulated over 2004-2017) to 0.36% (cumulated over 1999-2017), depending on which definition of R&D intensity we use. In Belgium, R&D affects patenting only during the R&DTC phase, with a 1% increase in R&D intensity yielding a 0.17% to 0.29% increase in patenting intensity.

Finally, only in France and in the UK do we observe a full R&D-innovation-productivity relationship. In both cases, the relationship is fragile and depends on which definition of R&D intensity is retained. In the UK, the R&D-innovation-productivity relationship is not affected by the R&DTC scheme. In France, we find that a 1% increase in R&D conducted under the second to fourth phases of R&DTC (1999-2017) entails an indirect 0.16% increase in productivity (measured by TFP). This increase is indirect because it is mediated by patenting intensity. The main policy implication we derive from all these results is that R&DTC (including a possible EU-wide “super-deduction" on R&D as part of the BEFIT proposal) are likely to help the EU reach its “R&D at 3% of GDP" objective, but should not be the only instrument implemented to spur innovation and productivity in the EU.

Figure 1: **R&D expenditures in % of GDP for selected EU countries, 1981-2019**



Source: OECD

Table 1: **Unit root tests for non-stationarity of main variables**

ln TFPG	-1.80^b	-1.82^b	-2.01^a	-3.23^a	-3.12^a	-3.57^a	-2.59^a	-2.88^b
	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$
	$T = 36$	$T = 36$	$T = 20$	$T = 43$	$T = 37$	$T = 35$	$T = 36$	$T = 35$
ln patenting intensity	-6.84^a	-8.71^a	-2.31^a	-5.31^a	-9.96^a	-7.64^a	-12.19^a	-11.48^a
	$N = 11$	$N = 11$	$N = 11$	$N = 11$	$N = 11$	$N = 11$	$N = 11$	$N = 11$
	$T = 34$	$T = 34$	$T = 20$	$T = 35$	$T = 36$	$T = 38$	$T = 37$	$T = 38$
ln (R&D/employment)	-0.16	- 1.63^c	-3.05^a	-2.34^a	-2.51^a	-2.42^a	-0.06	-5.33^a
	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$
	$T = 21$	$T = 22$	$T = 21$	$T = 35$	$T = 35$	$T = 46$	$T = 35$	$T = 37$
ln (R&D/VA)	-1.44^c	- 2.89^a	-2.26^b	-2.60^a	-1.56^c	-1.66^b	-0.22	-2.46^a
	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$	$N = 13$
	$T = 21$	$T = 22$	$T = 21$	$T = 35$	$T = 35$	$T = 46$	$T = 35$	$T = 37$

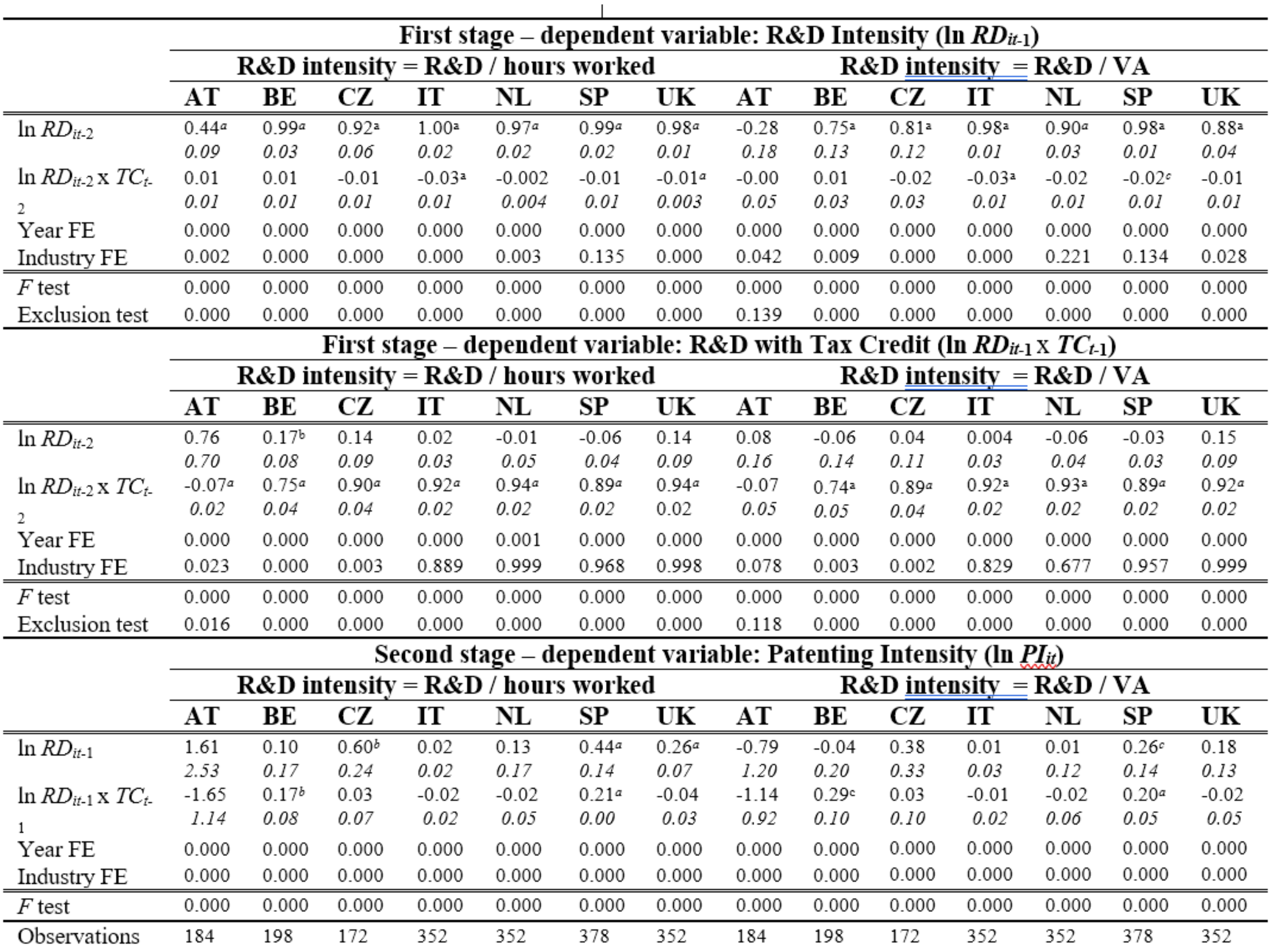
CZ: Czech Republic, NL: Netherlands

N: number of industries, T: years. In some countries, records of R&D stock start after records of productivity and patenting, which explains the shorter time dimension for the R&D intensity variables in these countries.

Significance levels: ^{a} p-value < 0.01, ^{b} p-value < 0.05, ^{c} p-value < 0.10.

Notes: In the UK, both log-R&D intensities are non-stationary. Our econometric modelling will thus rely on their first-difference, which are stationary with a test statistic of -9.42^a for $\ln(R\&D/\text{employment})$ and -12.13^a for $\ln(R\&D/\text{VA})$. The same problem occurs, to a lesser extent, in Austria, calling for the same cure. Again, the first-difference of the log-R&D intensity is stationary, with a test statistic of -6.41^a for $ln(R\&D/\text{employment})$ and -6.93^a for $ln(R\&D/\text{VA})$.

Table 2: **Innovation production function 2SLS estimates for countries with a single RTC period**



	First stage – dependent variable: R&D Intensity (ln RD_{it-1})													
	R&D intensity = R&D / hours worked							R&D intensity = R&D / VA						
	AT	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**	**AT**	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**
ln RD_{it-2}	0.44^{a}	0.99^{a}	0.92^{a}	1.00^{a}	0.97^{a}	0.99^{a}	0.98^{a}	-0.28	0.75^{a}	0.81^{a}	0.98^{a}	0.90^{a}	0.98^{a}	0.88^{a}
	0.09	*0.03*	*0.06*	*0.02*	*0.02*	*0.02*	*0.01*	*0.18*	*0.13*	*0.12*	*0.01*	*0.03*	*0.01*	*0.04*
ln RD_{it-2} x TC_{t-2}	0.01	0.01	-0.01	-0.03^{a}	-0.002	-0.01	-0.01^{a}	-0.00	0.01	-0.02	-0.03^{a}	-0.02	-0.02^{c}	-0.01
	0.01	*0.01*	*0.01*	*0.01*	*0.004*	*0.01*	*0.003*	*0.05*	*0.03*	*0.03*	*0.01*	*0.01*	*0.01*	*0.01*
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.002	0.000	0.000	0.000	0.003	0.135	0.000	0.042	0.009	0.000	0.000	0.221	0.134	0.028
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exclusion test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.139	0.000	0.000	0.000	0.000	0.000	0.000
	First stage – dependent variable: R&D with Tax Credit (ln RD_{it-1} x TC_{t-1})													
	R&D intensity = R&D / hours worked							**R&D intensity = R&D / VA**						
	AT	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**	**AT**	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**
ln RD_{it-2}	0.76	0.17^{b}	0.14	0.02	-0.01	-0.06	0.14	0.08	-0.06	0.04	0.004	-0.06	-0.03	0.15
	0.70	*0.08*	*0.09*	*0.03*	*0.05*	*0.04*	*0.09*	*0.16*	*0.14*	*0.11*	*0.03*	*0.04*	*0.03*	*0.09*
ln RD_{it-2} x TC_{t-2}	-0.07^{a}	0.75^{a}	0.90^{a}	0.92^{a}	0.94^{a}	0.89^{a}	0.94^{a}	-0.07	0.74^{a}	0.89^{a}	0.92^{a}	0.93^{a}	0.89^{a}	0.92^{a}
	0.02	*0.04*	*0.04*	*0.02*	*0.02*	*0.02*	0.02	*0.05*	*0.05*	*0.04*	*0.02*	*0.02*	*0.02*	*0.02*
Year FE	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.023	0.000	0.003	0.889	0.999	0.968	0.998	0.078	0.003	0.002	0.829	0.677	0.957	0.999
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exclusion test	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.118	0.000	0.000	0.000	0.000	0.000	0.000
	Second stage – dependent variable: Patenting Intensity (ln PI_{it})													
	R&D intensity = R&D / hours worked							**R&D intensity = R&D / VA**						
	AT	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**	**AT**	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**
ln RD_{it-1}	1.61	0.10	0.60^{b}	0.02	0.13	0.44^{a}	0.26^{a}	-0.79	-0.04	0.38	0.01	0.01	0.26^{c}	0.18
	2.53	*0.17*	*0.24*	*0.02*	*0.17*	*0.14*	*0.07*	*1.20*	*0.20*	*0.33*	*0.03*	*0.12*	*0.14*	*0.13*
ln RD_{it-1} x TC_{t-1}	-1.65	0.17^{b}	0.03	-0.02	-0.02	0.21^{a}	-0.04	-1.14	0.29^{c}	0.03	-0.01	-0.02	0.20^{a}	-0.02
	1.14	*0.08*	*0.07*	*0.02*	*0.05*	*0.00*	*0.03*	*0.92*	*0.10*	*0.10*	*0.02*	*0.06*	*0.05*	*0.05*
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	184	198	172	352	352	378	352	184	198	172	352	352	378	352

AT: Austria, BE: Belgium, CZ: Czech Republic, IT: Italy, NL: Netherlands, SP: Spain, UK: United Kingdom

Significance levels: ^{a} p-value < 0.01, ^{b} p-value < 0.05, ^{c} p-value < 0.10.

HAC standard errors are provided in *italics* below the estimates.

"Year FE" and "Industry FE" report the p-values of Fisher tests for the year and industry fixed effects, respectively.

Goodness-of-fit: "F test" reports the p-value of the usual Fisher test of a regression. In the first-stage regressions, "Exclusion test" reports the p-value of a Fisher test of the null hypothesis that the coefficients of the instruments are both equal to zero.

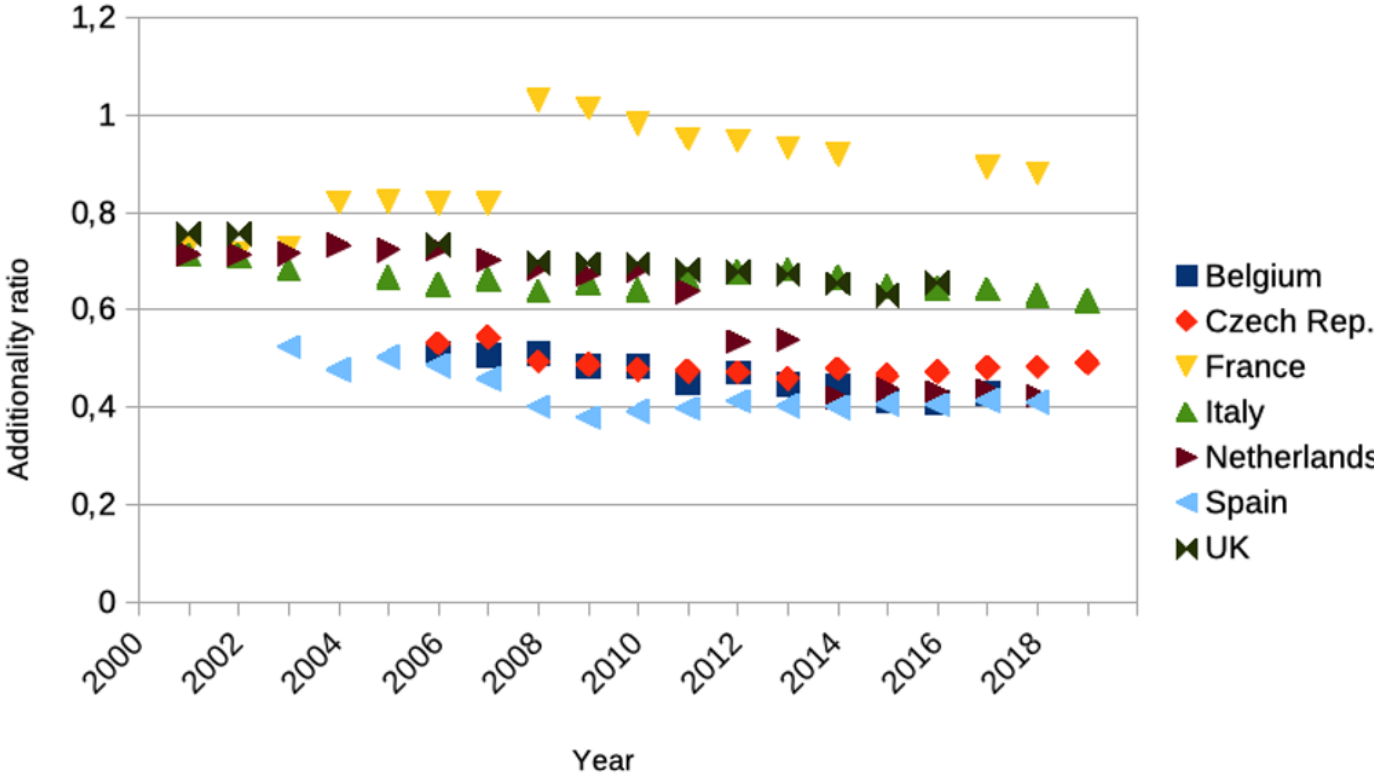
In addition, goodness-of-fit statistics at the very bottom of the table include: (1) the p-values of the Lagrange Multiplier (LM) and Wald versions of Kleibergen and Paap (2006)'s under-identification test (H_0: "Instruments are uncorrelated with the endogenous regressors"); (2) "Yes" ("No") if the estimation passes (does not pass) Kleibergen and Paap (2006)'s weak identification test (H_0: "Instruments are weakly correlated with the endogenous regressors") at the 5% level (the test statistic must be compared to the 5% level critical values tabulated in Stock and Yogo (2002)).

Table 3: **Third stage of a CDM-type model for countries with a single RTC period**

	Dependent variable: Total Factor Productivity (ln TFP_{it})													
	when R&D intensity = R&D / hours worked							**when R&D intensity = R&D / VA**						
	AT	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**	**AT**	**BE**	**CZ**	**IT**	**NL**	**SP**	**UK**
ln PI_{it-1}	-0.06	-0.12	-0.11	3.27^a	0.93^a	-0.06	2.13^a	-0.14	0.07	-0.51	2.55^a	-1.38	-0.05	3.44^a
	0.06	*0.22*	*0.18*	*0.76*	*0.41*	*0.13*	*0.35*	*0.16*	*0.11*	*0.33*	*0.75*	*1.54*	*0.20*	0.54
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	184	198	172	352	352	364	352	184	198	172	352	352	364	352

AT: Austria, BE: Belgium, CZ: Czech Republic, IT: Italy, NL: Netherlands, SP: Spain, UK: United Kingdom
Significance levels: ^{a} p-value $<$ 0.01, ^{b} p-value $<$ 0.05, ^{c} p-value $<$ 0.10.
HAC standard errors are provided in *italics* below the estimates.
"Year FE" and "Industry FE" report the p-values of Fisher tests for the year and industry fixed effects, respectively.
Goodness-of-fit: "F test" reports the p-value of the usual Fisher test of a regression.

Figure 2: **Yearly estimates of Antonelli (2020)'s measure of additionality**



Source: authors' own calculations based on OECD data (see Appendix B for details)

Table 4: **Innovation production function FE-2SLS estimates for France**

	First stage: R&D intensity									
	R&D intensity = R&D / hours worked					**R&D intensity = R&D / VA**				
	ln RD_{it-3}	ln RD_{it-3} x $TC1_{t-3}$	ln RD_{it-3} x $TC2_{t-3}$	ln RD_{it-3} x $TC3_{t-3}$	ln RD_{it-3} x $TC4_{t-3}$	ln RD_{it-3}	ln RD_{it-3} x $TC1_{t-3}$	ln RD_{it-3} x $TC2_{t-3}$	ln RD_{it-3} x $TC3_{t-3}$	ln RD_{it-3} x $TC4_{t-3}$
ln RD_{it-4}	1.02^a *0.01*	☐	☐	☐	☐	0.89^a *0.03*	☐	☐	☐	☐
ln RD_{it-4} x $TC1_{t-4}$	☐	0.87^a *0.03*	0.06^b *0.03*	☐	☐	☐	0.87^a *0.03*	0.05^c *0.03*	☐	☐
ln RD_{it-4} x $TC2_{t-4}$	☐	☐	0.80^a *0.04*	0.20^a *0.04*	☐	☐	☐	0.79^a *0.04*	0.20^a *0.04*	☐
ln RD_{it-4} x $TC3_{t-4}$	☐	☐	☐	0.75^a *0.04*	0.24^a *0.03*	☐	☐	☐	0.75^a *0.04*	0.24^a *0.03*
ln RD_{it-4} x $TC4_{t-4}$	☐	☐	☐	☐	1.00^a *0.04*	☐	☐	☐	☐	0.99^a *0.04*
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.439	0.999	0.999	0.999	0.032	0.447	0.999	0.999	0.999
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	Second stage – dependent variable: Patenting Intensity (ln PI_{it})	
	R&D intensity = R&D / hours worked	**R&D intensity = R&D / VA**
ln RD_{it-4}	0.70^a *0.07*	0.24^b *0.11*
ln RD_{it-4} x $TC1_{t-4}$	-0.02 *0.02*	-0.001 *0.03*
ln RD_{it-4} x $TC2_{t-4}$	0.04 *0.03*	0.09^b *0.04*
ln RD_{it-4} x $TC3_{t-4}$	0.06^b *0.03*	0.10^a *0.04*
ln RD_{it-4} x $TC4_{t-4}$	0.09^a *0.03*	0.16^a *0.05*
Year FE	0.000	0.000
Industry FE	0.000	0.000
Cum. effect	0.15^a 0.05	0.36^a 0.10
Yearly effect	0.005^a 0.001	0.01^a 0.002
F test	0.000	0.000
Autocorrelation	0.249	0.138
White test	0.171	0.039
Observations	352	352

Standard errors are provided in italics below the estimates.

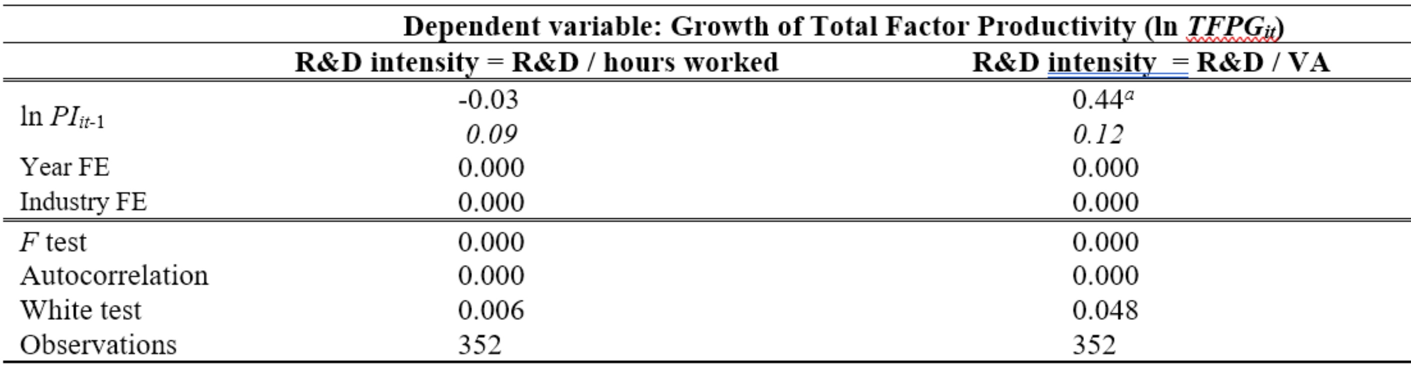
Significance levels: ^{a} p-value < 0.01, ^{b} p-value < 0.05, ^{c} p-value < 0.10.

"Year FE" and "Industry FE" report the p-values of Fisher tests for the year and industry fixed effects, respectively.

"Cum. effect" is an estimate of the cumulated effect of the R&DTC over the whole period and "Yearly effect" is an estimate of the average yearly effect over the period.

Goodness-of-fit: "F test" reports the p-value of the usual Fisher test of a regression. "Autocorrelation" reports the p-value of a test for the autocorrelation of the error term of the second-stage equation (H_0: "No autocorrelation"), conducted along the lines of (Wooldridge, 2002, pp.274-276). "White test" reports the p-value of a test for heteroskedasticity à la White (H_0: "Homoskedasticity"). Second-stage estimates are displayed with corrected standard errors whenever one of these two tests is significant.

Table 5: **Third stage of a CDM-type model-FE-2SLS estimates for France**



	Dependent variable: Growth of Total Factor Productivity (ln $TFPG_{it}$)	
	R&D intensity = R&D / hours worked	**R&D intensity = R&D / VA**
ln PI_{it-1}	-0.03	0.44^{a}
	0.09	*0.12*
Year FE	0.000	0.000
Industry FE	0.000	0.000
F test	0.000	0.000
Autocorrelation	0.000	0.000
White test	0.006	0.048
Observations	352	352

Significance levels: ^{a} p-value < 0.01, ^{b} p-value < 0.05, ^{c} p-value < 0.10.

HAC standard errors are provided in italics below the estimates.

Goodness-of-fit: “F test" reports the p-value of the usual Fisher test of a regression. “Autocorrelation" reports the p-value of a test for the autocorrelation of the error term of the second-stage equation (H_0: “No autocorrelation"), conducted along the lines of (Wooldridge, 2002, pp.274-276). “White test" reports the p-value of a test for heteroskedasticity à la White (H_0: “Homoskedasticity").