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Do direct subsidies stimulate new R&D outputs in firms? A comparison of the IMPULS, TIP and ALFA programmes

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OLEG SIDORKIN, MARTIN SRHOLEC

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O AUTORECH / ABOUT THE AUTHORS

Oleg Sidorkin

Joined IDEA as a researcher in October 2015. He earned his M.A. in Economics from CERGE-EI in 2008 and PhD. Degree in Economics in 2017 from CERGE-EI as well. In his research he focuses on economics of innovation, political economy and applied microeconomics.

Martin Srholec

Earned his PhD. degree in Economics from the University of Economics, Prague in 2003 and in Science, technology and innovation studies (2005) from the University of Oslo, Norway in 2005. From 2002 until 2010 he was based at the TIK centre, University of Oslo, Norway. Since 2010 he works as a Senior Researcher at CERGE-EI, the Economics Institute of the Czech Academy of Sciences. Since 2011 he is Associate Professor in CIRCLE, Lund University, Sweden.

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Do direct subsidies stimulate new R&D outputs in firms? A comparison of the IMPULS, TIP and ALFA programmes [1]

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Summary

- This study compares output additionality effects of the IMPULS, TIP and ALFA programmes, which provided direct public support of R&D to business enterprises in the Czech Republic. Using a large and rich firm-level dataset we employ a non-parametric propensity score matching estimator to find out whether these subsidy programmes stimulated additional R&D output in terms of applications for formal intellectual property (IP) protection, such as patents of invention and utility models, which would not be produced, if the subsidy was not provided.
- The results indicate additionality effects for IP protection in the Czech context. Business enterprises participating in the subsidy programmes are estimated to have been significantly more likely to apply for Czech IP protection within three years after the start of funding than their comparable non-participating counterparts. In contrast, however, the subsidy programmes do not seem to have made much difference to the firms' propensity to apply for international IP protection. Hence, the subsidies did not stimulate R&D outputs that were sufficiently novel to warrant IP protection abroad. Overall, the impacts appear to be lower for IMPULS than for TIP and ALFA. It should be emphasized that the results for ALFA, and in part TIP, must be interpreted as preliminary due to delays in data availability.
- Admittedly, the subsidy programmes were justified on the grounds of promoting competitiveness and growth of firms. The Czech market is quite small, with limited room

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for scaling up. Hence, the success of the programmes should be judged on whether they stimulated the generation of new knowledge at the global technological frontier, which can make a difference in major foreign markets and which in turn is of far higher economic value. Czech IP protection is arguably of little help in making a breakthrough abroad. Judging from this evidence, at least in this respect the programmes have fallen short of expectations.

- It well might be, furthermore, that a number of the programme participants applied for Czech IP protection instruments primarily in order to fulfil the formal requirements of the project evaluation framework. If the subsidy programmes are serious about supporting state-of-the-art technology, they should acknowledge as eligible only results that obtain internationally recognized IP protection. It would also help if the period for reporting project results was extended long beyond the duration of the subsidized project itself, so that firms do not shy away from proposing truly novel and bold research plans due to a fear of not obtaining the grant of a patent in time.
- The main limitation of this study is that it considers only one type of R&D output. Applications for IP protection are no doubt relevant, especially in some industries, and have the major analytical advantages that they are based on external review criteria and that harmonized data for both the subsidy recipients and the control group is readily available. Nevertheless, other R&D outputs are equally if not more relevant, such as non-patented inventions, new products introduced to the market and process innovations implemented in practice. Even more importantly, we ought to consider the subsidy programmes' wider impacts on employment and productivity. Addressing these impacts remains a major challenge for follow-up studies.

Studie 8 / 2017

Stimulují přímé dotace nové výsledky VaV ve firmách? Porovnání programů IMPULS, TIP a ALFA[2]

ČERVEN 2017

Oleg Sidorkin a Martin Srholec

Shrnutí

- Tato studie srovnává motivační účinky přímé státní podpory výzkumu a vývoje (VaV) v podnikatelském sektoru poskytnuté programy IMPULS, TIP a ALFA. Na základě rozsáhlé firemní databáze provádíme kvantitativní odhady toho, zda tyto dotační programy stimulovaly vytvoření dodatečných výsledků VaV v podobě žádostí o udělení ochrany duševního vlastnictví prostřednictvím patentů a užitných vzorů. Cílem je odpovědět na otázku, zda díky dotační podpoře vznikly nové vynálezy, které by bez dotací nebyly.
- Naše zjištění potvrzují motivační účinky těchto dotací na sklon firem žádat o ochranu duševního vlastnictví v rámci České republiky. Podnikatelské subjekty, které se účastnily dotovaných projektů, vykazují během prvních tří let od začátku státního financování významně vyšší výskyt žádostí o tento typ ochrany v České republice než velmi podobné avšak nedotované firmy. Nicméně žádný z těchto dotačních programů nevykazuje dopady na výskyt žádostí o ochranu duševního vlastnictví v mezinárodním měřítku. Z toho plyne, že tyto dotace nedokázaly podnítit VaV vedoucí k vynálezům, které by byly dostatečně průlomové, aby firmám stálo za to žádat o jejich ochranu v zahraničí. Odhadované motivační účinky vychází nižší pro program IMPULS než pro TIP a ALFA. Je však třeba zdůraznit, že odhady pro program ALFA a částečně také pro TIP je třeba brát jako předběžné, protože pro tyto programy ještě nejsou dostupná všechna data.

[2] Tato studie vznikla díky podpoře AV ČR v rámci programu Strategie AV21 a GA ČR projektu č. 17-09265S s názvem „Hranice empirického výzkumu veřejného financování podnikového VaV a inovací“. Za cenné připomínky k pokročilým verzím děkujeme Matěji Bajgarovi, Petru Horákovi a Danielu Münichovi a za umožnění přístupu k firemním mikrodatům z Amadeus databáze od Bureau Van Dijk děkujeme Janu Hanouskovi. Za případné nepřesnosti, opomenutí nebo chyby zodpovídají pouze autoři.

- Zdůvodnění společenského přínosu těchto dotačních programů bylo v zásadě založeno na očekávání, že povedou k vyšší konkurenční schopnosti a růstu firem. Nicméně český trh je poměrně malý a poskytuje omezený prostor pro expanzi. Z tohoto důvodu by měla být úspěšnost těchto programů v konečném důsledku hodnocena podle toho, zda stimulovaly vývoj nových technologií na hranici nejlepší světové praxe, které umožní firmám prorazit na náročných exportních trzích, a které tudíž mají velkou ekonomickou hodnotu. S vynálezy, jejichž ochrana platí pouze v České republice, se mezinárodní konkurenceschopnost nezvýší. Z tohoto pohledu účinky těchto programů prozatím zůstávají daleko za očekáváními.
- Nelze navíc vyloučit, že podpořené firmy zažádaly o ochranu duševního vlastnictví pouze v rámci České republiky spíše s cílem naplnit formální požadavky na dosažení výsledků pro účely hodnocení dotovaných projektů než s cílem ochránit drahocenné vynálezy před domácí konkurencí. Získání českých patentů anebo užitných vzorů k tomu totiž postačovalo. Jinak řečeno by bez dotací firmy o ochraně těchto vynálezů možná ani neuvažovaly, protože by to z čistě komerčního hlediska nemělo smysl.
- Pokud mají tyto a podobné dotační programy VaV skutečně přispívat ke zvyšování konkurenceschopnosti, měl by být za uznatelný výsledek považováno pouze udělení ochrany duševního vlastnictví s širokou mezinárodní působností. Za tímto účelem by ale bylo žádoucí prodloužit lhůtu pro dosažení výsledků na delší dobu po skončení dotovaného projektu, protože proces projednávání žádostí v patentových úřadech může být zdlouhavý. Jinak se totiž firmám nelze divit, pokud se zdráhají pustit do odvážnějších a novátorských projektů ze strachu, že k udělení patentu nedojde včas.
- Hlavním omezením této studie je, že se zaměřuje pouze na jeden druh výsledků VaV. Nástroje pro formální ochranu duševního vlastnictví jsou bezesporu relevantní, zejména v některých odvětvích, a jejich použití má značné analytické výhody, protože podléhají externím hodnoticím kritériím a protože jsou pro ně volně dostupná harmonizovaná data jak pro příjemce podpory, tak i pro kontrolní skupinu nepodpořených firem. Nicméně jiné druhy výsledků VaV mohou být pro firmy stejně či ještě důležitější, jako inovované produkty zavedené na trh, procesní inovace zavedené do praxe anebo obecně nepatentovatelné technologie. Z hlediska veřejných politik je ještě důležitější brát v úvahu i širší dopady těchto dotačních programů na zaměstnanost a produktivitu. Zjištění těchto dopadů zůstává výzvou pro navazující studie.

Introduction

The relevance of public support for business R&D is highly debated (Cunningham et al. 2012). As government takes an active part in financing business R&D activity, there is a growing need to understand how effective such subsidies are and whether they achieve their goals. Policy makers and taxpayers are rightfully concerned that public funds are used to support R&D projects that firms would carry out anyway, hence that the additionality effect is low (David et al. 2000 and Klette et al. 2000). Addressing these concerns and thoroughly evaluating R&D subsidy programmes is important for policy credibility, policy learning and maximizing the desired social impacts.

R&D support for business enterprises usually takes the form of direct subsidies (also called "cash grants") awarded on a competitive basis or indirect subsidies through tax credits (EY 2014). In the Czech Republic, direct R&D subsidies have been provided on a continuous basis through a variety of programmes since at least 1993 and a system of R&D tax deductions was introduced in 2005. According to OECD (2017), 0.11% of GDP was redistributed as direct government funding and 0.05% as indirect government support for business R&D expenditures in the Czech Republic in 2014. Hence, direct R&D subsidies are a traditional and dominant tool in Czech innovation policy.

Rigorous evaluation of R&D subsidy programmes is routinely performed in many advanced countries. As shown in the surveys by Cunningham, et al. (2012) and Zúñiga-Vicente, et al. (2014), there are dozens of estimates of the additionality effects of public subsidies in the scholarly literature. The principle of what has been dubbed as "counterfactual evaluation" in evaluation circles are promoted by the European Commission (2014). Nevertheless, public R&D programmes have been poorly evaluated in the Czech Republic (Arnold and Mahieu 2011, Srholec and Szkuta 2016). In fact, so far, no Czech R&D support programme has undergone an ex-post evaluation that stands up to international standards (Srholec 2015). National guidelines for the evaluation of R&D programmes are underdeveloped and the government is doing little to tackle this problem.

That said, there have been some notable bottom-up efforts recently. Horák (2016) and Srholec (2016) outlined how the principles of counterfactual evaluation can be used in the Czech context, which if fully implemented, have the potential to improve the situation. In particular, the Technology Agency of the Czech Republic (TA CR), established in 2009, has been investing in evaluation capabilities and has already performed promising ex-ante and interim programme evaluations (TA CR 2015, 2016 and 2017a); thus, there is a good chance that there will be rigorous ex-post evaluations after some of their programmes expire. Other major providers of R&D programmes, such as the Ministry of Industry and Trade of the Czech Republic (MIT), lag far behind in this respect. Therefore, this line of research is of great public importance both for improving evaluation methodology and for promoting evidence-based decision making in public policy.

A previous IDEA study on this topic by Palguta and Srholec (2016) showed one way in which this can be done. Using a regression discontinuity approach on rich micro data for participants in the 3rd call for proposals in the TA CR's ALFA programme, the study examined input additionality effects of direct subsidies for business R&D expenditures. The results indicate that the government subsidies had a positive impact on private R&D expenditure. Private R&D spending grew faster in subsidized firms just above the ranking threshold than in unsubsidized firms just below the threshold, even though there was no difference in their spending growth before the subsidies were received. The most significant difference was recorded for small enterprises. Nevertheless, the study could not strictly speaking infer on causal relationships, as there were also other differences between the firms close to the ranking threshold.

The aim of this paper is to bring fresh evidence on output additionality effects of direct R&D subsidies to business enterprises. Using a non-parametric propensity score matching estimator on a large firm-level database combined from ISVaV (Office of the Government of the Czech Republic 2016), PATSTAT (EPO 2016a) and Amadeus (Bureau Van Dijk 6), we examine whether subsidy programme participants generated applications for formal intellectual property (IP) protection that would not have been made otherwise. More specifically, we compare the effects of three major public R&D support programmes, namely IMPULS and TIP administered by the MIT and ALFA launched by the TA CR, the combined budget of which is nearly 30 billion CZK over the period 2004–2017. All three programmes were funded exclusively from the Czech national budget.[3]

Our main finding is that the subsidy programmes significantly stimulated firms to apply for Czech IP protection but did not make a difference to the firms' propensity to apply for international IP protection. From this follows that the programmes' additionality effects

[3] ALFA was superseded by EPSILON at the TA CR in 2015 and TIP was replaced by TRIO at the MPO in 2016, but the output additionality effects of these follow-up programmes are not considered in this study due to delays in data availability.

hold only for R&D outputs that are relevant locally but not in major foreign markets, for which new knowledge at the global technological frontier is generally required. Since the subsidies were justified on the grounds of promoting competitiveness and growth of firms, which in the Czech context implies expansion in foreign markets, the results indicate that at least in this respect the programmes have fallen short of expectations.

Literature review

The basic argument for using public R&D support programmes to stimulate innovation stems from the "public good" characteristics of R&D investments and market failures associated with it (Arrow, 1962). Firms might not have the capacity to appropriate the returns to their R&D investments in full, while other firms have opportunities to free-ride. Therefore, despite being socially valuable, private R&D investments are below a socially optimal level, and privately-funded projects are either not executed or are executed on a lower scale.

Furthermore, there is a problem associated with information asymmetry about R&D projects even if the firms could fully appropriate their returns (Hall, 2002). As R&D projects are risky, the assessments of project returns by borrowers and lenders could differ. There are barriers to sharing too many details about R&D projects between the inventor and the prospective funder due to concerns about disclosure to competitors. R&D outcomes are often intangible, which limits their applicability as a loan security (Močnik, 2001; Ughetto, 2008). As a result, socially desirable R&D projects may not be funded externally from private sources (Stiglitz & Wallsten, 1999; Stiglitz & Weiss, 1981).

The highest benefits of public R&D subsidies could, possibly, come from targeting specific firms that suffer severe financial constraints. For example, younger and smaller firms such as start-ups and academic spin-offs, which have little business experience, in many cases, have to rely on limited internal funds as a source of R&D investment (Zúñiga-Vicente, Alonso-Borrego, Forcadell, & Galán, 2014). As a result, public subsidies that support R&D for these firms would be desirable. At the same time, certain public policy goals, such as spillovers, are more difficult to achieve in SMEs than in large firms (Cunningham, Gök, & Larédo, 2012).

Although the goals of R&D support programmes could be quite diverse, the most important question for defining their efficiency is whether R&D subsidies complement ("crowd-in") or substitute ("crowd-out") private innovation inputs, such as R&D investments, and outputs, such as patents. In this sense output additionality is one of the most expected outcomes of direct public R&D interventions, which is why patents counts are considered in this respect.

The existing empirical evidence on the effectiveness of R&D subsidy programmes is mixed and suggests that effect of public R&D programmes depends on many factors, including but not limited to the firm's and R&D project's characteristics, the firm's past behaviour, the industry, the programme selection criteria, the subsidy amount and subsidisation rate, and the time since the subsidy under consideration (Zúñiga-Vicente et al., 2014). Moreover, the programme's average success may be driven by a few successful projects, while there could be many cases without any sizable effect (Cunningham et al., 2012).

Empirical findings for R&D subsidy programmes differ across countries, industries and programmes. Czarnitzki & Licht (2006) found a large degree of additionality in public R&D grants regarding patent applications in Germany. Hsu et al. (2009) found output additionality effects for R&D programmes in Taiwan, although they point out that patenting behaviour depends on evaluation criteria and differs across industry sectors. Cerulli and Poti (2012) found output additionality effects of publicly funded R&D expenditures on patent applications made by Italian firms, which are more oriented towards patenting and have lower decline of fixed capital. Other firms tend to exhibit crowding-out effects.

Fornahl et al. (2011) found little evidence that R&D subsidies affect German biotech firms' patent performance. The effect was somewhat larger for joint projects with two or more partners. Based on data for Italian firms, Catozzella & Vivarelli (2011) found that innovation subsidies had a negative effect on innovation productivity, measured as innovative sales over innovative expenditure. Based on Spanish data, Gelabert et al. (2009) found some evidence that subsidy programmes had crowding-out effects on appropriability (patents, models, trademarks, etc.) for firms with high levels of IP protection usage. Hence, there are estimates of both positive ("crowding-in") as well as negative ("crowding-out") effects and whether public R&D subsidies deliver the desired positive output additionality effects is an essentially empirical question.

Estimation strategy: matching estimator

Non-random assignment of R&D subsidies makes it problematic to draw conclusions about subsidy effects by simply comparing data on firms that received and did not receive subsidies. The firms that received subsidies are different from those that did not, therefore evaluators would need to separate the effects of subsidy selection (selection bias) from the actual effect of the subsidies themselves (average treatment effect on the treated). The selection bias comes from two sources: applicants' self-selection and actual project selection by the subsidy administrators based on formal criteria. It is likely that firms receiving R&D subsidies have also accepted government funds in the past (Zúñiga-Vicente et al., 2014), these firms are more innovative and their R&D projects in general have a higher probability of success (Cantner & Kösters, 2011). In addition, they may differ in other observable and unobservable characteristics.

Let us define the problem and possible solutions formally. We are interested in whether R&D subsidies complement ("crowd-in") or substitute ("crowd-out") private IP applications. Let treatment, i.e. whether a firm i receives a subsidy or not, be a binary random variable $T_i = \{0,1\}$. Variable Y_i would be an outcome of interest, i.e. whether that firm applied for IP protection or not, and Y_{1i}, Y_{0i} are the potential outcomes for a firm i in case it receives $T_i = 1$ or does not receive $T_i = 0$ treatment.

$$Y_i = \begin{cases} Y_{1i} \text{ } if \text{ } T_i = 1, & firm \text{ } received \text{ } subsidy \\ Y_{0i} \text{ } if \text{ } T_i = 0, & firm \text{ } did \text{ } not \text{ } receive \text{ } subsidy \end{cases}$$

The population value of the average treatment effect on the treated (ATT) is essential when we want to find the participants' average gain from participation in the treatment. ATT is defined in terms of the observed difference in average outcome (i.e. private IP applications) and selection bias:

$$\begin{aligned} ATT &= E[Y_{1i} - Y_{0i} | T_i = 1] = \\ &= \underbrace{(E[Y_i | T_i = 1] - E[Y_i | T_i = 0])}_{Observed \text{ } difference \text{ } in \text{ } average \text{ } Y_i} - \underbrace{(E[Y_{0i} | T_i = 1] - E[Y_{0i} | T_i = 0])}_{Selection \text{ } bias} \end{aligned}$$

In our case, firms that did not apply for R&D subsidies or did not receive subsidies $E[Y_{0i} | T_i = 0]$ are likely to be less R&D intensive and innovative, or have less promising R&D projects. This means that the firms which received subsidies have better values of Y_{0i}, making selection bias positive. Angrist & Pischke (2009) point out that random assignment could remove the selection bias, as it makes T_i independent of potential outcomes. As we only have non-experimental data, we need to use econometric techniques that enable us to estimate the subsidies' causal impact on the firms' private IP applications.

Historically, researchers have focused on testing the effects of subsidies using difference-in-difference estimators, sample selection models, instrumental variables, and various matching estimators (Zúñiga-Vicente et al., 2014). In this paper, build on the growing body of research that employs matching techniques to deal with selection bias. Non-parametric propensity score matching attempts to reproduce the results of experiments or randomized controlled trials based on observational data. This technique combines a group of firms that received subsidies with a group of firms that did not but whose observable characteristics are the same as for the first group with the help of estimated treatment probabilities (propensity scores).

There are several conditions we need to assume in order to estimate the effect of treatment using propensity score matching.

Assumption 1: Conditional independence assumption states that conditional on a scalar function of observable firm characteristics, which affect probability of treatment $p(X_i)$ or the propensity score, selection bias disappears. This assumption implies that unobservable firm characteristics do not affect the treatment assignment and outcome of interest.

$$\{Y_{0i}, Y_{1i}\} \perp T_i |\, p(X_i)$$

Assumption 2: Common support assumption states that the support of the conditional distribution of X_i given $T_i = 0$ overlaps with the support of the conditional distribution of X_i given $T_i = 1$. In other words, it states that for every X_i we have both treated and untreated observations. Formally, if we define $\bar{t}$ as the treatment level $\{0,1\}$, then the assumption 2 can be stated as follows:

$$0 < Prob(T_i = \bar{t} | X_i = x) < 1$$

Assumption 3: Stable unit treatment value assumption implies that treatment itself does not influence untreated firms, or, in other words, there are no "general equilibrium effects". In principle, this assumption could be a serious concern if there are sizeable spillover effects from interaction between treated and untreated firms, for example those in the same technological fields, regional clusters, via direct partnerships or common partners.

As far as the implementation of this strategy is concerned, the estimation depends on the choice of method for propensity score matching. For this paper, we rely on a matching method that does not explicitly assume a functional form for ATT estimation: propensity score nearest neighbour matching. More specifically, we use propensity score nearest-neighbour matching with three neighbours (NN 3) as the default estimator. As a robustness check, we also estimate nearest-neighbour matching with one (NN 1) and five neighbours (NN 5) as well as NN 3 with a caliper value of 0.01 and kernel matching with the biweight kernel. Where there are tied observations, the match is with all ties. Firms with propensity scores that are not on the common support are dropped. Also firms with propensity scores greater than 0.9 are eliminated from the sample, as suggested by Crump et al (2009).

In empirical tools, which are widely used to estimated propensity scores, such as `psmatch2` Stata command, standard errors do not take into account that propensity scores are estimated. As a result, researchers have widely used bootstrap to estimate standard errors non-parametrically. Abadie & Imbens (2008) showed that as a general case, bootstrapping is not valid for matching estimators. Abadie & Imbens (2015) suggested a method for estimating analytical standard errors, which was implemented in Stata command `teffects psmatch`, and which is therefore used as the preferred estimator in this paper (for more details on this estimator see StataCorp 2015).

Description of the R&D subsidy programmes

The purpose of this section is to provide a brief overview of the direct R&D support programmes, the output additionality effects of which are the focus of our interest in this study. The IMPULS and TIP programmes were administered by the MIT and provided funding during the periods 2004-2010 and 2009-2016, respectively. In the meantime, the TA CR was established in 2009 and launched a portfolio of new programmes including ALFA, which funded projects during the period 2011–2017. All three programmes were organized in annual calls for proposals, primarily targeted business enterprises although research organizations were also eligible, and allowed for proposals from both individual entities and consortia of several partners. All three programmes were financed exclusively from the national budget.

The main objectives of IMPULS were to boost the performance of industrial enterprises, particularly small and medium firms, increase competitiveness and modernize technology, with the ultimate goal of reducing the gap in economic development between the Czech Republic and advanced EU countries. The programme focused on supporting R&D projects that developed new materials, manufacturing products, production technologies and information control systems and technologies. For more details, see MIT (2003, 2011).

The TIP programme followed on from IMPULS not only chronologically but also in terms of its design. The programme was expected to boost competitiveness of the Czech economy and thus indirectly generate new jobs. The main focus was on funding R&D on new materials and products, new advanced technologies and new information and management systems. The primary target group of the programme was small and medium business enterprises engaged in industrial production. For more details see MIT (2009, 2013).

The ALFA programme was introduced to gradually replace TIP at the point when the new TA CR was supposed to take over from the MIT as the dominant provider of public support to business R&D; the latter was however later reversed by a new government. The programme's main objectives were to strengthen performance of businesses and increase competitiveness of the economy. The programme focused on supporting R&D in the fields of advanced technologies, materials and systems, energy resources, environmental protection and sustainable development of transport. The programme aims to promote public-private R&D collaboration. For more details see TA CR (2010, 2017b).

Table 1 provides a basic overview of the programmes by their calls for proposals. IMPULS was divided into five calls, while TIP and ALFA were each organized in four calls. The calls are dated by the first year in which the subsidized projects started to receive funding, which is denoted by "(t)" henceforth. In most cases the call was announced and the proposals evaluated during the preceding year, which implies "(t-1)".[4] All projects funded through IMPULS and TIP have been completed already, while some projects supported in the third and most in the fourth ALFA calls are still running. Nevertheless, as explained in more detail below, due to delays in reporting and data availability the full micro data is only accessible up to 2013, and incomplete data up to 2015.

All three programmes were quite large, funding hundreds of projects from budgets in billions of CZK. TIP had the largest total budget, ALFA supported the most projects,

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[4] The only exceptions are the third call of IMPULS and the first call of TIP, both of which were announced in January and provided funding before the end of the same calendar year.

while IMPULS was the smallest on both counts. It is also important to keep in mind, when interpreting the results of this study that the duration of the supported projects varied. According to the programme rules, the maximum permitted project duration was between 3.5 and 6 years in ALFA (the latter in the first call and the former in the last), and in between for IMPULS and TIP. In reality, the typical project duration was 3 years in IMPULS and 3 or 4 years in TIP and ALFA.

Generally speaking, this delineates the time horizon in which the immediate and direct output additionality effects of the programmes should be evaluated; however, we must keep in mind that granted IP protection, not merely the application, was acknowledged as an eligible project result in the evaluation methodology (CRDI 2013). Hence, the patent application, which is the focus of this study, needed to be submitted well in advance before the project ended, in order to be examined by the patent office in time for the project reporting purposes. It is reasonable to expect that the patent application is submitted, depending on the particular IP protection instrument and the patent office, a number of months if not years before the end of the project. Most of the patent applications are thus likely to have been concentrated in the first few years of the subsidized projects.

Table 1. Overview of the programmes

Programme	Year	Number of supported projects	Subsidy amount in million CZK	Average length of supported projects in years
IMPULS	call 1 - 2004	133	1,263	2.90
	call 2 - 2005	106	704	2.79
	call 3 - 2006	128	916	3.03
	call 4 - 2007	128	1,157	3.02
	call 5 - 2008	150	1,232	2.87
	TOTAL	645	5,271	2.93
TIP	call 1 - 2009	425	5,347	3.80
	call 2 - 2010	114	1,867	3.58
	call 3 - 2011	196	3,248	3.54
	call 4 - 2012	133	2,047	3.54
	TOTAL	868	12,509	3.67
ALFA	call 1 - 2011	256	2,807	3.58
	call 2 - 2012	245	1,918	3.43
	call 3 - 2013	167	1,843	3.44
	call 4 - 2014	288	2,584	3.74
	TOTAL	956	9,151	3.57

Note: Based on micro data on the individual projects.

Dataset

The analysis is based on a large micro dataset that provides rich information on firm's performance, inventive capabilities, structural characteristics and public support history; the dataset was combined from the following sources:

1. The Research, Development and Innovation Information System of the Czech Republic (ISVaV), which contains complete administrative data on public tenders, subsidy providers, programmes, projects, receivers and results in the field of R&D funded from the national budget (Office of the Government of the Czech Republic 2016).[5]

2. The PATSTAT database administered by the European Patent Office, which contains information on IP protection instruments filed in the main 40 patent authorities across the world, including the Czech Industrial Property Office. PATSTAT is the largest international database of its kind and contains details of 90 million IP documents (EPO 2016a).

3. Bureau Van Dijk's Amadeus database, which provides balance sheets, income statements, employment and demographic micro data on Czech firms with 25 and more employees (Bureau Van Dijk 2016).[6]

The PATSTAT database does not provide unique identification codes for the individual applicants, therefore, we manually matched the names of the organizations in PATSTAT that list the Czech Republic as their country of origin with the Register of Economic Subjects (ARES)[7] and assigned the unique taxpayer identification number (IČO) to each organization. After that, we merged the data from PATSTAT, Amadeus and ISVaV using this identifier.

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[5] The ISVaV data used in this study was valid on January 27, 2016 when a database snapshot was extracted from the original website: https://www.isvav.cz (Office of the Government of the Czech Republic 2016). Since then, the database has been moved to a new domain: https://www.rvvi.cz (Office of the Government of the Czech Republic 2017), which however suffers from incomplete records and limited functionality. Note that the ISVaV has unfortunately never provided data on unsuccessful applicants.

[6] In Amadeus database, missing data on the number of employees, location, legal form and industry was estimated using 1-year lag and 1-year lead.

[7] http://wwwinfo.mfcr.cz/ares/ares.html.en

In addition to business enterprises, the IMPULS, TIP and ALFA programmes also provided funding to public research organizations, including universities and research institutes, as members of project consortia. However, the question of the subsidies' output additionality effects is primarily relevant to profit-oriented private ventures. Hence, for the purpose of this study we limit the sample to subjects with the following legal forms:

1. General partnership (Veřejná obchodní společnost)
2. Private limited company (Společnost s ručením omezeným)
3. Joint-stock company (Akciová společnost)
4. Limited partnerships (Komanditní společnost)
5. Cooperative (Družstvo)

Moreover, it is well-established in the innovation literature that formal instruments of IP protection are used much more intensively in some industries than others (Hall et al. 2014). Arguably, it would make little sense to evaluate R&D outputs based on applications for formal IP protection instruments in sectors that usually rely on informal methods of protection, such as secrecy, lead time, or complexity of design. Hence, we further narrow down our sample to include only firms whose principal activity is classified as belonging to one of the industries (B, C, D and E) or services sectors (J and M), in which formal IP protection methods are known to be relevant means of protecting technology (alphabetical codes of NACE, rev. 2 classification in brackets):[8]

1. B - Mining and quarrying
2. C - Manufacturing
3. D - Electricity, gas, steam and air-conditioning supply
4. E - Water supply, sewerage, waste management and remediation activities
5. J - Information and communication
6. M - Professional, scientific and technical activities

[8] According to the merged PATSTAT-AMADEUS database, these sectors jointly account for about 89.2% of all applications for patents of invention filed by Czech enterprises with the selected legal forms during the period 2004-2013. These same sectors received the lion's share of public R&D subsidies distributed through the IMPULS, TIP and ALFA programmes. In particular, enterprises classified in C – Manufacturing and M - Professional, scientific, and technical activities stand out, with a combined share of about 80% of the total amount subsidies provided through all three programmes.

The analysis is focused on R&D output in terms of applications for patents of invention and utility models, which, taken together, we refer to as applications for IP protection. The main variables of our interest are the dummy for applying for IP protection domestically at the Industrial Property Office of the Czech Republic (direct applications and international applications entering national phase) and the dummy for applying for IP protection internationally (to one of four major patent offices: i) the US - USPTO; ii) Europe – EPO (filed under the European Patent Convention); iii) Japan - JPO; and iv) International Bureau of the WIPO (filed under Patent Cooperation Treaty).

2013 is the latest year for which complete data on IP protection applications is available in the PATSTAT database (Spring 2016 edition), due to delays in the publication process. First, there is a delay between filing and publishing of patent applications. In most countries, patent applications are only published 18 months after their earliest priority date, before which the application remains confidential to the patent office (EPO 2016b). Second, there is a lag of at least 6 months between a patent application being published and appearing in the PATSTAT database. As a result, the IP protection data are incomplete for projects that ended after 2013 or are still running, and thus must be in these cases used with caution.[9]

Admittedly, there are other relevant R&D outputs that ideally should be taken into account, such as non-patented (or even non-patentable) technologies with elements of tacit knowledge, innovated products introduced to the market and process innovations implemented in practice. Nevertheless, a major advantage of using the formal IP protection instruments is that the data rely on a clear definition based on an external review process, which makes them free of subjective assessment by the firms themselves and that these indicators have been widely used in the literature. Even more importantly, the formal IP protection instruments are the only types of R&D output that were acknowledged as eligible project results by the subsidy programmes, as stipulated in the national evaluation methodology (CRDI 2013), for which harmonized micro data is readily available both for the subsidy programme participants and the control group of non-participating firms. In other words, this is the only data on the basis of which a quantitative counterfactual evaluation of output additionality is possible.

In each call for proposals, a given firm could participate in one or several projects, as the main recipient or as part of a consortium, and could apply to receive money from

[9] As also emphasized below, this is a particular concern for the fourth call of TIP and the second and third calls of ALFA.

the state budget or to contribute to the proposed project only using its own private resources. In all these cases, we count the firm as a programme participant: the firm represents the so-called “treated” observation in the analysis. In other words, as soon as a firm is listed in the administrative records as participating in a subsidized project, it is considered to have been treated by the subsidy.

The longitudinal structure of the dataset is organized by the calls for proposals. All participants in projects funded in a given call are grouped together as a cohort, regardless of the exact start date or duration of their project. As a result, the data for each year refer to a particular programme call, such that the dataset is divided into five cohorts for IMPULS and four cohorts each for TIP and ALFA. The main advantage of delineating the treated status by calls is that the effects of the subsidies during the first (t), second (t+1) and third (t+2) year after the start of funding can be clearly distinguished. The fourth and last call of ALFA is not included in the analysis, because of the limited availability of recent IP protection data due to the publishing delay described above.

A firm may be treated in some calls of a programme but not in others. The subsidized projects typically last longer than one year, while the calls are announced annually. So if a firm is treated in one call but not in subsequent calls, this does not necessarily mean that the firm did not benefit from the programme in the latter years. It is quite likely, in other words, that a firm may be recorded as untreated for a year when it was still participating in a multi-year project supported from a previous call. In addition, the effect of participation may extend beyond the duration of the subsidized project. Admittedly, this potential overlap is problematic for the matching procedure. Hence, to avoid matching the treated firms with themselves just in a different period, the treated firms are eliminated from the sample for the calls in which they were not treated. As a result, the control group of untreated observations only includes firms that have never been treated in the given programme.

Descriptive overview

Table 2 provides details of how the sample for estimation is derived, by programme and call. The total number of programme participants irrespective of their legal form, thus including for instance public research organizations, is reported in the first column. The total number of business enterprises participating in the programmes defined by the five legal forms stated above is given in the second column, which is then further narrowed down to those present in the Amadeus database and in additional only to those with their principal activity classified in one the six selected sectors in the third and fourth columns, respectively. Finally, the last column contains the latter, for which full data are available for estimation; this constitutes the "effective" sample. The main sample reduction is clearly due to absence from the Amadeus database. For those recorded in Amadeus in the selected sectors, the drop-out due to missing data on particular variables is quite small, only 9-12% by programme, which is marginal.

Table 2. Number of programme participants

Programme	Year	Total (including public organizations)	Total business enterprises	Business enterprises in Amadeus	Business enterprises in Amadeus in the selected sectors	Effective sample with full data
IMPULS	call 1 - 2004	181	151	77	76	76
	call 2 - 2005	155	132	94	87	76
	call 3 - 2006	173	150	103	100	83
	call 4 - 2007	172	156	108	101	85
	call 5 - 2008	178	149	102	96	84
	TOTAL	859	738	484	460	404
TIP	call 1 - 2009	436	391	174	167	167
	call 2 - 2010	163	144	108	103	89
	call 3 - 2011	270	231	178	163	139
	call 4 - 2012	187	158	125	119	93
	TOTAL	1056	924	585	552	488
ALFA	call 1 - 2011	347	277	149	136	135
	call 2 - 2012	327	264	162	142	126
	call 3 - 2013	241	193	150	133	114
	TOTAL	915	734	461	411	375

In the next step, we compare firms' propensities to apply for Czech and international IP protection between those that participated in the subsidy programmes and those that did not. The initial hypothesis is that the subsidies provide additional incentives to generate this type of outcome. On the one hand, applying for IP protection locally is generally easier, faster and cheaper, so this might be a preferred strategy to generate eligible project results for reporting purposes. On the other hand, applying for IP protection internationally in any of the four major foreign patent offices, signals a higher quality of invention and a higher value IP application. The motivation for this comparison is to find out whether there are any "unconditional" differences at all, irrespective of whether the difference can be attributed to the impact of the programme.

Table 3 shows this comparison in the effective sample within the first three years of funding from the respective programme call, i.e. over the period (t) to (t+2). Clearly, the "treated" programme participants had a substantially higher propensity to apply for both Czech and international IP protection than the "untreated" non-participants. According to t-tests these differences are highly statistically significant in all cases with the exception of just one outlier. Nevertheless, it would be misleading at this point to consider the untreated to be a relevant control group and to associate this difference with the true effect of the subsidy programmes; this distinction between the two groups may result from the two-step selection of firms into applicants, and applicants into subsidy recipients, as explained above. Programmes may increase or reduce this difference depending on the effectiveness of the subsidies.

To find out whether this is the case, we compare the characteristics of the treated and untreated firms one year before the funding started, i.e. in the year (t-1), which mostly refers to the period when the call was announced and the project proposals evaluated (see Appendix Table A1 for full results). This reveals that there were indeed strong and highly statistically significant differences before the subsidies started. We can see that the firms that went on to receive subsidies were on average more likely to apply for IP protection even before they received any programme funding. Moreover, there were sizeable ex-ante differences in many other respects, including size, age, subsidy history, labour productivity and solvency.[10] As expected, the overall sample of non-participants is not a relevant control group for the subsidy participants and we therefore need to rely on the statistical propensity score matching method to pin down the impact of the programmes.

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[10] The solvency ratio, i.e. the firms' ability to meet their long-term financial obligations, is calculated as (Shareholders funds / Total assets) * 100%.

Table 3. Share of programme participants in the effective sample that applied for IP protection within three years of the start of funding

Programme	Year	Czech IP protection				International IP protection				N	
		Treated	Untreated	Difference		Treated	Untreated	Difference		Treated	Untreated
IMPULS	call 1 - 2004	0.408	0.047	0.361***	(0.026)	0.105	0.005	0.100***	(0.010)	76	2,632
	call 2 - 2005	0.342	0.041	0.301***	(0.024)	0.066	0.005	0.061***	(0.009)	76	3,887
	call 3 - 2006	0.289	0.037	0.252***	(0.022)	0.012	0.005	0.007	(0.008)	83	4,123
	call 4 - 2007	0.329	0.036	0.293***	(0.021)	0.082	0.005	0.077***	(0.009)	85	4,664
	call 5 - 2008	0.417	0.039	0.377***	(0.023)	0.048	0.004	0.043***	(0.008)	84	4,073
	TOTAL	0.356	0.039	0.317***	(0.010)	0.062	0.005	0.057***	(0.004)	404	19,379
TIP	call 1 - 2009	0.437	0.039	0.398***	(0.017)	0.072	0.006	0.066***	(0.007)	167	4,021
	call 2 - 2010	0.461	0.035	0.426***	(0.021)	0.090	0.006	0.084***	(0.009)	89	5,185
	call 3 - 2011	0.460	0.037	0.423***	(0.018)	0.072	0.005	0.067***	(0.007)	139	4,973
	call 4 - 2012†	0.484	0.030	0.454***	(0.019)	0.075	0.004	0.071***	(0.008)	93	5,614
	TOTAL	0.457	0.035	0.422***	(0.009)	0.076	0.005	0.070***	(0.004)	488	19,793
ALFA	call 1 - 2011	0.526	0.038	0.488***	(0.018)	0.104	0.006	0.098***	(0.008)	135	4,859
	call 2 - 2012†	0.452	0.031	0.421***	(0.017)	0.063	0.004	0.059***	(0.007)	126	5,488
	call 3 - 2013†	0.404	0.025	0.379***	(0.016)	0.053	0.002	0.050***	(0.006)	114	5,084
	TOTAL	0.464	0.031	0.433***	(0.010)	0.075	0.004	0.071***	(0.004)	375	15,431

*Note: Standard deviation in parentheses * p<0.05, ** p<0.01, *** p<0.001.*
† - IP application data are not complete due to the publishing delay.

Propensity score matching

First, we need to find a group comparable to the programme participants. For this purpose, we use the firms' observable characteristics to estimate a subsidy programme participation equation, from which we derive a propensity score that is at the core of the matching procedure. The results of the participation equation largely reproduce, in a multivariate framework, the patterns that were detected above (see Appendix Table A2 for details). All three programmes ceteris paribus favoured larger firms that were more solvent, applied for IP protection and had participated in subsidized R&D projects in the recent past. Some of the programmes were prone to support more productive firms, while conflicting evidence emerged on the age of firms. Differences across legal forms, industries and time trends are also accounted for. Overall, these variables are confirmed to be the salient features that explain a firm's probability to participate in the subsidy programmes.

Second, we perform traditional propensity score matching using the NN 3 estimator. Table 4 provides the baseline results. The effects of programme participation on the propensity to apply for IP protection are derived separately for protection in the Czech and international contexts, for the individual subsidy programmes and for the first (t), second (t+1) and third (t+2) years of funding from the respective programme calls. The estimated mean of the "treated" programme participants is in the fourth column and the estimated mean of their matched non-participating counterparts is in the fifth column. At the heart of our interest is the magnitude and statistical significance of the difference between these two figures reported next that indicate the effect of programme participation. N denotes the total number of observations. [11]

Our main finding is that once we have constructed a comparable control group, the differences in propensity to apply for IP protection between the treated and untreated firms decrease noticeably compared to the "unconditional" differences presented above. The results indicate that the subsidy programmes had highly statistically significant additionality effects on IP protection in the Czech context, at least as far as the second (t+1) and most notably third (t+2) years of funding are concerned, but largely inconclusive effects on IP protection in the international

[11] The diagnostics of the matching procedure, which turn out to be satisfactory, are presented in Appendix Tables A3 and A4 and Figures A1-A5.

context. In other words, after the matching the treated and untreated firms' difference in propensity to apply for Czech IP protection holds, albeit with a smaller magnitude as could be expected, but their difference in propensity to apply for international IP protection fizzles out.

Table 4. Propensity score matching estimates by the office of IP protection (NN 3 estimator, conventional)

IP protection	Programme	Year	Treated	Untreated	Difference		N
Czech IP protection	IMPULS	(t)	0.185	0.152	0.033	(0.025)	20,104
		(t+1)	0.168	0.139	0.028	(0.025)	20,104
		(t+2)	0.213	0.154	0.058**	(0.028)	20,104
	TIP	(t)	0.228	0.221	0.007	(0.027)	20,783
		(t+1)	0.287	0.196	0.091***	(0.024)	20,783
		(t+2)†	0.302	0.191	0.111***	(0.027)	20,783
	ALFA	(t)	0.285	0.239	0.046	(0.028)	16,027
		(t+1)†	0.296	0.205	0.091***	(0.030)	16,027
		(t+2)†	0.263	0.159	0.103***	(0.028)	16,027
International IP protection	IMPULS	(t)	0.023	0.033	-0.010	(0.011)	20,104
		(t+1)	0.025	0.025	0.000	(0.011)	20,104
		(t+2)	0.028	0.029	-0.002	(0.012)	20,104
	TIP	(t)	0.042	0.039	0.003	(0.018)	20,783
		(t+1)	0.042	0.025	0.018*	(0.011)	20,783
		(t+2)†	0.042	0.023	0.019*	(0.012)	20,783
	ALFA	(t)	0.042	0.048	-0.007	(0.017)	16,027
		(t+1)†	0.042	0.033	0.009	(0.013)	16,027
		(t+2)†	0.031	0.016	0.015	(0.010)	16,027

*Note: The effect of the subsidy programme is the difference between the estimated probabilities of applying for IP protection for treated and untreated firms. Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme. Abadie Imbens robust standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.*

† IP application data are not complete due to the publishing delay.

In the next step, we control for unobserved time-invariant fixed effects with the help of a difference-in-differences estimation. Using this method, we are able to account for differences that are constant, such as the firms' birth characteristics, or tend to change slowly over time, such as their innovative behaviour, but which are not represented by the variables in hand. More specifically, we combine the baseline model of propensity score matching and a conditional difference-in-differences model, as suggested by Blundell and Costa Dias (2000) and applied, for example, by Görg and Strobl (2007). Essentially, this method explores not only the differences between treated and untreated firms but also the differences before and after participating in the programme. The dependent variable in these estimates is the difference in the firm's probability to apply for IP protection between the year before funding from the programme call began and the respective year afterwards, i.e. the difference (t) - (t-1); (t+1) - (t-1); and (t+2) - (t-1).

Table 5 gives the updated results. Everything remains as before, except that the conditional difference-in-differences model is used instead of the conventional estimation. There are two main differences compared to the previous results. First and foremost, none of the estimated effects on international IP protection are statistically significant at the conventional levels, not even weakly as before, thus in statistical terms we cannot reliably rule out the possibility that the programmes had zero impact in this respect. Second, the effect of IMPULS subsidies on Czech IP protection is not statistically significant, which suggests that this programme did not make a tangible difference. Meanwhile the results for TIP and ALFA as regards Czech IP protection remain similar, albeit the statistical significance of the latter has decreased by a notch.[12]

[12] Note that the negative figures for Czech IP protection in both treated and untreated firms that are estimated using the difference-in-differences framework in the third year (t+2) of ALFA primarily testify to the fact that, as explained above, the data in the latter period are incomplete due to the publishing delay.

Table 5. Propensity score matching estimates by the office of IP protection (NN 3 estimator, conditional difference-in-differences)

IP protection	Programme	Year	Treated	Untreated	Difference		N
Czech IP protection	IMPULS	(t)	-0.015	-0.036	0.020	(0.033)	20,104
		(t+1)	-0.025	-0.044	0.019	(0.034)	20,104
		(t+2)	0.020	-0.032	0.052	(0.040)	20,104
	TIP	(t)	0.022	0.009	0.013	(0.034)	20,783
		(t+1)	0.076	-0.022	0.099***	(0.035)	20,783
		(t+2)†	0.096	-0.031	0.127***	(0.036)	20,783
	ALFA	(t)	0.006	-0.008	0.014	(0.045)	16,027
		(t+1)†	0.020	-0.065	0.085**	(0.042)	16,027
		(t+2)†	-0.017	-0.112	0.095**	(0.045)	16,027
International IP protection	IMPULS	(t)	0.003	-0.003	0.005	(0.015)	20,104
		(t+1)	0.005	-0.004	0.009	(0.015)	20,104
		(t+2)	0.008	-0.003	0.010	(0.015)	20,104
	TIP	(t)	0.009	0.012	-0.003	(0.017)	20,783
		(t+1)	0.009	-0.002	0.011	(0.017)	20,783
		(t+2)†	0.007	-0.007	0.014	(0.017)	20,783
	ALFA	(t)	0.008	0.010	-0.002	(0.024)	16,027
		(t+1)†	0.008	-0.008	0.017	(0.017)	16,027
		(t+2)†	-0.003	-0.024	0.022	(0.021)	16,027

*Note: The effect of the subsidy programme is the difference between the estimated probabilities of applying for IP protection for treated and untreated firms. Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme. Bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.*

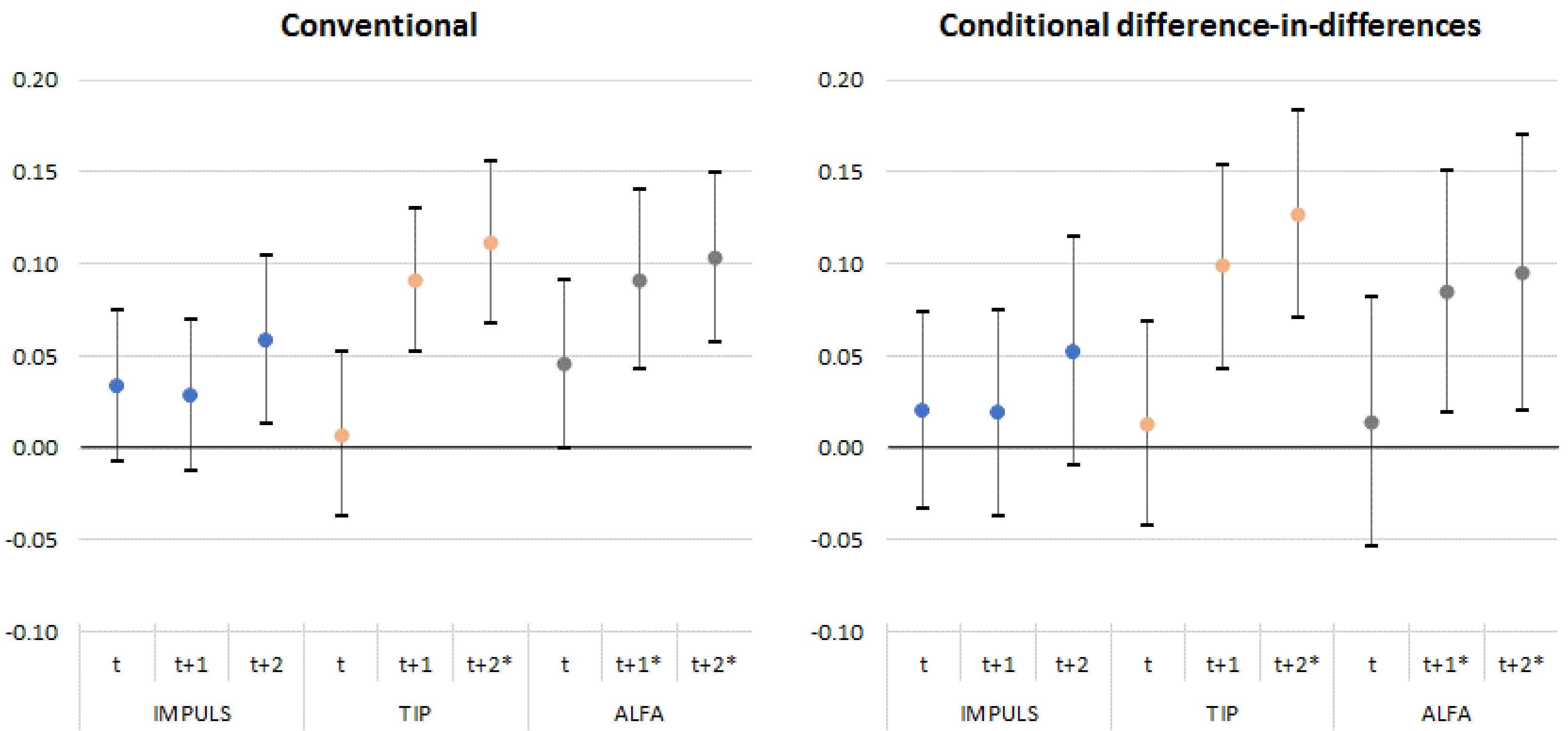
† IP application data are not complete due to the publishing delay.

So far we have only presented results based on the NN 3 estimator. To check whether the results are sensitive to the specification of the propensity score matching model, we also consider evidence based on the alternatives NN 1, NN 5, and NN 3 with 0.01 caliper and biweight kernel matching (see Appendix Tables A5 and A6 for details). Overall, the estimated differences between the treated and untreated firms are consistent with the results of the initial NN 3 specification. The only difference appears to be that a few of the results of the simplest NN 1 procedure differ in statistical significance when compared to the other estimators; otherwise the results appear to be quite robust.

Firms that apply for international IP protection are fairly rare. It well might be, therefore, that the effects on this outcome are estimated imprecisely, because the data was insufficient in terms of the underlying variability and the sample size, thus statistical power. Arguably, if this is the case, our analysis could be prone to “false negative” errors in statistical hypothesis testing, erroneously concluding that there was no effect. Hence, as a rudimentary test of this possibility, we re-run the models on pooled data from all three IMPULS, TIP and ALFA programmes (see Appendix Table A7 for details). None of the coefficients come out statistically significant at the conventional levels regardless of the matching procedure used and whether the conventional or difference-in-differences estimation is used. In fact, the estimated effects appear to be even less statistically significant than before, which is reassuring. From this we conclude that indeed the subsidy programmes did not make any difference to international IP protection applications.

Figure 1 provides a closer look at the magnitude of the estimated effects and respective 90% confidence intervals for Czech IP protection (see Tables 4 and 5 for details). Business enterprises that participated in the subsidy programmes are estimated to have been as much as 13 percentage points more likely to apply for Czech IP protection within three years of the start of funding than their comparable non-participating counterparts. The main effects differ noticeably both by programme and over time. As can be expected, there is not that much difference in the first year (t), because it is too early for activities that were stimulated by the subsidy to come to fruition; the effects start gaining steam in the second year (t+1) and the main thrust of the programmes is delivered in the third (t+2) year. Nevertheless, this holds primarily for TIP and ALFA, but to a substantially lesser extent for IMPULS, whose peak effect remains far below the other programmes.

Figure 1. Estimated effects of the programmes on the propensity to apply for Czech IP protection (NN 3 estimator)



Note: Average treatment effects on the treated with 90% confidence intervals. Each dot shows the effect of the respective subsidy programme, which is the difference between probabilities of applying for IP protection for treated and untreated firms derived from the propensity score matching estimates (see Tables 4 and 5 for details). Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme.

** IP applications data are not complete due to delays in the publishing process.*

Heterogeneity checks

In this section, we examine the heterogeneity of the output additionality effects with regards to i) size categories of firms; ii) industry versus services; and iii) instruments of IP protection. The analysis is focused on Czech IP protection, because this is where the strongest effects are concentrated and because the data is insufficient for deriving reliable estimates for international IP protection in the subsamples. The presented results are based on the combined propensity score matching and conditional difference-in-differences model, which is preferable from the methodological point of view. Nevertheless, as has been shown above, the results are robust to the model specification.

The magnitudes of the estimated effects and respective standard deviations are reported in figures, while tables with the full results are available in the appendix. For the sake of saving space, only the estimated differences between untreated and treated firms are reported, not the underlying propensities, are reported (this information is available from the authors upon request). It should be reiterated that the results for TIP in the third (t+2) year and for ALFA in the second (t+1) and third (t+2) years need to be interpreted with great caution, especially when the dataset is divided into subsamples, as the data on applications for IP protection are incomplete due to the publishing delay.

Firm size

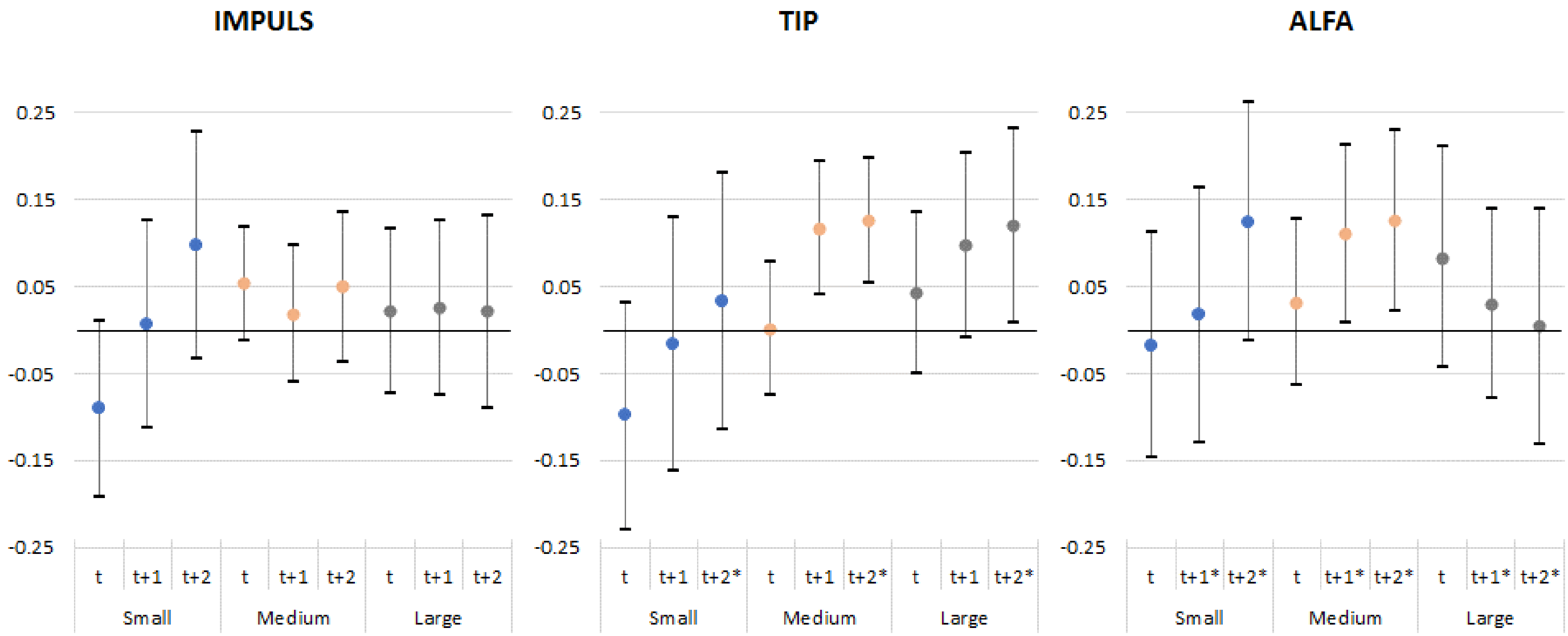
Following the classification by Eurostat (2017), we divide firms into three broad size categories depending on their number of employees:

1) *Small enterprises*: fewer than 50 persons employed;[13]
2) *Medium-sized enterprises*: 50-249 persons employed;
3) *Large enterprises*: 250 or more persons employed.

[13] Given the aforementioned limitation of the Amadeus dataset, the effective sample predominantly contains firms with 25 or more employees; hence in practice this category refers to enterprises with 25 to 49 employees.

Figure 2 depicts the main results (see Appendix Table A8 for details). None of the estimated effects are statistically significant for IMPULS, which reconfirms the disappointing results for this programme. Both TIP and ALFA seem to have worked quite well for medium-sized enterprises but the results are mixed otherwise. Somewhat surprisingly, small enterprises, which are usually the most strongly affected by subsidy programmes like these, do not stand out. It is fair to say that small enterprises do not drive the overall positive results. As for large enterprises, there is support for additionality effects from TIP, but not from ALFA yet, although the latter results are preliminary, as emphasized above.

Figure 2. Estimated effects of the programmes on the propensity to apply for Czech IP protection by firm size (NN 3 estimator, conditional difference-in-differences)



Note: Average treatment effects on the treated with 90% confidence intervals. Each dot shows the effect of the respective subsidy programme, which is the difference between probabilities of applying for IP protection for treated and untreated firms derived from the propensity score matching estimates (see Appendix Table A8 for details). Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme.

** IP applications data are not complete due to delays in the publishing process.*

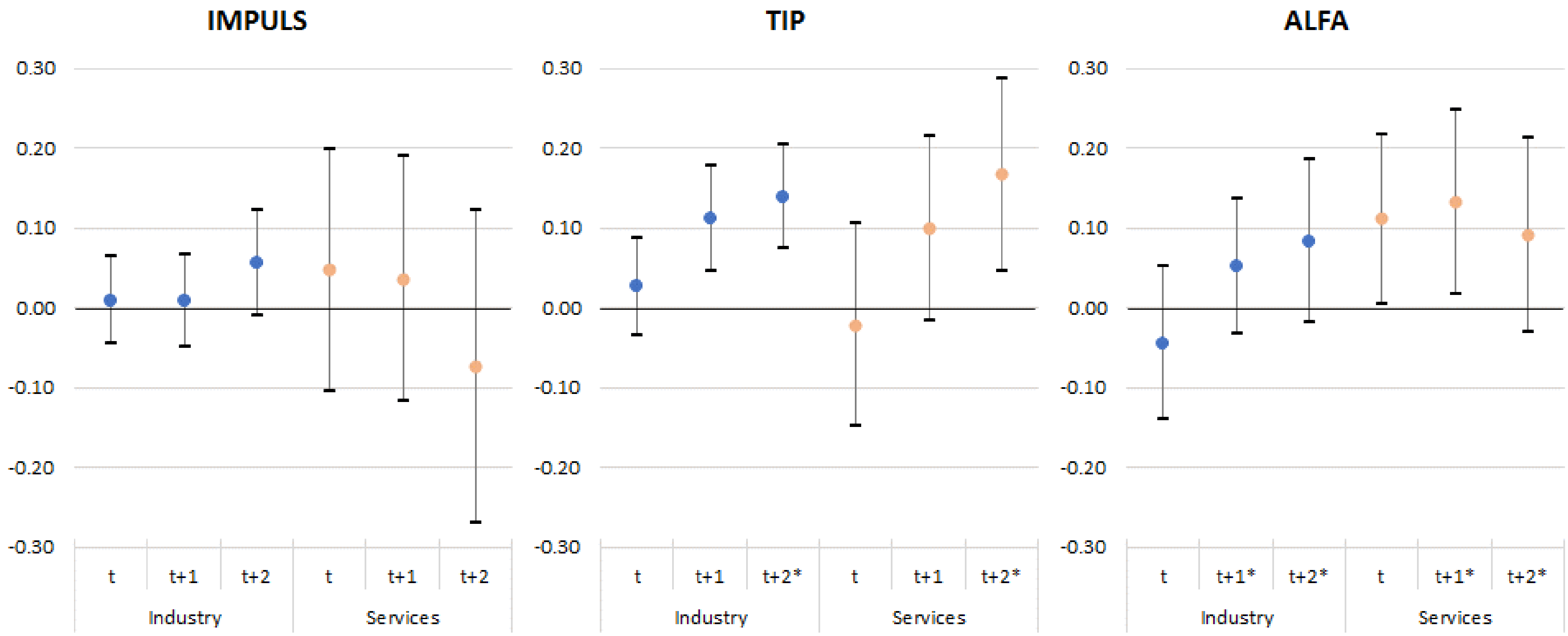
Sectoral differences

Sectoral differences are examined by dividing the firms into two groups along the traditional division between industry and services (alphabetical NACE codes, rev. 2 classification in brackets):

- *Industry* (B – Mining and quarrying; C – Manufacturing; D – Electricity, gas, steam and air-conditioning supply; E – Water supply, sewerage, waste management and remediation activities)
- *Services* (J –Information and communication; M – Professional, scientific and technical activities).

Figure 3 shows the main results (see Appendix Table A9 for details). Again, the effects of the programmes turn out to be fairly heterogeneous. The general pattern that the effects are much weaker for IMPULS than for TIP and ALFA is confirmed. For IMPULS the effects are not statistically significant at the conventional levels regardless of the sector, with the exception of the simplest NN1 procedure, which are not backed up by the other matching procedures. However, the steep drop in the estimated effect of IMPULS for services in the third (t+2) year can perhaps more than anything be attributed to data limitations and to the fact that the programme was explicitly focused on manufacturing. Overall, there does not seem to be a clear pattern of broad sectoral differences.

Figure 3. Estimated effects of the programmes on the propensity to apply for Czech IP protection by sectors (NN 3 estimator, conditional difference-in-differences)



Note: Average treatment effects on the treated with 90% confidence intervals. Each dot shows the effect of the respective subsidy programme, which is the difference between probabilities of applying for IP protection for treated and untreated firms derived from the propensity score matching estimates (see Appendix Table A9 for details). Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme.

** IP applications data are not complete due to delays in the publishing process.*

IP protection instrument types

Further, we look at the heterogeneity of results by the type of IP protection instrument (for additional details on the definitions see OECD 2009 and WIPO 2017):

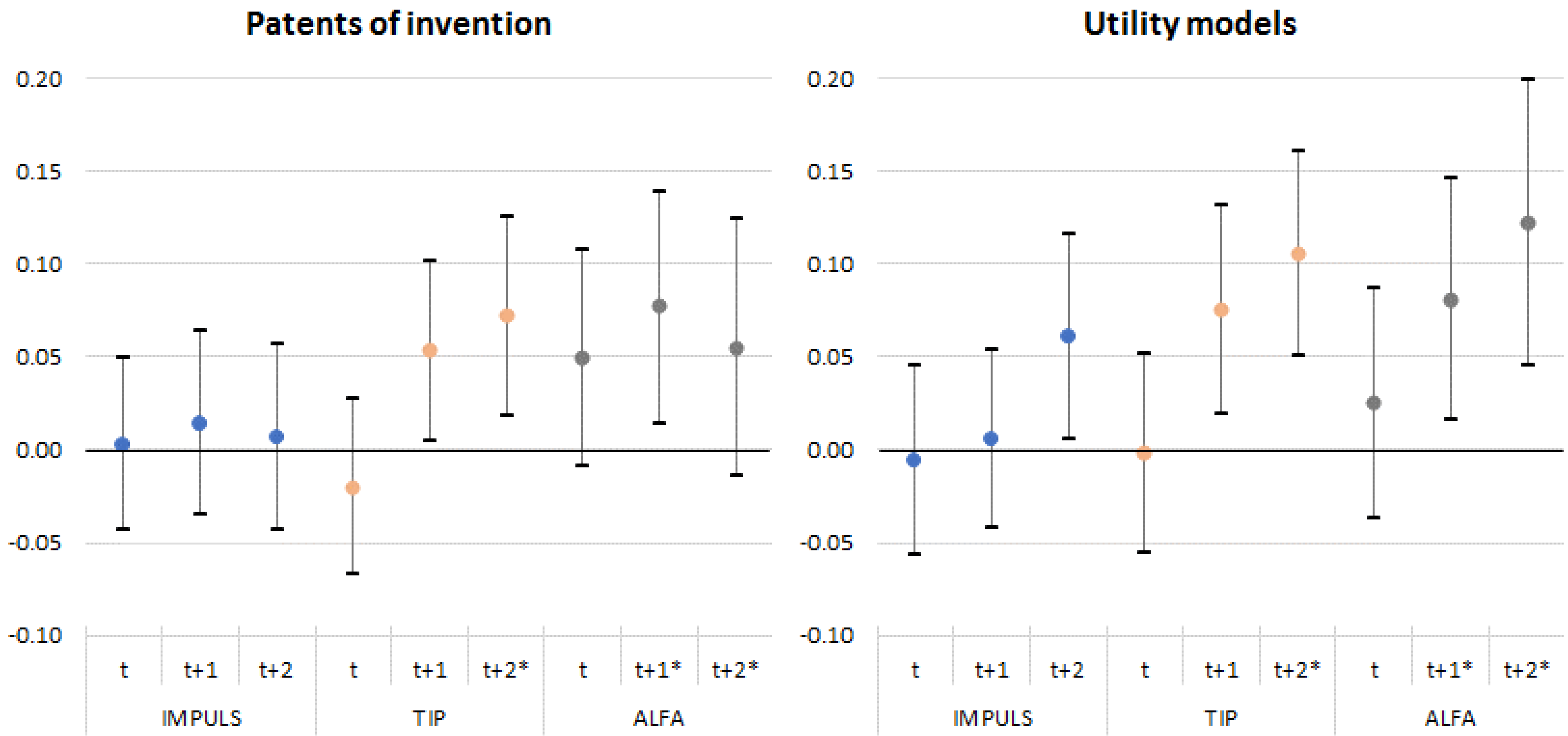
- *Patents of invention* – give an exclusive legal right to prevent others from using the invention in the specified country or region for up to 20 years from the date of filing. Patents should satisfy the conditions of subject matter, novelty, non-obviousness and industrial applicability.

- *Utility models* - a form of patent with less strict patentability requirements than traditional patents, lower costs of patenting and a shorter protection period.

From this follows that patents of invention are more substantial and difficult to obtain. Utility models are less demanding in their requirement for novelty and also cheaper in terms of the fees charged by the patent office. In addition, utility models require less administration, applications for them are usually examined, and hence the protection granted, more quickly by the patent office, and the publishing delay is shorter. It well might be, therefore, that firms rely on utility models more often, if anything for practical reasons, for the purpose of reporting outputs in the subsidized projects. In particular, the "petty" utility models appear quite attractive for this purpose.

Figure 4 provides the main results (see Appendix Table A10 for details). As far as IMPULS is concerned, the estimated effects are negligible, except for utility models in the third (t+2) year; any sign that this programme might have delivered output additionality effects in the results presented above was clearly driven by this category. The most significant effects from TIP and ALFA also concern utility models, with a clear increasing trend over time that seems to confirm the suspected strategic selection of IP protection type described above. Nevertheless, TIP and to some extent ALFA also had sizeable effects with a similar pattern on patents of invention, for which the data are still incomplete due to the publishing delay, so the jury is still out on the true extent of these effects.

Figure 4. Estimated effects of the programmes on the propensity to apply for Czech IP protection by the type of instrument (NN 3 estimator, conditional difference-in-differences)



Note: Average treatment effects on the treated with 90% confidence intervals. Each dot shows the effect of the respective subsidy programme, which is the difference between probabilities of applying for IP protection for treated and untreated firms derived from the propensity score matching estimates (see Appendix Table A10 for details). Positive values imply "crowding-in" effects: R&D subsidies stimulate IP applications, which would not be produced, if the subsidy was not provided. The effects are reported for the first (t), second (t+1) and third (t+2) year after the start of funding from the respective programme.

** IP applications data are not complete due to delays in the publishing process.*

Discussion and conclusion

The study provides first insights into the efficiency of the direct R&D subsidy programmes IMPULS, TIP and ALFA in accelerating R&D output of business enterprises measured by applications for IP protection. The results of a propensity score matching analysis, based on firm-level data, indicate that the programmes had strong additionality effects on Czech IP protection. However, the results are inconclusive for effects on international IP protection. It appears that these R&D subsidies motivated firms to use Czech IP protection instruments more frequently, possibly to fulfil the formal project output requirements in the evaluation framework, but did not stimulate the production of inventions at the global technological frontier that were sufficiently novel to warrant IP protection abroad.

Judging from this evidence, the success of the subsidy programmes was partial. On the one hand, participating in the subsidized projects pushed firms to protect with the help of the Czech IP instruments technologies that would not have been protected by formal means otherwise; thus, at the very least the firms learned how to do that. On the other hand, the programmes were justified on the grounds that they would promote competitiveness and growth of firms. The Czech market is quite small, with limited room for scaling up. Hence, to achieve these goals the programmes needed to stimulate new technology that could make a difference in foreign markets. Czech IP protection is arguably of little help in making a breakthrough abroad. In this respect, the results indicate that the programmes fell short of expectations.

If the subsidy programmes are serious about supporting the generation of state-of-the-art technology, which can boost international competitiveness, then only instruments of international IP protection, recognized in major foreign markets, should be acknowledged as eligible project results; Czech IP protection should not be considered sufficient. At the very least, programme providers should emphasise that the ambition to generate technology that is worth international IP protection is a desirable project output. Furthermore, since there is a substantial delay between submitting an application for IP protection to the major foreign patent offices, such as the USPTO, JPO and EPO, and the protection being granted, it would also help if the period for reporting results was extended long beyond the duration of the subsidized project itself, so that firms do not shy away from proposing truly novel and bold research plans due to a fear of not obtaining the grant of a patent in time to fulfil the formal project evaluation requirements.

It should be emphasized that the results for ALFA and in part for TIP are preliminary, because the data on applications for IP protection is incomplete due to the delay in their publishing process. In addition, the fourth and last call of ALFA could not be included in the analysis at all, because of the limited availability of IP protection data in recent years and because some of the supported projects are still running. Hence, it will only be possible to estimate the overall output additionality effects of ALFA using this methodology in several years' time. Moreover, so far we have only focused on the programmes' immediate short-term impacts, while what truly matters is whether the programmes deliver lasting long-term impacts on the participating firms' innovation behaviour.

As already noted, furthermore, the data limitations mean that we are not able to distinguish whether these R&D subsidies stimulated the generation of new technology that would not otherwise have been generated or whether they only stimulated firms to use IP instruments to protect existing or partly existing technology that would not otherwise have been formally protected. Either way, the subsidies had a "crowd-in" effect that should be seen as a positive impact, since there is evidence that formal instruments of IP protection remain underused in the Czech Republic (Heilemann 2014 and TA CR 2015). One positive effect of formal IP protection is that inventions are coded and disclosed to the market and can be accessed by others. As a result, those inventions are added to the knowledge pool and stimulate subsequent innovations. Even if the programmes only stimulated IP protection, which might be perhaps seen as an unintended positive impact, the learning involved has the potential to improve the efficiency of the firms' innovation activities in the future.

Finally, a major limitation of our analysis is that it only considers one type of R&D output: instruments of formal IP protection. In practical terms, using this data has major analytical advantages, because the instruments are clearly defined, based on external review criteria implemented by patent offices, and because harmonized data is available both for the subsidy recipients and a control group. Admittedly, however, there are other types of R&D outputs, such as non-patented inventions, new products introduced to the market and process innovations implemented in practice, which may be relevant. Even more importantly, an assessment of the subsidy programmes should consider their wider impacts on employment and productivity. The analysis presented in this study represents one step in this direction. Addressing the wider impacts remains a major challenge for future research.

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Appendix

Table A1. Comparison of programme participants and non-participants one year before treatment (t-1)

		IMPULS		TIP		ALFA	
Czech IP protection	Treated	0.189	(0.392)	0.216	(0.412)	0.287	(0.453)
	Untreated	0.017	(0.127)	0.016	(0.124)	0.016	(0.123)
	Difference	0.173***	(0.015)	0.201***	(0.013)	0.271***	(0.018)
International IP protection	Treated	0.026	(0.159)	0.038	(0.191)	0.051	(0.219)
	Untreated	0.002	(0.046)	0.002	(0.047)	0.002	(0.104)
	Difference	0.024***	(0.006)	0.036***	(0.006)	0.048***	(0.009)
R&D subsidy participant	Treated	0.667	(0.472)	0.825	(0.380)	0.821	(0.384)
	Untreated	0.008	(0.091)	0.009	(0.095)	0.011	(0.104)
	Difference	0.659***	(0.018)	0.816***	(0.012)	0.810***	(0.016)
Employees	Treated	477.4	(1179.9)	388.5	(777.3)	393.3	(1066.8)
	Untreated	170.7	(406.4)	154.2	(313.5)	152.6	(311.6)
	Difference	306.7***	(43.77)	234.4***	(24.63)	240.7***	(43.13)
Firm's age	Treated	10.7	(4.3)	14.2	(4.8)	15.7	(4.6)
	Untreated	10.4	(4.7)	13.2	(5.7)	13.7	(5.5)
	Difference	0.288	(0.164)	1.083***	(0.156)	1. 988***	(0.192)
log(Operating revenue per employee)	Treated	7.452	(0.765)	7.505	(0.790)	7.408	(0.821)
	Untreated	7.338	(0.963)	7.257	(0.986)	7.301	(0.915)
	Difference	0.114***	(0.029)	0.248***	(0.026)	0.106**	(0.034)
Solvency ratio	Treated	53.2	(25.9)	53.3	(25.2)	57.2	(23.08)
	Untreated	45.8	(28.8)	48.5	(30.4)	49.1	(30.0)
	Difference	7.415***	(0.943)	4.756***	(0.825)	8.090***	(0.962)
	N	20,109		20,797		16,045	

Note: Standard deviation in parentheses.

* p<0.05, ** p<0.01, *** p<0.001

Table A2. Subsidy programme participation equation (Logit)

	IMPULS		TIP		ALFA	
R&D subsidy participant (t-1)	2.776***	(0.203)	2.110***	(0.233)	2.566***	(0.239)
R&D subsidy participant (t-2)	0.342	(0.263)	1.179***	(0.261)	1.366***	(0.277)
R&D subsidy participant (t-3)	1.069***	(0.230)	1.264***	(0.203)	0.783***	(0.231)
Czech IP application (t-1)	0.527**	(0.219)	0.549***	(0.190)	0.929***	(0.214)
Czech IP application (t-2)	0.628***	(0.229)	0.146	(0.205)	-0.591**	(0.250)
Czech IP application (t-3)	0.051	(0.242)	0.325	(0.211)	0.255	(0.247)
International IP application (t-1)	-0.951	(0.594)	0.005	(0.441)	-0.662	(0.506)
International IP application (t-2)	0.343	(0.602)	-0.237	(0.487)	0.334	(0.579)
International IP application (t-3)	1.028*	(0.580)	0.546	(0.455)	1.165**	(0.488)
log(Number of employees)	0.205***	(0.062)	0.314***	(0.056)	0.233***	(0.069)
log(Firm's age)	-0.234**	(0.116)	0.135	(0.122)	0.541***	(0.172)
log(Operating revenue per employee)	0.028	(0.071)	0.211***	(0.069)	0.173**	(0.085)
ROA using P/L before tax (%)	-0.008	(0.005)	-0.001	(0.005)	0.003	(0.006)
Solvency ratio (%)	0.005**	(0.003)	0.005**	(0.003)	0.006**	(0.003)
Limited liability company (s.r.o.)	-0.785***	(0.134)	-0.583***	(0.125)	-0. 346***	(0.147)
Limited partnership (k.s.)	-2.094	(1.275)	..		..	
General partnership (v.o.s.)	..		1.400**	(0.644)	..	
Cooperative (družstvo)	-0.828	(0.603)	-1.745*	(1.022)	..	
C - Manufacturing	0.540	(0.747)	0.794	(0.783)	0.518	(0.712)
D - Electricity	0. 037	(0.900)	-0.622	(1.082)	-0.057	(1.014)
E - Water Supply	-1.042	(0.916)	-0.356	(0.906)	-0.163	(0.840)
J - ICT	0.314	(0.808)	0.013	(0.843)	0.639	(0.758)
M - Professional Activities	0.304	(0.769)	1.071	(0.796)	1.517**	(0.728)
Year of subsidy=2005	-0.440**	(0.195)	..		..	
Year of subsidy=2006	-0.441**	(0.194)	..		..	
Year of subsidy=2007	-0.543***	(0.193)	..		..	
Year of subsidy=2008	-0.609***	(0.197)	..		..	
Year of subsidy=2010	..	..	-1.524***	(0.173)	..	
Year of subsidy=2011	..	..	-1.113***	(0.157)	..	
Year of subsidy=2012	..	..	-2.013***	(0.176)	-0.625***	(0.168)
Year of subsidy=2013	..	..	..	..	-1.180***	(0.179)
Intercept	-5.136***	(1.014)	-7.955***	(1.045)	-8.943***	(1.142)
Region fixed effects	Yes		Yes		Yes	
Number of observations	20,109		20,797		16,045	
LR	$\chi2(38)=1419.82$***		$\chi2(37)=2102.33$***		$\chi2(34)=1684.04$***	
McFadden R^2	0.359		0.454		0.473	
McFadden R^2 (adjusted)	0.339		0.438		0.454	

*Note: Standard errors in parentheses; variables without index are 1-year lagged; baseline: Industry - Mining and Quarrying (B), year - 2004; 2009; 2011 (respectively), region – Prague and legal form - joint stock company; * p<0.05, ** p<0.01, *** p<0.001.*

Table A3. Quality of propensity score matching: observations on- and off-common support (NN 3 estimator)

Treatment	Common support	IMPULS	TIP	ALFA
Treated	On support	401	460	369
	Off support	3	28	6
Untreated	On support	19,705	20,309	15,670
	Off support	0	0	0
Total		20,109	20,797	16,045

Table A4. The number of observations reused in matching based on the weight of matched controls (NN 3 estimator)

	IMPULS			TIP			ALFA		
#	Weight	Freq.	Share (%)	Weight	Freq.	Share (%)	Weight	Freq.	Share (%)
1	0.33	563	76.08	0.33	547	70.04	0.33	375	69.19
2	0.67	85	11.49	0.67	112	14.34	0.67	56	10.33
3	1.00	31	4.19	1.00	52	6.66	1.00	29	5.35
4	1.33	20	2.70	1.33	21	2.69	1.33	29	5.35
5	1.67	12	1.62	1.67	13	1.66	1.67	16	2.95
6	2.00	8	1.08	2.00	11	1.41	2.00	16	2.95
7	2.33	6	0.81	2.33	4	0.51	2.33	3	0.55
8	2.67	5	0.68	2.67	7	0.90	2.67	3	0.55
9	3.00	3	0.41	3.00	5	0.64	3.00	1	0.18
10	3.33	3	0.41	3.33	2	0.26	3.33	2	0.37
11	3.67	1	0.14	3.67	2	0.26	3.67	3	0.55
12	4.00	1	0.14	4.00	1	0.13	4.00	1	0.18
13	4.33	1	0.14	4.33	2	0.26	4.33	4	0.74
14	4.67	1	0.14	4.67	1	0.13	4.66	0	0.00
15	5.00	0	0.00	5.00	1	0.13	5.00	1	0.18
16	5.33	0	0.00	5.33	0	0.00	5.33	1	0.18
17	5.67	0	0.00	5.67	0	0.00	5.67	1	0.18
21	7.33	0	0.00	7.33	0	0.00	7.33	1	0.18
	Total	740	100.0	Total	781	100.0	Total	542	100.0

Table A5. Propensity score matching estimates by the office of IP protection and matching estimator (conventional)

IP protection	Programme	Matching estimator	(t)		(t+1)		(t+2)		N
Czech IP protection	IMPULS	NN 1	0.043	(0.031)	0.023	(0.030)	0.050	(0.034)	20,104
		NN 3	0.033	(0.025)	0.028	(0.025)	0.058**	(0.028)	20,104
		NN 5	0.036	(0.024)	0.028	(0.024)	0.056**	(0.027)	20,104
		NN 3 (caliper 0.01)	0.033	(0.025)	0.028	(0.024)	0.074***	(0.024)	20,055
		Kernel	0.043*	(0.024)	0.036	(0.024)	0.063**	(0.027)	20,104
	TIP	NN 1	0.027	(0.031)	0.097***	(0.031)	0.095***	(0.032)†	20,783
		NN 3	0.007	(0.027)	0.091***	(0.024)	0.111***	(0.027)†	20,783
		NN 5	-0.009	(0.028)	0.094***	(0.025)	0.108***	(0.028)†	20,783
		NN 3 (caliper 0.01)	0.005	(0.024)	0.072***	(0.022)	0.103***	(0.023)†	20,731
		Kernel	0.002	(0.028)	0.082***	(0.027)	0.118***	(0.026)†	20,783
	ALFA	NN 1	0.001	(0.040)	0.064	(0.041)†	0.092**	(0.038)†	16,027
		NN 3	0.046	(0.028)	0.091***	(0.030)†	0.103***	(0.028)†	16,027
		NN 5	0.042	(0.026)	0.085***	(0.029)†	0.106***	(0.026)†	16,027
		NN 3 (caliper 0.01)	0.033	(0.027)	0.093***	(0.026)†	0.077***	(0.025)†	15,882
		Kernel	0.052	(0.034)	0.101***	(0.032)†	0.106***	(0.033)†	16,027
International IP protection	IMPULS	NN 1	0.001	(0.007)	-0.003	(0.009)	0.013*	(0.008)	20,104
		NN 3	-0.010	(0.011)	0.001	(0.011)	-0.002	(0.012)	20,104
		NN 5	-0.005	(0.010)	0.002	(0.010)	0.002	(0.010)	20,055
		NN 3 (caliper 0.01)	0.003	(0.007)	0.010	(0.006)	0.016**	(0.008)	17,683
		Kernel	-0.004	(0.011)	0.004	(0.011)	0.008	(0.011)	20,104
	TIP	NN 1	0.015	(0.015)	0.023**	(0.012)	0.021	(0.013)†	20,783
		NN 3	0.003	(0.018)	0.018*	(0.011)	0.019*	(0.012)†	20,783
		NN 5	-0.003	(0.017)	0.018*	(0.009)	0.022**	(0.010)†	20,783
		NN 3 (caliper 0.01)	0.004	(0.014)	0.011	(0.014)	0.016	(0.013)†	20,731
		Kernel	0.005	(0.014)	0.018*	(0.011)	0.020*	(0.011)†	20,783
	ALFA	NN 1	-0.003	(0.016)	0.020	(0.014)†	0.014	(0.011)†	16,027
		NN 3	-0.007	(0.017)	0.009	(0.013)†	0.015	(0.010)†	16,027
		NN 5	-0.008	(0.017)	0.009	(0.014)†	0.011	(0.011)†	16,027
		NN 3 (caliper 0.01)	-0.004	(0.013)	0.003	(0.015)†	0.003	(0.010)†	15,882
		Kernel	-0.005	(0.018)	0.009	(0.016)†	0.011	(0.012)†	16,027

*Note: Abadie Imbens robust standard errors in parentheses for nearest neighbour matching; bootstrapped standard errors after 1,000 replications in parentheses for kernel matching; * p<0.05, ** p<0.01, *** p<0.001.*
† IP application data are not complete due to the publishing delay.

Table A6. Propensity score matching estimates by the office of IP protection and matching estimator (conditional difference-in-differences)

IP protection	Programme	Matching estimator	(t)		(t+1)		(t+2)		N
Czech IP protection	IMPULS	NN 1	0.020	(0.036)	0.020	(0.036)	0.069*	(0.041)	20,104
		NN 3	0.020	(0.033)	0.019	(0.034)	0.052	(0.040)	20,104
		NN 5	0.025	(0.033)	0.012	(0.033)	0.052	(0.039)	20,104
		NN 3 (caliper 0.01)	0.034	(0.031)	0.026	(0.033)	0.051	(0.036)	20,104
		Kernel	0.034	(0.029)	0.026	(0.035)	0.051	(0.035)	20,104
	TIP	NN 1	0.015	(0.036)	0.096***	(0.036)	0.109***	(0.039)†	20,783
		NN 3	0.013	(0.034)	0.099***	(0.035)	0.127***	(0.036)†	20,783
		NN 5	0.016	(0.033)	0.096***	(0.034)	0.127***	(0.033)†	20,783
		NN 3 (caliper 0.01)	0.010	(0.031)	0.092***	(0.034)	0.131***	(0.031)†	20,783
		Kernel	0.010	(0.032)	0.092***	(0.033)	0.131***	(0.034)†	20,783
	ALFA	NN 1	0.006	(0.044)	0.064	(0.046)†	0.050	(0.052)†	16,027
		NN 3	0.014	(0.045)	0.085**	(0.042)†	0.095**	(0.045)†	16,027
		NN 5	0.016	(0.042)	0.087**	(0.042)†	0.094**	(0.045)†	16,027
		NN 3 (caliper 0.01)	0.027	(0.041)	0.083**	(0.041)†	0.100**	(0.044)†	16,027
		Kernel	0.027	(0.042)	0.083**	(0.040)†	0.100**	(0.045)†	16,027
International IP protection	IMPULS	NN 1	0.008	(0.015)	0.015	(0.016)	0.013	(0.016)	20,104
		NN 3	0.005	(0.015)	0.009	(0.015)	0.010	(0.015)	20,104
		NN 5	0.005	(0.015)	0.007	(0.014)	0.011	(0.014)	20,104
		NN 3 (caliper 0.01)	0.011	(0.013)	0.014	(0.015)	0.012	(0.015)	20,104
		Kernel	0.004	(0.014)	0.013	(0.014)	0.017	(0.013)	20,104
	TIP	NN 1	-0.002	(0.018)	0.011	(0.018)	0.017	(0.018)†	20,783
		NN 3	-0.003	(0.017)	0.011	(0.017)	0.014	(0.017)†	20,783
		NN 5	-0.001	(0.016)	0.011	(0.017)	0.016	(0.015)†	20,783
		NN 3 (caliper 0.01)	-0.003	(0.017)	0.009	(0.017)	0.014	(0.016)†	20,783
		Kernel	0.002	(0.015)	0.015	(0.014)	0.016	(0.013)†	20,783
	ALFA	NN 1	-0.011	(0.024)	0.017	(0.017)†	0.025	(0.021)†	16,027
		NN 3	-0.002	(0.022)	0.017	(0.016)†	0.021	(0.020)†	16,027
		NN 5	-0.003	(0.020)	0.015	(0.015)†	0.015	(0.020)†	16,027
		NN 3 (caliper 0.01)	0.008	(0.020)	0.017	(0.017)†	0.022	(0.021)†	16,027
		Kernel	-0.001	(0.018)	0.015	(0.015)†	0.014	(0.017)†	16,027

*Note: Bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.*
† IP application data are not complete due to the publishing delay

Table A7. Propensity score matching estimates for international IP protection based on pooled data from IMPULS, TIP and ALFA programmes

Estimation method	Matching estimator	(t)		(t+1)		(t+2)		N
Conventional estimation	NN 1	-0.013	(0.011)	0.003	(0.009)†	0.009	(0.008)†	49,321
	NN 3	-0.008	(0.008)	0.004	(0.008)†	0.009	(0.007)†	49,321
	NN 5	-0.010	(0.008)	0.001	(0.008)†	0.007	(0.007)†	49,321
	NN 3 (caliper 0.01)	-0.006	(0.007)	0.007	(0.008)†	0.013	(0.007)†	49,321
	Kernel	-0.006	(0.007)	0.005	(0.008)†	0.011	(0.007)†	49,321
Difference-in-differences estimation	NN 1	-0.006	(0.010)	0.006	(0.010)†	0.006	(0.009)†	49,321
	NN 3	-0.002	(0.010)	0.008	(0.009)†	0.014	(0.009)†	49,321
	NN 5	-0.005	(0.009)	0.006	(0.010)†	0.013	(0.009)†	49,321
	NN 3 (caliper 0.01)	-0.003	(0.009)	0.009	(0.010)†	0.014	(0.009)†	49,321
	Kernel	-0.004	(0.009)	0.007	(0.008)†	0.012	(0.008)†	49,321

*Note: Abadie Imbens robust standard errors in parentheses for nearest neighbour matching in conventional estimation and otherwise bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.*
† IP application data are not complete due to the publishing delay.

Table A8. Propensity score matching estimates for Czech IP protection by matching estimator and firm size (conditional difference-in-differences)

Programme	Size	Matching estimator	(t)		(t+1)		(t+2)		N
IMPULS	small	NN 1	-0.125*	(0.074)	0.042	(0.088)	0.083	(0.096)	6,276
		NN 3	-0.090	(0.062)	0.007	(0.078)	0.097	(0.078)	6,276
		NN 5	-0.083	(0.056)	0.004	(0.067)	0.104	(0.076)	6,276
		NN 3 (caliper 0.01)	-0.042	(0.065)	0.064	(0.071)	0.133	(0.080)	6,276
		Kernel	-0.084	(0.052)	0.024	(0.056)	0.108	(0.066)	6,276
	medium	NN 1	0.040	(0.043)	0.035	(0.055)	0.040	(0.057)	10,868
		NN 3	0.053	(0.043)	0.018	(0.044)	0.050	(0.054)	10,868
		NN 5	0.046	(0.035)	0.029	(0.047)	0.055	(0.049)	10,868
		NN 3 (caliper 0.01)	0.049	(0.043)	0.028	(0.046)	0.052	(0.048)	10,868
		Kernel	0.055	(0.032)	0.033	(0.039)	0.057	(0.050)	10,868
	large	NN 1	0.014	(0.063)	0.000	(0.069)	0.050	(0.075)	2,960
		NN 3	0.021	(0.054)	0.026	(0.061)	0.021	(0.065)	2,960
		NN 5	0.030	(0.061)	0.020	(0.061)	0.014	(0.060)	2,960
		NN 3 (caliper 0.01)	0.027	(0.066)	0.011	(0.061)	0.019	(0.075)	2,960
		Kernel	0.027	(0.050)	0.012	(0.055)	0.023	(0.059)	2,960
TIP	small	NN 1	-0.098	(0.083)	0.016	(0.083)	0.082	(0.089)†	7,315
		NN 3	-0.098	(0.084)	-0.016	(0.087)	0.033	(0.085)†	7,315
		NN 5	-0.089	(0.071)	-0.020	(0.086)	0.072	(0.086)†	7,315
		NN 3 (caliper 0.01)	-0.135*	(0.080)	-0.056	(0.090)	0.056	(0.085)†	7,315
		Kernel	-0.096	(0.063)	-0.004	(0.081)	0.066	(0.077) †	7,315
	medium	NN 1	0.030	(0.050)	0.108**	(0.052)	0.130**	(0.051) †	10,794
		NN 3	0.001	(0.047)	0.117***	(0.042)	0.126***	(0.045) †	10,794
		NN 5	0.016	(0.044)	0.112***	(0.042)	0.127***	(0.041) †	10,794
		NN 3 (caliper 0.01)	0.008	(0.049)	0.105**	(0.043)	0.115**	(0.045) †	10,794
		Kernel	0.008	(0.037)	0.100**	(0.039)	0.128***	(0.036)†	10,794
	large	NN 1	0.006	(0.058)	0.128*	(0.070)	0.077	(0.075)†	2,674
		NN 3	0.043	(0.051)	0.098	(0.066)	0.120*	(0.064)†	2,674
		NN 5	0.050	(0.056)	0.103*	(0.059)	0.119**	(0.058)†	2,674
		NN 3 (caliper 0.01)	0.057	(0.057)	0.101	(0.067)	0.116*	(0.063)†	2,674
		Kernel	0.049	(0.053)	0.109**	(0.055)	0.131**	(0.058)†	2,674
ALFA	small	NN 1	0.080	(0.088)	0.120	(0.105)†	0.253***	(0.094)†	5,935
		NN 3	-0.018	(0.072)	0.018	(0.097)†	0.124	(0.087)†	5,935
		NN 5	-0.043	(0.074)	0.013	(0.080)†	0.109	(0.077)†	5,935
		NN 3 (caliper 0.01)	-0.017	(0.066)	0.072	(0.090)†	0.126	(0.088)†	5,935
		Kernel	0.023	(0.075)	0.094	(0.080)†	0.150**	(0.070)†	5,935
	medium	NN 1	-0.005	(0.064)	0.094	(0.074)†	0.110	(0.067)†	8,100
		NN 3	0.031	(0.063)	0.110*	(0.066)†	0.126*	(0.064)†	8,100
		NN 5	0.047	(0.055)	0.140**	(0.060)†	0.147**	(0.059)†	8,100
		NN 3 (caliper 0.01)	0.012	(0.059)	0.110*	(0.066)†	0.126**	(0.063)†	8,100
		Kernel	0.048	(0.054)	0.126**	(0.052)†	0.122**	(0.061)†	8,100
	large	NN 1	0.088	(0.081)	0.025	(0.067)†	-0.038	(0.096)†	1,992
		NN 3	0.083	(0.078)	0.029	(0.065)†	0.004	(0.082)†	1,992
		NN 5	0.053	(0.077)	0.023	(0.065)†	0.010	(0.073)†	1,992
		NN 3 (caliper 0.01)	0.114	(0.084)	0.045	(0.081)†	0.033	(0.087)†	1,992
		Kernel	0.056	(0.066)	0.027	(0.063)†	0.023	(0.075)†	1,992

Note: Bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.
† IP application data are not complete due to the publishing delay.

Table A9. Propensity score matching estimates for Czech IP protection by matching estimator and industry (conditional difference-in-differences)

Programme	Size	Matching estimator	(t)		(t+1)		(t+2)		N
IMPULS	Industry	NN 1	0.022	(0.039)	0.022	(0.040)	0.074	(0.046)	17,759
		NN 3	0.009	(0.031)	0.008	(0.039)	0.056	(0.038)	17,759
		NN 5	0.019	(0.031)	0.017	(0.034)	0.056	(0.037)	17,759
		NN 3 (caliper 0.01)	0.011	(0.031)	0.001	(0.036)	0.055	(0.038)	17,759
		Kernel	0.016	(0.027)	0.010	(0.030)	0.053	(0.033)	17,759
	Services	NN 1	0.172*	(0.092)	0.141*	(0.084)	-0.016	(0.129)	2,345
		NN 3	0.047	(0.087)	0.036	(0.088)	-0.073	(0.114)	2,345
		NN 5	0.022	(0.083)	-0.003	(0.097)	-0.059	(0.112)	2,345
		NN 3 (caliper 0.01)	0.021	(0.081)	0.066	(0.074)	-0.042	(0.108)	2,345
		Kernel	0.065	(0.081)	0.046	(0.081)	-0.068	(0.100)	2,345
TIP	Industry	NN 1	0.014	(0.041)	0.095**	(0.047)	0.110***	(0.041)†	17,846
		NN 3	0.027	(0.039)	0.111***	(0.040)	0.139***	(0.043)†	17,846
		NN 5	0.010	(0.034)	0.083**	(0.036)	0.124***	(0.036)†	17,846
		NN 3 (caliper 0.01)	0.032	(0.037)	0.104***	(0.037)	0.137***	(0.037)†	17,846
		Kernel	0.018	(0.030)	0.089**	(0.035)	0.119***	(0.033)†	17,846
	Services	NN 1	-0.046	(0.081)	0.093	(0.077)	0.167**	(0.074)†	2,937
		NN 3	-0.022	(0.077)	0.099	(0.066)	0.167**	(0.066)†	2,937
		NN 5	-0.031	(0.074)	0.083	(0.069)	0.146**	(0.065)†	2,937
		NN 3 (caliper 0.01)	0.027	(0.070)	0.116*	(0.062)	0.194***	(0.060)†	2,937
		Kernel	-0.024	(0.067)	0.099	(0.066)	0.170***	(0.062)†	2,937
ALFA	Industry	NN 1	-0.096	(0.062)	0.056	(0.055)†	0.071	(0.071) †	13,570
		NN 3	-0.044	(0.057)	0.052	(0.052)†	0.084	(0.061)†	13,570
		NN 5	-0.017	(0.053)	0.072	(0.052)†	0.109**	(0.055)†	13,570
		NN 3 (caliper 0.01)	-0.052	(0.058)	0.077*	(0.045)†	0.102*	(0.059)†	13,570
		Kernel	-0.030	(0.048)	0.058	(0.041)†	0.093*	(0.052)†	13,570
	Services	NN 1	0.072	(0.072)	0.111	(0.083)†	0.059	(0.092)†	2,457
		NN 3	0.111*	(0.059)	0.133*	(0.072)†	0.092	(0.074)†	2,457
		NN 5	0.108**	(0.055)	0.128*	(0.072)†	0.085	(0.071)†	2,457
		NN 3 (caliper 0.01)	0.055	(0.065)	0.090	(0.078)†	0.043	(0.070)†	2,457
		Kernel	0.103*	(0.054)	0.121*	(0.065)†	0.078	(0.067)†	2,457

Note: Bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.
† IP application data are not complete due to the publishing delay.

Table A10. Propensity score matching estimates by matching estimator and type of Czech IP protection (conditional difference-in-differences)

IP protection	Programme	Matching estimator	(t)		(t+1)		(t+2)		N
Patents of inventions	IMPULS	NN 1	0.020	(0.032)	0.036	(0.034)	0.030	(0.033)	20,104
		NN 3	0.003	(0.027)	0.014	(0.029)	0.007	(0.029)	20,104
		NN 5	0.011	(0.025)	0.009	(0.029)	0.001	(0.028)	20,104
		NN 3 (caliper 0.01)	0.006	(0.027)	0.010	(0.030)	0.007	(0.029)	20,104
		Kernel	0.016	(0.023)	0.017	(0.025)	0.003	(0.027)	20,104
	TIP	NN 1	-0.020	(0.031)	0.057*	(0.032)	0.070**	(0.034)	20,783
		NN 3	-0.020	(0.028)	0.053*	(0.030)	0.072**	(0.032)	20,783
		NN 5	-0.021	(0.028)	0.055*	(0.029)	0.072**	(0.031)	20,783
		NN 3 (caliper 0.01)	-0.019	(0.028)	0.045	(0.030)	0.066**	(0.031)	20,783
		Kernel	-0.018	(0.025)	0.055**	(0.026)	0.070**	(0.028)	20,783
	ALFA	NN 1	0.036	(0.038)	0.062	(0.043)	0.017	(0.046)	16,027
		NN 3	0.049	(0.035)	0.077**	(0.036)	0.055	(0.041)	16,027
		NN 5	0.059*	(0.034)	0.077**	(0.037)	0.054	(0.039)	16,027
		NN 3 (caliper 0.01)	0.052	(0.035)	0.080**	(0.039)	0.054	(0.042)	16,027
		Kernel	0.057*	(0.031)	0.068**	(0.033)	0.046	(0.035)	16,027
Utility models	IMPULS	NN 1	-0.041	(0.034)	-0.018	(0.031)	0.056	(0.036)	20,104
		NN 3	-0.006	(0.030)	0.006	(0.029)	0.061*	(0.035)	20,104
		NN 5	0.002	(0.030)	0.009	(0.028)	0.059*	(0.033)	20,104
		NN 3 (caliper 0.01)	-0.001	(0.030)	-0.003	(0.028)	0.057*	(0.034)	20,104
		Kernel	0.007	(0.025)	0.002	(0.023)	0.057*	(0.030)	20,104
	TIP	NN 1	0.020	(0.034)	0.089**	(0.036)	0.091**	(0.036)	20,783
		NN 3	-0.002	(0.031)	0.075**	(0.032)	0.105***	(0.034)	20,783
		NN 5	-0.002	(0.030)	0.072**	(0.033)	0.117***	(0.031)	20,783
		NN 3 (caliper 0.01)	-0.001	(0.030)	0.072**	(0.032)	0.103***	(0.031)	20,783
		Kernel	-0.005	(0.026)	0.067**	(0.029)	0.104***	(0.029)	20,783
	ALFA	NN 1	0.020	(0.039)	0.064	(0.045)	0.101**	(0.048)	16,027
		NN 3	0.025	(0.039)	0.081**	(0.040)	0.122***	(0.043)	16,027
		NN 5	0.041	(0.036)	0.077**	(0.039)	0.124***	(0.043)	16,027
		NN 3 (caliper 0.01)	0.038	(0.037)	0.097**	(0.040)	0.139***	(0.045)	16,027
		Kernel	0.040	(0.032)	0.076**	(0.036)	0.114***	(0.037)	16,027

Note: Bootstrapped standard errors after 1,000 replications in parentheses; * p<0.05, ** p<0.01, *** p<0.001.
† IP application data are not complete due to the publishing delay.

Figure A1. Propensity score histograms for IMPULS, NN 3 estimator: Common support, Treated (with scores >0.1), Untreated (with scores >0.1) respectively

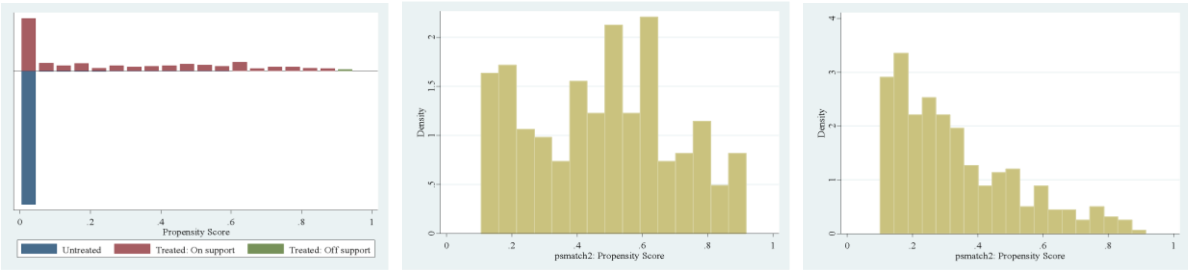


Figure A2. Propensity score histograms for TIP, NN 3 estimator: Common support, Treated (with scores >0.1), Untreated (with scores >0.1) respectively

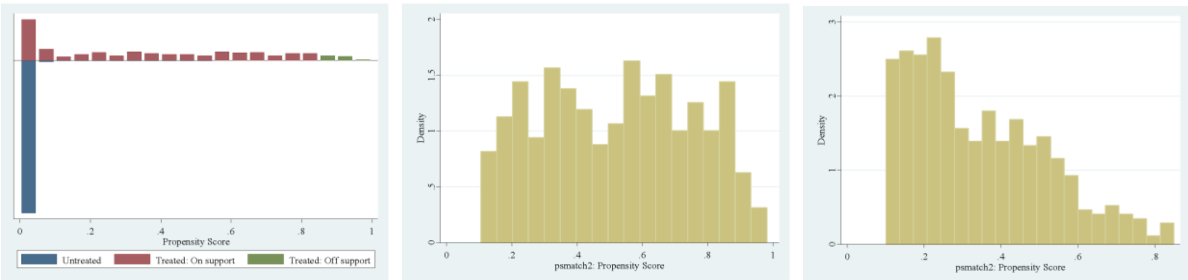


Figure A3. Propensity score histograms for ALFA, NN 3 estimator: Common support, Treated (with scores >0.1), Untreated (with scores >0.1) respectively

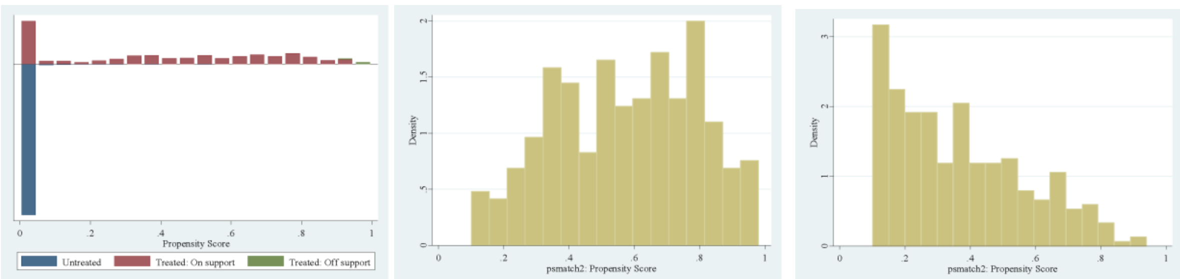


Figure A4. Absolute distance between propensity scores of treated and its matched controls for IMPULS, TIP and ALFA, respectively (NN 3 estimator)

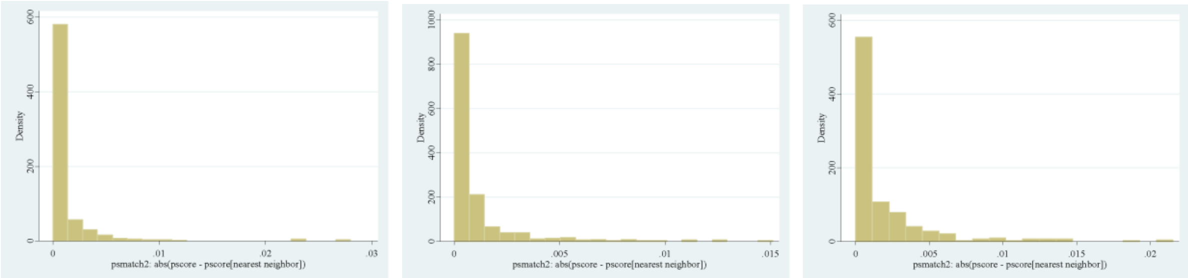
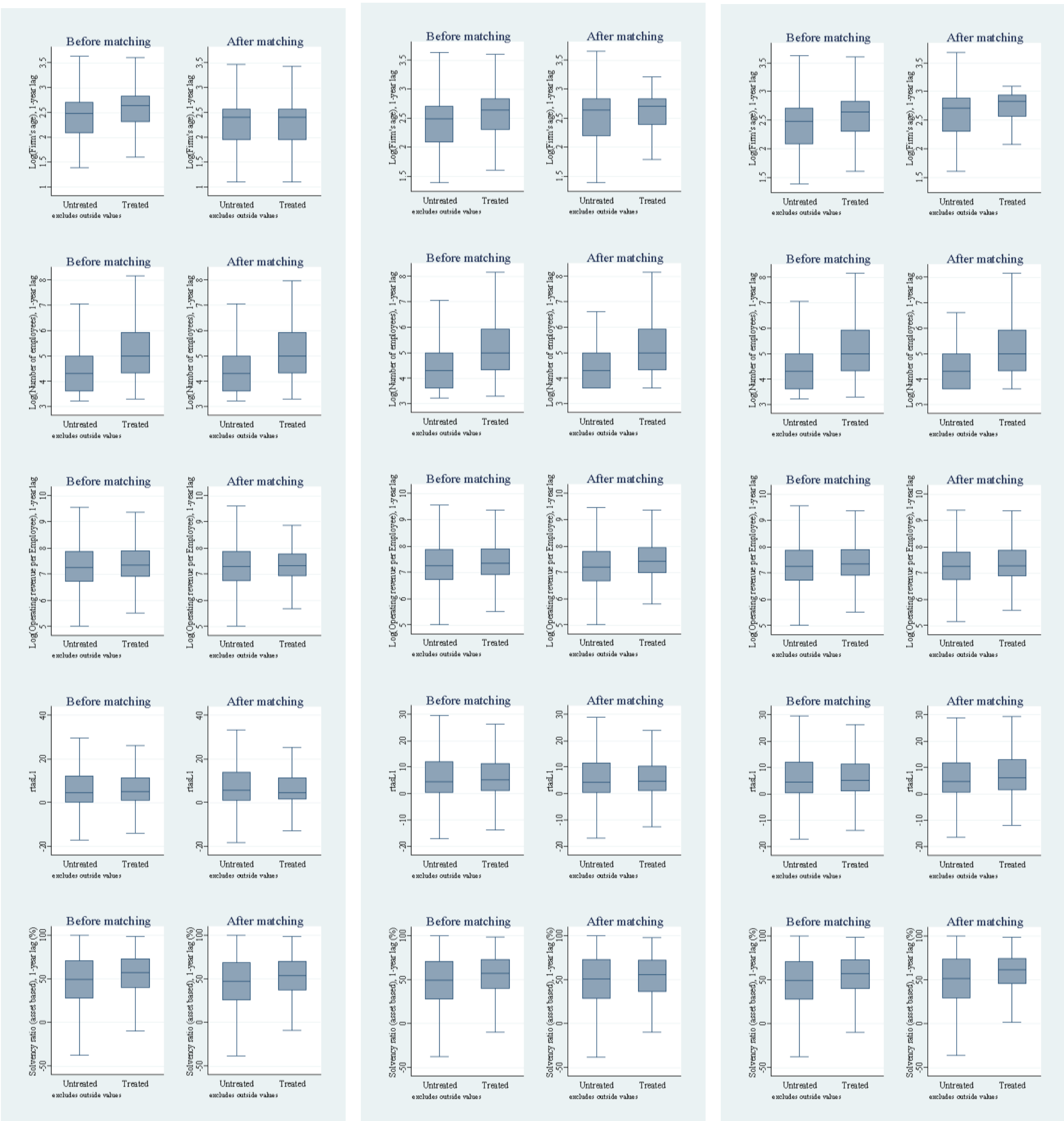


Figure A5. Box plots comparing variables before and after propensity score matching for IMPULS, TIP and ALFA programmes, respectively (NN 3 estimator)



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Do direct subsidies stimulate new R&D outputs in firms? A comparison of the IMPULS, TIP and ALFA programmes

Study of the Institut for Democracy and Economic Analysis (IDEA)

Vydavatel/Publisher: Národohospodářský ústav AV ČR, v. v. i., Politických vězňů 7, 111 21 Praha 1, Česká republika

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