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The effects of innovation policies on firm level patenting

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Abstract:
This paper examines the impacts of R&D tax credits and direct R&D subsidies on Norwegian firms' patenting, with a particular focus on environmental patenting. Whereas direct subsidies are aimed at projects with low private and high social return, tax credits do not discriminate between projects or technologies. We find that both direct subsidies and tax credits have significant positive effects on patenting in general. Although direct subsidies have triggered more patents, tax credits are more efficient in the sense that they have triggered more patents relative to the typical subsidy amount received. With regard to environmental patenting, we find no significant effects of tax credits, whereas the effects of direct subsidies are large and significant. A possible explanation is that environmental innovations face the environmental externality, greater knowledge externalities and require funding that is willing to take more risks and allow more patience. Tax credits currently favor small and medium sized firms and firms with relatively low R&D investments. For large firms, we find large and significant effects of direct subsidies, but no significant effects of tax credits.

Keywords: R&D tax credits, SkatteFUNN, direct R&D subsidies, environmental innovation, SMEs, Poission count model, fixed effects

JEL classification: C54, D22, O31, O38, Q55

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Sammendrag

Både direkte subsidier og skattefradrag gir flere patenter hos norske foretak. Når det gjelder miljørelatert teknologi, gir direkte subsidier størst effekt.

I studien «The effects of innovation policies on firm level patenting» ser forskeren Marit E. Klemetsen nærmere på effektene av FoU-politiske virkemidler på patentering i norske foretak, med et særlig fokus på miljørelatert teknologi.

Skattefradrag mest effektivt
Studien viser at både direkte subsidier og skattefradrag har signifikante, positive effekter på patentering generelt. Direkte subsidier har trigget flere patenter, men skattefradragene er mer effektive i den forstand at de har trigget flere patenter i forhold til de typiske subsidiebeløpene som foretakene mottar.

Miljøteknologi avhengig av langsiktig og risikovillig finansiering
Hva gjelder miljøpatenter viser studien ingen effekter av skattefradrag, mens effekten av direkte subsidier derimot er sterk og signifikant. En mulig forklaring er at miljøteknologi står overfor miljøeksternaliteter, genererer større kunnskapseksternaliteter, og i større grad er avhengig av langsiktig og risikovillig finansiering. For å stimulere denne typen teknologiutvikling bør subsidier fortsatt rettes mot prioriterte teknologiområder. Skattefradrag stimulerer i større grad til utvikling av teknologi som allerede ligger nære opp til de eksisterende markedsløsningene, og i mindre grad til de store teknologisprangene. Samfunnsgevinsten vil sannsynligvis øke dersom skattefradragene utformes slik at subsidiene reflekterer kunnskapseksternalitetene knyttet til prosjektet.

Subsidieres i tråd med potensiell verdi for samfunnet
Direkte subsidier fra Norges Forskningsråd og Innovasjon Norge er rettet mot prosjekter hvor den private gevinsten er lavere enn den potensielle verdien prosjektet har for samfunnet. Det vil si at direkte subsidier søker å subsidiere i tråd med størrelsen på kunnskapseksternalitetene knyttet til prosjektet. På den annen side, er skattefradrag fra SkatteFUNN-ordningen en rettighetsbasert ordning som er teknologinøytral i den forstand at foretaket selv kan bestemme hvilken type teknologi som skal utvikles.

Ingen effekter av skattefradrag hos store foretak
SkatteFUNN-ordningen favoriserer per i dag små og mellomstore foretak, fordi man antar at disse har lavere tilgang til privat finansiering. Hos store foretak identifiserer denne studien sterke og signifikante effekter av direkte subsidier, men ingen effekter av skattefradrag. Heller enn økte skattefradrag eller tilskudd til små og mellomstore foretak, bør man støtte foretak med lav tilgang til privat kapital gjennom låneordninger.

1 Introduction

A strict reliance on a market system will result in underinvestment in innovation, relative to the socially desirable level (Griliches, 2000; Martin and Scott, 2000). Market failures arise because of e.g. limited appropriability, financial constraints and external knowledge spillovers. For this reason, many countries undertake policies aiming to increase the R&D activity. The contribution of this paper is to examine the effects of public innovation policies in Norway on firms' propensity to patent. The policies that we consider are the R&D tax credit scheme (called *SkatteFUNN*) and direct R&D subsidies from the Research Council of Norway and Innovation Norway[1]. Moreover, we aim to provide insight into whether policy makers ought to stimulate environmental innovation specifically, in order to achieve a less distorted competition between environmental and non-environmental innovation, and whether the tax credit scheme ought to continue offering a higher percentage tax credit to small and medium sized firms (SMEs) than large firms.

A number of studies advocate that environmental innovations differ from other innovations. Environmental innovation stands out with respect to drivers and the importance of regulation (Horbach, 2008; Porter and Van der Linde, 1995). Several studies find that the development of environmental technologies are subject to a double externality problem. In addition to the knowledge externality, environmental innovation faces the environmental externality exerted by dirty input producers (Acemoglu et al., 2012; Dechezleprêtre et al., 2015; Jaffe et al., 2005; Rennings, 2000). The double externality problem reduces the incentives for firms to invest in environmental innovations. As long as markets do not punish environmental harmful impacts sufficiently, competition between environmental and non-environmental innovation is distorted (Rennings, 2000). Moreover, Dechezleprêtre et al. (2013) find that environmental technology patents have more citations. The authors argue that this is evidence of greater knowledge externalities, which motivates additional public R&D subsidies directed towards the development of environmental technologies. According

[1] A government body for promoting industry development.

to Mazzucato (2013), environmental innovation is an example of an innovation sector that relies on funding that is more willing to take risks and to invest in projects with longer time-horizons and lower expected returns. Despite the rich literature on differences between environmental and non-environmental innovation, we are not aware of any empirical studies that compare the effect of different innovation policies on general versus environmental innovation. Our empirical analysis seeks to fill this gap.

The interest by policy-makers in innovation arises from the premise that public policy is able to influence both the rate and the direction of innovation (Haščič and Migotto, 2015). Innovation policies to support private R&D activities should reflect the size of the external spillovers from the research (Goulder and Schneider, 1999; Straathof et al., 2014). Even if such external spillovers are found to differ between innovation sectors, the Norwegian R&D tax credit scheme offers the same subsidies for any type of technology or sector. Hence, tax credits do not aim specifically to finance according to the size of the external spillovers from the research. Instead, the tax credits favor small and medium-sized firms (SMEs) and firms with relatively low R&D costs (see Section 2.2). On the other hand, both the Research Council and Innovation Norway offer direct R&D subsidies intended for projects with low private and high social return. Hence, they aim to reflect the size of the external spillovers of the research project through specific programs.

There is a substantial amount of literature on the effects of public R&D subsidies on private R&D. A central debate is on whether public R&D funding crowds out private R&D, or if public R&D subsidies induce additional private R&D. Moreover, firms can benefit from other firms' previous accumulations of knowledge.[2] For a review, see e.g. David et al. (2000) or Hall et al. (2010). Almus and Czarnitzki (2003) use a matching strategy on firms in Eastern Germany and find that firms that received public R&D funding achieve a higher R&D intensity on average than firms in the control group. Bøler et al. (2014) find that the Norwegian tax credits have positive effects on R&D and imported inputs of intermediates,

[2]Often referred to as the "standing on shoulders"-effect. The benefits of such spillovers are not taken into account in firms' decisions with regard to R&D investments (Romer, 1990).

whereas Hægeland and Møen (2007a) identify positive effects of tax credits on R&D.

Increased R&D expenditures is not necessarily equivalent to increased productivity and human capital development. For instance, nominal R&D might increase because firms adapt to the policies by reclassifying spending that they otherwise would not have characterized as R&D. Policies with low administration costs and limited control routines, such as the tax credit scheme, could be particularly vulnerable to such adaptations. Other studies investigate the effect of R&D subsidies on innovation. Bérubé and Mohnen (2009) find that firms which receive direct R&D subsidies in addition to R&D tax credits are more innovative than firms which only receive tax credits. Cappelen et al. (2012) find that tax credits contribute to an increase in the rate of firms' innovation, but not to an increase in patenting. Horbach (2008) identifies effects of financial investment subsidies on innovation. However, none of the mentioned analyses use patent registry data – instead they use survey data with self-reported measures of innovation and patenting. Johnstone et al. (2010) identify effects of environmental policies on renewable energy patents. However, as this study is at the country level, several heterogeneity issues are likely to be present. Moreover, none of the studies mentioned above compare the effects of innovation policies on innovation in general and environmental innovation in particular.

In this study we use Norwegian firm level registry data on patents which recently have been assigned with firm identification numbers, allowing us to merge data on patents with various other data sets, such as innovation policy databases, accounting statistics and data on environmental regulations and education levels of employees. In most countries, there is no unique identifier allowing researchers to link intellectual property information directly to other firm-level data (Helmers et al., 2011).[3]

We contribute to the existing literature in three ways. First, we investigate potential differences between the response of an R&D tax credit scheme and direct R&D subsidies

[3]Instead, the names indicated on patent documents, including assignee and inventor names, and the firm names contained in firm-level databases are used to merge data sets. Matching firm names across data sets is challenging and prone to errors (Helmers et al., 2011; Tarasconi and Kang, 2015).

on innovation in general and environmental innovation in particular. Second, we include the entire population of Norwegian incorporated firms in our study. Previous studies are typically based on innovation surveys. For Norway, this limits the sample to large firms and a sub-sample of SMEs. Hence, we are able to identify effects of various innovation policies on SMEs as well. Third, according to both theoretical and empirical approaches to the economics of innovation (see Cohen, 2010, for a literature overview), other specific characteristics of firms are also likely to influence innovation. Our rich data set allows us to control for observed firm heterogeneity through a wealth of control variables. In the study on environmental patenting we also control for supply-side (both direct and indirect) regulations that the firms may face using firm specific data on non-tradable and tradable quotas as well as relative energy prices ("dirty" over "clean").

We find that both R&D tax credits and direct R&D subsidies have significant effects on patenting. Relative to the subsidies received, tax credits are more efficient in generating patents compared to direct subsidies. However, as the estimates do not capture patent value or commercialization, we cannot exclude that direct subsidies typically trigger more important or valuable innovations. Direct subsidies are aimed at projects with low private and high social return. When policy makers target priority technology areas, they are aware that such projects typically involve a higher risk of a lower return, even if the project has a high potential value. With regard to environmental innovation, we find no significant effects of tax credits. On the other hand, direct subsidies have large and significant effects on environmental patenting. Our empirical results confirm the notion that the conditions for environmental innovation stand out from innovation in general. The tax credit scheme does not take into account that environmental innovation is exposed to greater market failures such as path dependencies towards dirty technologies, public good issues, larger knowledge externalities, etc. Technology-neutral tax credits thus enhance the distorted competition between environmental and non-environmental innovation. For large firms, we find large and significant effects of direct subsidies, but no significant effects of tax credits. Vital but long-term or risky R&D projects would be facilitated if, rather than favoring SMEs and firms with relatively low R&D costs, tax credits were designed to reflect the size of the external spillovers from the research generated by the project.

The rest of the paper is organized as follows: Section 2 contains a description of the data and the variables used in the empirical analysis. The econometric model and the results are presented in Section 3. Finally, Section 4 concludes and suggests some policy implications.

2 Data sources and description of variables

Drawing on several sources, we have prepared a firm-level panel data set covering the entire population of Norwegian incorporated firms. The data span 19 years, from 1993 to 2011. To measure innovation, we use patent data from the Norwegian Patent Office.[4] The latter data source enables the identification of type of technology (environmental or non-environmental). The Norwegian patent data contains firm identification numbers allowing us to match patents to data sets on regulations and control variables from several other sources. The firm identification numbers allow for a more reliable match of the patent data to the other data sets. PATSTAT and the US patent office also offer firm identifications, but only as firm names. Even if the patent offices have harmonized the name use within their organizations, name harmonization with other data sources is challenging. The Norwegian firm identification numbers are unique for each firm and is used as a common identifier for all data sources.

Data on innovation policies are gathered from three different sources: Innovation Norway's (and predecessor's) databases, the PROVIS database from the Research Council of Norway and the SkatteFUNN database. Another advantage of using these data sources is that information related to R&D subsidies are in fact available for the entire population of

[4]Thanks to Pål Knudsen at Statistics Norway for supplementing the official data from the Norwegian Patent Office with complete IPC-codes from electronically available patent documents, as the official data set only includes the first IPC-code in the application.

firms that have received support.[5] Hence, we rely only on registry (not survey) data. Several studies on the effects of innovation policies rely on R&D surveys. However, comparing the data from the SkatteFUNN database and the Norwegian R&D survey data shows that the timing of the R&D support, and also often the reported sums received, differ greatly. There are also large discrepancies between the survey-reported patenting and the actual registered patents and patent application data from the Norwegian Patent Office.

The data mentioned above are supplemented with annual data from three different registers at Statistics Norway: The accounts statistics, the register of employers and employees, and the national education database. These data sources allow us to construct several control variables at the firm level. In order to control for supply-side policies, which are likely to matter for environmental innovation, we include firm level data on electricity-, petroleum- and gas prices, and tradable carbon emission quotas from the Energy and Environmental Accounts and the National Accounts at Statistics Norway. Finally, we have data from the Norwegian Environmental Agency (NEA) on direct regulations of all land based Norwegian firms that have emission permits from the NEA. A detailed description of the key variables is provided below, where they are grouped into three main categories: measures of innovation (Section 2.1), measures of innovation policies (Section 2.2), and other determinants of innovation (control variables – Section 2.3).

2.1 Innovation measures

We use patent applications and granted patents as measures of innovative activities. When studying firms' responses to policies, the input activity can be a more appropriate measure of the incentive than successful outcomes of the activity. On the other hand, the analysis on granted patents allows us (at least partly) to take into account the quality of the innovation.

An advantage of using patent data is that patent documents provide information about the nature of the innovation, so that they can be classified by technological area. To

[5] If more than one firm participates in a project, the data from the PROVIS-database are only available for the main contractor firm.

identify environmental patents, we follow Johnstone et al. (2010), Lanzi et al. (2011), and Dechezleprêtre et al. (2013), and classify the technology based on the International Patent Classification (IPC) codes developed by the World Intellectual Property Organization.[6] Environmental technologies are broadly defined as patents that have direct or indirect effects on the environment, by e.g. improving energy or fuel efficiency, preventing pollution through source or waste reduction, eliminating pollution after it has occurred ("end-of-pipe"), etc.

A potential issue in relation to patent data is that we cannot distinguish valuable from insignificant patents. Many patents have little value, and so the number of patent applications (or even granted patents) is primarily a measure of innovative activity or effort, rather than the value of the innovations. Moreover, patenting is only one means of protecting innovations. Innovators may prefer secrecy to prevent the public disclosure of an innovation required by patent law, or to save the significant fees associated with filing patents (Dechezleprêtre et al., 2011). On the other hand, there are very few examples of economically significant innovations that have not been patented (Dernis and Guellec, 2001; Dernis and Khan, 2004). Thus, despite their drawbacks, it is reasonable to assume that patents are strongly correlated with innovations.

We see from Figure 1 that the number of non-environmental patent applications increases until 2007, but then decreases. This drop in non-environmental patent applications is possibly due to the financial crisis. Strikingly enough, environmental patent applications do not drop during or after the crisis. The annual numbers of granted patents are increasing in the first years, but towards the end of the period both the number of environmental and non-environmental granted patents drop. Keeping in mind that the number of environmental patent applications is increasing in the same period, the drop from 2009 and onwards is likely, at least partly, due to the processing time at the Patent Office which is typically two to three years. Using data on granted patents thus involves timeliness problems (censoring), and we return to this issue in Section 3.

[6] http://www.wipo.int/classifications/ipc/en/est/index.html

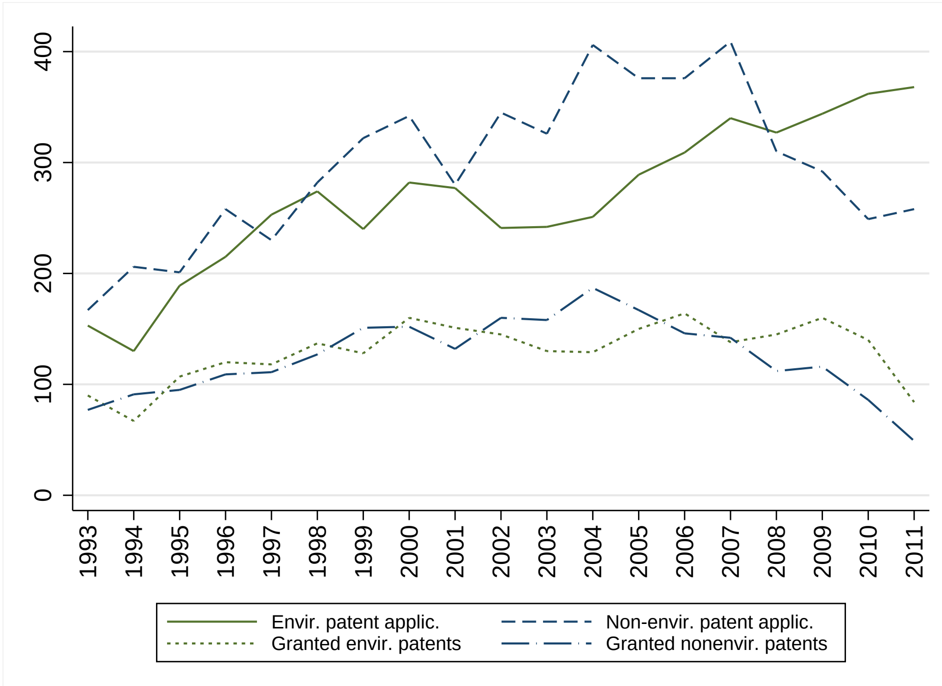

Figure 1: Yearly sum of patent applications and granted patents.

2.2 Innovation policy measures

The Norwegian innovation policy instruments can be grouped into two main categories: i) tax credits, which are rights-based subsidies, given that some formal requirements are fulfilled by the applicant; and ii) direct subsidies intended for projects with low private and high social returns. Direct subsidies aim to reflect the size of the external spillovers from the research. The primary difference between these two innovation policy instruments is that the former typically allows firms to choose projects, whereas the latter usually is accompanied by a government directed project choice (David et al., 2000). As a result, direct subsidies involve competition between agents. The two types of subsidies are thus exposed to different types of selection biases. A frequently advocated argument against direct subsidies is that the state should not try to "pick winners". Mazzucato (2013) argues that we need to shift the focus away from the worry that the state is picking winners, and towards the needs of complex, network dependent, high-risk, and patience-demanding innovation sectors. A main difference between public and private venture capital is that public venture capital is willing to invest in areas with much higher risk, while allowing a longer time-horizon and lower expectations of future returns. Examples of innovation sectors that rely particularly on such conditions are the computer industry, the internet, the pharmaceutical-biotech industry, nanotech and the emerging green tech sector.

The development of environmental technologies is exposed to a joint market failure (referred to in the literature as the *double externality problem*). In addition to the knowledge externality, environmental innovation suffers from the environmental externality exerted by dirty input producers.[7] These combined market failures provide a strong rationale for a portfolio of public policies that foster emissions reduction (supply-side) as well as the development and adoption of environmentally beneficial technology (demand-side) (Jaffe et al., 2005). Supply-side environmental regulations, such as e.g. taxes on pollution, can spur environmental innovation by creating incentives for less polluting technologies. Dechezleprêtre et al. (2013) argue that once some mechanism (e.g. taxes on pollution) is in place to internalize the environmental externality, there is no reason a priori to implement R&D policies specifically targeting clean technology development. However, using environmental (supply-side) regulations both to reduce emissions and to stimulate R&D would lead to excessive distortions (Acemoglu et al., 2012). Acemoglu et al. (2012) thus argue that an optimal policy involves immediately directing R&D towards clean technologies. Moreover, Dechezleprêtre et al. (2013) identify larger knowledge spillovers (measured as patent citation counts) within clean technologies than within other types of technologies. Hence, the authors argue that pollution pricing should be complemented with specific support for clean innovation, e.g. through additional direct R&D subsidies that go beyond standard policies in place to internalize knowledge externalities. De Marchi (2012) finds that environmental innovation relies more on cooperation with larger networks of external partners.

Traditionally, Norwegian R&D subsidies have mainly been given as direct subsidies to

[7] Acemoglu et al. (2012) find that environmental innovation suffers from market size effects ("path dependence") and price effects (a productivity advantage of dirty inputs).

firms (Hægeland and Møen, 2007b). The Research Council and Innovation Norway provide different types of direct subsidies.[8] The Research Council offers strategic and targeted subsidies for research where at least 50 percent of the project is expected to be financed by the firm itself.[9] They also have larger programs designed to build long-term knowledge to encourage innovation, enhance value creation, as well as help find solutions to important challenges facing society. Innovation Norway offers direct subsidies in the form of direct grants, high-risk loans and guaranties. Both the Research Council[10] and Innovation Norway[11] offer direct subsidies for priority thematic and technology areas, such as e.g. environmental technologies.

Tax incentives have become an increasingly popular policy tool over the last decades, and in several countries it is a supplement to direct R&D subsidies.[12] In Norway, a R&D tax credit scheme (*SkatteFUNN*) was proposed and passed as a part of the Norwegian tax system by the parliament in December 2001. The program was introduced in January 2002 to SMEs[13] but extended to all firms in the following year. It was believed that an R&D tax credit scheme would provide more stable conditions for the business community than direct grants (Cappelen et al., 2010). Firms are entitled to tax credits as long as the R&D project has been approved by the Research Council. Firms can deduct from their taxes a certain amount of their R&D expenditures. Currently, tax credits favor SMEs and – because of a maximum tax relief limit – firms with relatively low R&D investments.[14] The limit makes

[8] The Research Council and Innovation Norway not only provide support intended to enhance innovation. The policy assignments from the government to Innovation Norway can be specified in three separate categories: In addition to innovation, they support regional development and offer financial lending intended to improve survival probabilities. We exclude support intended for the two latter objectives from our data in order to identify the effects from subsidies aimed at innovation. In addition to innovation subsidies, the Research Council provides support for e.g. project establishments and knowledge-building projects not directly related to innovation, which we exclude from our data.

[9] Direct subsidies from Innovation Norway typically covers a larger percentage of the project cost. See the home page of Innovation Norway (in Norwegian) for more details.

[10] http://www.forskningsradet.no/en/Research_areas/1252498540762

[11] http://www.innovasjonnorge.no/no/finansiering/miljoteknologi/

[12] R&D tax incentive schemes are widely adopted in advanced economies including the United States, Japan, and all EU countries except Germany and Estonia (Straathof et al., 2014).

[13] Firms with a) less than 250 employees, and b) a yearly sales income not exceeding 50 million Euros or a yearly profit not exceeding 43 million Euros (§ 16-40-5 Regulations for Law of Taxation)

[14] From 2003 the *SkatteFUNN* scheme granted large firms 18 percent of R&D expenses related to an approved project up to a limit of 4 million NOK (approximately 0.5 million euros). From 2009 and onwards the maximum limit increased to 5.5 million NOK. Hence, the maximum tax relief for a large firm (until 2014 when the limit increased

Table 1: Patent and innovation subsidy statistics and firm sizes[1], 2002-2011

	Sum[2] tax credits			Sum[2] dir. subs. (RCN and IN)			Patent applications		
Year	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
2002	634,793	44,908	519	423,063	184,144	131,719	389	87	193
2003	1,011,367	181,201	50,441	388,790	167,213	138,310	356	106	174
2004	1,108,595	201,914	56,154	376,750	155,426	126,858	415	87	185
2005	872,582	168,711	53,914	404,525	173,325	127,191	404	107	179
2006	860,095	164,653	50,395	589,808	209,654	203,542	385	99	210
2007	811,023	135,141	42,230	686,028	213,676	208,123	406	95	269
2008	830,868	130,598	43,293	847,496	232,874	201,247	451	90	191
2009	965,339	167,356	44,990	2,198,721	441,983	333,572	477	102	157
2010	986,536	178,587	57,233	1,615,357	347,524	200,851	408	80	173
2011	1,059,070	182,810	58,165	1,526,396	342,462	274,767	457	89	134

[1]Small firms: <50 employees, medium firms: $[50, 250)$ employees, large firms: ≥ 250 employees
[2]The figures are in 1000 NOK

the program relatively less appealing to firms that currently have much resources invested in R&D (as firms are not subsidized on the margin for expenses exceeding the limit). A rationale for favoring SMEs is that these may face greater financial constraints. Although low access to loans or private venture capital can hinder innovation, it is in practice difficult to identify firms that truly are exposed to such constraints, and the best solution is thus not necessarily higher percentages tax credits or grants. Another rationale behind favoring SMEs is the notion that innovation and economic growth is created by "entrepreneurial" small firms. However, there is little empirical evidence to support this notion. As Mazzucato (2013) points out, the relationship between firm size and innovation is sensitive to various factors such as industry or technology specific effects. Moreover, many of the small firms tend to be young. Based on the current design, the purpose of tax credits is not to reflect the size of the external spillovers from the research. Unlike direct subsidies, the Norwegian tax credit scheme does not discriminate between types of projects or technologies. However, even if tax credits may make marginal projects profitable, firms will still focus on projects

again) was 5.5*0.18=0.99 million NOK (113 000 euros, based on the mean exchange rate 1 NOK≈8.73 EURO per 2009). For SMEs the rate is 20 percent. The tax refund takes place the year after the actual R&D expenses have occurred. If the firm does not pay enough taxes, they get the remaining tax credit as a direct grant. See Cappelen et al., 2010 for more details.

Table 2: Incorporated firms receiving innovation subsidies, 2002-2011

	Tax credits (SkatteFUNN)			Direct subsidies (RCN)			Direct subsidies (IN)		
Year	Sum[1]	Firms	Median[1]	Sum[1]	Firms	Median[1]	Sum[1]	Firms	Median[1]
2002	689,341	1749	315	555,635	375	533	190,001	284	400
2003	1,253,382	3176	314	535,383	381	500	163,879	282	348
2004	1,375,581	3481	318	503,798	311	690	158,871	291	300
2005	1,099,471	2690	330	557,220	344	750	153,467	248	250
2006	1,077,706	2512	356	776,391	423	907	238,650	329	250
2007	988,549	2369	343	793,604	441	1000	314,931	337	300
2008	1,004,758	2241	373	837,773	590	636	444,337	404	373
2009	1,177,685	2242	420	1,045,084	442	1052	1,929,191	760	700
2010	1,222,357	2328	410	1,340,699	397	1511	823,033	551	440
2011	1,300,046	2347	437	1,503,256	315	3051	640,368	480	435

[1]The figures are in 1000 NOK

with the greatest short-term returns. Tax credits may not be the best policy tool to promote new technologies that are not close to the market (Dechezleprêtre et al., 2015; David et al., 2000). Moreover, it is unlikely that tax credits contribute in reducing the market failures and challenges that face the development of environmental technologies in particular.

Table 1 provides some statistics of the total sum of R&D subsidies received and patent applications for small and large firms. During the years 2002-2011, 282,891 firms can be categorized as small, 5,525 firms as medium sized and 1,030 firms as large. Even if large firms receive only 4 percent of the tax credits and 16 percent of the direct subsidies, they hold 24 percent of the patent applications. Medium sized firms receive 14 percent of the tax credits, 20 percent of the direct subsidies, and hold 12 percent of the patent applications. Finally, small firms receive 82 percent of the tax credits, 63 percent of the direct subsidies, and hold 53 percent of the patent applications. It seems that the larger the firm, the more innovative it is, relative to the funding. A possible explanation is that large firms respond more efficiently to the policies (i.e., that the policy maker gets a higher return for subsidizing large firms). Another possibility is that larger firms are more innovative regardless of the policies. We investigate this further at the firm level below (see Tables 10-11 and the discussion in Section 4).

Table 3: Patent statistics based on innovation subsidy received, 2002-2011

Subsidy received	Firms	Applications	Granted	Applications (envir.)	Granted (envir.)
Only tax credits	5,871	1,752	796	765	359
Only direct subsidies[1]	1,580	462	191	239	108
Both subsidies[2]	1,993	3,499	1,546	1,752	841
Neither subsidy	287,734	1,270	433	612	227

[1]Either from the Research Council or Innovation Norway
[2]Tax credits and direct subsidies from either the Research Council or Innovation Norway

Table 2 illustrates some statistics for firms that receive subsidies in the time period 2002-2011. During the years 2003-2006 the total sum of tax credits from SkatteFUNN exceeds the total sum of direct subsidies from the Research Council and Innovation Norway combined. The opposite is true for the years 2002 and 2007-2011.[15] The median amount of tax credits received is somewhat lower than the median amount of direct subsidies, but a larger number of firms receive tax credits than direct subsidies. Table 3 displays patent statistics for firms based on whether or not they receive subsidies from some given source in the time period 2002-2011. Firms that receive both direct subsidies and tax credits have a much higher propensity for patenting than firms which only receive subsidies from one source.[16]

In our empirical analysis, we use dummy variables to measure the effect of the two types of R&D subsidies. The fact that direct subsidies are typically larger than tax credits at the firm level is thus not taken into account. A firm receiving a large amount of support can have a higher propensity for patenting, *cet. par.* However, taking this into account by including weights for amounts received, would imply that we actually measure the effect of R&D investments, as the subsidies received typically constitute some percentage of the firm's R&D. An alternative is to control for R&D expenditures. However this would significantly reduce the sample size as R&D data are only available for a sub-sample of Norwegian firms. Moreover, this would eliminate some of the effects that we are interested in estimating, as

[15]The huge increase in direct subsidies from Innovation Norway in 2009 was a part of the government efforts to compensate for the financial crisis.
[16]A large share of the 1,580 firms that only receive direct subsidies are firms that receive support only from Innovation Norway.

R&D expenditures and patenting are highly correlated. When interpreting the marginal effects in Section 3, we should relate these estimates directly to the subsidies received.

Bøler et al. (2014) and Hægeland and Møen (2007a) investigate effects of the Norwegian tax credit scheme. In order to reduce bias the studies use a difference-in differences approach and exploit that, for a given firm, only R&D investments up until NOK 4 million were eligible for the tax credits. Firms that already invest more than the cap are not subsidized at the margin and hence have little or no incentive to increase their R&D. They thus argue that this provides exogenous variation in the selection of firms that were given support (the treatment group) and the ones which were not (the control group). However, data on R&D are only available in survey data (and for a sub-sample of Norwegian firms) and what the firm would have invested in the absence of the tax credit scheme is not observable. Moreover, it is questionable whether this method is usable when firms can receive support over several years. Finally, firms have an incentive for tax planning. That is, to inflate reported R&D in years they are given a tax relief (adapt the timing) or by claiming tax credits against spending that they would not previously have classified as R&D (OECD, 2007). We thus do not believe the cap provides an exogenous selection of a treatment and control group. In any case, we want to study the effects not only of tax credits, but also of direct subsidies (where there is no such limit on R&D expenditures). Instead, we choose a count data model with fixed effects. We return to the modeling issue in Section 3.

2.3 Control variables

Contrary to studies at the industry level, our analysis takes into account firm heterogeneity, and thereby reduces the problem of omitted variables bias. We use the number of employees as a measure of firm size. Profit margin (profits divided by total revenue) is a measure of the financial resources of the firm. Capital intensity is measured as tangible fixed assets excluding buildings and land (in fixed prices) relative to the number of employees. The share of employees with masters' education or more is included as a measure of employee

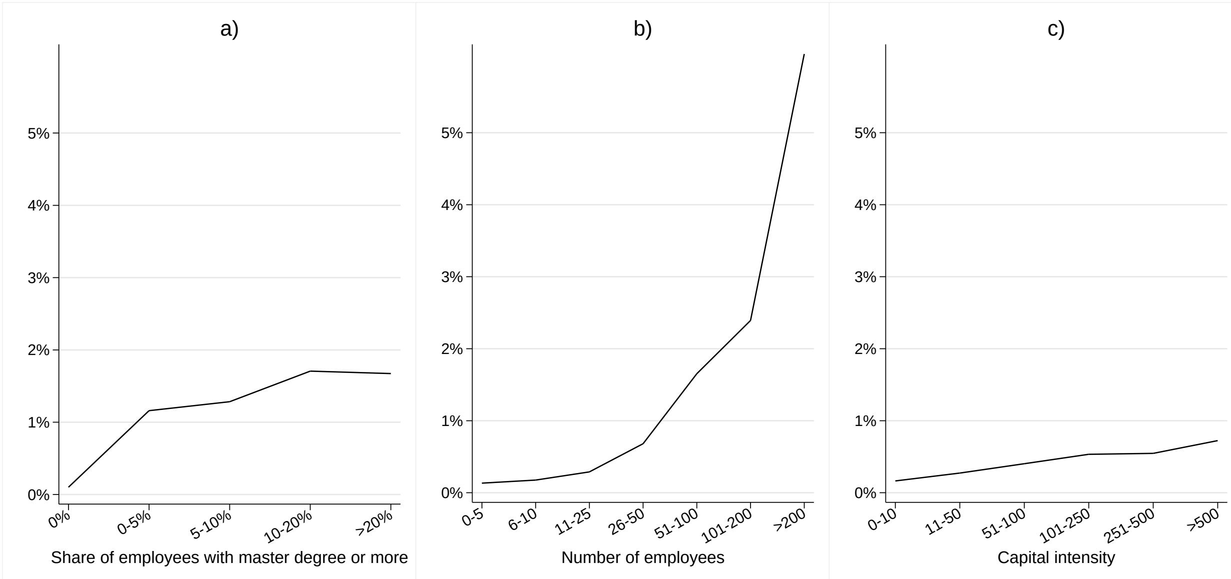

Figure 2: Firm characteristics (intervals on the horizontal axes) and the probability of at least one patent application in a firm-year (y-axes). The sample mean value is 0.6 percent.

skill. Figure 2 shows that several firm specific characteristics are important drivers of innovation and should be included as control variables. A positive relationship between the propensity for patenting and employee skill is illustrated in panel a. Firm size is also positively correlated with patenting (panel b). Panel c illustrates that the propensity for patenting increases moderately with capital intensity.

Figure 3 depicts the share of firm-years[17] in each of the aggregated industries with at least one patent application,[18] and at least one granted patent, as well as the share of firms in the industries that at least once in the estimation period receive R&D tax credits, direct R&D subsidies from the Research Council (RCN) or Innovation Norway (IN). The upper panel shows large differences between industries with regard to the propensity for patenting. An additional explanation can be that some industries tend to rely more on other means of profiting from their innovations than patenting. The three top industries in terms of propensity for patenting are Mining; Manufacturing of chemicals, pharmaceuticals, rubber

[17]A firm-year is the observation of one firm in one year.

[18]That is, the number of firm-years with at least one patent application divided by the total number of firm-years in the industry.

and plastic; and Manufacturing of metals and minerals. Whereas the two latter industries are among the top three receivers of (all types of) subsidies, Mining is not. Hence, while the general tendency is that the industries that relatively often receive subsidies also have a relatively high propensity for patenting, this is not always the case. We include industry dummies in order to pick up industry fixed effects, such as e.g. differing strategies on how to protect and appropriate income from their innovation. We deal with common trends by including year fixed effects.

Environmental regulations (supply-side policies) intended to affect production and consumption patterns can encourage environmental innovation by making pollution more costly (Jaffe et al., 2005; Lanjouw and Mody, 1996; Horbach, 2008; Klemetsen et al., 2013; Porter and Van der Linde, 1995; Popp, 2003; Brunnermeier and Cohen, 2003). In the analysis of environmental innovation we thus add firm level controls of direct (technology standards and non-tradable emission quotas) and indirect environmental regulations (taxes and tradable emission quotas).

In Norway, any emission that harms or may harm the environment is, as a general rule prohibited. If a firm wishes to emit polluting substances it has to apply for a permit from the Norwegian Environment Agency (NEA). The NEA regulates and monitors the environmental performance of polluting operations involving more than 200 pollutants to air and water. The regulations consist of both non-tradable emission quotas and technology standards. When a firm is granted a permit, the NEA assigns each firm to a risk class. The assignment to a risk class is based on the strength of the recipient of the emission (e.g. the vulnerability of a river, its wind and stream conditions, popularity of a recreation area, etc.) and the emission level. The risk classes vary from 1 (the highest) to 4 (the lowest), where risk class 1 comprises firms considered to be potentially highly environmentally harmful. A higher risk class is associated with higher regulatory costs for the firm in several ways. They are subject to more frequent and more costly inspections, and warnings of higher fines. This may provide an incentive for innovation. However, it may also be the case that unobserved firm heterogeneity is correlated with risk class without being caused by it. An example is heterogeneity with regard to emissions, since firms that emit regulated substances may be more likely to develop new technology or products based on them than firms that do not.

Environmental taxes are usually levied on energy goods. Ideally, we would like to investigate the effect of such taxes on patenting. However, in the data we cannot separate the energy pre-tax prices from the emission taxes. In any case, the firm adjusts to the total energy prices, including taxes. Energy prices of gas, petroleum and electricity are calculated as the firm's use in NOK relative to the firm's use in kWh.[19] The relative energy price is calculated as the price of dirty energy (weighted gas and petroleum prices) relative to the prices of clean energy (electricity). Electricity is clean energy as hydro power is the main source of electricity production in Norway. High relative input prices can provide incentives to innovate in factor reducing technologies (Hicks's induced innovation theory). Norway is part of the EU Emission Trading Scheme (ETS), which regulates carbon emissions in the EU and EFTA area. The ETS was introduced in 2005, and extended (phase 2) in 2008. We include a dummy which is equal to 1 if the firm receives tradable emission quotas from the ETS in a given year.

[19]Electricity prices are firm-specific in the energy-intensive part of the manufacturing industries, because prices are based on long-term contracts. Other firms purchase electricity at market prices.

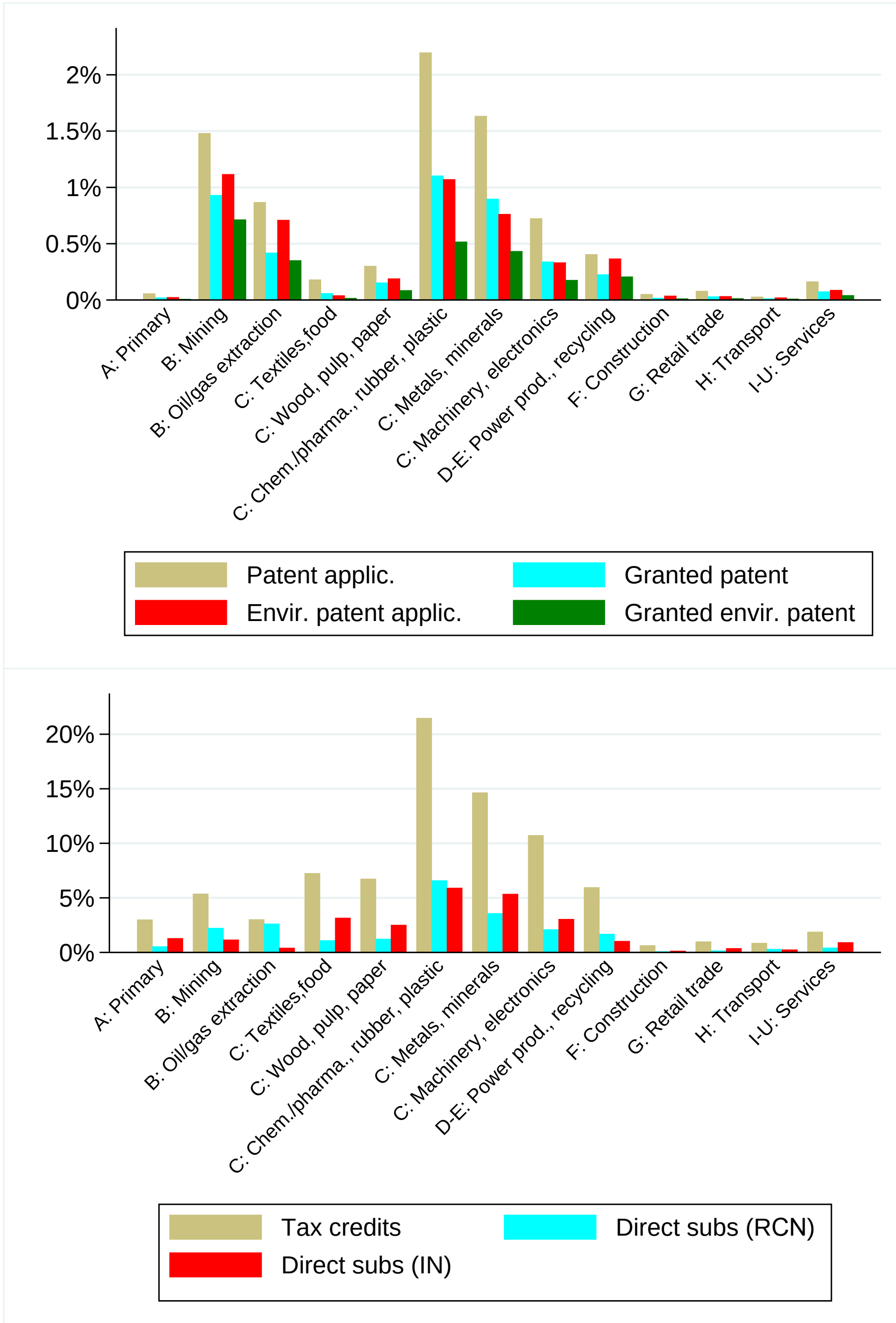

Figure 3: The share of firms in each industry which during 1993-2011 have at least one patent application, environmental patent application, granted patent or granted environmental patent (upper panel), and which at least once have received R&D tax credits or direct R&D subsidies from the Research Council (RCN) or Innovation Norway (IN) (lower panel).

Table 4: Sample summary statistics, 1995-2011

	All firms		Patenting firms	
Variable	Mean	Median	Mean	Median
Patent applications	.006	0	.401	0
Granted patents	.003	0	.186	0
Environmental patent applications	.003	0	.185	0
Granted environmental patents	.001	0	.093	0
Taxcredits (1000 NOK)[1]	6.93	0	129.4	0
Direct subsidies RCN (1000 NOK)[2]	6.35	0	237.7	0
Direct subsidies IN (1000 NOK)[3]	2.82	0	55.4	0
Tax credits (share)[1]	.015	0	.221	0
Direct subsidies RCN (share)[2]	.004	0	.110	0
Direct subsidies IN (share)[3]	.002	0	.027	0
Share of high-skilled employees	.057	0	.155	.023
Number of employees	15	4	122	15
Profit margin[4]	-.360	.041	-2.51	.046
Capital intensity[5]	298.3	38.8	820.6	77.8
Relative energy prices	.97	.80	1.04	.82
EU ETS dummy	.0002	0	.002	0
Dummy for risk class=1	.0004	0	.009	0
Dummy for risk class=2	.0009	0	.017	0
Dummy for risk class=3	.0029	0	.028	0
Dummy for risk class=4	.0012	0	.013	0
Number of firm-year observations	1,276,265		18,469	
Number of firms	179,410		1,715	

[1]Tax credits were present in the years 2002 and onwards
[2]Direct subsidies from the Research Council were present in the entire period
[3]Direct subsidies from Innovation Norway were present from 2000 and onwards
[4]Operating profits relative to operating income
[5]Tangible fixed assets excluding buildings and land (in 1000 NOK per employee)

2.4 Sample summary statistics

Our initial sample consists of 366,265 incorporated Norwegian firms over the time period 1993-2011. However, as we study the effects of innovation policies in years *t-1* and *t-2* on patenting in year t, innovation policies in the years 1993-1994 are automatically missing and dropped. Moreover, we drop observations with missing values. Our final unbalanced panel data set consists of 1,276,265 (firm-year) observations and 179,410 firms. Finally, in the fixed effects models, firms which never patent are automatically dropped from the analysis. The estimation sample in the main model (Table 6, column II) thus consists of

Table 5: Share of firm-years across industries, 1995-2011

Industry	Percent
Primary	1.56
Mining	0.37
Oil and gas extraction	0.12
Manufacturing of textiles and food	3.79
Manufacturing of wood, pulp and paper	1.05
Manufacturing of chem., pharmac., rubber and plastic	0.56
Manufacturing of metals and minerals	2.08
Manufacturing of machinery and electronics	3.72
Power production and recycling	0.51
Construction	12.51
Retail trade	31.58
Transport	5.34
Services	36.83
Total	100

22,989 (firm-year) observations and 1,974 firms. Table 4 provides summary statistics for the main variables. In addition, we include year fixed effects to control for common trends, and industry dummy variables to capture industry-specific effects. The thirteen industries are aggregated as shown in Table 5 and are based on the official industry classification SIC 2007.

3 Empirical model and results

As already stated, our main research question is whether the two main types of innovation policies – R&D tax credits and direct R&D subsidies – spur innovations in the form of patenting. In line with the discussion in Section 2.2, we examine this question using dummy variables indicating whether the firm receives subsidies from the various types of innovation policies. We then investigate whether there is a connection between the innovation policies and patenting.

In our empirical model, the dependent variable, P_{it}, is a count variable denoting the number of patent applications of firm i in year t.. We assume that P_{it}, given a vector of explanatory variables, x_{it}, and the firm-specific (random or fixed) effect, ν_i, has a Poisson distribution with mean

$$E(P_{it}|x_{it}, \nu_i) \equiv \lambda_{it} = exp(x'_{it}\beta + \nu_i). \tag{1}$$

The Poisson-family of distributions has two main benefits. First, provided the conditional mean λ_{it} (the expected number of patent applications) is correctly specified, it yields a consistent quasi-maximum likelihood estimator of β even if the assumption of a Poisson-distribution does not hold (see Gourieroux and Monfort, 1995, Ch. 8.4). Second, it yields a consistent estimator of β also when ν_i is a fixed effect (and possibly correlated with x_{it}). The latter does not hold for other common count models, such as e.g. the Negative Binomial model.

Let us now define $TC_{it} = I\left(\max\left\{TaxCredit_{i,t-1}, TaxCredit_{i,t-2}\right\} > 0\right)$ as the dummy variable which is 1 if the firm received tax credits in year t-1 *or* t-2.[20] Similarly, we define $DS_{it} = I\left(\max\left\{DirSub_{i,t-1}, DirSub_{i,t-2}\right\} > 0\right)$ as the dummy variable which is 1 if the firm received direct subsidies from the Research Council or Innovation Norway in year t-1 or t-2. We assume that the log of the expected number of patent applications, λ_{it} (see equation 1) is given by the following equation:

$$\ln(\lambda_{it}) = \pi \cdot TC_{it} + \gamma \cdot DS_{it} + \mathbf{X}'_{it}b + \nu_i \tag{2}$$

where $\mathbf{X}_{it}$ is a column vector containing the control variables described in Section 2.3, including dummies for year (1993-2011) and industries (see Table 5 for a list). The two explanatory variables of main interest are the innovation policies which enter equation (2) with lagged values to eliminate the potential problem of reversed causality, i.e., that patenting may affect the innovation policy, rather than the other way around. We include the two previous years since pinpointing the effect from the policy is challenging, and since many

[20] $I(A)$ is the indicator variable which is 1 if the statement A is true and zero if not.

firms receive subsidies over several years. To avoid reverse causality with regard to the control variables, the vector $\mathbf{X}_{it}$ also contains lagged (t-1) values, except for the industry and year dummy variables, which refer to year t.

We acknowledge that the random effects (RE) model does not solve the simultaneity issues. Most importantly, firms that receive subsidies from any of the two types of policies, are more likely to be innovative regardsless of whether they obtain subsidies or not. The RE model is thus not appropriate for identifying causal effects of the policies, and these results are mainly useful for providing descriptive statistics. On the other hand, the fixed effects (FE) specification captures correlation between unobserved firm specific effects and observed right-hand side variables. This comes at the cost of throwing out from the analysis firms that never patent, as time-invariant variables are automatically dropped in a fixed effects specification. As a result, the FE model is appropriate for investigating the intensity of innovation rather than the propensity to innovate.[21]

The parameters of main interest in equation (2) are π, which reflects the effects from the tax credits, and γ, which reflects the effects from direct subsidies from the Research Council or Innovation Norway. We can interpret π and γ as the expected increases in the number of patent applications resulting from receiving subsidies from the policy in question, relative to the expected number of patent applications without the subsidy. From equation (10) in Cameron and Trivedi (2014) it follows that for a subsidized firm the marginal effect, ME_{it}, of receiving tax credits or direct subsidies in year $t-1$ or $t-2$ on the expected number of patents, λ_{it}, are

$$\begin{aligned} \mathrm{ME}_{it}^{TC} &= \gamma E\left(P_{it}|TC_{it}=0, DS_{it}, \mathbf{X}_{it}, \nu_i\right) \\ \mathrm{ME}_{it}^{DS} &= \pi E\left(P_{it}|TC_{it}, DS_{it}=0, \mathbf{X}_{it}, \nu_i\right) \end{aligned} \tag{3}$$

[21] Mohnen and Röller (2005) find that the phase of the innovation process, i.e. the probability of becoming an innovator and the intensity of innovation, are subject to different constraints. However, as they point out, their results are based on cross-sectional evidence. Hence, they are not able to solve potential endogeneity issues. We choose to use a fixed effects specification where the endogeneity issues are significantly reduced, even if this means that we disregard firms that never patent.

By summing up the marginal effects, ME_{it}^{TC}, for the subsidized firms over all firm-years where $TC_{it} = 1$, we get an estimate of the total number of patents that are triggered by tax credits, and similarly for ME_{it}^{DS} over firm-years with $DS_{it} = 1$ for direct subsidies.

3.1 Results

The estimation results[22] of the basic version of our econometric model in equation (2) including all patent applications and granted patents are presented in Tables 6-7. The estimated effects on environmental patent applications and granted patents are displayed in Tables 8 and 9. In these estimations we add controls (included in $\mathbf{X}_{it}$ in equation (2)) for direct and indirect environmental regulations, described in Section 2.3. Finally, we do a robustness check with regard to the effects of the innovation policies on the patenting of SMEs and large firms respectively (see Tables 10-11).

3.1.1 All technologies

Table 6 contains the results of the effects of innovation policies on the number of patent applications, whereas Table 7 displays the effects on the number of granted patents. RE and FE correspond, respectively, to the random and fixed effects specification of ν_i (the firm-effect). The estimated coefficients of the variables involving the innovation policies are displayed in the two first rows of both tables.

From the results in Table 6, it appears that both tax credits and direct subsidies have positive and significant effects on innovation. The estimated relative effect of tax credits (π) on the expected number of patent applications is 0.63 in the RE model (significant at the 1 percent level) and 0.23 in the FE model (significant at the 5 percent level). This means that the estimated relative increase in expected number of patent applications stemming from obtaining tax credits compared to not obtaining the subsidy is 0.23 (in the FE model). The estimated relative effect of direct subsidies (γ) on the expected number of patent applications

[22] The results are obtained using the *xtpoisson* command in STATA.

Table 6: Results: Effect of innovation policies on patent applications

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.630***	.010	.165**	.072
Direct subsidies	γ	.679***	.042	.230**	.099
Share of high-skilled employees		1.581***	.002	.029	.162
Firm size (1000 employees)		.040**	.019	.026	.021
Profit margin		.0001	.0001	.0002	.0003
Capital intensity		.002***	.0005	.001***	.0004
Sum of ME (Tax credits)				367**	144
Sum of ME (Direct subsidies)				687**	261
Number of firm-year observations		1,276,265		18,469	
Number of firms		179,410		1,715	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

is 0.68 (significant at the 1 percent level) in the RE model and 0.17 in the FE model (significant at the 5 percent level). Tax credits thus appear to have just slightly smaller effects than direct subsidies. We see that in the FE model, the hypothesis that $\pi = \gamma$ cannot be rejected. Hence, we do not find any support for significant differences between the effects of the two different types of innovation policies on the number of patent applications. The estimates based on the RE specification are much larger than those of the FE model. This indicates that there are in fact serious selection issues present that invalidate the RE specification assumptions. Not surprising, firms that apply for R&D subsidies are likely to be more innovative than firms which do not apply. The RE specification is thus primarily useful for providing a descriptive representation of the policies. Henceforth we only give detailed descriptions of the FE results, and unless stated otherwise, all results refer to the FE model.

With regard to the control variables, the estimated coefficients of employee skill, firm size and capital intensity are positive and significant in the RE model. However, in the FE model, only capital intensity is significant.

Table 7: Results: Effect of innovation policies on granted patents

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.836***	.008	.193*	.101
Direct subsidies	γ	.972***	.006	.195**	.098
Share of high-skilled employees		1.902***	.002	.062	.272
Firm size (1000 employees)		.054**	.020	.023	.020
Profit margin		.0001	.0002	.0001	.0003
Capital intensity		.0002	.0002	.0002	.0002
Sum of ME (Tax credits)				183*	86
Sum of ME (Direct subsidies)				293**	131
Number of firm-year observations		1,276,265		10,377	
Number of firms		179,410		962	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

We replicate the results of Table 6 in Table 7, with granted patents instead of filed patent applications. This allows us (at least partly) to take into account the quality of the innovation. For this analysis, we excluded the last observation year (2011) to ensure that at least 90 percent of the applications of the last included year (2010) were processed at the date of our patent data extraction (May 2014). This is due to the timeliness issues described in Section 2.1.

Our findings from the analysis of the effects on patent applications are mostly replicated in Table 7. The estimated relative effect of tax credits (π) on the expected number of patents is 0.19 (significant at the 10 percent level). The estimated relative effect of direct subsidies (γ) on the expected number of patents is 0.20 (significant at the 5 percent level). Similar to Table 6, the effect of direct subsidies is marginally greater than the effect of tax credits. However, we cannot reject that $\pi = \gamma$, and thus we cannot say that the effects of the two different types of innovation policies differ. If the issue of direct subsidies “picking winners” is imminent, we could perhaps expect a drop in the estimated effect of direct subsidies on granted patents. Our results do not indicate any such tendency.

The estimates of the control variables are quite similar to those of Table 6, with the exception of the estimate of the parameter attached to capital intensity, which is now insignificant.

By summing up the marginal effects calculated as indicated in equation (3) tax credits are estimated to have triggered 367 patent applications and 183 granted patents. Similarly, direct subsidies are estimated to have triggered 687 patent applications and 293 granted patents. Direct subsidies have thus triggered almost twice as many patents compared to tax credits, even if the estimates of the relative effects, the estimates of π and γ, are almost identical. On the other hand, firms receiving tax credits typically acquire around half of the amount as firms receiving direct subsidies.[23] Moreover, tax credits were introduced some years later than direct subsidies.[24] Taking these factors into account, tax credits can be seen as more efficient in generating patents than direct subsidies. However, as the number of patents by itself does not provide an indication of their relative importance and impact, we cannot exclude the possibility that direct subsidies trigger more valuable innovations.

3.1.2 Environmental technologies

Table 8 displays estimated effects of innovation policies on environmental patent applications, whereas Table 9 displays effects on granted environmental patents. The estimated coefficients of the innovation policy variables are displayed in the two first rows of both tables. From the FE results in Table 8, it appears that both tax credits and direct subsidies have positive effects on environmental patenting. The estimate of π is only 0.16 and not significant at any conventional level. On the other hand, direct subsidies (γ) have highly positive and significant effects on environmental innovation. The estimated relative effect

[23] Comparing the number of patents triggered by the two types of policies with the administrative costs of the policies, the differences in relative efficiency would be larger. However, one of the explanations for the low administrative costs of the tax credits is lower requirements of documentation. Hence, the possibility of tax motivated adaptations are more likely to be present. It is possible that firms claim tax credits against spending that they would not previously have classified as R&D (OECD, 2007). Norwegian studies find tendencies of such adaptions (Fjærli, 2007; Olgyai et al., 2006). Administrative costs are thus not necessarily an advisable benchmark to measure efficiency. More research on possible tax evasion and avoidance resulting from R&D policies is thus necessary.

[24] Tax credits were introduced in 2002, whereas the Research Council provided direct R&D subsidies in the entire estimation period (1995-2011). Innovation Norway started providing direct innovation subsidies from around 2000.

Table 8: Results: Effect of innovation policies on environmental patent applications

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.718***	.005	.156	.097
Direct subsidies	γ	.882***	.016	.248**	.116
Share of high-skilled employees		1.888***	.002	.113	.190
Firm size (1000 employees)		.074***	.010	.051**	.021
Profit margin		.0001	.0002	.0002	.0004
Capital intensity		.052***	.008	.001***	.0004
Relative energy prices ("dirty"/"clean")		.022	.024	.031	.049
Risk class = 1		3.172***	.120	.548**	.263
Risk class = 2		1.567***	.256	.068	.356
Risk class = 3		1.541***	.055	.034	.841
Sum of ME (Tax credits)				158	89
Sum of ME (Direct subsidies)				389**	158
Number of firm-year observations		1,276,265		9,765	
Number of firms		179,410		900	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

on the expected number of patents is 0.25 (significant at the 5 percent level).

With regard to the control variables, the estimated coefficients of firm size and capital intensity are positive and significant. Firm size was not significant in Table 6. Hence, scale effects only seem to be present for firms which innovate in environmental technologies, and not necessarily for firms that innovate in other types of technologies. A possible explanation is that environmental innovation generate larger knowledge spillovers, as suggested by Dechezleprêtre et al. (2013).

The estimated coefficients of environmental regulations that firms may be exposed to are displayed in the four last rows. The estimated coefficient of relative energy prices is positive but not significant. Hence, based on these results, we cannot confirm that an increase in the ratio between prices on dirty and clean energy leads to increased incentives for environmental innovation. The estimated coefficients of the risk class dummies, reflecting

Table 9: Results: Effect of innovation policies on granted environmental patents

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.875***	.070	.174	.118
Direct subsidies	γ	1.142***	.006	.230*	.135
Share of high-skilled employees		2.131***	.004	.412	.390
Firm size (1000 employees)		.059**	.030	.024	.018
Profit margin		.0001	.0002	.0001	.0003
Capital intensity		.0002	.0002	.018	.013
Relative energy prices ("dirty"/"clean")		.024	.021	.046	.040
Risk class = 1		2.991***	.121	.567	.808
Risk class = 2		2.109***	.176	.418	.510
Risk class = 3		1.410***	.028	.041	.227
Sum of ME (Tax credits)				83	51
Sum of ME (Direct subsidies)				193*	100
Number of firm-year observations		1,276,265		5,716	
Number of firms		179,410		519	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

direct regulations, are positive and decreasing with risk class, which may reflect that firms in risk class 1 are more strictly regulated, but also that they are typically dirtier and perhaps more likely to invent new environmental technologies notwithstanding the regulatory regime. The reference category consists of the firms in risk class 4 and the firms that are not regulated by the NEA. The estimated coefficient of the highest risk class (1) is significant at the 5 percent level, whereas the risk class 2 and 3 dummies do not enter significantly. These estimates should be viewed as control variables rather than causal effects, as discussed in Section 2.3.[25]

In order to take into account some patent quality aspects, we replicate the results of Table 8 in Table 9, with granted environmental patents instead of environmental patent applications. Our findings from the analysis of the effects on patent applications are mostly

[25]See Klemetsen et al. (2013) for an analysis of the causal effect of direct regulations on innovation of environmental technologies.

Table 10: Results: Effect of innovation policies on patent applications: SMEs

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.939***	.013	.195***	.076
Direct subsidies	γ	.732***	.021	.120*	.069
Share of high-skilled employees		1.907***	.039	.101	.152
Firm size (1000 employees)		1.299	.177	.691***	.154
Profit margin		.0004	.0003	.0002	.0003
Capital intensity		.001	.002	.001***	.0003
Sum of ME (Tax credits)				268***	93
Sum of ME (Direct subsidies)				137*	71
Number of firm-year observations		1,261,748		15,976	
Number of firms		177,959		1,516	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

confirmed in Table 9. The estimated relative effect on the expected number of patents stemming from R&D tax credits is 0.17 (but not significant at any conventional level). The estimated relative effect of direct subsidies on the expected number of patents is 0.23 (significant at the 10 percent level).

Regarding the control variables, none of the estimates are now significant. This is likely due to the decrease in sample size (519 firms in Table 9 compared to 900 in Table 8).

We estimate the sum of marginal effects as indicated in equation (3). The estimates of the number of environmental patent applications and granted patents triggered by direct subsidies are 389 and 193, respectively. Tax credits are estimated to have triggered 158 patent applications and 83 granted patents, but the estimates are not significant at any conventional level. This finding is likely to reflect that environmental innovation is more exposed to externalities and that the design of the tax credit scheme does not take this into account by being technology neutral.

Table 11: Results: Effect of innovation policies on patent applications: Large firms

Poisson Count model		RE		FE	
Explanatory variables:	Coef.	Est.	S.E.	Est.	S.E.
Tax credits	π	.147*	.092	.061	.118
Direct subsidies	γ	.552***	.092	.395**	.202
Share of high-skilled employees		.271	.254	.021	.174
Firm size (1000 employees)		.034	.026	.035	.032
Profit margin		.028	.006	.012	.014
Capital intensity		.002***	.0003	.009***	.0003
Sum of ME (Tax credits)				52	99
Sum of ME (Direct subsidies)				696***	113
Number of firm-year observations		14,517		2,493	
Number of firms		1,451		199	

Full set of industry and year dummies are included but not reported.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors.

3.1.3 SMEs and large firms

Table 10 displays estimated effects of innovation policies on patent applications in SMEs, whereas Table 11 displays effects on patent applications in large firms. Similar to in Table 1 small and medium sized firms are here defined as having less than 250 employees, and large firms as having 250 or more employees. From the results in Table 10, it appears tax credits have positive and highly significant effects on patenting in SMEs. The estimated coefficient is 0.20 (significant at the 1 percent level). Summing up the marginal effects, tax credits are estimated to have triggered 268 patent applications among SMEs. However, from Table 11 we see that tax credits are estimated to have triggered 52 patent applications among large firms, but this estimate is far from significant. The lack of effect on large firms could mean that the return of the policy investments to large firms are lower. However, as larger firms are more innovative (see Section 2.2), it is more likely that the lack of effect is due to the fact that tax credits provide less incentives for large firms. First, as large firms receive a smaller tax credit refund percentage (18 compared to 20 percent for SMEs). Second, as

R&D spending increase with firm size, larger firms' R&D are likely to more often exceed the tax credit limit, and thus not incentivized on the margin. As the most innovative firms are likely to already invest substantially in R&D, the maximum limit is likely to prevent the private returns from tax credits from ending up where they would have the largest effect. Direct subsidies, on the other hand, have positive and significant effects on patenting in both groups of firms, although much larger effects on patenting in large firms. The estimated coefficients are 0.40 for large firms (significant at the 5 percent level) and 0.12 for small firms (significant at the 10 percent level). Summing up the marginal effects, we estimate the direct subsidies to have triggered 696 patent applications among large firms and 137 patent applications among SMEs.

4 Conclusions and policy implications

We find that both R&D tax credits and direct R&D subsidies have significant positive effects on patenting in general. Although direct subsidies have triggered more patents, tax credits are more efficient in the sense that they have triggered more patents relative to the typical subsidy amount received. However, as these results do not take into account that the value of patents differ, we cannot exclude the possibility that direct subsidies trigger more valuable patents than tax credits.

Innovation policies to support private R&D activities should first and foremost reflect the size of the external spillovers from the research. Direct subsidies from the Research Council and Innovation Norway are thus targeted specifically towards projects with low private return and high social return, such as e.g. the development of environmental technologies. Our results indicate that tax credits do not stimulate environmental technologies significantly, whereas we identify large and significant effects from direct subsidies on environmental innovation. This finding is likely to reflect that environmental innovation is more exposed to market failures and that the design of the tax credit scheme does not take this into account by being technology neutral. First, environmental innovation is exposed to the environmental externality. Second, the literature suggests that environmental innovation generates larger knowledge externalities. Third, the development of environmental technologies is an example of an innovation sector that often requires more risk taking, larger initial investments and a longer time horizon. Neither the market nor technology-neutral innovation policies remove the barriers for perfect competition between environmental and non-environmental innovation. Targeting R&D subsidies specifically towards prioritized technology areas that generate larger externalities is thus likely necessary in order to foster major innovation leaps and new technologies that are not already close to the market.

The Norwegian tax credits favor SMEs as these statistically are exposed to more financial constraints. Furthermore, due to a budget constraint, firms with relatively low R&D expenditures are more incentivized. Our results indicate that both tax credits and direct subsidies have positive and significant effects on patenting in SMEs. However, whereas the effects of direct subsidies on patenting in large firms are high and significant, there are no significant effects of tax credits on patenting in large firms. This finding is likely to reflect that tax credits provide less incentives for larger firms. This can both be as large firms receive a slightly smaller percentage deduction from the taxes (18 rather than 20), but also as ambitious R&D projects that exceed the tax credit limit are not incentivized on the margin. An end of the current positive discrimination of SMEs is thus likely to steer tax credits to where they would have the largest effects. However, loans or grants early in the innovation process are more likely to facilitate access to capital than a tax credit offered in retrospect. Moreover, loans offer a better solution than grants as we cannot identify the firms which truly have low access to private venture capital.[26]

[26]The benefit of using loans instead of grants in order to reduce financial constraints is that loans are less likely to be misused as the firm will have to pay interest.

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