Norwegian School of Economics
Bergen, Fall 2022

Venture Capital and Public Grants' Contribution to Innovation

An empirical analysis assessing the effect of venture capital and public grants on innovation in Norway and Sweden

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Abstract

This thesis investigates the impact of public grants and venture capital disbursements on innovation in Norway and Sweden. We examine this through estimating the potency of VC disbursements and public grants agianst resarch & development expenditures in the respective countries. To investigate the funding types' impact on innovation, we use Kortum and Lerner's (2000) methodology. Our data consist of annual business enterprise R&D expenditures, VC disbursements, public grants, and patent data for Norway and Sweden in 2007-2020.

We find that venture capital accounted for 1.82% of the combined patenting activity in Norway and Sweden in the period from 2007 to 2020. The results suggest that venture capital has a positive effect on innovation, but that venture funding is less potent in generating patents compared to business enterprise R&D expenditures. Our findings are not consistent with previous empirical studies applying the same methodology on the US and Euopean market. They found venture capital to be more potent in innovation creation than business enteprise R&D.

To our knowledge, we are the first to apply this methodology on public grants, in order to investigate public funding's contribution to innovation. Our findings suggest that public grants are less potent than business enterprise R&D in generating patenting acitivty. Further, our results imply that public grants have a negative impact on patents, and is thus harmful for innovation creation in Norway and Sweden.

Preface

This master thesis is written as a part of the Master of Science in Economics and Business Administration at the Norwegian School of Economics (NHH). We are both majoring in Financial Economics with minors in New Business Development. Writing this thesis has been both educational, challenging, and rewarding. We are grateful for the opportunity to immerse ourselves in this topic.

We would like to express our sincerest gratitude towards our supervisor Tore Leite who has contributed with helpful and professional feedback throughout the process. We would also like to thank Abelia at the Confederation of Norwegian Enterprise (NHO), and especially Sondre Jahr Nygaard and Elin Mathisen for their knowledge, insightful discussions, and help with connecting us to various data sources. We also want to thank Invest Europe, the Norwegian Industrial Property Office, the Swedish Patent and Registration Office, Innovation Norway, Vinnova, and Sikt for providing us with the essential data material. Without these data contributions, it would not have been possible to carry out our master thesis.

Finally, we would like to thank our friends and family. Writing our master thesis would not have been the same without the support and encouragement from all of you.

Bergen, December 2022

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1. Introduction

A common issue for startups is the financing gap (OECD, 2006). The financing gap entails that small and medium-sized firms could use funds productively if they were available but are not able to obtain funding from the formal financial system. Startups are often unable to finance innovation projects internally and banks are reluctant to provide them with loans, due to the high risk and lack of collateral. As a result, a financing gap arises, and startups rely on receiving external financing to pursue innovation projects. Such external financing can either be privately or publicly funded.

In this thesis, we want to investigate the impact private and public funding have on innovation in Norway and Sweden. We aim to investigate this matter by looking into venture capital (VC) disbursements and public grants, and their impact on patents, as a measurement of innovation output. It is important to emphasize that innovation is not only a product of funding. Other factors including culture, history, politics, tax policies, and human capital are all probable variables to fit into the innovation creation equation. Moreover, the effect of external funding is not only interesting from a theoretical point of view. While VC firms invest in a startup's equity, public grants are direct cash transfers to young companies. This raises the question of which is more likely to fuel innovation. If the contribution to innovation between the two funding sources varies to a large extent, this can be valuable information when designing innovation policies.

In this thesis, we will consider venture capital disbursements and public grants for both countries since we find it interesting to look at whether one funding source is more potent in creating innovative output than the other. The relationship between VC disbursements and innovation was first investigated by Kortum and Lerner (2000). Their study investigated VC's impact on the number of patents in the United States' manufacturing sector. Later, Popov and Roosenboom (2009) replicated the study and applied the methodology to the European private equity market.

To investigate the differences in innovation creation of the two funding sources, we apply Kortum and Lerner's methodology (2000) to assess the relationship between venture capital and patent activity in Norway and Sweden from 2007-2020. We use the same methodology to investigate the relationship between public grants and patenting activity in Norway between 2007-2020 and Sweden between 2011-2020. The analysis consists of reduced-form regressions on the number of patent applications, patent grants, business enterprise R&D expenditures, VC disbursements, and public grants on aggregated annual data covering eight sectors in Norway and Sweden. We run regressions on both patent grants and patent applications to examine if the sources of funds have different impacts on successful patents and the willingness to apply for patents. In contrast to Kortum and Lerner (2000), we apply their methodology to public grants in addition to venture disbursements. To our knowledge, it is the first time this methodology has been applied to public grants, and the first time someone has compared the effect of public grants to venture disbursements in Norway and Sweden.

Our findings suggest that venture disbursements in Norway and Sweden accounted for approximately 2% of the combined innovation in Norway and Sweden between 2007-2020. The average ratio of venture disbursements to business enterprise R&D expenditures (VC/R&D) was approximately 39%. Based on the methodology of Kortum and Lerner (2000), venture capital is argued to be more potent in creating innovation if venture disbursements' contribution to innovation (approximately 2%) is higher than the VC/R&D ratio (approximately 39%). Since venture disbursements' contribution to innovation is lower than the VC/R&D ratio in our findings, it is implied that venture capital is less potent in generating innovation output than business enterprise R&D in Norway and Sweden.

It is found that a euro invested in public grants is less effective in generating innovation than investing a euro in business enterprise R&D. Moreover, public grants provided by Innovation Norway and its Swedish equivalent, Vinnova, are found to have a negative contribution to innovation. When calculating the share of innovation created through public grants, we get a negative estimate of -3.2%, insinuating that public grants harm the innovation output in Norway and Sweden.

The thesis' chapters are structured in the following manner. Chapter 2 provides the literature review and gives insight into innovation as a concept, patents, the role of R&D for innovation, information and literature on venture capital, and public grants. Thereafter, the methodology this thesis follows is described. Chapter 3 provides information regarding our datasets and Chapter 4 displays descriptive statistics. Chapter 5 and 6 presents our use of the methodology and results before we present our findings, interpretations, implications, limitations, and recommendations in Chapter 7. The final chapter concludes our thesis.

2. Literature Review

This chapter begins by defining innovation and discussing its relationship to economic growth. Further, we discuss patents and their function as a measurement of innovation, before looking at R&D and innovation. We then review the literature on public grants and venture capital before describing the findings from Kortum and Lerner (2000) and Popov and Roosenboom (2009), who developed and applied the methodology used in this thesis.

2.1 Innovation and Economic Growth

To investigate the differences in innovation between Norway and Sweden we need a clear understanding of the meaning behind the innovation term. The OECD defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD, 2005). The Norwegian government and Innovation Norway use a definition based on Schumpeter's definition from the book "The Theory of Economic Development" (1934): "A new product, service, production process, application or form of organization that has been introduced to the market or used in production to create economic value." The latter definition emphasizes that innovation must create economic value. The introduction of new products is considered to have a distinctly positive effect on economic growth in the form of increased revenues and employment, while process innovations are justified by the fact that they participate in cost-cutting (Smith, 2009). Howbeit, the latter may have more ambiguous effects or be more difficult to document.

It is considered axiomatic that innovation activity has been the most important component in the creation of long-term economic growth (Rosenberg, 2004). There are two recognized ways of increasing output in the economy. One can increase the number of inputs going into the productive process, or one can generate more outputs from the same number of inputs. Moses Abramovitz (1956) measured the growth in output of the US economy between 1870-1950. His results showed that the growth in inputs, capital and labor, only accounted for approximately 15% of the actual output growth in the economy. Thus, statistically speaking, there was an unexplained residual of 85%. The Nobel Prize in Economics winner, Robert Solow, researched the same matter using a different methodology and time period than

Abramovitz and found the same size of the residual (Solow, 1957). The fact that both found the exact same sized residual persuaded the majority of economists that technological innovation must be a major force in the growth output of industrialized economies.

2.2 Patents

The World Intellectual Property Organization (WIPO) defines a patent as the exclusive right granted for an invention (WIPO, n.d.). The patent holder holds protection provided by the state to be the only one with the right to use the invention and exploit it commercially. In order to receive a patent, one needs to provide technical information regarding an invention, which needs to be disclosed to the public in a patent application. In most countries, the patent protection has a duration of 20 years, meaning that after the protection period, anyone can make use of the invention without consent from the patent owner. An invention is a process or product that provides a new method of doing something, or a new technical solution to a problem (WIPO, n.d.). This means that patents are only granted to inventions, not necessarily everything that qualifies as innovation. Quantifying innovation can be difficult, but patents are generally accepted as a measurement of innovation (Fagerberg, Nelson, & Mowery, 2005).

We want to further address the issue of measuring innovation. As stated by both OECD's and the Norwegian government's definition, innovation inherently implicates novelty. This leads to questions of what qualifies as novel and how novelty can be quantitatively measured. The former includes definitional issues such as if the innovation needs to be new to a firm, to a country or to the entire world, and whether it needs to be a radically novel idea or if incremental change also counts. Related to measurement issues, quantitative measurements require some qualitatively similar level across entities, howbeit meaningful technological measurements rarely exist across different products. Furthermore, as stated by Kline and Rosenberg (1986), innovation is a non-linear process formed by several small interactions and feedbacks, which are difficult to measure.

Data on research & development expenditures have traditionally been a common measure of innovation due to its relative uniform reporting style and long data history (Fagerberg, Nelson, & Mowery, 2005). However, R&D is initially an input, not an output, which does not account for other relevant input factors or that R&D can be used inefficiently (Kleinknecht, van

Montfort, & Brouwer, 2001). Using patents as a measure of innovation will solve some of these problems. First, patents are granted after input factors are used and is therefore a measure of output. The patent system also has history dating back for centuries, has a slow-to-change classification system and the data are publicly available (Fagerberg, Nelson, & Mowery, 2005). An inherent requirement of receiving a patent is novelty. However, as mentioned, patents are granted to inventions. This does not include every form of innovation, as some innovations are not patentable, e.g., organizational or business model innovations. In addition, some innovations are kept as trade secrets, or the patent is never turned into something that creates value, which the Norwegian government's definition requires. Lastly, some patenting activity is done in a strategic manner solely with the purpose of hindering competitors (Fagerberg, Nelson, & Mowery, 2005).

Hagedoorn and Cloodt (2003) examined the innovative performance of nearly 1200 international companies in four different high-tech industries, to investigate if one could find one or several indicators of innovative performance. They found that R&D expenditures, patent counts and citations, as well as new product announcements, are all indicators that capture innovative performance. Despite issues raised by Fagerberg, et. al. (2005), Hagedoorn and Cloodt's (2003) findings suggest that there is a strong statistical overlap between these indicators and that they are strong enough to be considered suitable by themselves. Using this as a basis, patent counts can be accepted as an appropriate indicator to assess innovation performance.

By protecting the rights to an invention, patents are meant to facilitate innovation (WIPO, n.d.). Patents reward inventors if their inventions become commercially successful. Since their invention is protected, they serve as an incentive for the inventors in the sense that others cannot copy their work. Society benefits from new technology, and revenues from inventions can be invested into further R&D which may facilitate more innovation in the future. Further, patents convert knowledge into tradable assets, which can lead to both business growth and job creation.

However, it also creates a deadweight loss since it slows down the diffusion of innovations. This can be explained through the Reward Theory of Patents of Nordhaus (1969). When granted a patent, the patent owner ultimately holds a monopoly on the invention. In a monopoly, the patent owner decides the price, and consumers decide the quantum. Due to the monopolist's pricing of the invention, a deadweight loss occur. As a result, there is a social cost to ensuring that innovation is rewarded. On the other hand, undertaking a research and development project to develop an innovation often comes with large initial investments. If the innovation then becomes available for anyone to use and an object of pure competition, its product or service may be sold at margin cost. The developers might then not be able to recover their initial investment. This decreases the motivation to take on large R&D projects, and thus have detrimental effect on innovation (Charles, 2018, p. 144).

2.3 The Role of R&D in Innovation

Research and experimental development (R&D) is defined as "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge" (Manual, 2015). Further, to be classified as an R&D activity the activity must satisfy five criteria: It has to be (1) novel, (2) creative, (3) uncertain, (4) systematic, and (5) transferable and/or reproducible. There are three types of R&D activities. These are basic research, applied research, and experimental development. In the context of innovation, it is the latter that is the most relevant. Experimental development refers to systematic work which draws on knowledge from both research and practical experience and produces new knowledge that can be applied to new or improved products or processes (Manual, 2015).

The relationship between R&D and innovation has been studied extensively in numerous papers. Pakes and Griliches (1980) were among the first to use patents as a measure of innovation. Through the use of patents, they found a significant relationship between R&D and innovation. Following Pakes and Griliches (1980), several related papers found similar results (Geronikolaou & Papachristou, 2008). For instance, Hall, et al. (1986) found that the relationship between R&D and patenting seems to be quite strong even when one control for firm size, permanent patenting policy, and effects of the firm's R&D history. However, they stress that patents are not the only output of R&D, but a fraction of the output. The fraction it accounts for can vary over industry and possibly over time.

2.4 Public Grants

Public grants can be defined as a financial good a firm receives from the government in exchange for meeting certain criteria. Grants may be direct cash transfers, assets, discounted loans, guarantees, reduced fees, and professional assistants, and they are instruments with the intention to stimulate the economy (Regnskapsstiftelsen, 2008). In this thesis we will analyze public grants provided by the government through Innovation Norway and Vinnova. We will focus on direct cash transfers from these public institutions to private enterprises.

Innovation Norway is a Norwegian state and county municipality-owned company, with the purpose of facilitating value-creating business development in Norway (Det kongelige nærings- og fiskeridepartement, 2021). The Swedish equivalent of Innovation Norway is Vinnova. They are the Swedish Agency for Innovation Systems, and their stated mission is to promote sustainable growth through developing innovation systems and finance research and innovation (Government Offices of Sweden, n.d.).

The traditional economic reasoning for providing public grants and public policies promoting entrepreneurship is to correct for market failures (i.e., asymmetric information, high transaction costs, achieving positive externalities, and uncertainty) (Ondřej, Stjepan, & Smaranda., 2021). Various researchers have researched public grants' effect on productivity and firm performance. Cappelen, Raknerud, and Rybalka (2013) found that the return on R&D for Norwegian firms receiving public grants from the Research Council of Norway was the same as firm's private R&D spending.

Ondřej, Stjepan, and Smaranda (2021) conducted a systematic review of empirical evidence on public small and medium-sized enterprise (SME) grants and firm performance in the EU. They found that sixteen out of eighteen research papers regarding public grant's effect on employment reported that public grants have a positive effect. Further, measuring labor and total factor productivity, six studies reported positive effects on labor productivity, while seven studies reported negative or non-significant results. The results for total factor productivity are even less favorable to productivity gains, where five studies reported positive effects and seven studies reported negative or non-significant effects. To summarize, in terms of employment, firm survival, sales, fixed and tangible assets, public grants are mostly reported to have positive effects, while the results regarding labor and total factor productivity are more mixed.

A study examining if government funding helps innovation in the US found that institutional interactions can increase the impact of private innovation (Rathje & Katila, 2018). On the other hand, two papers based on interviews with the National Institutes of Health suggested that public funding lead to a decrease of patented innovations due to the institution's restrictive and tedious selection process (Azoulay, 2011) (Pahnke, 2015). We have however not seen any articles investigating the relationship between public grants and patents in the Scandinavian countries.

2.5 Venture Capital

Venture capital can be defined as a form of specialized financial intermediation that provides funding to firms with the goal to realize capital gains by either having them acquired or publicly listed, usually within a few years (Da Rin & Penas, 2015). In May 2020, seven of the top eight publicly traded firms worldwide had been backed by VC prior to their initial public offerings (Lerner & Nanda, 2020). In the US, these companies included Alphabet, Apple, Amazon, Facebook, and Microsoft.

Small and medium-sized firms who wishes to pursue innovation activities often experience not being granted loans from banks, due to a lack of collateral. Pursuing technical innovation is a major source of gaining a competitive advantage but requires both large and risky investments. Banks are naturally reluctant towards risky projects, which makes these firms reliant on receiving other external funding (Da Rin & Penas, 2015). Venture capital is a prominent funding source for innovative companies. VC firms have great focus on both the screening and monitoring process of their portfolio firms, in addition to advising them. Staged financing is also widely used by venture capital firms (Wang & Zhou, 2004). By investing in stages, or rounds, the venture capital firm gains more control and reduces potential moral hazard, in addition to incentivizing the venture funded firm to perform well. This structure of how VC firms operate allows them to select potentially high-growth firms and help bring them to success.

2.6 VC and Patents as a Measurement of Innovation

Several research papers have stressed the role of venture capital in creating innovation activity. Most of the research have analyzed US evidence, including Timmons and Bygrave (1986), Hellman and Puri (2000), Kortum and Lerner (2000), and Lerner (2002). Concerning European venture capital, Bottazi and Da Rin (2002) found that the European venture market lagged behind the American market, but that it has a substantial contribution to the European stock market's development of innovative firms.

The most frequently applied proxy for venture capital's effect on innovation is patent grants and patent applications (Geronikolaou & Papachristou, 2008). Kortum and Lerner (2000) were among the first researchers to investigate venture capital's relation to patent creation. They based their methodology on Griliches' (1986) work on a patent production function and R&D's impact on patents. They found that venture disbursements were more potent than R&D in the US manufacturing industries. Popov and Roosenboom (2009) utilized the methodology of Kortum and Lerner (2000) and applied it to the European market for private equity (PE). They found that PE is more potent in generating innovation than business enterprise R&D, but that it is less potent compared to venture capital in the US.

2.6.1 Kortum and Lerner (2000)

As stated, Kortum and Lerner (2000) investigated the relationship between venture capital and patents. Using sample data from 20 different US manufacturing industries between 1965 and 1992, they discovered that venture capital and business enterprise R&D expenditures have a significant impact on patents.

Their main assumption is that venture disbursements and business enterprise R&D expenditures are the only sources of innovation. They utilize Griliches' (1986) patent production function. This function states that the number of patents (in a given year and industry) is given by the amount of R&D and VC disbursements, accounting for the two variable's substitution factor, the effect of VC, and a return-to-scale parameter. This patent production function will be described in detail in our methodology chapter. Following a series of reduced-form regressions, Kortum and Lerner (2000) compare the contribution of venture disbursements to business enterprise R&D expenditures dependent on patent grants and applications.

Kortum and Lerner (2000) note that when venture funding is relatively small compared to business enterprise R&D, it is reasonable to estimate venture disbursement's contribution to patents through a linear approximation of the patent production function. A linear approximation offers a more conservative estimation of venture funding's effect on innovation. They use the ratio of venture disbursements to R&D expenditures to estimate venture funding's effect, which is applicable when the VC/R&D ratio approaches zero. This is only logical when one is evaluating the null hypothesis that the effect of venture disbursements on patenting activity is zero.

To evaluate if venture capital is more potent in creating innovation than private R&D, they compare the venture capital percentage that accounts for innovation to the VC/R&D ratio. Between 1983-1992, the VC/R&D ratio averaged less than 3%, while their findings suggest that venture capital accounted for 8% of industrial innovation. Since the VC/R&D ratio is lower than venture capital's contribution to innovation, they conclude that venture disbursements are more potent in innovation creation than R&D spending. They found that a dollar invested in venture capital is approximately three times more valuable in generating patents compared to a dollar invested in R&D. Kortum and Lerner (2000) also addresses the potential problem of proving causality in the relationship between funding and innovation. They came to the conclusion that their findings do seem to hold up also after testing for causality issues.

2.6.2 Popov and Roosenboom (2009)

Popov and Roosenboom (2009) utilized the methodology of Kortum and Lerner (2000) and applied it to a European cross-country sample to investigate the contribution of PE disbursements on innovation. They chose to include later stage buy-outs in their data, rather than solely focus on venture disbursements as Kortum and Lerner (2000) did. Popov and Roosenboom (2009) used sector data provided by the European Venture Capital Association (today, Invest Europe), which included all sectors that PE firms invested in, in contrast to Kortum and Lerner (2000) who only investigated manufacturing industries.

Their findings suggest that European PE firms are more potent in creating innovation compared to private R&D, but that European private equity is less potent in the generation of patents than American venture capital. They found that PE accounts for 12% of industrial innovation between 1991-2004 and that the PE/R&D ratio averaged 8%. More specifically, they found that a 1% increase in private equity increases the number of United States Patent and Trademark Office (USPTO) patents by almost 0.05%.

3. Dataset

Annual business enterprise R&D expenditures, patent applications and grants, VC disbursements, and public grants for Norway and Sweden are all included in the dataset we have constructed for this thesis. Except for public grants in Sweden, which span from 2011 to 2020, the data cover the years 2007 through 2020. To provide a more comprehensive perspective of how venture capital investments, public grants, and R&D affect the patenting activity in Norway and Sweden, the annual data are further segmented into industry sectors. By segmenting the data into industry sectors, we are able to expand the dataset into eight observations per year and can control for possible outliers if needed.

The business enterprise R&D expenditures are collected from Statistics Norway and Statistics Sweden. Patent data are collected from the countries' national patent bureaus. The venture capital disbursements are gathered from Invest Europe's Activity Reports. Finally, the public grants data are provided by Innovation Norway and Vinnova. Descriptive statistics of parts of the dataset are provided in Tables 1 and 2.

Descriptive Statistics for Norway								
Year	Patent Grants from application year	Patent Grants	Patent Applications	R&D	VC Disbursements	VC/R&D	Public Grants	PG/R&D
2007	443	428	642	1 934 221	1 086 507	56 %	184 468	10 %
2008	454	387	625	2 056 267	1 067 302	52 %	157 876	8 %
2009	493	373	640	1 930 667	702 823	36 %	166 919	9 %
2010	436	437	569	2 136 368	1 735 633	81 %	170 457	8 %
2011	413	409	542	2 362 108	975 751	41 %	187 095	8 %
2012	393	386	508	2 620 726	983 681	38 %	201 105	8 %
2013	423	491	536	2 666 856	1 412 046	53 %	190 619	7 %
2014	386	457	511	2 732 224	1 855 417	68 %	175 290	6 %
2015	382	458	531	2 856 757	1 495 759	52 %	188 222	7 %
2016	490	537	631	2 961 598	949 740	32 %	152 232	5 %
2017	440	511	612	3 134 633	1 872 887	60 %	160 674	5 %
2018	422	573	601	3 108 581	838 924	27 %	151 512	5 %
2019	339	493	548	3 271 737	2 328 706	71 %	156 556	5 %
2020	243	419	536	3 136 262	1 979 622	63 %	813 151	26 %
Average	**411**	**454**	**574**	**2 636 358**	**1 377 486**	**52 %**	**218 298**	**8 %**

Table 1: Descriptive statistics for Norway. Annual patenting activity, business enterprise R&D expenditures, venture capital disbursements, venture capital to R&D ratio, public grants, and public grants to R&D ratio between 2007 and 2020.

Year	Patent Grants from application year	Patent Grants	Patent Applications	R&D	VC Disbursements	VC/R&D	Public Grants	PG/R&D
2007	1000	1022	2512	7 365 391	3 257 938	44 %	-	-
2008	946	1012	2368	7 679 722	2 252 068	29 %	-	-
2009	902	987	2123	7 490 048	972 602	13 %	-	-
2010	940	1097	2167	8 408 754	2 740 437	33 %	-	-
2011	688	823	1981	8 958 837	3 334 274	37 %	41 633	0.71 %
2012	767	833	2062	9 507 794	2 217 414	23 %	63 911	0.85 %
2013	748	593	2119	9 781 058	935 535	10 %	81 196	0.93 %
2014	779	517	1981	9 321 535	1 290 790	14 %	91 310	1.13 %
2015	825	728	2014	9 086 162	1 690 025	19 %	105 340	0.80 %
2016	930	740	2020	9 833 579	1 799 378	18 %	72 394	1.22 %
2017	845	899	1979	10 504 966	1 895 782	18 %	120 003	0.90 %
2018	736	876	1832	10 447 051	2 613 699	25 %	94 199	0.71 %
2019	632	792	1791	10 684 143	3 792 965	36 %	74 663	1.00 %
2020	396	1249	1763	11 489 969	3 650 670	32 %	107 204	0.74 %
Average	**795**	**869**	**2 051**	**9 325 644**	**2 317 398**	**25 %**	**85 185**	**0.90 %**

Table 2: Descriptive statistics for Sweden. Annual patenting activity, business enterprise R&D expenditures, venture capital disbursements, venture capital to R&D ratio, public grants, and public grants to R&D ratio (2011-2020) between 2007 and 2020.

The original data used in our dataset are reported differently compared to our final dataset. To conduct our analysis, we are dependent on comparable numbers which are not achievable through the original data. Numbers are reported in different currencies, some values are missing, and the industry sectors are organized after various standards. Therefore, we have converted the data through existing frameworks and created our own distribution systems to match the sectors, in addition to converting currencies to euros.

Choosing which industry sector framework to use is necessary so that the data will be comparable. Invest Europe reports data using its own sector framework, which divides VC disbursements into 12 categories (Invest Europe, 2016). R&D and public grants are reported using the NACE Rev. 2 standard which offers a more detailed system of four-digit industry codes. Further, the patent data are reported using WIPO's 35 technology fields, segmenting patents according to their field of technology (Schmoch, 2008). As Invest Europe's categories have the widest sector segmentation, we choose to convert our data into the Invest Europe classification. (European Commission, 2008). We have therefore distributed R&D, public grants, and patents to their appropriate Invest Europe category.

Due to the inconsistency in sector frameworks, our main concern is to align these three classifications in a comparative matter. To align the data, we make some adjustments to the dataset, which makes it possible to transform the different frameworks into Invest Europe's sector classification. Following this section, we will explain the applied adjustments and the reasoning behind them.

3.1 VC Disbursements

Our VC disbursements data are provided by Invest Europe. The organization represents the private equity community across Europe. They gather annual data on private equity and venture capital investments, divestments, and fundraising. In this thesis, we will only use data on venture capital investments. The data we are utilizing in this thesis are called "Market Statistics" which allocate funding based on the location of the portfolio company that receives VC disbursements (Invest Europe, n.d.). This means that the data consist of Norwegian and Swedish venture-backed firms receiving funding from both domestic and international VC firms.Our VC disbursements data are provided by Invest Europe. The organization represents the private equity community across Europe. They gather annual data on private equity and venture capital investments, divestments, and fundraising. In this thesis, we will only use data on venture capital investments. The data we are utilizing in this thesis are called "Market Statistics" which allocate funding based on the location of the portfolio company that receives VC disbursements (Invest Europe, n.d.). This means that the data consist of Norwegian and Swedish venture-backed firms receiving funding from both domestic and international VC firms.

Our chosen analysis timespan are the years of 2007 to 2020 as our dataset on VC disbursements only includes data from this period. As stated, Invest Europe allocates VC disbursements to 12 different sectors. Each sector contains one or multiple NACE Rev. 2 codes and can be converted to the NACE standard through a correspondence table provided by Invest Europe (Invest Europe, 2016). Since the data are aggregated to their sector classifications, we are dependent on converting all the other datasets to Invest Europe's sector classification. The VC disbursements are linked to the companies' primary sector.

3.2 Business Enterprise Research and Development Expenditures

The business enterprise R&D data are reported by Statistics Norway and Statistics Sweden. They are reported in the respective country's standard for industry grouping, both of which is based on NACE Rev. 2. The Norwegian Standard is called SN2007 (Statistics Norway, 2009), while the Swedish standard goes under the name SNI 2007 (Statistics Sweden, 2007). The data from the countries' statistical bureaus are both reported on an aggregated level which results in the SN2007 and SNI 2007 codes to perfectly match with the companies' NACE codes. Originally, some of the R&D sector groupings contained multiple NACE codes, for instance combining both agriculture and mining in the same sector. This makes it impossible for a perfect conversion to the Invest Europe sectors.

To make the R&D data convertible to the Invest Europe sector classifications, we created a distribution system based on Invest Europe's conversion table. This distribution system let us assign weights to the NACE codes, making a more precise conversion to the Invest Europe sectors possible (See Appendix II and III). To utilize such a distribution system, an important assumption is that each subgroup of the NACE code is assigned the same amount of R&D expenditures. Based on this assumption, we assign weights of R&D expenditures to each sector. This is unlikely to hold, and one should therefore take some precautions when interpreting the results.

Some of the sectors reported after NACE Rev. 2 by the statistical bureaus fit perfectly with the Invest Europe classifications and can therefore be converted directly. Examples of sectors that can be directly converted are the NACE sectors "C21 Manufacture of basic pharmaceutical products and pharmaceutical preparations" and "C22 Manufacture of rubber and plastic products." C21 and all its sub-sectors fit in the Invest Europe sector "Biotech and healthcare," while C22 fully belongs to the "Chemicals and materials" Invest Europe sector. Still, some NACE sectors could not be directly converted, for instance "C16 Lumber and wood products industry." C16 has nine sub-sectors, and seven of these sub-sectors are included in the "Consumer goods and services" Invest Europe sector while the remaining two are in the "Construction" Invest Europe sector. The weighting factor is given by dividing the number of observations in the Invest Europe sector by the total number of NACE sub-codes. This results in a weighting factor of 7/9 for "Consumer goods and services" and 2/9 for the "Construction" sector.

Further, we had to create two distribution tables, since the combination of NACE codes are different for Norway and Sweden. While Norway reported on "A03 Fishing and aquaculture" specifically, Sweden combined that category with "Mining and extraction." Overall, the Swedish data are more aggregated compared to the Norwegian data which makes the conversion less precise. Another caveat that we must account for is that the Swedish data are reported biannually. To obtain a complete set of data, we calculated the average between the following and the previous year to estimate the missing values. This should also be taken into account when considering the results as this may lead to inaccuracies. Lastly, the business enterprise R&D data were reported in NOK and SEK. In our analysis, we convert all currencies to EUR in thousands. The currency conversion is done by using the annual average currency exchange rate for the respective years between SEK, NOK, and EUR.

3.3 Public Grants - Vinnova and Innovation Norway

The public grants data are based on Innovation Norway's public grants from 2007-2020 and Vinnova's public grants from 2011-2020. Innovation Norway and Vinnova are state- and county municipality-owned companies, and their purpose is to be the state and the county municipalities' instrument to realize value-creating business development throughout the respective countries (Garvik, 2022) (Government Offices of Sweden, n.d.). They redistribute state and country municipality income to businesses and initiatives.

Data provided by Vinnova contains data on all private companies that have received direct cash transfers from 2011-2020. Originally, the Innovation Norway data included loans, guarantees, and other instruments which we do not classify as a grant for the purpose of this analysis. To make our analysis based on direct cash transfers, these entries have been excluded from the Innovation Norway dataset. Innovation Norway also reports on all enterprises, not only private companies. We have therefore filtered out public companies and organizations. Furthermore, we have excluded data entries on public grants given to foreign countries which Norway is obligated to give through EU initiatives (Tveit, 2022).

Further, both Innovation Norway and Vinnova report grants using their national standard for industry classifications, SNI 2007 for Sweden, and SN2002 (for the years 2007-2009) and SN2007 (for the years 2010-2020) for Norway. These are five-digit codes, where the first four digits corresponds to the NACE Rev. 2 code. We remove the fifth digit where they occur and transform the sector codes to NACE Rev. 2. Since the dataset is not aggregated, we can match the sectors perfectly to the Invest Europe framework through their conversion table.

We have used NACE codes that are connected to the relevant project that received the grant when this has been available, as this makes for a better match with the patent data. This differ from the venture disbursements and R&D data where the company's NACE code is applied. When the project NACE code for public grants is not available, we have used the company's NACE code. There are however some entries that have neither been assigned a project nor a company NACE code, in both the Innovation Norway and Vinnova datasets. These entries have been removed from the datasets, but this number is low. About 3.7% of Innovation Norway's entries did not contain a NACE code. Finally, both datasets have been converted from their respective national currency to euros in thousands to match the rest of the data.

3.4 Patent data

The patent data are provided by the Norwegian Industrial Property Office and the Swedish Intellectual Property Office and spans from 2007-2020. These are the national patent offices in the respective countries, and the patent data consists of patent applications directly to the national office or through the PCT in national phase. The PCT is short for "The Patent Cooperation Treaty," which among other functions, supports applicants in obtaining international patent protection (WIPO, n.d.). When one files for an international patent through the PCT, one can apply for protection in several countries simultaneously. The PCT has 155 contracting states. Howbeit, the national patent offices are the ones who grant the application, and this takes at least 30 months from the filing of the application. This is what is called PCT in national phase, and these applications are included in both the Norwegian and Swedish data.

To investigate how VC and public grants affect patents in Norway and Sweden, it is important that the patent data report on only Norwegian and Swedish firms applying for patents in the respective countries. Foreign applicants also apply for patents in these countries but to include those filings will give us misleading results since it does not provide the country-specific information we are aiming for. Furthermore, a large number of Norwegian and Swedish patent filings are made to other national offices, such as the USPTO and the European Patent Office (EPO), but these filings are not included in our data. At the same time, it is likely that most of the Norwegian and Swedish companies applying for patents at the USPTO and the EPO also applies for local patents.

Our data consist of patent applications and patent grants from 2007-2020, where patent grants are measured in two different ways. First, we have patents granted between 2007 and 2020, with the earliest application date being January 1, 1990. These are reported by their grant date. Second, we have patents that have been applied for and granted between 2007 to 2020, and these granted patents are reported according to their application date. These patent grants based on the application year have a declining trend since it can take several years to grant an application. According to the Norwegian Industrial Property Office, it normally takes 12-24 months from first filing to granting the patent, and as noted, at least 30 months if the application is filed through the PCT (WIPO, n.d.). Therefore, getting a patent granted can take some time, which results in lags in the data. We will return to this in the Results chapter.

Both the Norwegian and Swedish patent offices report their patent data by classifying them into WIPO's 35 technology fields, also known as the International Patent Classification (IPC V8). These technology fields are based on the technology that the patent demonstrates and are not necessarily linked to the business' primary company sector. In our dataset, we have converted these technology fields to Invest Europe's sectors. To convert the technology fields to the respective sectors we utilized WIPO's "NACE Rev. 2 – IPC V8 concordance table" (Eurostat, 2015) This table provides a corresponding NACE code to each WIPO technology field (IPC V8), making a conversion possible. After converting the technology fields to NACE codes, the codes are transformed into Invest Europe sectors. We end up with eight sectors. Sectors that are not included due to not being assigned patents in the WIPO register are "Agriculture," "Financial and insurance activities," "Infrastructure," and "Real estate."

4. Descriptive Statistics

This chapter of the thesis provides an overview of our data. The statistics show the Swedish and Norwegian data separately and focus on the eight sectors that are utilized in the analysis. The descriptive statistics include patenting data which are based on the three different patent registrations “patent grants from application year,” “patent grants,” and “patent applications” for the respective sectors, as stated in the Dataset chapter. Business enterprise R&D, VC disbursements, and public grants are also divided into the eight Invest Europe sectors. Swedish public grant data are only available from 2011, which should be kept in mind throughout the analysis. We have also included the VC/R&D ratio and public grants/R&D ratio, to give an indication of the relative relationship between the different sources of innovation funding. These ratios are important elements in the analysis where we evaluate the impact of the two funding sources on innovation. The ratios are employed in the original methodology of Kortum and Lerner (2000), and we will return to these measures later.

Descriptive Statistics for Norway - Sectors								
Sector	Patent Grants from application year	Patent Grants	Patent Applications	R&D	VC Disbursements	VC/R&D	Public Grants	PG/R&D
Biotech and healthcare	12	16	20	119 888	95 991	80 %	15 295	13 %
Business products and services	147	159	194	844 197	188 649	22 %	64 539	8 %
Chemicals and materials	6	9	11	121 637	10 983	9 %	9 302	8 %
Construction	28	29	42	42 721	20 233	47 %	7 565	18 %
Consumer goods and services	26	31	35	212 550	157 808	74 %	60 674	29 %
Energy and environment	100	106	139	259 000	336 082	130 %	10 785	4 %
ICT	53	66	82	924 897	535 968	58 %	39 909	4 %
Transportation	39	39	51	111 468	39 336	35 %	10 229	9 %
SUM	**411**	**455**	**574**	**2 636 358**	**1 385 051**	**57 %**	**218 298**	**11 %**

Table 3: Descriptive statistics for Norway. Annual averages of patenting activity, business enterprise R&D expenditures, venture capital disbursements, VC/R&D ratio, public grants, and PG/R&D ratio between 2007 and 2020.

As shown in table 3, the sector with the highest annual average patenting activity regarding both grants and applications is “Business products and services,” followed by “Energy and environment.” “Business products and services” accounts for over 35% of the overall patent grants from the application year, and “Energy and environment” accounts for almost 25%. These two sectors are also the sectors with the highest business enterprise R&D expenditures. Looking at venture disbursements, “ICT (Communications, computers and electronics)” is the sector receiving the most funding, followed by “Energy and environment,” and “Business products and services." Looking at the other end of the scale, "Chemicals and materials" has the lowest patent count, totaling only 1.5% of the patent count of annual averages in the category "patent grants from application year." We also note that this is the sector with the lowest VC funding, accounting for 0.8% of the total venture disbursements. Further, "Biotech and healthcare," and "Consumer goods and services" are sectors producing a low number of patents compared to their funding rate.

Looking at the VC/R&D ratio, the averaged ratio for all sectors is 57%, and 52% when averaging over the years 2007-2020 instead of averaging over sectors. By looking at the ratio, there are some obvious outliers, which are "Energy and environment," "Biotech and healthcare," and "Consumer goods and services." The energy sector's ratio is 130%, which is surprising, considering the large petroleum industry in Norway. By having large corporations in oil and gas, one would assume the business enterprise R&D spending to be higher. We believe that the high VC funding primarily comes from investments in renewable energy firms, but we do not have microdata to confirm that hypothesis.

Public grants are direct cash transfers given by Innovation Norway, and from the descriptive statistics, one notices that "Consumer goods and services" deviates the most from the average with a ratio of 29%. This sector is also one of the sectors that are generating the least patents. Further, the sectors receiving the least funding from Innovation Norway is "Energy and environment" and "ICT" with ratios of 4%. The energy and ICT sectors produce a substantial number of patents. Lastly, the average amount spent on the eight sectors each year is EUR 218,298,000, which is over ten times less than the Norwegian business enterprise R&D.

Descriptive Statistics for Sweden - Sectors								
Sector	Patent Grants from application year	Patent Grants	Patent Applications	R&D	VC Disbursements	VC/R&D	Public Grants	PG/R&D
Biotech and healthcare	44	49	218	1 339 993	417 380	31 %	18 256	1.36 %
Business products and services	309	345	674	2 395 478	619 916	26 %	27 991	1.17 %
Chemicals and materials	12	12	53	233 441	31 037	13 %	2 032	0.87 %
Construction	77	87	169	52 015	54 303	104 %	639	1.23 %
Consumer goods and services	56	63	173	875 026	432 600	49 %	3 700	0.42 %
Energy and environment	65	67	142	191 600	97 714	51 %	1 492	0.78 %
ICT	120	125	379	2 132 029	572 235	27 %	19 150	0.90 %
Transportation	112	120	217	2 324 182	92 213	4 %	11 925	0.51 %
SUM	**795**	**869**	**2 025**	**9 543 765**	**2 317 398**	**38 %**	**85 185**	**0.91 %**

Table 4: Descriptive statistics for Sweden. Annual averages of patenting activity, business enterprise R&D expenditures, venture capital disbursements, VC/R&D ratio, public grants, and PG/R&D ratio (2011-2020) between 2007 and 2020.

Looking at Table 4 we get an overview of the Swedish sectors. The annual average patenting activity is similar to Norway with “Business products and services” having the highest patent count, implying that there is a relationship between patents and industry. This is something we will control for in our analysis. This sector accounts for nearly 39% of the patent grants from the application year. The other two sectors with relatively high patenting activity are “ICT” and “Transportation.” The R&D expenditures follow a similar tendency to the patents, with “Business products and services” as number one, followed by “Transportation,” and “ICT.” VC disbursements are also the highest for “Business products and services,” then “ICT,” followed by “Consumer goods and services.”

Similar to Norway, the least patented sector is “Chemicals and materials” with a share of 1.5% of patent grants from the application year. This sector is also at the bottom for VC disbursements, and it uses third to last R&D spending. Moving over to the VC/R&D ratio, the clear outlier is “Construction” which receives more VC funding than business enterprise R&D expenditures. The VC/R&D ratio for Sweden is noticeably lower than Norway with an average ratio of 25% from 2007 to 2020, and 38% when averaging over the different sectors.

When studying the public grants provided by Vinnova, we notice that most grants go to “Business products and services” and “ICT.” Looking at the PG/R&D ratios, we see that they are much lower than the Norwegian ratios. The average R&D ratio for all the sectors is 0.91% for Sweden and 11% for Norway. This is partly due to the fact that Sweden has substantially higher business enterprise R&D spending than Norway, even though Swedish public grants are also lower in absolute numbers. When looking into Vinnova's annual report from 2013, we see that Sweden prioritizes funding to universities over private enterprises. The latter only receives 28% of the total funding (Vinnova, 2014), while Innovation Norway primarily provides funding to private enterprises.

4.1 Substantial Differences in the VC/R&D Ratio

When examining Norway's VC/R&D ratio, we were surprised that the ratio was so high. In Popov and Roosenboom (2009) they calculate the Norwegian PE/Industrial R&D ratio to be 10% in 2001-2004. Popov and Roosenboom (2009) have also used Invest Europe data, but they use the data Invest Europe classifies as “Industry Statistics” while we use “Market Statistics” (Invest Europe, n.d.). By definition, “Industry Statistics” obtains data on all investments done by the respective countries' VC firms. “Market Statistics” obtains data on the investment amount the portfolio companies in each respective country have received. This takes into account that domestic VC firms may invest internationally, and that domestic portfolio companies may receive international VC funding. We argue that this latter data is a substantially better measure, as it is a more direct measurement of innovation growth in the respective countries. It should be noted that “Market Statistics” were not available when Popov and Roosenboom (2009) wrote their paper.

By investigating “Industry Statistics” and “Market Statistics” more closely, it becomes clear that Norwegian PE and VC firms invest a lot less in international companies than international and domestic PE and VC firms invest in Norwegian companies. This difference is the reason why our VC disbursements are higher compared to Popov and Roosenboom's (2009) PE numbers. On the other hand, the deviations in “Industry Statistics” and “Market Statistics” are not too substantial when looking at the Swedish numbers. Popov and Roosenboom (2009) report Sweden's PE/R&D ratio to be 15% in 2001-2004, and when looking at “Industry Statistics” and “Market Statistics” for Sweden, the difference in amounts is predominantly smaller compared to Norway. Notably, “Industry Statistics” is higher than “Market Statistics.” This tells us that more Swedish PE and VC firms are investing in international companies compared to Norwegian PE and VC firms. This can explain why the Swedish ratio does not increase as much as the Norwegian ratio in our thesis compared to Popov and Roosenboom (2009).

Lastly, it should also be mentioned that Sweden is one of the countries with the highest R&D spending in the world, according to the GII index (WIPO, 2022). The European Union's goal was that its member states should invest 3% of their GDP in R&D by 2020 (European Council , 2010). In 2020, the average share of GDP spent on R&D totaled 2.31%, not reaching the EU goal. As depicted in the figure below, we see that Sweden is among the few countries that have achieved the objective and has on average spent approximately 3.3% of their GDP on R&D between 2007-2020. Norway on the other hand, spent an average of approximately 1.8% of its GDP, which is lower than the European average (The World Bank, 2022). The substantial differences in R&D spending can partly explain the lower and more sensible VC/R&D ratio in Sweden, compared to Norway.

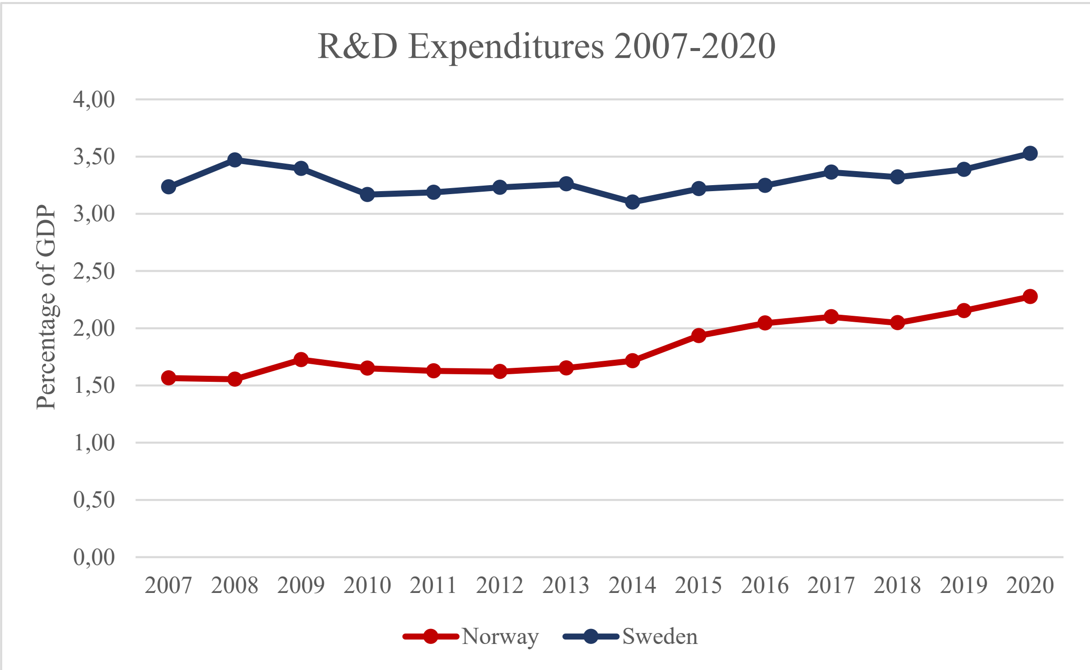

Figure 1: Total R&D expenditures as a percentage of GDP
for Norway and Sweden between 2007 and 2020.

5. Methodology

As stated, our goal with this thesis is to evaluate how venture funding and public grants affect innovation output in Norway and Sweden, in addition to investigate how the potency of the two funding sources may differ in the respective countries.

To examine these research questions, we will utilize Kortum and Lerner's (2000) original methodology and assumptions on VC potency regarding patenting activity and conduct various series of reduced-form regressions. The starting point of these regressions will be a Constant Elasticity of Substitution (CES) production function that estimates patent grants and applications as a function of business enterprise R&D expenditures and venture capital disbursements. This will be referred to as the patent production function. We will also assess the impact of public grants, by substituting VC disbursements with the countries' public grants contributions.

We will then execute likelihood-ratio tests to investigate if the original (unconstrained) patent production function offers a better fit than a constrained production function. We will run likelihood-ratio tests on two constrained models, to compare the goodness-of-fit. The constrained functions are the patent production function where we restrict the substitution parameter ρ to 1 and 0. When restricting the substitution parameter to 1, we assume that venture capital disbursements, public grants, and business enterprise R&D are perfect substitutes for the creation of innovation output. A substitution factor of 0 implies that they are not substitutable. Then, the equation transforms into a Cobb-Douglas function. We run regressions on both cases and move forward with the model offering the best fit.

Finally, we will linearize the equations to extract a more conservative estimate of the patent production function. The reasoning for the methodology and the assumptions it entails will be explained throughout the analysis. In the next chapter, the results will be thoroughly interpreted and discussed.

Before applying Kortum and Lerner's (2000) methodology we want to emphasize that their model is based on several assumptions and simplifications. The main assumption in their model is that patenting activity is a result of only business enterprise R&D expenditures and

VC disbursements. This is a clear simplification since patenting activity depends on several factors including the patentee's behavior and technological bursts (Kortum & Lerner, 2000). Further, it is assumed that VC, public grants, and R&D are perfect substitutes as means for creating patents. Howbeit, business enterprise R&D expenditures are likely to include some VC and public grant financed research. This lowers the probability to extract the isolated impact of VC disbursements and public grants on patent creation conditional on business enterprise R&D expenditures.

We have also experimented with adding lags to our data, to account for any time delay before funding has effect on patents, and that it can take several years to get patent applications granted. Adding lags did not change our estimates substantially or provide higher significance. We have therefore not moved forward with a lagged regression. It is worth noting that empirical literature also has found R&D spending and patent applications to occur at roughly the same time (Hall, Griliches, & Hausman, 1986). In addition, Kortum and Lerner (2000) argues that there should not be many years between VC funding and patenting. This is due to the nature of venture partnerships, where pressure from the VC firm leads to faster commercialization of products, and this is in line with their findings.

5.1 The Patent Production Function

The starting point of this analysis is Kortum and Lerner's (2000) patent production function. The CES production function provides a first glance at the relationship between patent creation, business enterprise R&D expenditures, and VC disbursements. We apply the same approach for investigating the effect of public grants by replacing VC disbursements with public grants. The patent production functions are presented in equation 1 and 2.

$$P_{it} = \left(R_{it}^{\rho} + bVC_{it}^{\rho}\right)^{\frac{\alpha}{\rho}} u_{it} \tag{1}$$

$$P_{it} = \left(R_{it}^{\rho} + bPG_{it}^{\rho}\right)^{\frac{\alpha}{\rho}} u_{it} \tag{2}$$

The dependent variable, Patenting (P) is a function of business enterprise R&D expenditures (R) and VC disbursements (VC) (Public grants (PG)). (u) denotes the error term and captures the effects that cannot be explained by the model. Such effects include the propensity to patent and technological bursts. All variables included in the production function are indexed by sector (i) and year (t). Further, there are three parameters included in the function. The parameter (b) will be our main focus and it captures VC disbursements and public grants' roles in the function. Any $b > 0$ indicates that VC (PG) has a positive impact on innovation output. However, if $b = 0$, the patent production function reduces to its standard form, where business enterprise R&D expenditures is the only input. The standard form is presented in equation 3.

$$P_{it} = R_{it}^{\alpha} u_{it} \tag{3}$$

The parameter (ρ) is the substitution parameter and measures the degree of substitution between VC (PG) and business enterprise R&D. If $\rho = 1$, the input variables are perfect substitutes, and the function reduces to equation 4 and 5.

$$P_{it} = (R_{it} + bVC_{it})^{\alpha} u_{it} \tag{4}$$

$$P_{it} = (R_{it} + bPG_{it})^{\alpha} u_{it} \tag{5}$$

If $\rho = 0$, the patent production function approaches the functional form of Cobb-Douglas, depicted in equation 6 and 7.

$$P_{it} = R_{it}^{\frac{\alpha}{1+b}} VC_{it}^{\frac{\alpha}{1+b}} u_{it} \tag{6}$$

$$P_{it} = R_{it}^{\frac{\alpha}{1+b}} PG_{it}^{\frac{\alpha}{1+b}} u_{it} \tag{7}$$

Lastly, the parameter (α) captures the return to scale, in other words, the percentage change in patenting activity by a one percent increase in both R and VC (PG).

6. Results

6.1 Non-linear Least Squares Estimates

We begin our analysis by providing non-linear least squares estimates of the patent production function. This will be considered as our full or unconstrained model. Further we will conduct analyses where we constrict the model to $\rho = 0$ and $\rho = 1$ to investigate if a constricted model provides a better fit for our model. Finally, we will linearize the model offering the best fit to extract a more conservative estimate of venture disbursements and public grants' contribution to innovation. The linearized specification will be considered as our main model.

To conduct the non-linear least squares analysis, we start by taking the natural logarithm of the production function and obtain equation 8 and 9.

$$\ln P_{it} = \frac{\alpha}{\rho} \ln(R_{it}^{\rho} + bVC_{it}^{\rho}) + \ln u_{it} \tag{8}$$

$$\ln P_{it} = \frac{\alpha}{\rho} \ln(R_{it}^{\rho} + bPG_{it}^{\rho}) + \ln u_{it} \tag{9}$$

Through the logged equations we run regressions on both countries, for both VC disbursements and public grants. The dependent variable is the logarithm of patent grants, patent applications, and patent grants from the application year, in each sector and year. We use the different dependent variables to investigate if VC disbursements and/or public grants affect successful patents, or the willingness to apply for patents. The independent variables are the logarithm of business enterprise R&D expenditures and the logarithm of VC disbursements (public grants). Further, dummy variables for each sector and year are included as controls.

We run the regressions on Norway and Sweden. In addition, we choose to also run the regressions on both Norway and Sweden combined. By combining the countries, we achieve a higher number of observations which may give us a more robust analysis. This can help us achieve a general explanation of the effect funding have on patents but cannot explain the individual relationship in each country.

VC	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Return to scale (α)	0.25069	0.23531	0.20113	3.851e-01	0.284197	0.29875	0.28736	0.24386	0.22849
	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****
Substitution parameter (ρ)	0.20742	0.75025	0.27583	1.582e-04	0.129911	0.03545	0.45918	1.12084	1.11214
	0.282895	*0.879850*	*0.4244*	*0.99765*	*0.951521*	*0.812744*	*0.182673*	*0.337831*	*0.258846*
Venture capital parameter (b)	0.28167	0.12141	0.39346	6.185e-05	-0.007676	-0.01357	0.45482	1.02283	1.82633
	0.305407	*0.804443*	*0.4395*	*0.99766*	*0.940346*	*0.824502*	*0.133264*	*0.372940*	*0.401558*
N	112	112	112	112	112	112	224	224	224

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 5: Unconstrained non-linear least squares regressions of VC on the patent production function. Includes Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

Looking at parameter b in table 5, which represents VC's contribution to innovation, we see that all estimates are positive, but not statistically significant. We can therefore not determine if VC funding influences the patenting activity in Norway, Sweden, or the two countries combined. Looking at the parameter ρ, we see that the estimate is mostly ranging between 0.2 and 1, insinuating that R&D and VC are partly to highly substitutable, but they are not significant. The parameter α is the only significant parameter (at the 1% level) and ranges from approximately 0.2 to 0.3. These results are similar to the results in Kortum and Lerner (2000), where they had an α ranging from 0.2 to 0.22. The parameter is small, but not implausible.

The non-linear least squares regressions for public grants are presented in table 6. The α parameter is statistically significant for public grants (at the 1% level) for Sweden and the countries combined. The substitution parameter has a remarkably wider range but is only significant for granted patents in Sweden and patent grants from the application year for the combined countries. The b parameter is positive for Sweden and Norway, but not statistically significant. However, when combining the two countries, the b parameter takes a negative value and is highly significant for patents granted from the application year. This implies that public grants do have a negative effect on innovation. These are intriguing results which we will explore further later in our analysis. However, for now, we want to focus on the substitution parameter ρ.

We want to investigate the ρ parameter more thoroughly since most of our results are not significant, except for the public grants regression on patent grants for Sweden and patent grants from the application year of the combined countries, respectively.

PG	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Return to scale (α)	4.012e-06	1.745e-01	1.100e-01	1.205e-02	3.547e-01	3.468e-01	0.31570	0.24790	0.24849
	0.999966	*0.37303*	*0.642*	*0.8856*	*1.84e-14 ******	*0.04684 **	*< 2e-16 ******	*< 2e-16 ******	*< 2e-16 ******
Substitution parameter (ρ)	1.161e-05	1.438e+00	-5.790e+01	9.712e-03	-6.745e+01	-5.459e+01	0.48650	0.75828	0.65977
	0.999991	*0.95484*	*0.674*	*0.9936*	*1.23e-10 ******	*0.99998*	*0.340831*	*0.80688*	*0.000473 ******
Public grants parameter (b)	8.762e+03	5.374e+03	9.486e-10	1.011e+02	1.208e-09	1.098e-23	-0.59404	-0.39800	-1.13605
	0.999999	*0.99513*	*0.999*	*0.9987*	*0.987023*	*1.00000*	*0.285940*	*0.83753*	*< 2e-16 ******
N	112	112	112	80	80	80	192	192	192

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 6: Unconstrained non-linear least squares regressions of public grants on the patent production function. Includes Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

To investigate if venture disbursements and public grants are indeed substitutes for R&D, we perform likelihood-ratio tests (see Appendix I). By running such a test, we investigate if the full (unconstrained) model is a better fit than a nested (constrained) model for estimating our regressions. Since we are interested in the substitution parameter, ρ, we test for the nested models with $\rho = 1$ and $\rho = 0$. If $\rho = 1$, venture disbursements (public grants) and business enterprise R&D are considered perfect substitutes. If, $\rho = 0$, they are not substitutable.

The likelihood-ratio test fails to reject that $\rho = 1$ for VC. This means that the nested model, which is constrained to $\rho = 1$, offers a better fit than the full model. It does however reject that $\rho = 1$ on public grants for patent grants from the application year in Norway and for public grants on all patenting activity in Sweden. Moreover, when running the likelihood test for $\rho = 0$, it rejects that $\rho = 0$ for nearly all VC and public grants. The exceptions are VC on grants from the application year in Norway, patent applications in Sweden, and public grants in Norway on patent grants. Since the majority of the $\rho = 0$ regressions are rejected, it is implied that the full model offers a better fit compared to restricting the model to $\rho = 0$.

The likelihood results suggests that the substitution parameter lies between one and zero, but since it rejects $\rho = 0$ in all cases except three (18 cases in total), we would like to focus more on the constrained version moving forward, where $\rho = 1$. This is due to the likelihood test suggesting that restricting the model to $\rho = 1$ is a better fit compared to the full model.

Hence, the substitution parameter is now taken as exogenous. We constrain the parameter to 1 and find the natural logarithm of equations 4 and 5 and obtain equations 10 and 11. By constraining the parameter to 1, we assume that VC, public grants, and R&D are perfect substitutes. In the constrained equation, the parameter b has the interpretation of the potency of a euro of venture disbursements (public grants) relative to a euro of business enterprise R&D.

$$ln\ P_{it} = \alpha \ln(R_{it} + bVC_{it}) + \ln u_{it} \tag{10}$$

$$ln\ P_{it} = \alpha \ln(R_{it} + bPG_{it}) + \ln u_{it} \tag{11}$$

From table 7 we see that the constrained version did not have a substantial effect on our VC results. The b parameter is still not significant, and our return to scale parameter is similar to our initial results.

VC p=1	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Return to scale (α)	0.26568	0.23580	0.21072	0.395324	0.282349	0.290596	0.292878	0.24363	0.22808
	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****
Substitution parameter (ρ)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	---	---	---	---	---	---	---	---	---
Venture capital parameter (b)	0.49711	0.12543	0.76521	0.081390	0.116122	0.017768	0.720746	0.90059	1.60900
	0.24411	*0.777727*	*0.3481*	*0.25160*	*0.501447*	*0.848168*	*0.070891* .	*0.164858*	*0.110679*
N	112	112	112	112	112	112	224	224	224

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 7: Constrained non-linear least squares regressions of VC on the patent production function. $\rho = 1$ case for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

On the other hand, the constrained regressions on public grants have some notable changes, see table 8. Now the b parameter is significant for Norway and the two countries combined on patent applications and patents granted from the application year. The estimates are negative, insinuating that public grants contribute negatively in terms of generating innovation. These results suggest that public grants are between -1 and -1.2 times as potent in creating innovative activity compared to business enterprise R&D. It should be noted that the likelihood test rejects that $\rho = 1$ for public grants in Sweden on all patenting activity and grants from the application year in Norway. Since $\rho = 1$ was rejected on patent grants from the application year in Norway, we should be cautious with the interpretation of the significance in this regression. The remaining significant results were on the other hand not rejected by the likelihood test.

PG p=1	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Return to scale (α)	0.27693	1.684e-01	0.221155	0.390358	0.28418	0.353301	0.306029	0.24712	0.24144
	*< 2e-16 ****	*0.3992*	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****	*< 2e-16 ****
Substitution parameter (ρ)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	---	---	---	---	---	---	---	---	---
Public grants parameter (b)	-1.09185	6.892e+02	-1.226436	42.615225	74.94962	9.287960	-0.958152	-0.56338	-1.22959
	*2.86e-09 ****	*0.9588*	*< 2e-16 ****	*0.115872*	*0.400483*	*0.652648*	*0.003049 ***	*0.56288*	*< 2e-16 ****
N	112	112	112	80	80	80	192	192	192
Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.									

Table 8: Constrained non-linear least squares regressions of public grants on the patent production function. $\rho = 1$ case for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

6.2 Cobb-Douglas Production Function Estimates

Despite that the likelihood ratio tests rejected $\rho = 0$ in most cases, they were not able to reject $\rho = 0$ for VC on patent grants from the application year in Norway, patent applications in Sweden, and public grants in Norway on patent grants. We therefore want to supplement our analysis with the Cobb-Douglas estimation. We take the natural logarithm of the Cobb-Douglas function and obtain the following equations.

$$\ln(P_{it}) = \frac{\alpha}{1+b}\ln(R_{it}) + \frac{\alpha b}{1+b}\ln(VC_{it}) + u_{it} \tag{12}$$

$$\ln(P_{it}) = \frac{\alpha}{1+b}\ln(R_{it}) + \frac{\alpha b}{1+b}\ln(PG_{it}) + u_{it} \tag{13}$$

In table 9 our estimates from the Cobb-Douglas production function ($\rho = 0$) for venture funding are presented for Norway and Sweden and the countries combined. Table 10 presents the equivalent results for public grants. To obtain our estimates, we regress the logarithm of patent grants, patent grants from the application year, and patent applications in each sector and year on the logarithm of business enterprise R&D and the logarithm of VC disbursements. In addition, we use both sector and year dummies as controls. This is to control for potential policy changes affecting patenting activity in the respective country and to control for sectors' natural proclivity to patent.

VC	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Venture capital	0.011	-0.014	0.009	0.0004	-0.002	-0.003	0.015	0.001	0.009
	*(0.006)**	*(0.010)*	*(0.007)*	*(0.005)*	*(0.008)*	*(0.007)*	*(0.009)**	*(0.007)*	*(0.007)*
Private R&D	-0.079	0.382	-0.221	0.122	0.133	0.403	0.826	0.443	0.545
	(0.227)	*(0.361)*	*(0.266)*	*(0.066)**	*(0.108)*	*(0.098)****	*(0.043)****	*(0.035)****	*(0.036)****
R^2	0.937	0.856	0.931	0.970	0.952	0.963	0.820	0.855	0.874
N	112	112	112	112	112	112	224	224	224

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 9: Venture capital Cobb-Douglas production function estimates ($\rho = 0$ case) for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

The first observations regarding the Cobb-Douglas regressions in table 9 are that only patent applications in Norway and for the combined countries are significant at the 10% level. They are slightly positive, suggesting that VC disbursements have a positive effect on patent applications. More precisely, a one percent increase in VC disbursements in Norway and the combined countries lead to a 1.1% and 1.15% increase in patent applications, respectively. The remaining VC coefficients are not statistically significant and can therefore not explain VC's effect on patenting activity.

Business enterprise R&D expenditures are significant at the 1% level for patent applications, patent grants, and grants from the application year for the combined countries. This suggests that business enterprise R&D expenditures do have a positive effect on innovation. Further, R&D is significant and positive at the 10% level for patent applications, and significant at the 1% level for patent grants from the application year for Sweden.

We also experimented with removing outliers in the dataset to investigate if that would provide stronger signals. A large outlier in the venture disbursement dataset is the "Biotech and healthcare" sector. However, removing this sector or other potential outliers did not lead to any substantial changes in the results. We suspect that few observations is the reason for the lack of significance, especially since the combined countries are reporting the most significant results. This will be discussed further later in the thesis.

PG	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
Public Grants	-0.093	0.217	-0.034	0.009	-0.005	-0.106	-0.309	-0.047	-1.172
	(0.096)	*(0.151)*	*(0.112)*	*(0.044)*	*(0.074)*	*(0.064)*	*(0.035)****	*(0.033)*	*(0.032)****
Private R&D	-0.133	0.487	-0.249	0.048	-0.083	0.169	0.765	0.375	0.5
	(0.233)	*(0.365)*	*(0.271)*	*(0.074)*	*(0.125)*	*(0.107)*	*(0.042)****	*(0.040)****	*(0.039)****
R^2	0.935	0.856	0.930	0.974	0.959	0.972	0.871	0.861	0.891
N	112	112	112	80	80	80	192	192	192

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 10: Public grants Cobb-Douglas production function estimates ($p = 0$ case) for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

In table 10, the results from the Cobb-Douglas regressions investigating the effect of public grants are provided. The first important observation is that patent applications and patent grants from the application year for the combined countries are significant at the 1% level. This suggests that public grants negatively affect innovation. The results suggest that a one percent increase in public grants leads to a 30% and 17% decrease in patent applications and grants from the application year, respectively. These results are implausibly large, but signal that public grants harm patenting activity. The remaining public grants coefficients are not significant, but they all report negative estimates, except for patents granted in Norway, and patent applications in Sweden.

Business enterprise R&D expenditures are highly significant and positive for patent applications, grants, and grants from the application year for the combined countries. We expect that few data points is the reason for non-significant results for the remaining regressions. We note that none of the cases that did not reject $\rho = 0$ have significant results in the Cobb-Douglas estimation. We will therefore only move forward with the $\rho = 1$ case.

6.3 Linear Specification Estimates ($\rho = 1$)

We proceed our analysis with the constrained model, $\rho = 1$. Now, the parameter b will be estimated through a linear approximation of the patent production function. This approximation has the advantage of yielding a conservative estimation of the impact VC disbursements (public grants) have on patenting. Since some of our previous coefficients seemed to be implausibly large, a conservative approach may give us more reliable estimates. Since the likelihood test suggested that the $\rho = 1$ restricted model offers the best fit for our model, and this linear specification offers a more conservative estimation, we will consider this to be our main model.

The linear approximation was introduced by Griliches (1986) where he argues that a Taylor expansion of the function's logarithm is appropriate in the case where one input is substantially smaller than the other. The inputs in the equation are business enterprise R&D and venture capital disbursements (public grants). The linear approximation interprets the observed averaged impact of VC/R&D (PG/R&D) ratio on patenting as the maximum marginal impact. In other words, the ratio between venture capital (public grants) and business enterprise R&D needs to approach zero.

Howbeit, our VC disbursements are considerably greater relative to the VC disbursements in Kortum and Lerner (2000). Their sample dates back to the 1960s when VC disbursements were a smaller proportion of business enterprise R&D compared to today. Our averaged VC/R&D ratio is 52% for Norway and 25% for Sweden. These ratios are considerably greater than the ratio of less than 3% used in Kortum and Lerner's (2000) analysis. By having a ratio of 3%, their ratio is small enough to justify using the Taylor expansion.

Popov and Roosenboom (2009) investigated PE disbursements in Europe, and their PE/R&D ratio for 1991-2004 was 8%. This is still substantially lower than our ratio. The large deviations between Kortum and Lerner (2000) and Popov and Roosenboom's (2009) ratios compared to ours, may be partly explained by our use of more recent figures. Further, as mentioned, Popov and Roosenboom (2009) operate with Invest Europe's "Industry Statistics" instead of "Market Statistics", which can explain why their numbers are lower.

Regarding our PG/R&D ratio, the Taylor expansion is more suited. The average ratio for Norway is 11% and only 0.91% for the Swedish counterpart. These numbers are substantially smaller than the business enterprise R&D expenditures and suit the argumentation for the Taylor expansion.

Despite our VC/R&D ratios being considerably higher compared to previous papers, we choose to continue with the linear approximation for both VC disbursements and public grants. The linear approximation is more conservative compared to the other estimation methods, which can help justifying a higher ratio. It also provides a closer comparison to Kortum and Lerner's (2000) original work. However, the high ratio is likely to have an impact on our final results and should therefore be interpreted with caution.

By linearizing equations 10 and 11, they convert to equations 14 and 15.

$$\ln P_{it} = \alpha \ln R_{it} + \alpha b(VC_{it}/R_{it}) + \ln u_{it} \tag{14}$$

$$\ln P_{it} = \alpha \ln R_{it} + \alpha b(PG_{it}/R_{it}) + \ln u_{it} \tag{15}$$

Tables 11 and 12 report the results of the linearized regressions. Starting with the VC regressions, the estimates are significant and positive for patent applications in Norway. However, the corresponding R&D estimates are not significant. Turning to the combined countries, the estimates are more interesting. Patent applications (5% level) and grants from the application year (5% level) are significant and positive. The corresponding R&D estimates are also highly significant and positive.

VC	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
VC/R&D (αb)	0.026	-0.019	0.020	-0.007	-0.013	-0.003	0.035	0.012	0.031
	*(0.012)***	*(0.019)*	*(0.014)*	*(0.009)*	*(0.015)*	*(0.013)*	*(0.017)***	*(0.014)*	*(0.014)***
Private R&D (α)	-0.076	0.390	-0.218	0.112*	0.115	0.400	0.851	0.448	0.564
	(0.226)	*0.363*	*(0.265)*	*(0.067)*	*(0.110)*	*(0.100)****	*(0.043)****	*(0.035)****	*(0.035)****
R^2	0.938	0.855	0.931	0.970	0.953	0.963	0.821	0.856	0.876
N	112	112	112	112	112	112	224	224	224

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 11: Linearized regressions of VC for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

Note that the measurement for VC in table 11 are estimates for the VC/R&D ratio (αb). This entails that to derive b, we must divide the αb estimate on the α estimate. Consider the estimate of venture disbursements on patent applications for the combined countries of 0.035. Since this is an estimate for the product of α and b, we must divide it by the estimate of α, 0.851, to retrieve the estimate of b, the implied potency of venture funding. This leaves us with a b estimate of 0.411. Since only the estimations for the combined countries provide significant results, we will only calculate the b parameter for that category. Patent applications and grants from the application year for the combined countries have b parameters of 0.10 and 0.21, respectively. This implies that VC disbursements have greatest effect on patent grants that are based on their application year.

Regarding the public grants regressions, depicted in table 12, we only have significant results for patent applications and grants from the application year for the combined countries. The results are highly significant and negative, and the corresponding R&D expenditures are also highly significant. The results imply that public grants have a negative effect on patenting activity for the combined countries. These are interesting results which we will discuss further in the Discussion chapter. To retrieve the parameter b, we follow the same procedure as we did for venture disbursements and divide the αb estimate by the α estimate. This results in a b parameter of -0.68 and -0.52 for patent applications and grants from the application year, respectively. These results suggest that public grants contribute negatively to innovation.

PG	Norway			Sweden			Combined		
Parameter	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)	Applied	Granted	Granted (application y)
PG/R&D (αb)	-0.093	0.217	-0.034	0.009	-0.005	-0.106	-0.309	-0.047	-0.172
	(0.096)	*(0.151)*	*(0.112)*	*(0.044)*	*(0.074)*	*(0.064)*	*(0.035)****	*(0.033)*	*(0.032)****
Private R&D (α)	-0.226	0.704	-0.284	0.057	-0.088	0.064	0.455	0.328	0.328
	(0.265)	*(0.416)**	*(0.309)*	*(0.083)*	*(0.140)*	*(0.120)*	*(0.058)****	*(0.056)****	*(0.053)****
R^2	0.935	0.856	0.930	0.974	0.959	0.972	0.871	0.861	0.891
N	112	112	112	80	80	80	192	192	192

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. Sector and year dummies are included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 12: Linearized regressions of public grants for Norway, Sweden (2011-2020), and the countries combined between 2007 and 2020.

6.4 Robustness Tests

The focus of our paper is to use data on public grants and venture capital to see the effect of such funding on innovation. However, other dynamic characteristics, such as human capital and patent protection levels, can affect innovation activity. We try to account for these external factors by using a cross-country setting but since we only have two countries, and these two countries are quite similar, the changes in dynamic characteristics might not be measured very well in our dataset.

Furman, et al. (2002) and Kanwar & Evenson (2003) have featured GDP per capita, patent protection and human capital as characteristics with empirically proven effects on innovation. Human capital can be seen as the competency of the relevant country’s educated population, while the level of protection a patent holds in a given country can affect the monetary value of patents and thus the willingness to innovate. Furthermore, the level of publicly funded R&D can also contribute to innovation, while GDP per capita is a characteristic that can capture other omitted variables, such as the population’s ability to pay for new technologies (Popov & Roosenboom, 2009).

We confront concerns about autocorrelation of residuals. As policy changes may create shocks in the willingness to innovate, the error term in our regressions may be affected. An example is changes in personal income tax relative to capital gains tax (Da Rin, Nicodano, & Sembenelli, 2006). This may have the implication that our standard errors are unnaturally low. If the error term is following a random walk, we should estimate our results in differences rather than levels (Popov & Roosenboom, 2009).

As these changes are probable to last over time, we can compute differences in values five years apart and execute a first-difference regression. In addition, venture capital and public grants are usually paid in fixed stages instead of in steady streams. This means that a grant received in 2007 might be spent in 2008. We therefore calculate 2-year averages for each dependent and independent variable (e.g., the mean of patent grants, the mean of VC disbursements and the mean of GDP per capita in the period 2007-2008) and take the differences for each variable in time periods of 5 years. For instance, the difference between the means of variables in 2007-2008 and the means of variables in 2012-2013, and the difference between the means of variables in 2014-2015 and the means of variables in 2019-2020.

As we concluded that the $\rho = 1$ linear approximation offers the best fit in our analysis, we choose to only perform the first-difference estimation on this model. Further, we only conduct the first-difference analysis on the combined countries since the countries individually do not have enough observations for any meaningful results. In addition, we only obtain significant results in the linearized regressions on the combined countries, making the individual countries less interesting to analyze further.

We only have data on GDP (The World Bank, n.d.), human capital (Global Data Lab, n.d.), patent protection (Property Rights Alliance, 2022), and public R&D per country and year (Eurostat, 2022), and not per sector, which means that we are limited to our aggregated per-year numbers of funding and patents. With two countries, this leaves us with 16 observations for venture funding and 13 observations for public funding.

In Table 13, we have added measurement variables for human capital, public R&D, GDP per capita, and patent protection. Human capital is measured using the number of mean years of schooling for each year and country. Patent protection is measured using the International Property Rights Index's measure of patent protection. We have also controlled for country differences (not reported in the table).

In our paper, we have used two-year periods instead of three- or four-year periods as Popov and Roosenboom (2009) have. While Popov and Roosenboom (2009) focus on PE and argue that such disbursements may be spent up to four years after the funding date, it is likely that public funding is spent faster. Our dataset reveals that around 41% of Innovation Norway's funding is granted to brand new companies in the start-up phase and other initiatives that are likely to spend grants in a short timeframe. We therefore view two-year averages as a more representative measure. This also gives us an increase in the number of observations.

	Granted		Applied		Granted (application y)	
VC/R&D (αb)	-0.035		-0.056		0.364	
	(0.054)		*(0.037)*		*(0.091)****	
PG/R&D (αb)		-0.238		-0.010		-0.366
		(0.133)		*(0.100)*		*(0.138)***
Private R&D (α)	-4.456	-6.026	-0.099	-0.600	2.175	-0.622
	*(1.271)****	*(1.410)****	*(0.863)*	*(1.066)*	*(2.145)*	*(1.467)*
Mean years of schooling	-16.555	-21.106	-0.193	0.324	16.710	3.935
	*(5.190)***	*(5.530)***	*(3.525)*	*(4.182)*	*(8.757)**	*(5.757)*
Public R&D	-0.178	0.462	-0.106	-0.063	0.184	-1.277
	(0.371)	*(0.443)*	*(0.252)*	*(0.335)*	*(0.627)*	*(0.461)***
GDP per captia	0.591	0.875	-0.399	-0.478	-1.457	0.273
	(0.342)	*(0.402)**	*(0.232)*	*(0.304)*	*(0.577)***	*(0.418)*
Patent Protection Index	-0.002	-1.034	-1.065	0.066	6.360	4.030
	(1.332)	*(1.612)*	*(0.905)*	*(1.219)*	*(2.247)***	*(1.678)**
R^2	0.896	0.940	0.850	0.916	0.865	0.958
Adjusted R^2	0.804	0.856	0.718	0.799	0.746	0.900
N	16	13	16	13	16	13

Note: Dependent variable is the logarithm of the numbers of patents granted, applications, and granted after application year. A country dummy is included in the regressions, but not included in the table. Standard errors are shown in parentheses. *** denotes statistical significance at the 1%, ** at the 5%, and * at the 10% level.

Table 13: First-difference regressions of public grants and venture capital for Norway and Sweden combined between 2007 and 2020 (2011-2020 for Sweden).

From table 13, we only obtain significant values for VC and public grants when looking at patents granted from the application year. The coefficient for the VC/R&D ratio is positive while the coefficient for PG/R&D ratio is negative (at the 5% level). This is in line with our previous findings. It should be noted that we do not find statistically significant results for the private R&D coefficient in patents granted from application year, which we do find in our previous regressions. This implies that our findings should be taken with some caution. It should be noted that we only have 16 and 13 observations in the difference analyses, and this can affect the robustness results. Using a larger dataset could return results that in a better way accounts for omitted variables.

7. Discussion

In this chapter, the results from the various reduced-form regressions will be interpreted and compared to the findings in Kortum and Lerner (2000) and Popov and Roosenboom (2009). We will also highlight the implications of our findings, certain limitations in our analysis, and provide recommendations for further research.

7.1 Major Findings

Throughout our analysis, we did not find any significant findings on each country's venture capital disbursements. Howbeit, when grouping the countries, we did get significant and positive results for venture capital in the $\rho = 1$ linearized specification. We believe that we got significant results in this specific analysis since the likelihood test suggested that restricting the model to $\rho = 1$ offers the best fit for our model. As the model offers a better fit, this makes finding significant results more likely. Further, when combining the countries, we achieve a higher number of observations. The finding suggests that venture disbursements do spur innovation, which is in line with the findings of Kortum and Lerner (2000) and Popov and Roosenboom (2009).

We find that venture capital disbursements have the greatest impact on patent grants from the application year. This result is reasonable since this measure aligns funding and the granted patent to the same year. The result implies that venture disbursements have a greater impact on ultimately successful patents than the willingness to apply for patents.

The results investigating the effect of public grants for the combined countries were generally more significant and provided very interesting results. The Cobb-Douglas estimation ($\rho = 0$), the constrained equation ($\rho = 1$), and the linearized specification showed significant and negative results for public grants. These negative estimates suggest that providing firms with public funding has a negative effect on innovation activity and is essentially destroying innovation. We also find significant and negative results in the constrained ($\rho = 1$) estimation for public grants in Norway specifically. The results suggest that public grants from Innovation Norway have a negative effect on patenting activity, and thus innovation. When gathering all the analyses, the results insinuate that venture capital disbursements have a positive effect, while public grants have a negative effect, on innovation in the combined countries, conditional on business enterprise R&D expenditures.

To measure the effect venture disbursements and public grants have on innovation, we utilize the same formula as in Kortum and Lerner (2000). This formula gives an indication of how venture disbursements and public grants relate to innovation and can be compared to the respective VC/R&D and PG/R&D ratios.

$$b(VC/R\&D)/(1 + b(VC/R\&D)\,) \quad (16)$$

$$b(PG/R\&D)/(1 + b(PG/R\&D)\,) \quad (17)$$

From our calculations of parameter b, venture disbursements seem to be less potent in creating innovation than business enterprise R&D. This is not in line with the results in Kortum and Lerner (2000) and Popov and Roosenboom (2009). Public grants have a negative b parameter, suggesting that it is not only less potent but harmful for creating innovation output. Hence, a euro invested in R&D seems to be more efficient in spurring innovation compared to a euro invested in venture capital. The same argument holds for public grants, with the addition that it seems to be damaging for creating innovation output. The potency of venture disbursements and public grants for the countries combined are depicted in table 14.

Norway and Sweden combined						
	b	VC/R&D	VC potency	b	PG/R&D	PG potency
Patent grants	-	38.61 %	-	-	5.16 %	-
Patent applications	0.06	38.61 %	2.08 %	-0.68	5.16 %	-3.64 %
Patent grants application y	0.041	38.61 %	1.56 %	-0.52	5.16 %	-2.76 %

Table 14: Results from the linearized specification for the countries combined. VC/R&D ratio, venture capital potency, PG/R&D ratio, and public grants potency (2011-2020 for Sweden). Between 2007 and 2020.

Table 14 does only contain the b parameters for the countries combined from the linearized regression. This is because it provides the most conservative estimation, and we find significant results for both venture capital and public grants. From the constrained equation

$\rho = 1$, we have significant results for Norway, making it possible to calculate b. However, it is not significant when linearizing the equation. Therefore, Norway alone is not included.

7.2 Interpretation and Implications

The positive effect of venture disbursements in the linearized specification is in line with the findings of Kortum and Lerner (2000) and Popov and Roosenboom (2009). However, since our b estimates are lower than our VC/R&D ratio, it suggests that business enterprise R&D is more effective in generating innovative output, which is contradictory to their findings.

There are several possible reasons for why our results deviate from their findings, of which we believe too few data points is one of the reasons. An important argument for why we believe this, is based on the fact that the results' significance level immediately improves when we double our observations by combining the countries. Further, the venture capital landscape in Norway and Sweden looks vastly different compared to what the US VC landscape did during the timespan of Kortum and Lerner's (2000) analysis. This results in a considerably higher VC/R&D ratio in our analysis affecting the interpretation of venture capital's potency. The PG/R&D ratio is on the other hand more in line with Kortum and Lerner's (2000) VC/R&D ratio, arguably making it a better fit. We see several significant results using this ratio. This can indicate that the high VC/R&D ratio in our analysis is part of the reason for the deviation in the potency results.

Finding that venture funding has a positive effect on innovation is in line with our referenced literature, and as expected when one looks at the business model of a venture capital firm. A VC firm selects portfolio companies that portray great growth projections and can incentivize the funded firm by investing in different rounds and setting targets for the company. They often take an active part in the company with the mission to receive a high return on their investments, which in itself may stimulate to more innovative output. Innovation Norway also have certain prerequisites for recipients but monitoring and involvement are less prevalent compared to venture capital (Innovation Norway, 2022). This means that the companies receiving grants may not have great growth projections or the same characteristics as venture-funded firms.

Since Innovation Norway and Vinnova are not involved in the same way a venture firm is, the company receiving the grant may not have the same incentives to innovate and might not invest the grant optimally. Research presented in our literature review found that public grants have positive effects on employment, but most findings that investigate public grants' effect on total factor productivity show negative or non-significant results. Similarly to our analysis, total factor productivity is calculated through a production function and measures the output relative to the input involved in a production process (Kohli, 2015). Total factor productivity captures the effect of changes in technology, institutions, and other productivity shocks. The change in technology can arguably be linked to changes in innovation. The negative and non-significant findings on public grants and total factor productivity may therefore align to some degree with our findings of reduced innovation activity through patent creation.

Our negative results for public grants are compelling since the providers of these grants, Innovation Norway and Vinnova, are meant to spur innovation. If public grants do contribute negatively to innovation, then this contradicts the overall goal of publicly funding innovative firms in Norway and Sweden. Public funding is collected from taxpayers' money to facilitate technological advancements (and economic prospering). According to our research, taxpayers' money does not contribute to technological advancements but rather contributes negatively.

However, it should be emphasized that the contribution of public grants is measured against enterprise business R&D expenditures. Many of the firms receiving public grants are smaller firms that are likely to not have the funds to finance their own internal R&D projects (Da Rin & Penas, 2015). Although public grants show negative results on innovation creation, public grants give the recipient firms the possibility to innovate. Howbeit, it raises the discussion of whether other instruments for innovation creation should be utilized instead of direct cash transfers to achieve higher innovation activity.

7.3 Limitations

As stated, there are several limitations in our analysis. We have discussed the relatively low number of observations as a limitation, and we believe that if the number of observations was greater, it would be possible to achieve significant estimates for each country. By having significant results for each country, one can compare Norway and Sweden and investigate if there are any substantial differences between the potency of the funding sources in the two countries.

Further, the datasets used in the analysis report business sectors after different frameworks, making it necessary to create a conversion table. Due to some of the datasets being aggregated, it is not possible to achieve a perfect conversion. Moreover, the patenting data are provided with the technology field of the invention instead of the sector of the patent holding company. It is therefore likely that some patents are allocated to other sectors than the primary sector of the company.

Furthermore, our data has been filtered for the purpose of this analysis. This could make our results less suited to reflect actual relationships. However, we believe this filtering should have made it more likely to see a positive relationship between public grants and patenting. For instance, the Invest Europe sector "Real estate," which receives considerable amounts of funding from Innovation Norway but spurs very few patents, is not included in our dataset. In addition, we have removed state-owned and foreign companies from the Innovation Norway dataset, as they are not believed to have much patenting activity in Norway. As our final results shows a negative relationship, this filtering should make the negative relationship even more trustworthy.

It is likely that Innovation Norway and Vinnova have a tendency to grant funding to companies in the start-up phase who are not mature enough to apply for or be granted patents. This generates the possibility that any patent application or grant does not occur until years after the public funding took place. Since we use aggregated data distributed over years rather than company specific data, this could distort our results. However, this should have been accounted for in our lagged regressions. As noted in the Methodology chapter, we did not find results that deviated substantially from the non-lagged regressions.

Finally, the Swedish and Norwegian VC/R&D ratio is prominently larger compared to the ratio in Kortum and Lerner (2000), making it less accurate for the linear specification. The deviation in the ratios is likely to have affected our results. The specification do however fit the public grants data better, which arguably makes the results for the public grants more reliable than the venture capital results. Another assumption we made is that Kortum and Lerner's (2000) finding of a causal relationship between funding and innovation holds for our analysis as well.

We conducted a first-difference test to assess the robustness of the analysis. The results are statistically significant and hence back up our findings that public grants have a negative impact on innovation and that venture capital contributes positively to innovation. However, we did not get significant results for R&D’s contribution to innovation, which weakens the results of our robustness analysis. We only received significant results when looking at the countries combined and when looking at patent grants from the application year. It is worth noting that our first-difference estimation contains few observations, which are likely insufficient to present us with reliable results. Howbeit, based on the first-difference estimation, our results do seem to be somewhat robust.

The limitations mentioned are important to keep in mind, and one should therefore treat our results with some caution.

7.4 Recommendations for Further Research

Due to our interesting findings regarding public grants' negative effect on innovation, we encourage further studies on said topic. In order to obtain more data points, and perhaps more accurate results, we recommend using a data sample that can match firms’ public grants or venture funding and their patenting activity instead of matching sectors. By increasing the likelihood of significant results through more observations, it is also possible to compare the countries and investigate if the effect differs from one another. Gathering more insight on this topic can be very beneficial for designing new innovation policies, making innovation efforts more efficient and successful.

8. Conclusion

This thesis has attempted to measure venture capital disbursements' and public grants' impact on innovation in Norway and Sweden from 2007 to 2020. As a measurement for innovation, we investigate the contribution the two external funding sources have on patent applications, grants, and grants from the year they were applied for. To our knowledge, we are the first to apply the methodology of Kortum and Lerner (2000) to investigate public grants' effect on innovation. Based on the original study and the study from Popov and Roosenboom (2009), we expected to find that venture disbursements are more potent in generating innovation output than business enterprise R&D.

Our results suggest that venture disbursements have a positive effect on innovation when looking at Norway and Sweden as a combined entity. In addition, we find that venture funding has the greatest impact on patent grants measured from the year they applied for patent protection. When investigating the countries by themselves, we are not able to get significant results, likely due to few observations. Howbeit, the venture capital potency is lower than the VC/R&D ratio in all scenarios which suggests that business enterprise R&D is more potent in creating innovation output in Norway and Sweden.

The results regarding public grants from Innovation Norway and Vinnova are especially interesting. When combining the two countries, we retrieve significant and negative results in nearly all of our estimations. Negative results suggest that public grants are not only less potent in creating innovation than business enterprise R&D but also reduces overall innovation output. We found that public grants have the most negative effect on patent applications, suggesting that public grants reduce the willingness to apply for patent protection more than the ultimately successful patents.

Throughout the analysis, we have introduced numerous variations of our dataset to control for the robustness of the results. We get significant results for public grants in most scenarios, and our robustness test conducted through a first-difference analysis provides us with some significant results, which infer that our findings are somewhat robust.

The findings obtained in this thesis on venture disbursements' effect on innovation are contradictory to the findings in the original study. Kortum and Lerner (2000) found that venture disbursements in twenty manufacturing sectors in the US accounted for 8% of industrial innovation in the respective sectors between 1983-1992, with a VC/R&D ratio of 3%. Popov and Roosenboom's (2009) findings suggest that PE accounted for 12% of innovation in Europe, with a PE/R&D ratio of 8%. We found that VC disbursements accounted for approximately 2% of innovation in Norway and Sweden with a VC/R&D ratio of approximately 39%. Even though we found positive effects of venture capital in our analysis, venture disbursements are found to be less potent than R&D, which deviates from their studies.

We advise that this thesis should be seen as a first draft of investigating the impact of venture disbursements and public grants in Norway and Sweden. Our results are likely to be affected by adjustments and conversions in the datasets, and we believe that few data points have affected our results. Howbeit, we hope that our findings will encourage further research on venture capital and public grants' contribution to innovation. We believe that increasing the sample size by collecting data on the firm level would result in a very interesting study, which might contribute to designing new innovation policies.

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Appendix

I. Likelihood-Ratio Tests

		Patent grants	Applications	Patent grants (application y)
p=1	VC Norway	-	-	-
	VC Sweden	-	-	-
	VC Combined	-	-	-
	PG Norway	-	-	Rejects p=1
	PG Sweden	Rejects p=1	Rejects p=1	Rejects p=1
	PG Combined	-	-	-
p=0	VC Norway	Rejects p=0	Rejects p=0	-
	VC Sweden	Rejects p=0	-	Rejects p=0
	VC Combined	Rejects p=0	Rejects p=0	Rejects p=0
	PG Norway	-	Rejects p=0	Rejects p=0
	PG Sweden	Rejects p=0	Rejects p=0	Rejects p=0
	PG Combined	Rejects p=0	Rejects p=0	Rejects p=0

Appendix 1: Likelihood-ratio tests for $\rho = 1$ and $\rho = 0$. Assessing the goodness of fit of the full statistical model and the extreme cases, $\rho = 1$ and $\rho = 0$. The test could not reject the hypothesis in the blank cells.

II. Distribution System – NACE Rev. 2 to Invest Europe Sectors (Sweden)

Invest Europe Sectors

Distribution system based on Statistics Sweden's clustering of NACE Rev. 2 codes

	Observations		Agriculture		Biotech and healthcare		Business products and services		Chemicals and materials		Construction		Consumer goods and services		Energy and environment		ICT		Real estate		Transportation		Infrastructure	
NACE Code	# of Ind.	# sub-codes	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w
A01-03+B05-B09	3	85	55	0.6					20	0.2					10	0.1								
C16	2	9									2	0.2	7	0.8										
C13+C15+C18	3	29							14	0.5			7	0.2			8	0.3						
C19-C20	3	28							20	0.7			3	0.1	5	0.2								
C23	3	33					10	0.3			21	0.6	2	0.1										
C25	2	26					23	0.9			3	0.1												
C26	4	19			2	0.1	3.5	0.2					3.5	0.2			10	0.5						
C27	3	17											7	0.4	6	0.4	4	0.2						
C28	2	27					26	1.0	1	0.04														
C31-32	2	21			2.0	0.1							19	0.9										
C33	4	12			1	0.1	7	0.6					1	0.1							3	0.3		
D35+E36-E39	2	31					2	0.1							29	0.9								
F41-F43	3	32									22	0.7			2	0.1							8	0.3
G47	3	47			1	0.02							42	0.9			4	0.1						
G45-46+I55-56	7	68	1	0.01			48	0.7	3	0.04	1	0.01	9	0.1			3	0.04			3	0.04		
H49-H53	3	39					2	0.1							2	0.1					35	0.9		
L68+N77-81	4	54					33	0.6			1	0.02	12	0.2					8	0.1				
M72	2	6			4	0.7	2	0.3																
M73-75+N82+84-99	4	124			23	0.2	21	0.2					71	0.6			9	0.1						

Appendix 2: The distribution table developed to distribute Sweden's business enterprise R&D expenditures from NACE. Rev. 2 to Invest Europe sectors. The industries are divided by "Obs" and "w." "Obs" denotes the number of observations within the NACE code, while "w" denotes the weight given to the industry based on the number of observations.

III. Distribution System – NACE Rev. 2 to Invest Europe Sectors (Norway)

Invest Europe Sectors																						
Distribution system based on Statistics Norway's clustering of NACE Rev. 2 codes																						
	Observations		Agriculture		Biotech and healthcare		Business products and services		Chemicals and materials		Construction		Consumer goods and services		Energy and environment		ICT		Transportation		Infrastructure	
NACE Cod	# of Ind.	# sub-codes	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w	Obs	w
B05-B09	2	23							20	0.9					3	0.1						
C13	2	15							14	0.9			1	0.1								
C16	2	9									2	0.2	7	0.8								
C19-C20	3	28							20	0.7			3	0.1	5	0.2						
C23	3	33					10	0.3			21	0.6	2	0.1								
C25	2	26					23	0.9			3	0.1										
C26	4	15			2	0.1	1.5	0.1					3.5	0.2			8	0.5				
C27	3	17											7	0.4	6	0.4	4	0.2				
C28	2	27					26	1.0	1	0.04												
C33	4	12			1	0.1	7	0.6					1	0.1					3	0.3		
D35	2	12					2	0.2							10	0.8						
F41-F43	3	32									22	0.7			2	0.1					8	0.3
G46	6	57	1	0.02			44	0.8	3	0.1	1	0.02	5	0.1			3	0.1				
H49-H53	3	39					2	0.1							2	0.1			35	0.9		
M72	2	6			4	0.7	2	0.3														

Appendix 3: The distribution table developed to distribute Norway's business enterprise R&D expenditures from NACE. Rev. 2 to Invest Europe sectors. The industries are divided by "Obs" and "w." "Obs" denotes the number of observations within the NACE code, while "w" denotes the weight given to the industry based on the number of observations.