LUND UNIVERSITY
School of Economics and Management

Bachelor's Program in Economy and Society

Doctoral Degrees in the Light of R&D Funding Allocations to Private Firms

by

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To address contemporary challenges like climate change, technological innovation becomes ever more important. Innovation is the product of a vast array of interactions between actors in the economy and it is vital to understand the relations between these. This quantitative study examines the interplay between highly skilled human capital and public R&D funding to private sector firms at the regional level in Sweden. The study assesses the number of doctoral degrees awarded across six different research areas and the public R&D funding allocated to private firms by Vinnova, the Swedish innovation agency. The data analysed spans the eight Swedish NUTS2 regions between 2003 to 2021. Whereas the number of doctorates remains relatively constant across regions and years, a general increase in funding is observed. A positive relationship is found between the total number of doctoral degrees issued across all research areas and the amount of funding allocated. Specifically, one additional PhD awarded in any research area corresponds to a 0.218% increase in the amount of funding provided by Vinnova. Results vary considerably when doctoral degrees are split up by research area. A significant relationship is found for additional doctorates in medicine and health sciences, social sciences, and technical sciences. Significance varies depending on the statistical model. Overall, mixed results across different research areas point towards the importance of region-specific characteristics in the allocation of public R&D funds by Vinnova in Sweden.

Keywords: Innovation, Doctoral Degrees, Research and Development, Funding, Regions, Research Area

EOSEK12
Bachelor's Thesis (15 credits ECTS)
June 2023
Supervisor: Phillip Jonas Kreutzer
Examiner: Anna Tegunimataka
Word Count: 13013

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List of Abbreviations

EIS	European Innovation Scoreboard
EU	European Union
Formas	Government Research Council for Sustainable Development
GDP	Gross Domestic Product
GRP	Gross Regional Product
HEI	Higher Education Institution
NUTS	Nomenclature of Territorial Units for Statistics
R&D	Research and Development
RIS	Regional Innovation Scoreboard
RISE	Research Institute of Sweden AB
SDG	Sustainable Development Goal
SEK	Swedish Kronor
SQM	Square Meter
UKÄ	Universitäts Kanslersämbientet, The Swedish Higher Education Authority
VINNOVA	Swedish Innovation Agency (Innovationsmyndighet)
WIPO	World Intellectual Property Organization

1 Introduction

1.1 The Problem

Throughout history major changes in the economy have been accompanied by innovation. Joseph Schumpeter drew attention to this with his philosophy of creative destruction, which remains relevant in today's competitive and global economy, albeit in connection with new, contemporary challenges such as climate change (Ziemnowicz, 2020; Pacala & Socolow, 2004). In the light of such challenges, the economy will again need to forego drastic change but in a shorter amount of time. One example of drastic change is the concept of "green growth," which involves the successful innovation of sustainable technologies to reduce carbon emissions and the cost of carbon-efficient production methods, products, and lifestyles (Jacobs, 2013).

The innovation required for the success of concepts like green growth demands significant investment in research and development (R&D). Yet, according to economic theory, research in one period depends on the expected amount of research in the next period, an often-discouraging prospect for firms who see no future profit opportunities as a result (Aghion & Howitt, 1992). Private sector investment in R&D consequently suffers from the public goods problem of being non-rivalrous and non-excludable (Arrow, 1962; Becker, 2015; Nelson, 1959). To address this and achieve an optimal level of investment in R&D for new technologies, government or public R&D funding is essential (Becker, 2015).

Recognizing the urgency of innovation to combat timely challenges, academic research increasingly focused on empirical evidence of the efficiency of public R&D subsidies to the private sector (Becker, 2015; Heshmati & Loof, 2005; Coccia, 2010). Simultaneously, region-specific characteristics and capacities, such as human capital, are central to understanding what drives innovation over time (Rodríguez-Pose, 2018; Spiezia & Weiler, 2007). Given the need to transition to a cleaner economy, it is crucial to understand the impact of pre-existing, regional capabilities on public R&D funding to maximize the efficient allocation and policy circumstances surrounding such grants.

1.2 Relevance and Aim

Governments pledge higher shares of their budgets to support R&D and foster innovation. Sweden consistently ranks as an innovation and sustainability leader which makes it a relevant case study of regional differences in public R&D funding (European Commission, Directorate-

General for Research and Innovation, Hollanders, H., Es-Sadki, N. & Khalilova, A, 2022). Awareness of regional differences in the performance of publicly funded R&D schemes is a prerequisite for their effective allocation (Gustavsson Tingvall & Videnord, 2017). Spatial differences underlie many factors, of which human capital is a key one. Previous studies indicated that a region's human capital influences the effectiveness of private and public R&D funding and innovation (Becker, 2015; Griffith, Redding & Reenen, 2004; Piekkola, 2007).

Human capital and especially highly skilled workers, such as doctoral degree holders, are commonly located in metropolitan regions, favouring local knowledge spillovers and multiplier effects, while this is less the case in rural regions (Biscaia et al., 2017; Moretti & Thulin, 2013; Piekkola, 2007; u & Nardinelli, 2002). In respect to the impact of highly skilled human capital, Gustavsson Tingvall and Videnord (2017) found that firms in regions with greater human capital wealth are more likely to exhibit growth effects after receiving public R&D grants.

This study, therefore, examines the relationship between the distribution of public R&D grants from the Swedish innovation agency Vinnova (Innovationsmyndigheten) to private firms and the regional pool of skilled labour, measured through doctoral degrees awarded in the region. To add additional detail, the study examines the impact of doctoral degrees issued across the six different research fields humanities and arts, agricultural and veterinary sciences, medicine and health sciences, natural sciences, social sciences, and technical sciences at Higher Education Institutions (HEIs) across Sweden. The research question guiding this study is:

To what extent does the regional pool of highly skilled human capital, measured by doctoral degrees across six research fields, affect the amount of public R&D funding private firms in the same region receive from Vinnova?

While there is a wealth of literature investigating the effectiveness of public R&D grants to private firms and factors which influence the allocation of such grants, previous studies did not examine in detail the regional relationship to doctoral degree holders and specific research areas which may be especially important to stimulate public R&D grants to the private sector. Thus, this study seeks to contribute to a holistic understanding of what factors influence the allocation of public R&D funding. The study provides additional insights through a self-constructed panel data set which observes the eight Swedish NUTS2 (Nomenclature of Territorial Units for Statistics) over a 19-year period, from 2003 to 2021.The study hopes to bridge the gap between academia, the private sector, and policymakers and help to ensure that public R&D funding is used effectively and intentionally to foster innovation to address contemporary challenges.

1.3 Scope and Limitations

This study's scope is Sweden, specifically the eight Swedish NUTS2 regions Upper Norrland, Central Norrland, North Central Sweden, East-Central Sweden, Stockholm, West Sweden, Småland and the Islands, and South Sweden. It follows the total number of doctoral degrees awarded in six different research areas, humanities and arts, agricultural and veterinary sciences, medicine and health sciences, natural sciences, social sciences, and technical sciences. The data on doctoral degrees by HEI was extracted from the statistical data base of the Swedish Higher Education Authority (Universitäts Kanslersämbientet, UKÄ) (UKÄ, 2023c) and then summed by region. Furthermore, the dataset contains the amount of funding provided by Vinnova to private companies, delivered on request by the author on the 5th of April and the 10th of May 2023, and summed by region. Lastly, it includes two structural indicator variables Gross Reginal Product (GRP) and population density which were obtained from Statistics Sweden (Statistics Sweden, 2022e; Statistics Sweden, 2023b).

The main limitations of this study are twofold. First, Vinnova funding programs represent only a small part of government R&D funding to the private sector, and second, doctoral degrees are only one possible measure of highly skilled human capital. The results of this study, therefore, cannot be generalized per se. Further limitations are outlined in detail in section 4.3.

1.4 Outline of the Thesis

The thesis starts by contextualizing the Swedish R&D and human capital landscape in terms of funding and doctoral education. It then provides a literature review which dives into university-industry relationships, firms propensity to apply for and receive public R&D grants as well as a presentation of the Swedish regions based on their innovation capacity determined by the EU's Regional Innovation Scoreboard (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021; (RIS)). Subsequently, the methodology section presents the data as well as the methods and limitations of this study. The results of the analysis are presented in two parts; first, examining the relationship between the total sum of doctoral students and public R&D funding to private firms, and second, the relationship when each research area is considered separately. Finally, the discussion contextualizes the results in the previous literature and points out the importance of the region-specific effect. The study is concluded by providing a summary of the insights and future research possibilities.

2 Context

This section provides an overview of the R&D and highly skilled human capital landscape in Sweden. Because the terms innovation and R&D are used frequently throughout this study the official definitions by the OECD and Eurostat (2018, p.20) are established.

*An **innovation** is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).*

Inseparable from innovation and central to this study is the concept of R&D, which corresponds to the following definition by the OECD (2015, p.28):

***R&D** comprise 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.*

Furthermore, R&D activities and innovation are characterized by the five features: new, creative, uncertain, systematic, and transferable and/or reproduceable (OECD, 2015, p.28). The term R&D encompasses three types of activities: Basic research, applied research, and experimental development. The Frascati Manual (OECD, 2015) and the Oslo Manual (OECD & Eurostat, 2018) are guidelines for collecting, reporting, and using data on innovation, research, and experimental development.

2.1 The Swedish Innovation System

Innovation systems, as explained by Schwab and Zahidi (2020), are complex mechanisms which involve the generation of ideas, and their translation into products and commercialization. The success of an innovation system, according to the authors, depends on multiple factors, including a business culture which is willing to take risks and change. Furthermore, they explain, innovation systems are accompanied by a set of regulations and administrative norms which create entrepreneurial climates. Part of a successful innovation system is a strong knowledge generation sector (universities, research centres, and laboratories) and their collaboration with business (Schwab & Zahidi, 2020).

Sweden is internationally known as a successful innovation system. Since 2020, the country ranks as one of the top three most innovative high-income economies in the world, according to the Global Innovation Index (WIPO, 2021). The European Innovation Scoreboard (EIS) also identified Sweden as the innovation leader among EU countries and emphasizes Sweden's public-private co-publications, lifelong learning initiatives, international scientific co-publications, employed ICT specialists, and foreign doctoral students as strengths of the country’s innovation capacity (European Commission, Directorate-General for Research and Innovation, Hollanders, Es-Sadki & Khalilova, 2022). As relative weaknesses compared to other innovation leaders, the EIS points to Sweden's job mobility of human resources in science and technology, resource productivity, government support for business R&D, non-R&D innovation spending, and exports of mid- to high-technology goods.

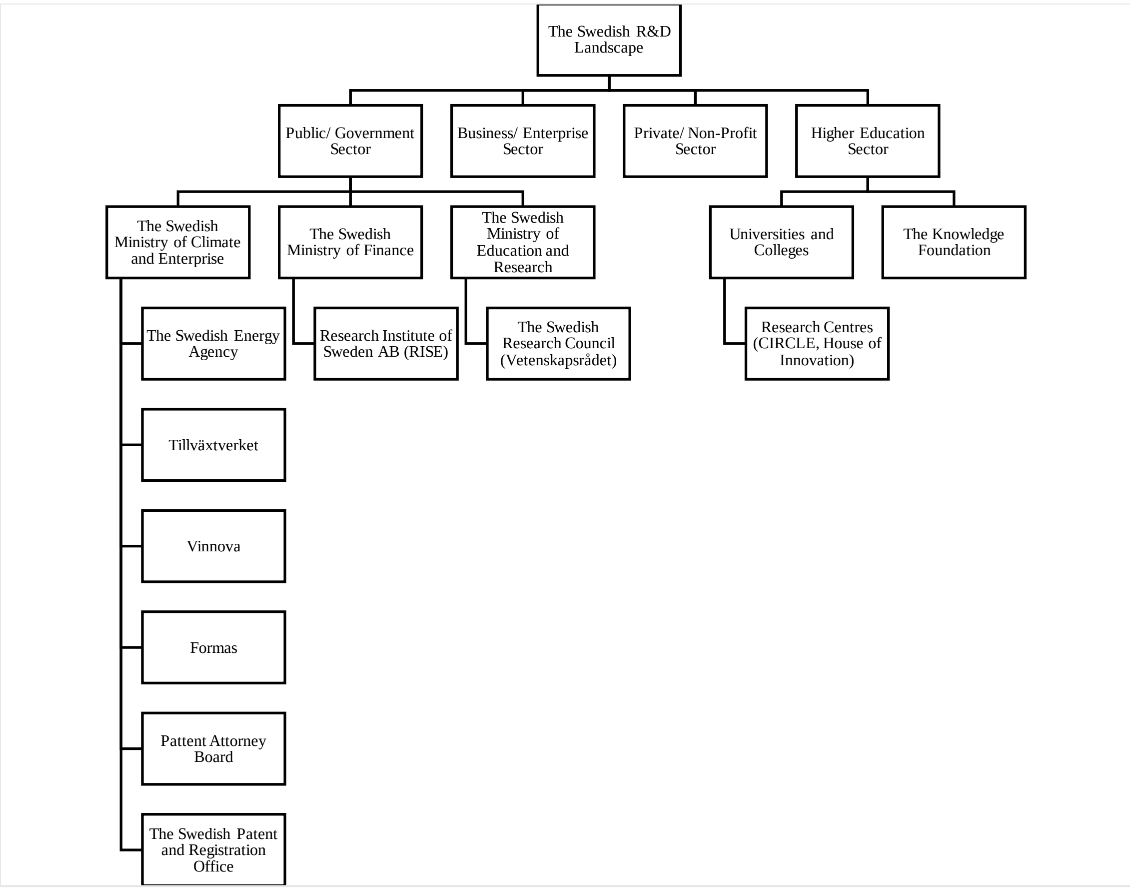
Vinnova, the Swedish Energy Agency (Energimyndigheten), and the Government Research Council for Sustainable Development (Formas), currently fund seventeen strategic innovation programs which facilitate collaboration, create sustainable solutions to global, societal challenges, and increase Sweden's international competitiveness (Vinnova, 2022). The programs include, for example, bio innovation, mobility services, transport infrastructure or aerospace technology and aim to foster collaboration between companies, universities, and research organizations. The strategic innovation programs are a prime example of Sweden's strong emphasis on innovation and R&D in relation to sustainability and social impact.

2.2 The Swedish R&D Landscape

R&D in Sweden is conducted, supported, and funded by four different sectors: the public sector, the business sector, the non-profit sector, and the higher education sector (Statistics Sweden, 2022a). Within each of these sectors, there are several actors who distribute and receive R&D funding. The organizational chart in Figure 1 provides insight into the structure of the Swedish R&D landscape.

Because this study focuses on public R&D funding, a description of the actors within the public sector follows. The Swedish Ministry of Climate and Enterprise, the Swedish Ministry of Finance, and the Swedish Ministry of Education and Research are responsible for several government agencies who carry out R&D activities and distribute the funding allocated by the Swedish Parliament (Riksdag) and the government (Government Offices of Sweden, 2014). The ministries also manage several R&D companies which are wholly or partially owned by the state, as well as foundations and other organizations in the innovation space (Government Offices of Sweden, 2014).

Figure 1 - Organizational Chart of the Swedish R&D Landscape



Source: Author’s own graphic based on Government Offices of Sweden (2014)

The Ministry of Climate and Enterprise oversees four of the main agencies for innovation and R&D, namely Vinnova, the Swedish Energy Agency, the Swedish Agency for Economic and Regional Growth (Tillväxtverket), Formas, as well as the Patent Bar Association and the Swedish Patent and Registration Office (Government Offices of Sweden, 2014). The Ministry of Finance oversees the Research Institute of Sweden AB (RISE) and the Ministry of Education and Research oversees the Swedish Research Council (Vetenskapsrådet). Table 1 provides an overview of the specific functions of these agencies.

Table 1 - Overview of Tasks by Agencies in the Swedish R&D Landscape

Organization	Function
Energiemyndigheten	• Support of R&D on the supply, conversion, distribution, and use of energy • Assistance to the development of new technologies
Vinnova	• Build Sweden's innovation capacity and contribute to sustainable growth • Create incentives and opportunities for organizations to collaborate • Transfer knowledge and skills • Expert authority for innovation policy • National contact authority for the EU framework program for research and innovation
Tillväxtverket	• Promote sustainable growth and competitive companies throughout Sweden • Offer knowledge, networks, and financing
Formas	• Fund research and innovation, develop analyses, and conduct evaluations within the areas of environment, agricultural sciences, and spatial planning • Conduct evidence syntheses analyses which aim to make it easier for Sweden to achieve its environmental objectives
RISE	• Facilitate collaboration programs with industry, academia, and the public sector • Contribute to competitiveness, sustainability, and resilience with knowledge, equipment, and experience • Strengthen capabilities for transition and reform
Vetenskapsrådet	• Fund research and research infrastructure in all scientific disciplines • Advise the government on research policy • Work to increase the understanding of long-term societal benefits of research

Source: Author’s own table, based on information from Energimyndigheten (2023), Vinnova (2022), Tillväxtverket (n.d.), Formas (2020), RI.SE (n.d.), and Vetenskapsrådet (n.d.)

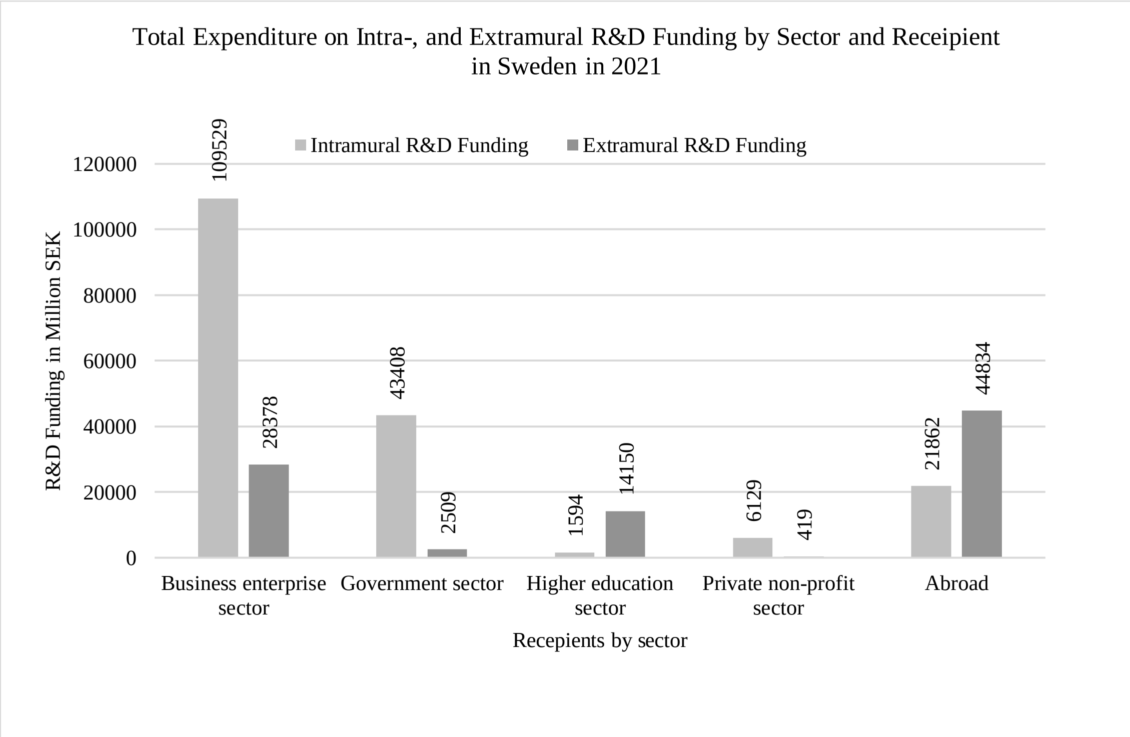
Sweden also provides an R&D tax incentive, which accounted for a 19,59 % exemption of employer’s social security contributions in 2021 (OECD, 2021). Statistics Sweden (2023a) reported that enterprises who claim deductions for R&D and the amounts they claimed doubled in 2020, compared to 2019. Labor input for R&D activities, according to Statistics Sweden (2022a), amounted to just under 112,000 full-time employees in 2021, a decrease of 3,1 % from 2020. Of those employed full-time in R&D, most are within the business enterprise sector and the higher education sector.

2.2.1 R&D Funding Flows

This section provides an overview of the allocation of R&D funds and funding flows between the different sectors. It is distinguished between "intramural" R&D, which stays within the same sector, and “extramural" R&D, which is received by organizations outside the sector. Funding from the government sector, allocated to the private sector, is considered “extramural” R&D funding (Vetenskapsrådet, 2019). Total intramural R&D spending in Sweden in 2021 was SEK 184.4 billion, an increase of 1,8 % from 2020 (Statistics Sweden, 2022a). Total Swedish extramural R&D spending amounted to SEK 90.289 billion in 2021 (Statistics Sweden, 2022b).

Figure 2 provides insight into the total expenditure on intramural and extramural R&D funding by sector and recipient in Sweden in 2021, based on numbers by Statistics Sweden (2022d) and Statistics Sweden (2022b). As shown, the share of intramural R&D funding within business, government, and the private non-profit sector is much larger than expenditures on extramural R&D. The governments total extramural R&D funding expenditure in 2021 was SEK 2509 million. HEIs, according to Vetenskapsrådet, (2022), account for about 25 percent of total Swedish R&D expenditure and are largely publicly funded. Approximately half of the overall funding of HEIs goes directly to the institutions, while the remainder is distributed by government agencies.

Figure 2 - Total Expenditure on Intra-, and Extramural R&D Funding by Sector and Recipients in Sweden in 2021

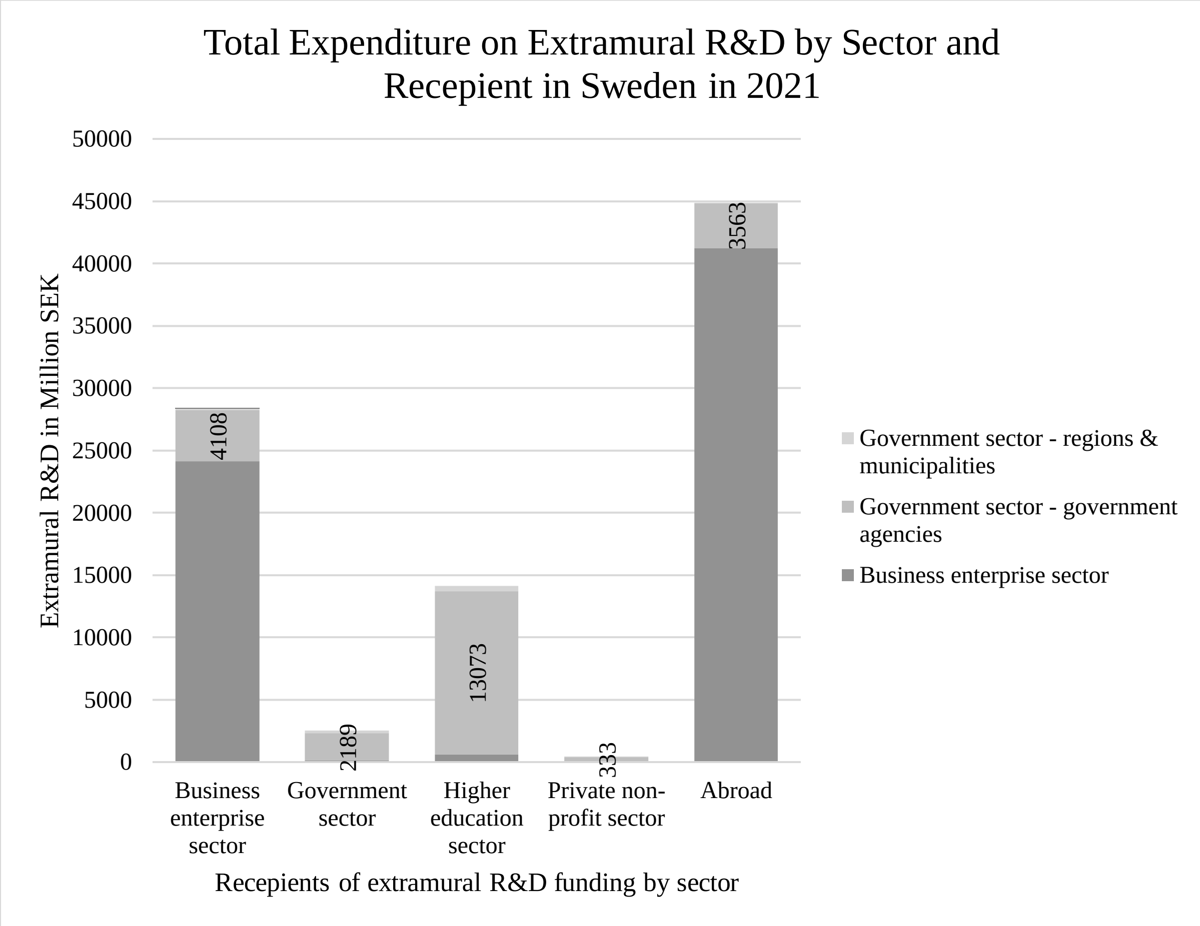


Source: Statistics Sweden (2022b; 2022d)

Note: Current Prices, SEK million

Figure 3 takes a closer look at the composition of extramural R&D funding. The government sector consists of central government agencies, regions, municipalities, and local and regional R&D units and public non-profit organizations (Statistics Sweden, 2022b). Numbers reported by Statistics Sweden (2022b) do not include extramural R&D funding allocations by the higher education sector. As observable in Figure 3, government agencies distributed a total of SEK 4108 million in R&D funding to the private sector in 2021. Hence, the business sector is the second largest recipient of extramural R&D funding by government agencies after the higher education sector. The share of funding distributed by government agencies also includes R&D grants by Vinnova in 2021. Statistics Sweden (2022c) reports that Vinnova was ranked second among the ten entities with the highest expenditure on outsourced R&D in 2021. It was exceeded by Vetenskapsrådet and followed by Energimyndigheten.

Figure 3 - Total Expenditure on Extramural R&D by Sector and Recipient in Sweden in 2021



Source: Statistics Sweden (2022b)

2.3 Skilled Human Capital in Sweden

Human capital is defined as an economic resource which represents the skills, knowledge, and qualifications possessed by the labour force (Merriam-Webster, n.d.). To Goldin (2014) this encompasses the idea that there are investments in people in the form of education, training, and health, and that those investments increase a person's productivity. In economic history, human capital underlies the aspects of technological change and economic growth which many parts of the world experienced (Goldin, 2014).

Since this study concerns the extent to which doctorates affect the propensity of firms in a region to receive public R&D funding, the following section outlines the Swedish education system along with the tertiary education cycle, which represent doctoral education. Naturally, there are many other definitions of high-skilled human capital and many ways in which education constitutes an important asset for business and innovation, especially nowadays when increasing digitalization eases access to knowledge. However, as Goldin

(2014) points out, the transmission and retention of knowledge may not have reached the "masses" of people if it were not for institutions such as schools and universities. Moreover, Ph.Ds. play a vital role in the development of future innovation by providing trained researchers, required to advance knowledge and explore emerging topics (OECD, 2019).

In an international R&D comparison, Sweden performs well, not least because of the large number of employees dedicated to research (European Commission et. al., 2022). The distribution of researchers reflects the structure of the R&D system in Sweden, with a small public institute sector, a large higher education and R&D-intensive business sector (Monaco, Barriere, Gurell, Karlsson, & Aldberg et al., 2016). The number of researchers in the higher education sector makes the doctoral degree an interesting variable to better understand the impact of high-skilled human capital on public R&D funding for private firms.

2.3.1 The Swedish Education System

Sweden's emphasis on education is frequently pointed to as one of the explanations for the country's innovative capacity and in the Swedish school system children go to school for at least 10 years (Swedish Institute, 2022). Upper secondary school is optional but necessary to be able to enter university, colleges, and higher vocational education. Post-secondary education at the university level, is defined in Sweden by the requirement that education must be based on scientific or artistic practice (UKÄ, 2023a). All courses, programs, and qualifications are assigned to one of three cycles: the first, leading to a bachelor's degree, the second to a master's degree, and the third, leading to a doctoral degree (UKÄ, 2023a). UKÄ (2023a) explains that the division in cycles is part of Sweden's adaptation to the Bologna Process, which aims to make higher education more comparable across countries.

2.3.2 Doctorate Degrees and Third-Cycle Education

The third cycle of study at a Swedish HEI leads to either a Licentiate degree (120 university credits after the second cycle of study) or a Doctorate degree (240 university credits after the second cycle of study) with corresponding degrees in the fine, applied, and performing arts (UKÄ, 2023a). Swedish higher education has a strong focus on research. In terms of monetary value, more than half of the activities at HEIs consist of third-cycle research and education (UKÄ, 2023a). Overall, the country's HEIs differ significantly in size, with the largest university hosting more than 45,000 students in the 2018/2019 academic year and the smallest university having fewer than 100 enrolled students. It is important to highlight that not all HEIs offer third cycle education or focus to the same extend on research (UKÄ, 2023b).

Some general factors about third-cycle education in Sweden are that it involves courses, independent study, research, and writing a thesis in close collaboration with a supervisor (Studera.nu, 2022). Furthermore, many programs include research seminars, and most doctoral students are employed by their university, where they are also responsible for some first- and second-cycle teaching (Studera.nu, 2022). The doctoral degree comprises 240 credits, which is equivalent to 4 years of study, however, the actual average duration of study is 4.2 years (Studera.nu, 2022).

Lundh (2022) reports a total of 17,400 doctoral students at Swedish universities in the fall of 2021 and that 2670 doctoral degrees were issued. Doctoral fellowships were the most common source of funding in all research areas, and men were more likely than women to have an industry-funded doctoral fellowship.

3 Literature Review

The literature review departs by providing an overview of the role of public R&D funding for innovation and private sector R&D investment in economic theory. It then considers the innovation capacity of the eight Swedish NUTS2 regions based on the EU's Regional Innovation Scoreboard (RIS). Then the literature review considers the role of doctorates in university-industry relations to develop a theoretical understanding of the relationship between doctorates and the amount of public R&D funding received by firms. Subsequently, the process of firms who apply for public R&D schemes, such as the Vinnova programs, is examined. Finally, two hypothesis to be examined in this study are developed.

3.1 The Role of Public R&D Funding for Innovation and Private Sector R&D Investment

In industrial organization, some of the key issues of non-price competition revolve around the incentives for firms to innovate (Pepall, Richards & Norman, 2014). Pepall et. al. (2014) explain that firms can compete by investing in R&D projects to discover cost-saving innovations and new consumer products. However, the question that arises with this type of competition is whether the market leads to an efficient outcome of private firms' R&D investment from society's perspective (Link & Scott, 2013).

According to Link and Scott (2013), economic theory argues that market failure may occur in the context of private sector R&D investment because perfect competition can prevent firms from fully realizing the gains generated by their R&D investments. As Arrow (1962) noted, the optimal allocation of firm's innovation resources fails because of indivisibility, unpredictability, and uncertainty. The numerous market failures associated with private R&D investment provide a strong argument for government intervention and policy to support R&D (Oxford Economics, 2020; Pepall et. al., 2014).

As a result, public R&D funding for private firms has been the subject of numerous empirical studies. For example, a recent research paper by Oxford Economics (2020) found that a 1 % increase in public R&D investment increases private R&D investment by 0,23 to 0,38 % in the same year. Economic theory and empirical findings therefore suggest that public R&D funding by government agencies to the private sector can correct potential market failures and stimulate firm's investment in R&D. This reiterates the need to understand exactly what factors affect how much public funding firms receive.

3.2 Innovation Capacity of the Swedish Regions: RIS Results

The EU's RIS is the regional extension of the EIS which assesses the innovation performance of European regions under several indicators (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021). The scoreboard considers two indicators of skilled human capital: lifelong learning, and the percentage of the population aged 25 to 34 with a tertiary education degree. Tertiary education here corresponds to the number of people with post-secondary education and not doctoral degrees. The number of doctoral graduates is considered in the EIS; however, because of missing data on the regional level this indicator is not included in the RIS. Since this study compiled regional data of doctoral graduates by research area in Sweden it fills this gap.

The research capacity of the regions is represented in the RIS through the indicator's international scientific co-publications, scientific publications among the 10% most cited publications worldwide, and public-private co-publications per million inhabitants. Table 2 summarizes the indicators of the RIS which are relevant to this study. Numbers in the table are normalized on a scale from 0 (lowest) to 1 (highest).

Table 2 shows four of eight regions obtained the status innovation leader and the other four are considered strong innovators. So, although all regions perform excellently compared to other European regions, differences between the Swedish regions can be observed. For example, East-Central Sweden, Upper Norrland, and South Sweden, score high on R&D expenditure of the public sector and the three indicators of research capacity, while the regions Småland and the Islands and North Central Sweden score lower on these indicators. Stockholm sticks out because it scores lower in public sector R&D spending but close to 1 in almost all other indicators.

Overall, the RIS indicators lead to the insight that the four regions classified as innovation leaders perform better on average in the publication indicators and tertiary education than the four regions classified as strong innovators (a possible exception is the region Upper Norrland). This also applies to public sector R&D spending, although public R&D spending to private companies is not specifically accounted for.

Table 2 - RIS Indicators of Public R&D Spending, Tertiary Education, and Research Strength

Region	Status	R&D expenditure public sector	Tertiary education	International scientific co-publications	Most-cited scientific publications	Public-private co-publications
Stockholm	Innovation Leader	0.663	1.000	1.000	0.795	1.000
East - Central Sweden	Innovation Leader	1.000	0.759	1.000	0.705	0.956
South Sweden	Innovation Leader	0.795	0.816	0.946	0.650	0.837
West Sweden	Innovation Leader	0.573	0.771	0.864	0.828	1.000
North – Central Sweden	Strong Innovator	0.145	0.543	0.428	0.549	0.462
Central Norrland	Strong Innovator	0.187	0.462	0.399	0.5230	0.397
Upper Norrland	Strong Innovator	1.000	0.614	1.000	0.589	0.897
Småland and Islands	Strong Innovator	0.152	0.585	0.491	0.478	0.355

Source: European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, (2021)

3.3 The Role of Doctorates in University-Industry Relations

Next the relationship of doctoral graduates at the university-industry interface is investigated. In university-industry relations, doctorates are commonly attributed three roles: the production of knowledge, the transfer of knowledge, and the formation and maintenance of network ties between universities and firms (Thune, 2009).

Thune (2009) argues that concerning the production of knowledge in recent years applied academic research increased together with the collaboration between HEIs, business, and government. The author emphasizes that greater university-industry collaboration requires doctoral graduates to develop additional skills to satisfy non-academic requirements next to their area-specific expertise. Collaboration is also highlighted as an important funding criterion by Vinnova.

The impact of doctorates in facilitating knowledge transfer becomes evident when considering that postgraduate recruitment is a key factor for companies to collaborate with universities in research (Faulkner, Senker & Velho, 1995). Faulkner et. al (1995) note that companies recruite researchers from universities to enable the transfer of tacit and formal knowledge. According to the authors, particularly tacit knowledge, i.e., knowledge that is gained through experience, intuition, and interaction with other researchers, adds value to foster innovation.

Considering the role of Ph.Ds. for innovation in firms, Lund Vinding (2004, cited in Thune, 2009) characterizes three interrelated mechanisms: their contribution to a firm's stock of scientific knowledge, their trained ability to absorb knowledge and to understand complex contexts fast, and their role in reducing the gap in language and cognitive orientation between firms and higher education. This ties in with the third role of doctorates of forming and maintaining university-industry networks.

Regarding the outcomes of collaboration between universities and industry, Guldbandsen and Smeby (2005, cited in Thune, 2009) find a significant relationship between industry funding and research performance. Specifically, they find that among all tenured university professors in Norway, professors with industry funding describe their research to a greater extend as applied, collaborate more with researchers in academia and industry, and report higher numbers of scientific publications and entrepreneurial outputs.

In summary, the results of this section are consistent with the assumption that there are numerous benefits of university-industry collaboration which improve R&D and innovation. Returning to the research question and the relationship between the number of doctorate graduates and public R&D funding for private firms, findings in this section may indicate a positive relationship between the two variables.

3.4 Firms Propensity to Apply for Public Sector R&D Funding

To understand whether firms in regions with a greater pool of doctorates receive more public R&D funding, it is essential to understand what factors drive a firm's decision to apply for funding schemes and their propensity to receive it. Exploring evaluation criteria and firm characteristics as determinants of public R&D funding decisions, Falk and Svensson (2020) outline three stages that firms undergo to receive public R&D: First, firms decide to apply for grants, the project proposal is evaluated by the authority, and funds are either allocated or not.

Falk and Svensson (2020) identify the degree of innovativeness, knowledge gain, expected spill over effects, and future potential of the project as the main indicators of whether a project will be awarded R&D investment. Moreover, they conclude that firm-specific characteristics such as low R&D expenditures or low labour productivity do not lead to a disadvantage in receiving public R&D grants. This, they argue, should encourage young firms or those in low-technology sectors to apply more for R&D grants.

The decision, whether a firm applies for funding, is examined in a study by Aschhoff (2010). The author's results indicate that companies who repeatedly participate in the same grant program are more likely to receive funding. This indicates a time effect of public R&D funding, as applications from the same firms in a region can accumulate over years.

Blanes and Busom (2004) go even further and consider a firm's experience with R&D projects as path dependent. The authors assume that previous funding application experience makes it easier for firms to expand their R&D projects portfolio without incurring higher initial costs.

Furthermore, Aschhoff (2010) asserts that human capital positively affects whether a firm participates in a subsidy program and that, for previously subsidized firms, the amount of skilled human capital plays a key role in determining whether the firm will receive support again. Blanes and Busom (2004) specifically emphasize the importance of skilled human capital in planning, designing, and implementing R&D projects.

A study by Afcha and Lucena (2022) examines the impact of human capital on R&D subsidies and firm innovation among Spanish firms. Their results show that the added effect of R&D subsidies is heterogeneous and depends on the firm-specific human capital profile. The authors find that a higher proportion of doctorates and researchers in a firm amplifies the effect of R&D subsidies on the number of patent applications of a firm.

Gustafsson, Gustavsson Tingvall and Halvarsson (2020) examine characteristics of Swedish firms seeking public grants. They conclude that firms who choose to apply for a subsidy over market production, potentially due to lower opportunity cost of subsidy-seeking, are characterized by lower productivity but have a higher proportion of highly educated employees. The authors explain that skill-intensive firms with high administrative capacity may be better able to manage grant applications and produce projects that granting agencies find worthwhile.

The results of this section suggest that skilled human capital matters both for a firm's initial decision to apply for public R&D funding and for the effectiveness of such grants when received. The final decision of agencies evaluating and administering such grants, seems however, not to depend on specific firm characteristics.

3.5 Research-Specific Nuances and Post-graduation Destinations

This section provides insight into differences in applied and basic research as well as doctoral graduate destinations to investigate potential differences between the research areas. It is important to stress that no literature comparing similar research areas as this study and their impact on public R&D funding allocations was found.

Lam (2007) examines emerging forms of career models which support the flow of knowledge between universities and industry. She develops the concept of overlapping internal labour markets between the two sectors which create a pool of shared human resources to engage academic scientists in joint knowledge production and connect the company's human resources to the universities' networks. She observes a trend among the surveyed companies of her study to have strategic relationships with a small number of key institutions.

Examining trends in the destinations of doctoral students in Sweden, Lundh (2022) finds that of the 1998-2015 doctoral graduates, 81% are established in the labour market three years after graduation. The highest establishment is found among engineering graduates at 88% and the lowest among humanities and arts at 72%. Moreover, 44% of Ph.D. graduates in Sweden still work in higher education, of which 29% work at the same institution where they received their Ph.D..

3.6 Regional Effects of Public R&D Funding in Sweden

Considering the regional focus of this study this section examines previous literature findings on the allocation of R&D subsidies to Swedish regions. Engberg, Boschma and Balland (2020) examine whether Vinnova research and innovation programs correlate with the development of new industries and technologies across Swedish regions and whether this relationship is stronger for collaborative R&D projects.

Eneberg's et. al. (2020) study utilized the number of employees in higher education as a regional control variable for skilled human capital. They find evidence that local, pre-existing capabilities determine the entry of new industries and new technologies across regions. This confirms, the authors explain, that regions tend to diversify into new activities strongly linked to existing local activities. If, according to them, a region lacks relevant knowledge and skills, the higher is the cost of developing new activities and industries.

Yet Engberg et. al. (2020) reveal that regions who received R&D grants from Vinnova in a particular industry or technology are more likely to diversify into that same industry. Given their findings, the authors emphasize policy implications, such as the use of R&D funding, to promote the development of new activities in Swedish regions with a focus on collaborative R&D.

Their finding that effectiveness of public R&D funding partly depends on regional capabilities, points to the importance of R&D funding programs considering these local features. This includes the regional pool of highly skilled human capital.

3.7 Hypothesis Development

The existing literature on associations between high-skilled human capital and public R&D funding for the private sector leads to the formulation of two alternative hypotheses. Connecting the role of doctorates in university-industry relations, a firm's decision to apply for R&D funding, and the importance of pre-existing local capabilities of regions, the first hypothesis is:

Hypothesis I: Firms in regions with a greater stock of highly skilled human capital, as measured by doctorate degrees awarded by HEIs in the region, receive more public R&D funding.

Subsequently, the second hypothesis investigates if the research field in which doctorate degrees were awarded, impacts the amount of public R&D funding received by a region:

Hypothesis II: The relationship between the amount of public R&D funding received by firms and doctoral degrees awarded, varies by area of research.

4 Methodology

The analysis of this study is divided into two parts. First, spatial patterns of Vinnova's public R&D funding to private sector firms and the regional pool of highly skilled human capital summed across all research areas are analyzed. Second, differences across doctoral degrees in the six different research areas and their relationship to funding allocations are examined. This section presents the data and methods used to explore the relationships between the variables.

4.1 Description of the Empirical Data Set

The self-assembled panel data set includes a total of 152 observations across the eight Swedish NUTS2 regions. It covers 19 years, from 2003 to 2021. The dataset is strongly balanced and fixed, i.e., all regions have data points for all years and identical regions and years are observed. The dependent variable is the total amount of funding awarded by Vinnova to all private companies in a region. The data was provided to the author on request by Vinnova on the 5th of April and the 10th of May 2023. The independent variables are the sum of doctoral degrees awarded by HEIs in each region and split up by the six research areas of humanities and arts, agricultural and veterinary sciences, medicine and health sciences, natural sciences, social sciences, and technical sciences. Data on doctoral degrees was extracted from UKÄ (2023c) for each HEI and then summarized under the corresponding NUTS2 region. UKÄ is an independent government agency that monitors and analyzes Swedish higher education (UKÄ, 2023b). The number of doctoral degrees serves as an indicator of highly skilled human capital.

The period 2003 - 2021 was selected due to the availability and overlap of detailed funding data from Vinnova programs and Ph.Ds. The dataset also includes two structural control variables, gross regional product (GRP) and population density, obtained from Statistics Sweden. The inclusion of GRP and population density is based on the EU RIS assessment of structural indicators of a region's innovation capacity (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021). Table 3 lists all variables included in the dataset.

Table 3 - List of Variables

Variable	Unit	Role
Sum of Vinnova funding to private companies	Million SEK	Dependent

Natural logarithm of funding		Dependent
GRP	Million SEK	Independent
Population density	Inhabitants per sqm	Independent
Total doctoral degrees across all research fields		Independent
Doctoral degrees in Humanities and Arts		Independent
Doctoral degrees in Agricultural and Veterinary Sciences		Independent
Doctoral degrees in Medicine and Health Sciences		Independent
Doctoral degrees in Natural Sciences		Independent
Doctoral degrees in Social Sciences		Independent
Doctoral degrees in Technical Sciences		Independent

4.1.1 Doctoral Degrees by Research Area in Sweden

In Sweden, UKÄ publishes annual statistics on third-cycle education and doctoral degrees awarded by institution, research area, topic, and aim (UKÄ, 2023c). Research area was chosen to separate the degrees as it provides a larger number of observations by region and research area to enable statistical analysis. There are six research fields:

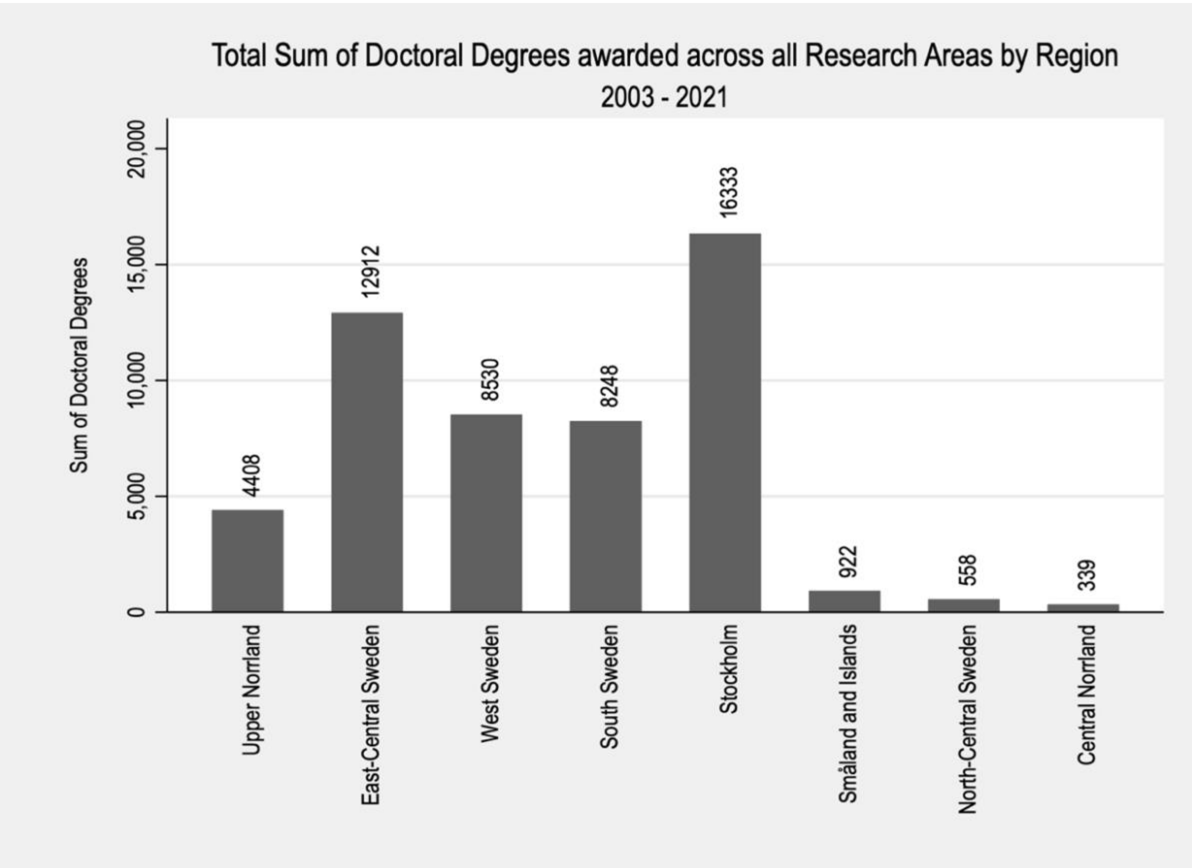
1) Humanities and Arts
2) Agricultural and Veterinary Sciences
3) Medicine and Health Sciences
4) Natural Sciences
5) Social Sciences
6) Technical Sciences

Doctoral degrees were selected as independent variables for analysis of the research question because they represent one of many important measures of high-skilled human capital. Moreover, no previous analysis of the relationship between doctoral degrees across the six research areas and R&D funding by Vinnova was found. Therefore, this study contributes to an improved understanding of the interplay between these variables.

Each HEI which was remarked by UKÄ to have awarded a doctoral degree between 2003-2021 was assigned to the NUTS2 region of its main campus. Official addresses were obtained from Studera.nu (2023). Table A.2 in appendix A includes a list of all HEIs included in this study. Most campuses of HEIs with multiple campuses are in the same NUTS2 region. Because UKÄ does not observe the number of doctoral degrees awarded by campus, if HEI campuses are in multiple NUTS2 regions, the total sum of doctoral degrees was assigned to the region which is home to the main or largest campus of the HEI. In the cases of Umeå university doctoral degrees were assigned to Umeå, Upper Norrland, and for Uppsala university and Sveriges lantbruksuniversitet (SLU) they were assigned to Uppsala, East Central Sweden

In the case of SLU, this poses a limitation because campuses in Umeå and Alnarp also host a larger share of doctoral students in agricultural and veterinary sciences. Therefore, findings of the research field agricultural and veterinary sciences are strongly focused on the region East-Central Sweden.

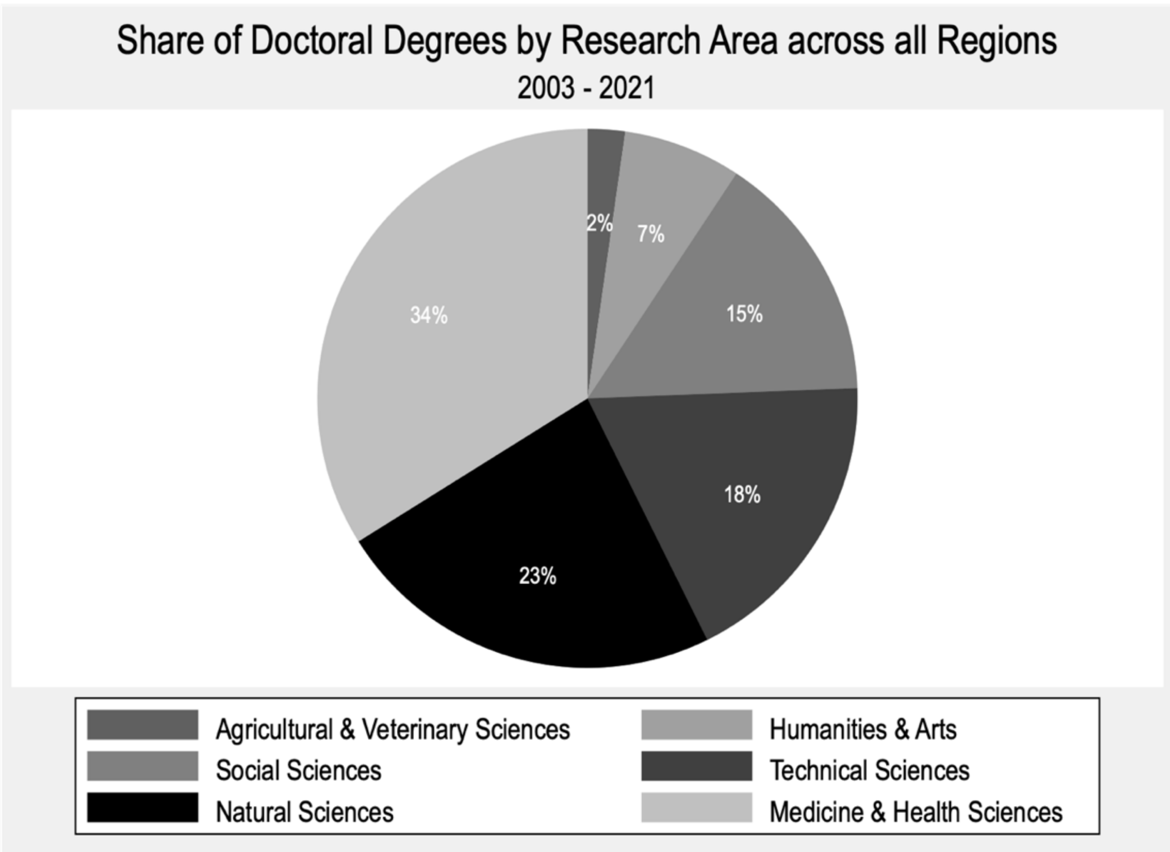
Figure 4 - Total Sum of Doctoral Degrees awarded across all Research Areas by Region



Source: Adapted from UKÄ (2023c)

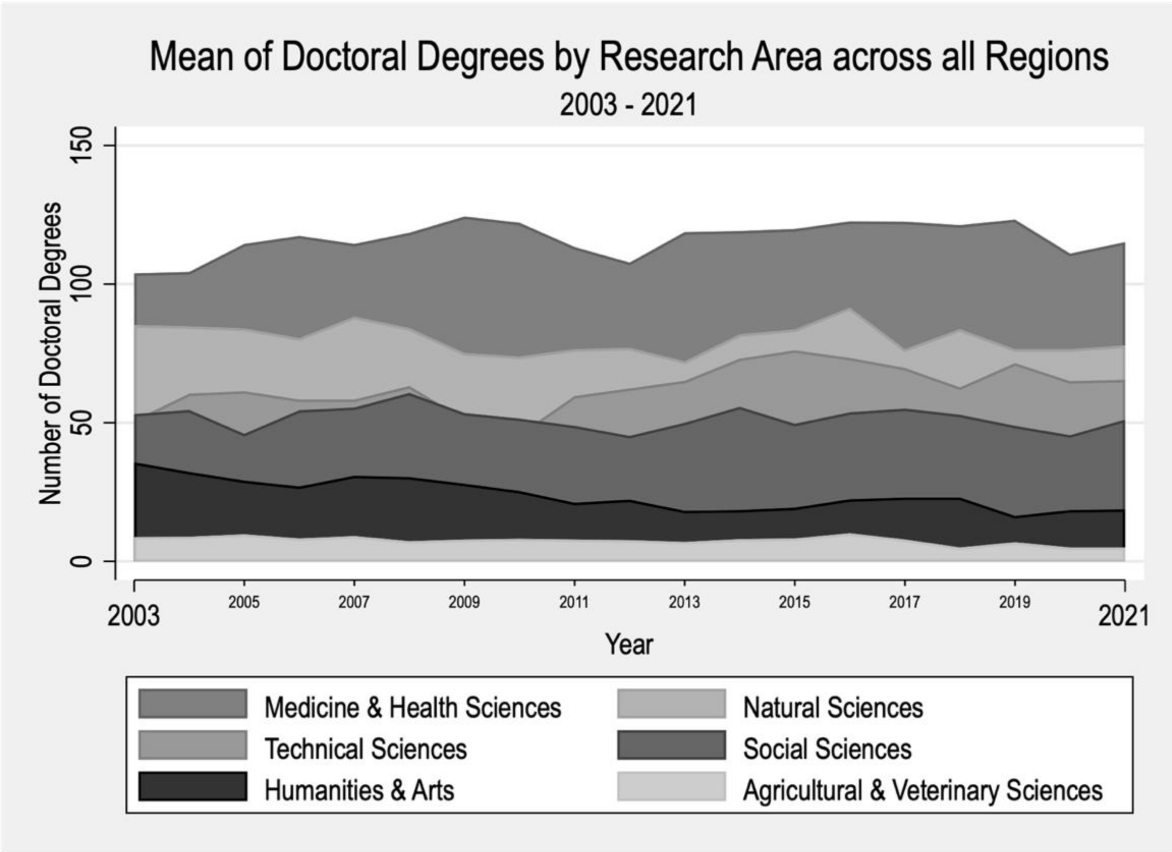
Between 2003 and 2021, 52.250 doctoral degrees were awarded across Sweden. Figure 4, Figure 5 and Figure 6 visualize the main characteristics of the independent variables. Figure 4 shows that overall, most doctoral degrees were awarded by HEIs in the regions Stockholm, East-Central Sweden, West Sweden, and South Sweden. Figure 5 shows the share of degrees by research area. The highest share of Ph.Ds. was awarded in medicine and health sciences (33.9%), followed by natural sciences (23.42%) and technical sciences (18.29%). Figure 6 presents the development of the average number of degrees issued by research area over time. It shows the average number of degrees issued by research area in Sweden has stayed relatively constant. A slight decline can be noticed in the humanities and arts, while the average number of degrees in technical sciences increased between 2003 and 2021.

Figure 5 - Share of Doctoral Degrees by Research Area across all Regions



Source: Adapted from UKÄ (2023c)

Figure 6 - Mean of Doctoral Degrees by Research Area across all Regions



Source: Adapted from UKÄ (2023c)

4.1.2 Vinnova Public R&D Funding

This section introduces the dependent variable public R&D funding to private sector firms by Vinnova. Vinnova employs about 200 people and is headquartered in Stockholm with branches in Brussels, Silicon Valley, and Tel Aviv (Vinnova, 2023). Vinnova's funding was chosen as the dependent variable because of Vinnova's mission to build Sweden's innovation capacity and contribute to sustainable growth (Vinnova, 2023). Moreover, Vinnova encourages collaboration between academia and industry to foster knowledge transfer. The agency invests approximately SEK 3 billion in research and innovation each year, therefore, providing companies and organizations with support to experiment and test new ideas before they become profitable (Vinnova, 2023).

The data on Vinnova funds is available on request and was provided to the author by the agency. It provides detailed information on the funded organizations, their workplace, type of organization, funded project, call for proposals, program, coordinator, year of decision, and status of the project. For this data set the total amount of funding for private companies by NUTS2 region was calculated.

Project Funding Evaluation

Vinnova's (2020) step-by-step guide to apply for funding provides inside in the agency's project evaluation. It strives to fund projects which benefit society and cannot be realized without government support. All funds are distributed through calls for proposals with an application framework and guide. Vinnova usually does not fund all costs and follows national state aid rules for competitive reasons. Experts assess all applications and discuss their recommendations with Vinnova's management before funding is awarded. The main criteria analysed for each application are:

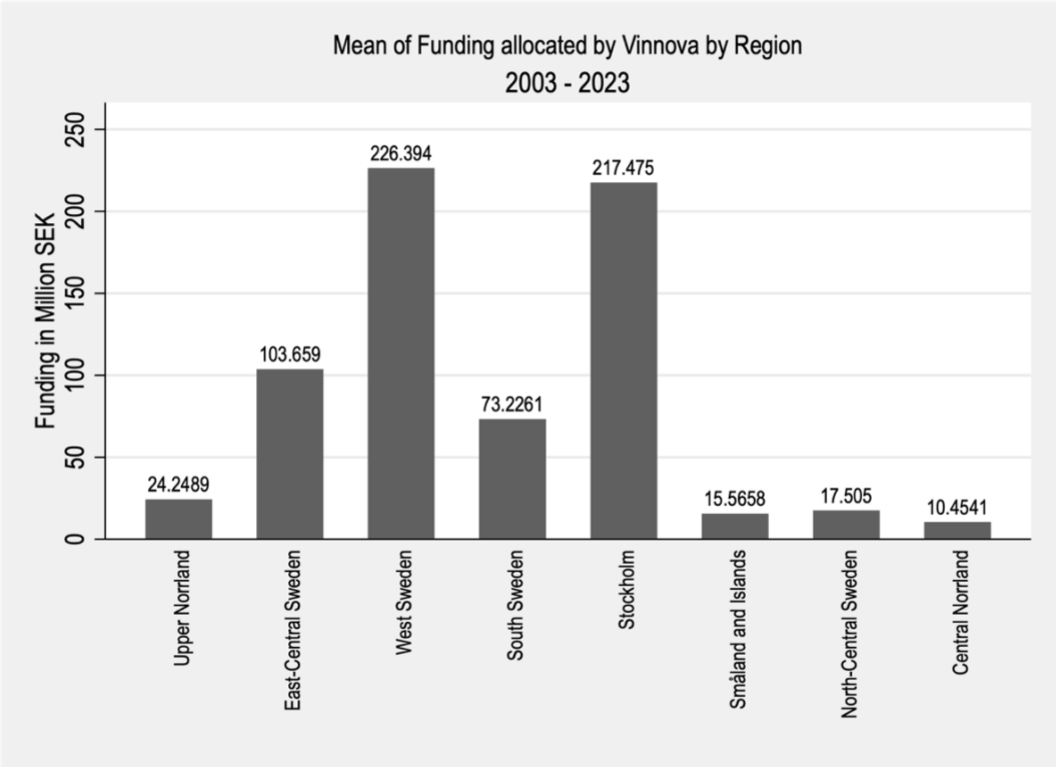
1) Potential: the expected impact and value of the project and its importance to society if goals are met
2) Stakeholders: the capacity of the participants to carry out the project and achieve the desired results and impact
3) Feasibility: how realistic and credible is the project plan and that the project achieves the desired outcome?

Descriptive Statistics of Funding allocated by Vinnova

Vinnova's funding is reported in SEK. Figure 7 presents the average funding allocation by region over the years 2003 to 2021. It is possible to see the considerable variation in funding allocations across Sweden's regions. Stockholm and West Sweden received by far the highest average of funding, followed by East-Central Sweden and South Sweden. The three regions in northern Sweden and Småland and the Islands received on average much less funding for private firms.

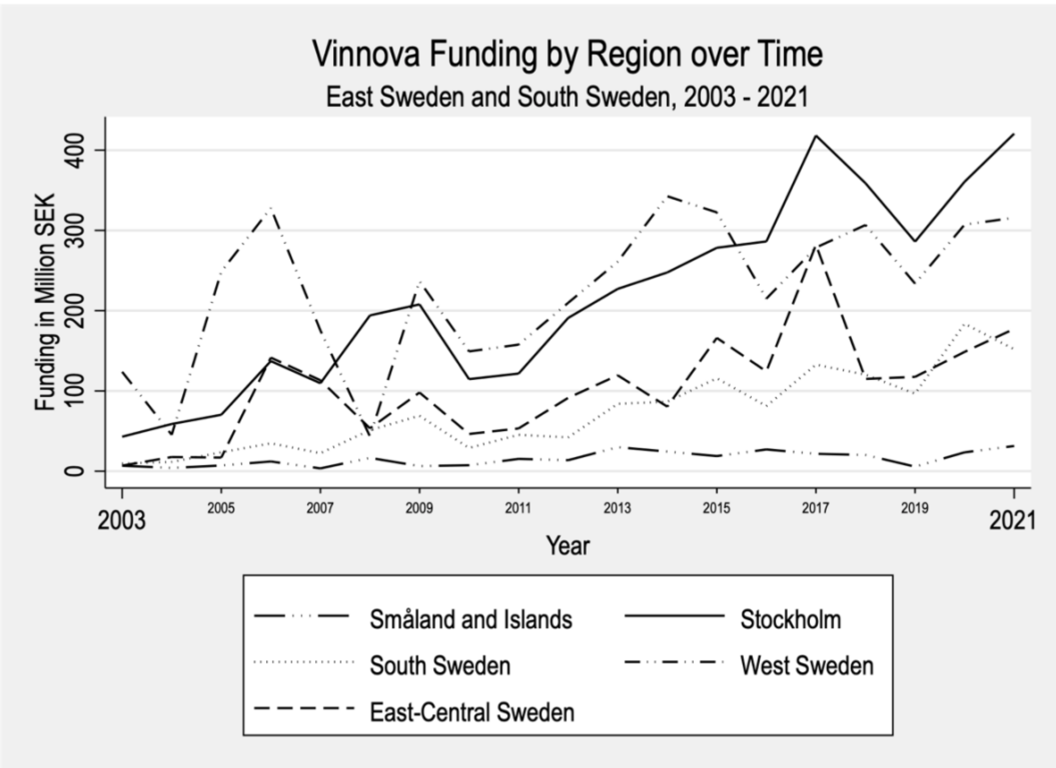
Figures 8 and 9 present the allocation of funds over time, split by region in North, East, and South Sweden. This is to demonstrate variations on two different scales. Figure 8 shows that Småland and the Islands received consistently the lowest funding over time among the southern regions in Sweden. Patterns of growth are visible for the four regions previously classified by the RIS as innovation leaders, Stockholm, East-Central Sweden, West Sweden, and South Sweden. Finally, investigating Figure 9, a growth trend of funding allocations is visible in Upper and Central Norrland. North-Central Sweden, however, shows consistent variation.

Figure 7 - Mean of Funding allocated by Vinnova by Region



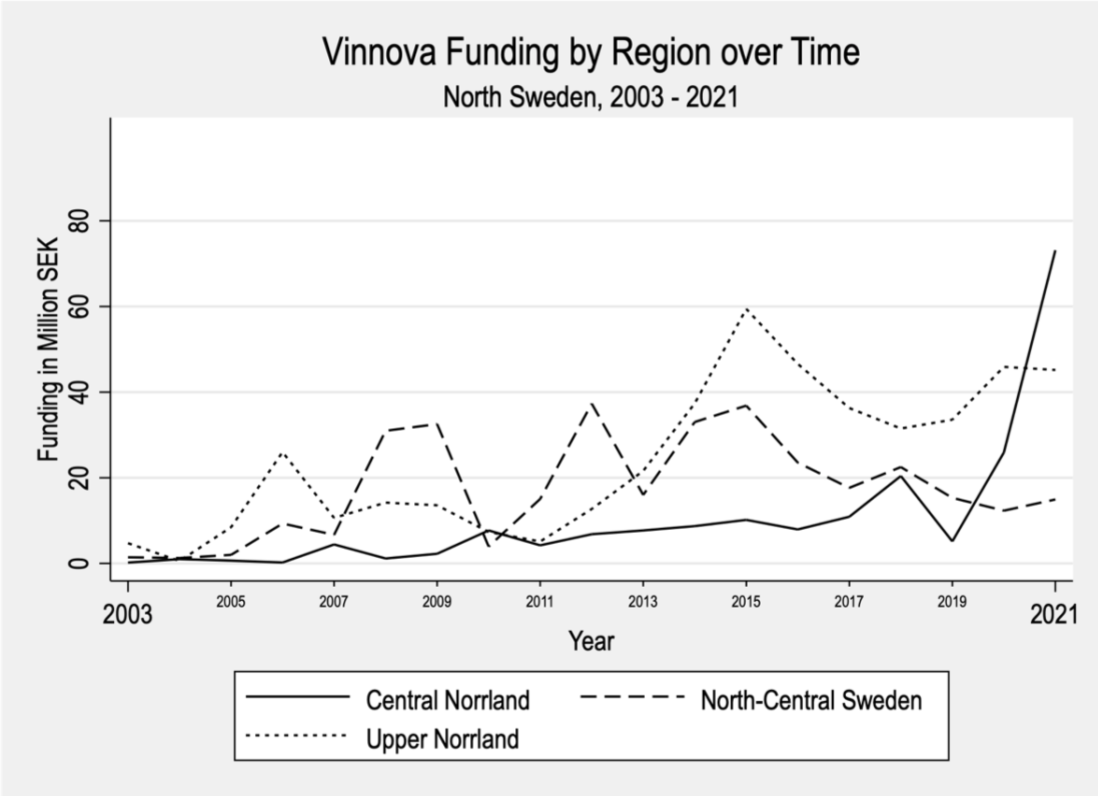
Source: Authors own calculations based on data provided by Vinnova (2023)

Figure 8 - Vinnova Funding by Region over Time, East Sweden, and South Sweden



Source: Authors own calculations based on data provided by Vinnova (2023)

Figure 9 - Vinnova Funding by Region over Time, North Sweden



Source: Author's own calculations based on data provided by Vinnova (2023)

4.1.3 Structural Indicator Variables

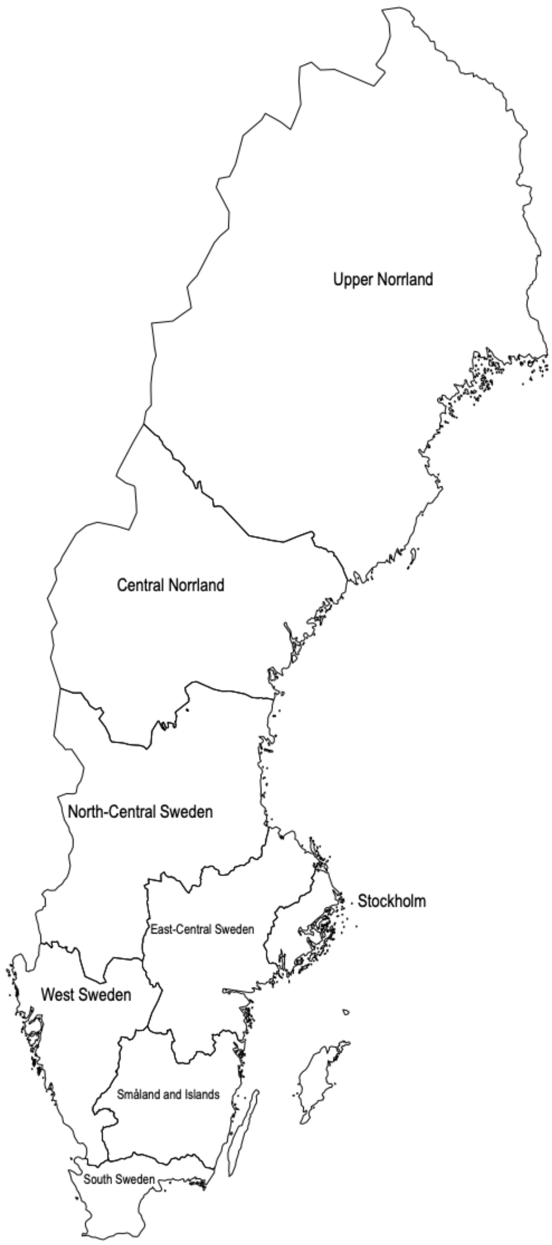
The data includes the two structural indicator variables GRP in current prices (SEK million) and population density by NUTS2 region, retrieved from Statistics Sweden (2022e) and Statistics Sweden (2023b). To calculate population density the total population of each region was divided by the number of sqm of land in the region.

Both structural indicator variables are included based on their importance for a regions innovation capacity, as elaborated by the RIS (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021). The RIS states that more densely populated regions bring people and businesses closer together and encourage the diffusion of knowledge through a higher number of government and education institutions which employ high-skilled individuals.

Furthermore, according to the RIS, GRP is one of several indicators of the size of a region's economy, which denotes the market value of all final goods and services produced in a region. The RIS report adds that GRP can help to understand how much public R&D funding a region receives.

Figure 10 shows the geographical location of the NUTS2 regions. The NUTS classificational is the EU statistical system to break up its economic territory (Eurostat, 2023). The eight NUTS2 regions comprise the 21 Swedish counties. A list of all counties by NUTS2 region is included in Table A.1 in appendix A.

Figure 10 - Map of the Swedish NUTS2 regions



Source: Author's own map using coordinate data from the Eurostat and GISCO (n.d.)

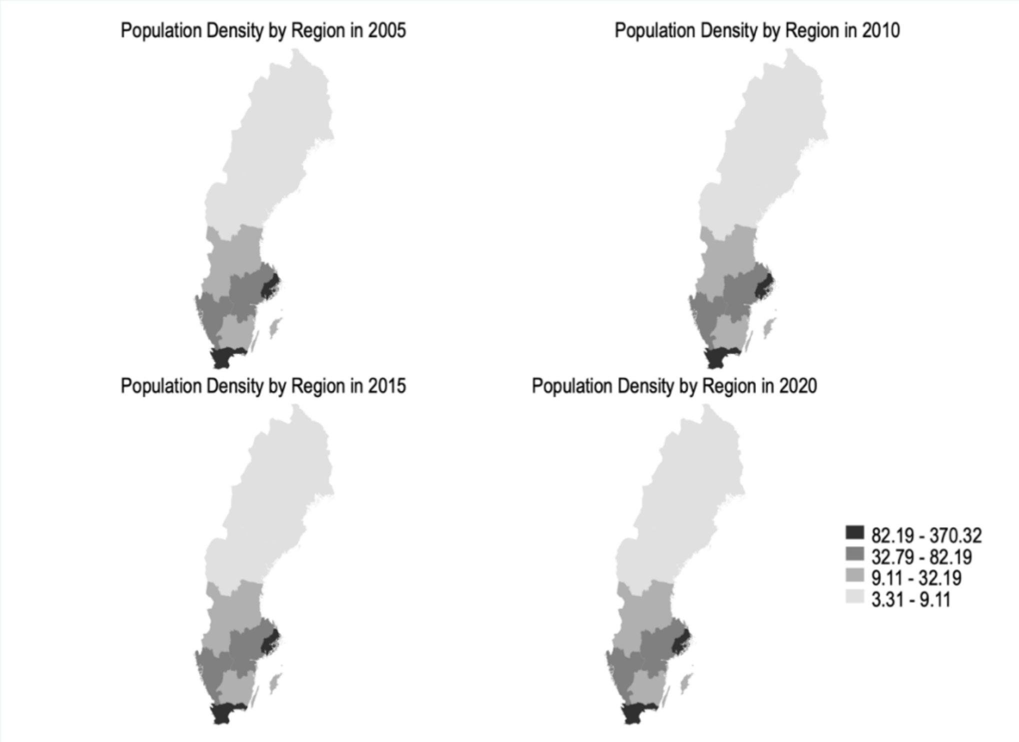
Population Density

Figure 11 presents population density of the regions for the years 2005, 2010, 2015 and 2020. Stockholm, which represents a region of its own and incorporating the capital city Stockholm has the highest average population density with 326,14 inhabitants per sqm, followed by South Sweden with 102,17 inhabitants per sqm. Upper and Central Norrland have the lowest average population density over the years with 3.36 and 5.25 inhabitants on average per sqm. Population density across the regions stayed relatively constant over the years.

GRP

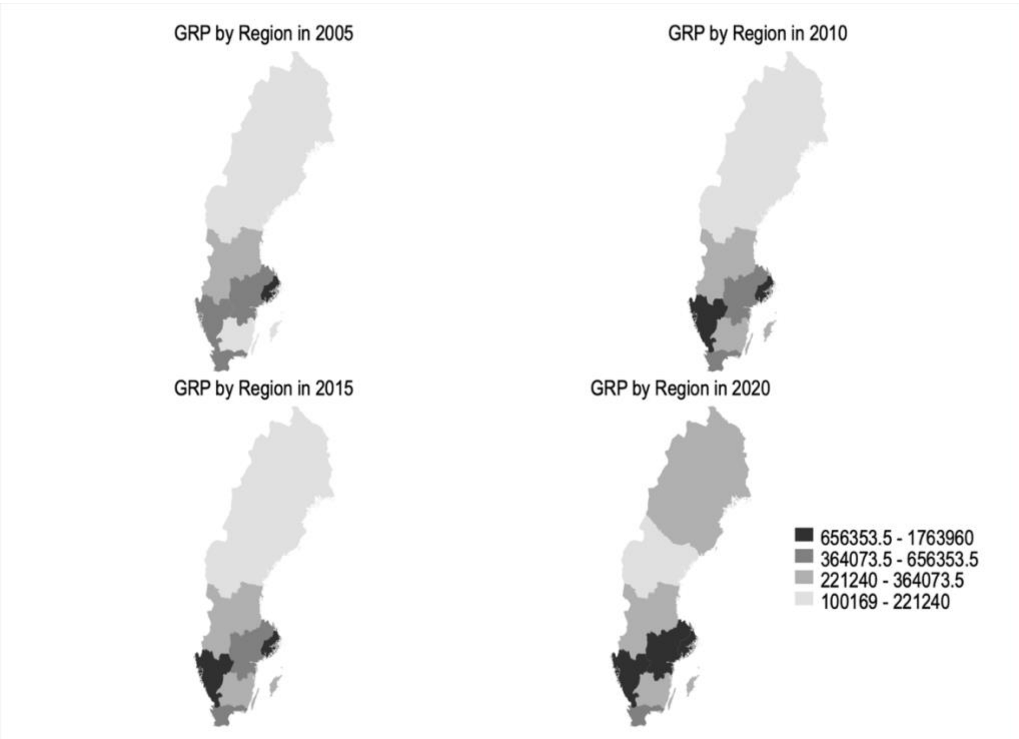
Figure 12 provides an overview of the same benchmark years for GRP in Million SEK. Stockholm and West Sweden, home to Sweden's largest cities Stockholm and Gothenburg, have the highest GRP, followed by South Sweden and East-Central Sweden. Compared to population density, GRP increased in several regions over the years. Between 2015 and 2020, Upper Norrland's GRP increased, so that only Central Norrland remains in the lowest GRP quartile.

Figure 11 - Population Density by Region



Source: Author’s own maps using population data from Statistics Sweden (2023b) and coordinate data from the Eurostat and GISCO (n.d.)

Figure 12 - GRP by Region in Million SEK



Source: Author’s own maps using population data from Statistics Sweden (2022e) and coordinate data from the Eurostat and GISCO (n.d.)

4.2 Method

The analysis of this study starts with a visualization of the changes and persistence of the patterns of funding allocations and the total number of Ph.Ds. for the reference years 2005, 2010, 2015, and 2020. Multiple regression models are used to initially examine the relationship between the total number of doctoral degrees awarded and the funding allocated by Vinnova. Subsequently, the relationship between the number of doctoral degrees awarded in each research area and the funding allocated by Vinnova is examined.

The regression analysis of each part begins with a pooled ordinary least squares (Pooled OLS) model. Since this model does not capture region-specific effects, which are assumed to be present, a fixed effects (FE) model and a random effects (RE) model are thereafter applied as preferred methods of analysis. A full list of the Gauss-Markov assumptions which apply to the pooled OLS, RE, and FE models is included in appendix B.

The dependent variable funding is transformed to its natural logarithm (ln) to capture non-linear aspects of the data. The independent variables are not transformed, as this would incur the cost of missing data points for the years and research areas in which zero degrees were awarded. Therefore, all regressions become log-linear models, which are interpreted as a percentage point change in the dependent variable if the explanatory variable increases by one unit.

Equation (1) represents the general model of this study and guides the first part of the analysis with the total sum of doctoral degrees awarded, GRP, and population density as explanatory variables.

$$(1)\ \log(funding) = \beta_0 + \beta_1 totalexamina + \beta_2 grp + \beta_3 popdensity + \varepsilon_{it}$$

A regression model which includes all six explanatory variables for each research field is likely to suffer from multicollinearity and produce inconsistent results. Table B.2 in appendix B indicates the strong correlation between the variables representing the six research areas. Therefore, to avoid multicollinearity, six separate regression models, (3) to (7), for the second part of the analysis are utilized. Each includes the number of doctoral degrees within a research area, GRP, and population density as the explanatory variables.

$$(2)\ \log(funding) = \beta_0 + \beta_1 humart + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$

$$(3)\ \log(funding) = \beta_0 + \beta_1 agrivet + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$

$$\text{(4) } \log(funding) = \beta_0 + \beta_1 medhelath + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$
$$\text{(5) } \log(funding) = \beta_0 + \beta_1 natural + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$
$$\text{(6) } \log(funding) = \beta_0 + \beta_1 social + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$
$$\text{(7) } \log(funding) = \beta_0 + \beta_1 technical + \beta_2 grp + \beta_3 popdensity + \varepsilon_t$$

Moreover, all regressions contain clustered robust standard errors because, after performing a Breusch-Pagan test for heteroskedasticity, the null hypothesis that the error terms have constant variance was rejected for regressions (1) to (7). The error terms are clustered by NUTS2 region as this represents the nature of the panel data.

Fixed Effects Model versus Random Effects Model

The FE and RE model are common to examine panel data with individual-, or region-specific, effects over time. Wooldridge (2013) explains that the FE estimator allows for correlation between the unobserved, individual specific effect α_i and the explanatory variables. For the RE estimator, however, the author explains that α_i must be independent of the explanatory variables.

In deciding between the two estimators, Wooldridge (2013) argues that the FE estimator is generally preferred because correlation between α_i and the explanatory variables often occurs in the analysis of larger geographic units like regions. The Hausman test, a statistical tool used to determine whether a FE or RE model yields consistent coefficients, was conducted for each of the models of this study. The mixed results reported in Table 4 reemphasizes the need to examine the parameter estimates of both FE and RE models. Nevertheless, there is a strong theoretical case that the FE model produces more efficient parameter estimates (Wooldridge, 2013). The one-way error component ε_{it} in both models is defined as (i), where α_i represents the region-specific effect and $\mu_{it}$the error terms.

$$\text{(i)} \qquad \varepsilon_{it} = \alpha_i + \mu_{it}, \quad i = 1, \dots, n, \; t = 1, \dots . T$$

Table 4 - Hausman Test Results for Model (1) to (7)

Model	Prob > chi2	Preferred Model
(1) Total sum of doctoral degrees	0.0555	Random
(2) Humanities & Arts	0.0002	Fixed
(3) Agricultural & Veterinary Sciences	0.0221	Fixed

(4) Medicine & Health Sciences	0.1516	Random
(5) Natural Sciences	0.0138	Fixed
(6) Social Sciences	0.0633	Random
(7) Technical Sciences	0.0178	Random

4.3 Limitations

Limitations of this study are four-fold. First, the question if the presence of highly skilled human capital - doctoral graduates - has a casual effect on the level of public R&D funding to the private sector across Swedish regions remains open. This study did not include lagged variables of funding allocations, making it difficult to determine causality. Because the relationship between academia and industry takes time to deepen, a study over a longer period may be required.

The second limitation concerns the relatively small number of doctoral degrees awarded in some research areas and regions, especially remoter areas. The research field agricultural and veterinary sciences, for instance, is only represented in two regions in the data, which limits generalizations of results. Furthermore, doctoral graduates are assumed not to move region post-graduation, which may depart from reality.

Similarly, thirdly, Vinnova programs represent only a small portion of the public R&D grants awarded to the private sector in Sweden. Thus, a larger scale analysis including other funding programs and R&D sources can provide additional insights.

Fourth, the amount of funding firms receive depends on how many firms apply to public R&D schemes. Therefore, a thorough understanding of which firms apply for grants is an important prerequisite. A sample which distinguishes between firms who collaborated with academia and who not, would be optimal to determine the impact of skilled human capital on public R&D distribution to private firms.

5 Results

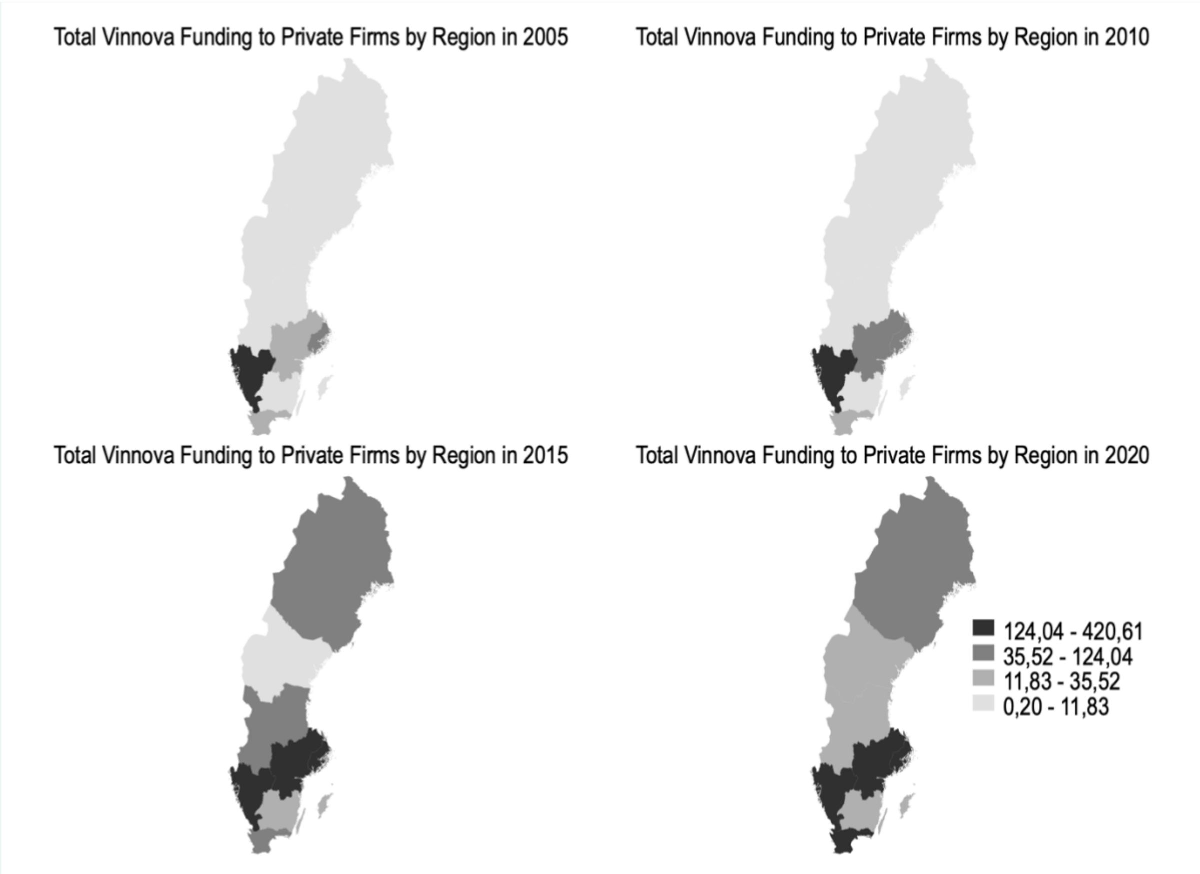
5.1 Regional Patterns of Public R&D Funding and Doctorate Degrees

The map in Figure 13 depicts the evolution of Vinnova's R&D program funding patterns for private companies. A general increase in R&D funding over the years is evident, however, the increase in funding allocations is even more evident when comparing the northern regions and

Småland and Islands over time, which have received higher funding amounts, especially since 2015.

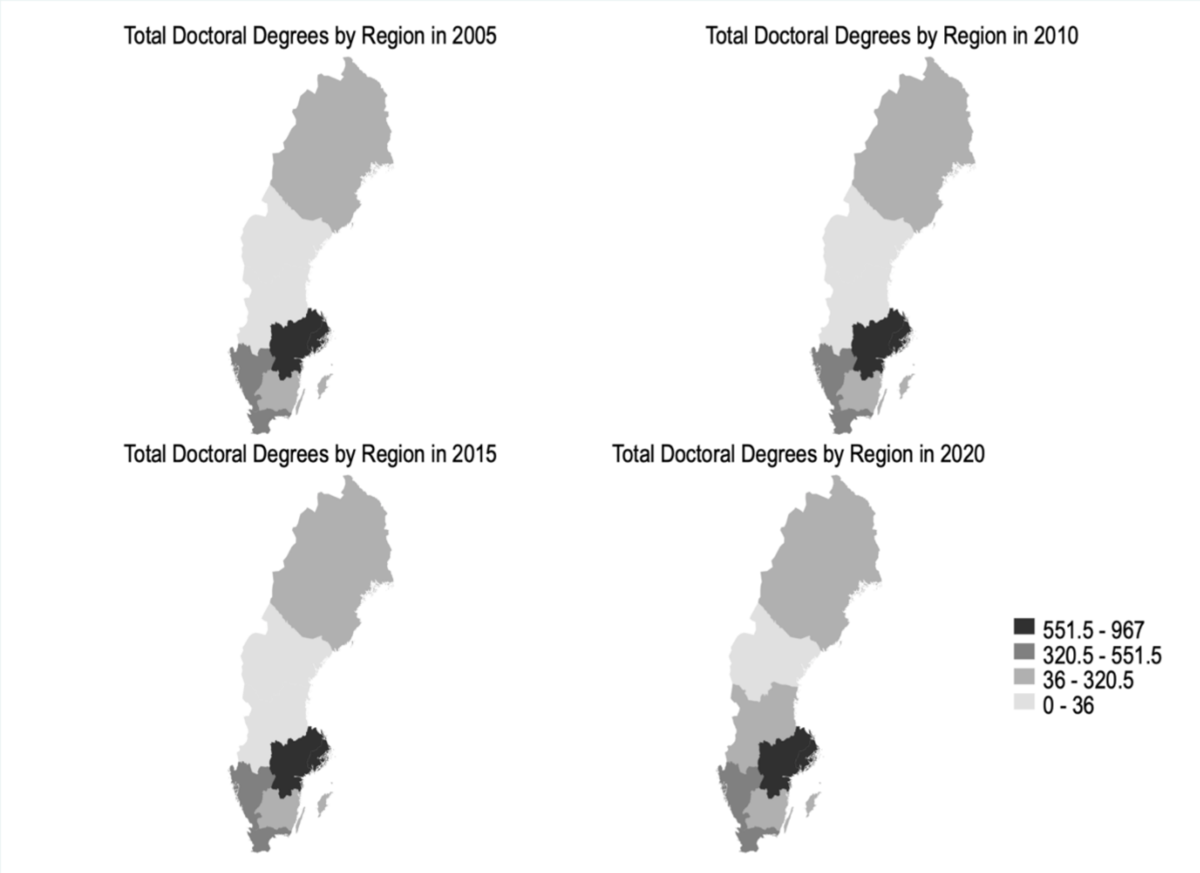
In contrast, the total number of doctoral degrees awarded remained evenly distributed among the regions and over the years, as shown in Figure 14. North-Central Sweden is the only region which ascended to a higher quartile in 2020. The number of doctorates is highest in East-Central Sweden and Stockholm, likely because of the number of HEIs in these regions.

Figure 13 - Map of Total Vinnova Funding to Private Companies by Region



Source: Author’s own maps using population data from Statistics Sweden (2022e) and coordinate data from the Eurostat and GISCO (n.d.)

Figure 14 - Map of Total Doctoral Degrees by Region



Source: Author's own maps using population data from Statistics Sweden (2022e) and coordinate data from the Eurostat and GISCO (n.d.)

Heterogeneity between regions with respect to funding and over time is shown in Figure 15 and 16. Stockholm, West Sweden, East-Central Sweden, and South Sweden have the highest mean. Moreover, the figures illustrate a high standard deviation of funding in regions such as Central and Upper Norrland which indicates that funding allocations vary greatly by project and year.

Heterogeneity, observed over time, reinforces the trend of an overall increase in Vinnovas funding allocations between 2003 and 2021. Slight decreases in 2010 and 2019 can be observed. Heterogeneity can be a sign of omitted variables, which cause correlation between the explanatory variables and the error term (Park, 2011). Because the FE model accounts for correlation between region-specific effects and explanatory variables, results visible in figures 15 and 16 support the use of FE models in the following regression analysis.

Table 5 illustrates the correlation between the independent variables and the natural logarithm of funding. All independent variables show a positive and moderate to strong correlation with the dependent variable, indicating they move into the same direction.

Figure 15 - Regional Heterogeneity

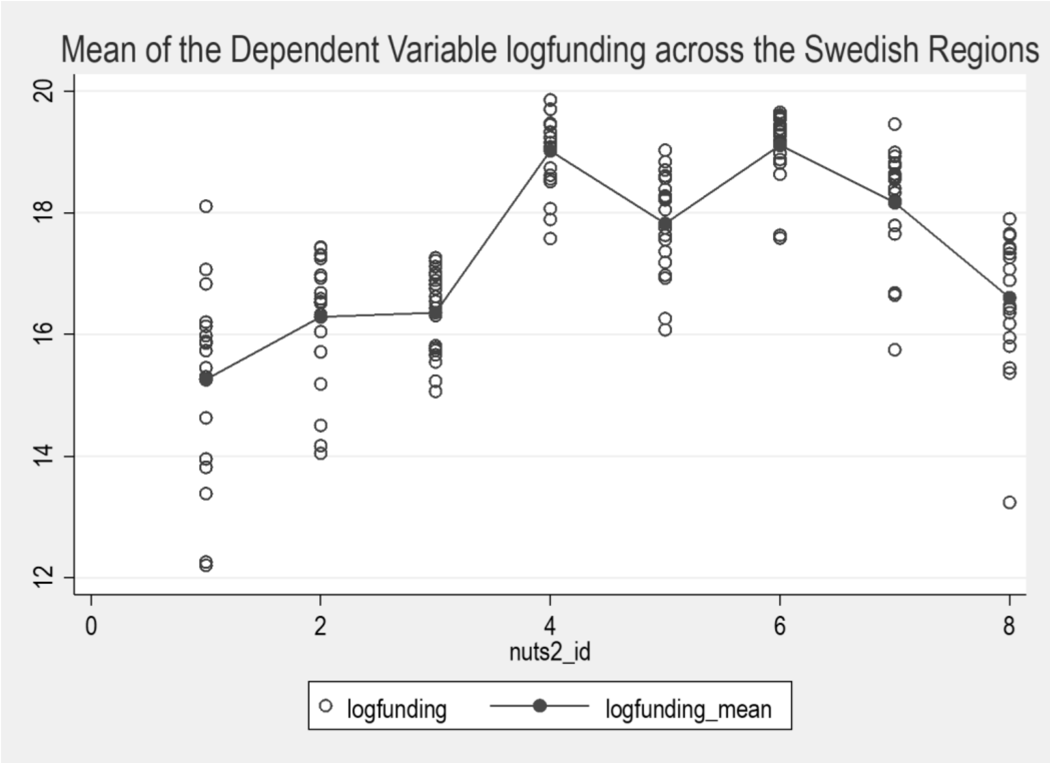


Figure 16 - Heterogeneity over Time

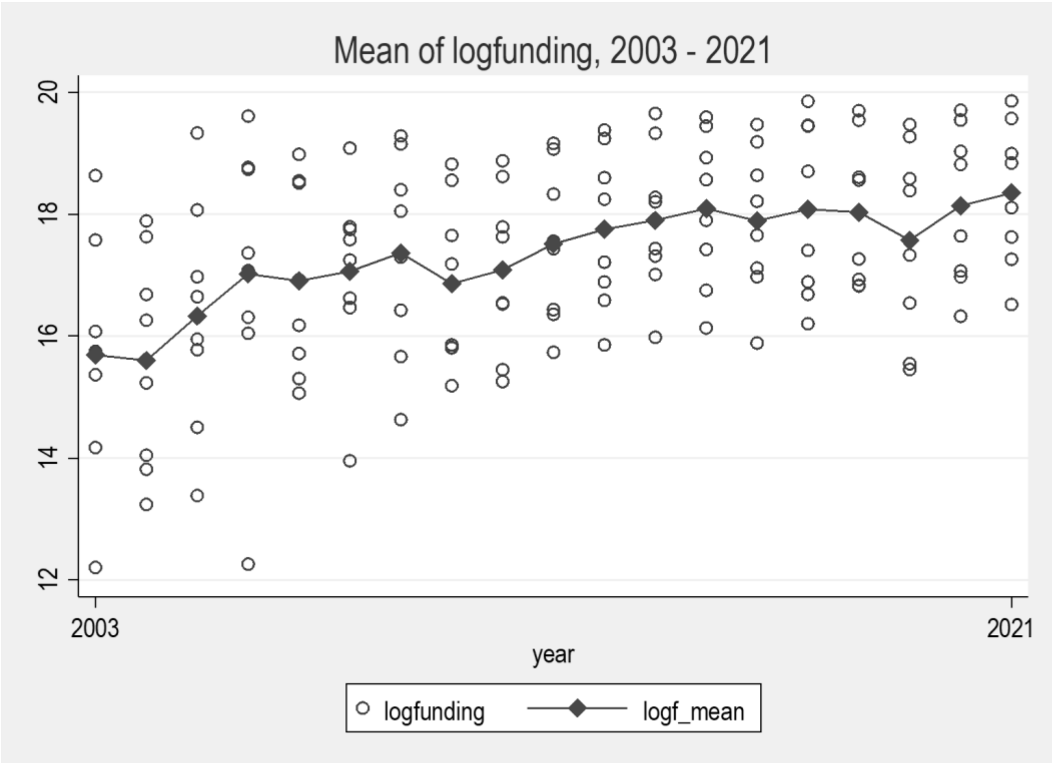


Table 5 - Correlation between the Dependent and Independent Variables

Variable	Correlation with logfunding
Gross Regional Product	0.7650
Population Density	0.5508
Humanities and Arts	0.6068
Agricultural and Veterinary Sciences	0.1709
Medicine and Health Sciences	0.6799
Natural Sciences	0.6368
Social Sciences	0.7031
Technical Sciences	0.7493
Total Doctoral Degrees	0.7128

5.2 Regression Analysis: Total Sum of Doctoral Degrees

Regression (1) examines the relationship between Vinnova funding for private companies and the total sum of doctoral degrees in Sweden. The pooled OLS model is used as a starting point to examine the relationship between the variables, although it gives inconsistent results based on previous reasoning. The results of the pooled OLS model of (1) are shown in Table 6.

Based on these initial findings, it appears that a SEK 1 million increase in GRP increases Vinnova's private sector funding by 0.00046%. Although this effect is small, it is significant at the 0.01 level. The parameter estimate of doctoral degrees is also significant at the 0.1 level, and indicates an increase in funding of 0.082% if, ceteris paribus, one more doctorate is awarded across all research areas. The negative effect of population density is surprising given the positive correlation between population density and the dependent variable. According to the model, Vinnova funding decreases by 0.98% if population density increases by one more inhabitant per sqm.

Table 6 - Pooled OLS Model (1) Total Sum of Doctoral Degrees

Model	**Pooled OLS**
	(1) Total Sum of Doctoral Degrees
VARIABLES	Natural logarithm of funding
GRP	4.63e-06***

	(7.34e-07)
Population density	-0.00988***
	(0.00186)
Total sum of doctoral degrees	0.00188*
	(0.000815)
Constant	15.14***
	(0.258)
Observations	152
R-squared	0.691

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 7 considers the RE and FE models of the total sum of doctoral degrees (1). The parameter estimate for the total sum of doctorates is significant at the 0.05 level for the RE model, indicating a 0.218% increase in funding when, ceteris paribus, an additional doctorate is awarded across all research areas. Although the beta coefficient for the FE model is not significant, it indicates a 0.163% increase in funding when an additional doctorate is awarded.

The RE and FE model provide more accurate standardized coefficients after adjusting for the region-specific effect. The Hausman test, with the null hypothesis that the difference in coefficients is not systematic, yields prob > chi2 = 0.0555, suggesting that the RE model provides unbiased, consistent, and efficient parameter estimates. By contrast, theory suggests, the FE model is the correct choice for geographic units like regions (Wooldridge, 2013).

Both models are preferable over the pooled OLS model. This is confirmed by the rejection of the null hypotheses of the F-test (prob > F = 0.0000 for the FE model) and the Breusch-Pagan-Lagrange multiplier test (prob > chibar2 = 0.0018 for the RE model), indicating a goodness-to-fit improvement by the FE and RE estimator.

Table 7 - RE and FE Model (1) Total Sum of Doctoral Degrees

Model	**RE**	**FE**
	(1) Total Sum of Doctoral Degrees	(1) Total Sum of Doctoral Degrees
VARIABLES	Natural logarithm of funding	Natural logarithm of funding
GRP	4.35e-06***	6.49e-06**
	(9.79e-07)	(2.66e-06)
Population density	-0.0101***	-0.0441
	(0.00236)	(0.0275)

Total sum of doctoral degrees	0.00218**	0.00163
	(0.00101)	(0.00239)
Constant	15.19***	16.81***
	(0.300)	(0.693)
Observations	152	152
R-squared		0.258
N of NUTS2	8	8
Prob > chibar2	0.0018	
Prob > F		0.0000

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The GRP beta coefficients in the RE model is with 0.00000453 percentage points, only slightly smaller than the value obtained from the pooled OLS. Its counterpart in the FE model increased, indicating a 0.00065% increase in funding when GRP increases by SEK 1 million. Both beta coefficients for population density remain negative but differ across the models. The RE model suggests a 1.01% decrease in funding with each additional resident per sqm, while the FE model suggests a 4.41% decrease, however, not at a significant level.

The differences between the structural indicator variables in the RE and FE models can be due to the relationship of the variables with the region-specific, unobserved effect. Since population density and GRP are broad structural indicators for a region, it is likely that they are correlated with some part of α_i.

5.3 Regression Analysis: Differences between Research Areas

This part examines the differences in the relationship between the natural logarithm of funding by Vinnova, and doctoral degrees awarded in the six research areas. Similarly, the analysis proceeds by examining the relationship between the variables in separate pooled OLS, FE and RE models for regressions (2) to (7), each presenting one research area.

Tables 8 and 9 present the pooled OLS models for regressions (2) to (4), and (5) to (7), respectively. The structural indicators GRP and population density each share a common feature with their counterparts in the previously analyzed models. The parameter estimate for GRP is small but positive, ranging from a 0.000417 % increase in funding for a SEK 1 million increase in GRP in the model for doctoral degrees in natural sciences, to a 0.000549 % increase in the model for agricultural and veterinary sciences. The effect is significant at the 0.01 level for all models.

Considering the beta coefficients of the pooled OLS models of the various research areas, a significant effect can be found at the 0.05 level for the humanities and arts, medicine and health sciences, and social sciences, and at the 0.01 level for technical sciences. An additional doctorate in the humanities and arts is associated with a 1.71% increase in funding. The impacts are 0.62%, 1.30%, and 1.22% for medicine and health sciences, social sciences, and technical sciences, respectively. Degrees in agricultural and veterinary sciences are associated with a 0.39% increase in funding and in natural sciences with a 0.46% increase, though not at a significant level.

Table 8 - Pooled OLS of (2) Humanities & Arts, (3) Agricultural & Veterinary Sciences, and (4) Medicine & Health Sciences

Pooled OLS	(2) Humanities & Arts	(3) Agricultural & Veterinary Sciences	(4) Medicine & Health Sciences
VARIABLES	Natural logarithm of funding	Natural logarithm of funding	Natural logarithm of funding
GRP	5.08e-06***	5.49e-06***	4.86e-06***
	(6.82e-07)	(9.26e-07)	(6.86e-07)
Population density	-0.00917***	-0.00822***	-0.0125***
	(0.00136)	(0.00202)	(0.00255)
Humanities & Arts	0.0171**		
	(0.00608)		
Agricultural & Veterinary Sciences		0.00393	
		(0.00299)	
Medicine & Health Sciences			0.00617**
			(0.00235)
Constant	15.10***	15.22***	15.15***
	(0.274)	(0.385)	(0.261)
Observations	152	152	152
R-squared	0.683	0.655	0.692

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 9 - Pooled OLS of (5) Natural Sciences, (6) Social Sciences, and (7) Technical Sciences

Pooled OLS	(5) Natural Sciences	(6) Social Sciences	(7) Technical Sciences
VARIABLES	Natural logarithm of funding	Natural logarithm of funding	Natural logarithm of funding
GRP	5.01e-06***	4.58e-06***	4.17e-06***
	(8.54e-07)	(6.06e-07)	(8.70e-07)
Population density	-0.00893***	-0.00848***	-0.00993***
	(0.00192)	(0.00147)	(0.00213)
Natural Sciences	0.00461		
	(0.00244)		
Social Sciences		0.0130**	
		(0.00491)	
Technical Sciences			0.0122***
			(0.00250)
Constant	15.16***	15.04***	15.25***
	(0.312)	(0.246)	(0.299)
Observations	152	152	152
R-squared	0.675	0.696	0.693

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The results of the Hausman test in Table 4 for regressions (2) to (7) suggests that the FE estimator is preferred for models (2), (3), (5), and (7). Conversely, the null hypothesis under the Hausman test was not rejected for model (4), and (6), indicating the RE model to be the statistically adequate choice. Given the theoretical background and the mixed results of the Hausman test, both the RE and FE results for all research areas are reported.

Table 10 and 11 outline the FE model results by research area. The beta coefficients of GRP in the FE models continue to vary within a small margin of 0.000006 percentage points, with significance at the 0.05 level for regressions (5), (6), (7), (8), and at the 0.1 level for regression (2). Population density has a negative but not significant beta coefficient in all models.

The only significant beta coefficient among the research areas was found for medicine and health Sciences, indicating a 0.42% increase in allocations with each additional doctorate. Unexpectedly, the beta coefficient for humanities and arts turned negative in the FE and indicates a 0.15% decrease in funding with each additional doctorate. For the research areas agricultural and veterinary sciences, natural, and technical sciences, for which the Hausman test indicated the FE model as the best choice, the beta coefficients indicate a not significant increase in funding of 0.41%, 0.17%, and 0.09%, when an additional Ph.D. is awarded.

Table 10 - FE Models for (2) Humanities & Arts, (3) Agricultural & Veterinary Sciences, and (4) Medicine & Health Sciences

FE	(2) Humanities & Arts	(3) Agricultural & Veterinary Sciences	(4) Medicine & Health Sciences
VARIABLES	Natural logarithm of funding	Natural logarithm of funding	Natural logarithm of funding
GRP	5.57e-06	6.54e-06*	6.18e-06**
	(2.97e-06)	(3.05e-06)	(2.61e-06)
Population density	-0.0388	-0.0444	-0.0408
	(0.0284)	(0.0313)	(0.0269)
Humanities & Arts	-0.0149		
	(0.0127)		
Agricultural & Veterinary Sciences		0.00405 (0.0164)	
Medicine & Health Sciences			0.00421** (0.00136)
Constant	17.79***	17.34***	16.79***
	(0.509)	(0.688)	(0.724)
Observations	152	152	152
R-squared	0.266	0.255	0.259
Prob > F	0.0001	0.0000	0.0006
N of NUTS2	8	8	8

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 11 - FE Models for (5) Natural Sciences, (6) Social Sciences, and (7) Technical Sciences

FE	(5) Natural Sciences	(6) Social Sciences	(7) Technical Sciences
VARIABLES	Natural logarithm of funding	Natural logarithm of funding	Natural logarithm of funding
GRP	6.57e-06**	6.50e-06**	6.38e-06**
	(2.48e-06)	(2.48e-06)	(2.42e-06)

Population density	-0.0452 (0.0259)	-0.0419 (0.0252)	-0.0431 (0.0255)
Natural Sciences	0.00174 (0.00660)		
Social Sciences		0.0104 (0.00757)	
Technical Sciences			0.000873 (0.00561)
Constant	17.27*** (0.759)	16.66*** (0.698)	17.29*** (0.536)
Observations	152	152	152
R-squared	0.256	0.266	0.255
Prob > F	0.0000	0.0003	0.0006
N of NUTS2	8	8	8

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The RE models for regressions (2) to (7) are displayed in Table 12 and 13. The Hausman test indicated the RE model is the accurate choice for models (4), and (6). The parameter estimates of GRP are significant at the 0.01 level in all regressions and vary by a 0.000004 percentage point increase in funding for a SEK 1 million increase in GRP. Values for population density are also significant at the 0.01 level. They vary between a decrease in funding of 1.28% to 0.896% per additional resident per sqm.

Significant beta coefficients are found for the medical and health sciences, social sciences, and technical sciences at the 0.05 and 0.01 level. They indicate an increase in funding allocations, by 1.38% for social sciences, 1.03% for technical sciences, and 0.74% for medicine and health sciences with an additional Ph.D. within the area is awarded.

Table 12 - RE Models for (2) Humanities & Arts, (3) Agricultural & Veterinary Sciences, and (4) Medicine & Health Sciences

RE	(2) Humanities & Arts	(3) Agricultural & Veterinary Sciences	(4) Medicine & Health Sciences
VARIABLES	Natural logarithm of funding	Natural logarithm of funding	Natural logarithm of funding
GRP	4.90e-06***	4.42e-06***	4.44e-06***

	(1.04e-06)	(1.24e-06)	(8.54e-07)
Population	-0.00818***	-0.00584*	-0.0128***
density	(0.00246)	(0.00311)	(0.00274)
Humanities &	0.0105		
Arts	(0.00703)		
Agricultural &		0.00395	
Veterinary		(0.00274)	
Sciences			
Medicine &			0.00737***
Health Sciences			(0.00239)
Constant	15.28***	15.57***	15.23***
	(0.410)	(0.479)	(0.308)
Observations	152	152	152
N of NUTS2	8	8	8

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 13 - RE Models for (5) Natural Sciences, (6) Social Sciences, and (7) Technical Sciences

RE	(5) Natural Sciences	(6) Social Sciences	(7) Technical Sciences
VARIABLES	logfunding	logfunding	logfunding
grp	4.43e-06***	4.44e-06***	4.02e-06***
	(1.16e-06)	(8.82e-07)	(1.08e-06)
popdensity	-0.00768***	-0.00862***	-0.00896***
	(0.00268)	(0.00218)	(0.00295)
natural	0.00430		
	(0.00298)		
social		0.0138**	
		(0.00543)	
technical			0.0103***
			(0.00359)
Constant	15.38***	15.07***	15.37***
	(0.416)	(0.332)	(0.359)
Observations	152	152	152
N of NUTS2	8	8	8

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

6 Discussion

This section evaluates the results based on the two hypotheses and contextualizes them with the literature. After reviewing the findings, the research question of the study is assessed.

6.1 Regionally Consistent Doctorates and Increased R&D Funding

Since the research question of the study was analyzed in two parts, this section discusses the findings of the first, the relationship between the sum of doctorates in a region and their relationship to the amount of funding issued by Vinnova to the private sector. The first hypothesis, firms in regions with a greater stock of high-skilled human capital, as measured by the total sum of doctoral degrees within that region, receive more public R&D funding, is accepted.

Evaluating the results of the first part of the regression analysis, the relationship between the total number of Ph.Ds. and Vinnova funding was significant at the 0.05 and 0.1 level in both the pooled OLS and RE model, but not significant in the FE model. The pooled OLS model showed a 0.19% increase in funds to the private sector and the RE model a 0.218% increase, when an additional doctoral degree was awarded in any research area.

The analysis showed that the total number of doctoral graduates by region remained relatively constant over time and among the regions. Given that the number of HEIs within the regions also remained constant, this is not surprising. Stockholm and East-Central Sweden hosted the highest average number of doctoral graduates, followed by West and South Sweden. In the northern regions, and in Småland and the Islands, the number of doctoral graduates was significantly lower. Conversely, R&D funding by Vinnova increased throughout Sweden and all regions benefitted from higher allocation over the years. This underscores, the EIS (European Commission, Directorate-General for Research, and Innovation, et. al., 2022), and WIPO’s (2021) assessments of Sweden's position as a global innovation leader.

The analysis of dependent and independent variables in this study are also consistent with the RIS ranking of the Swedish regions (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021). Stockholm, East-Central, West and South Sweden not only have the highest average number of Ph.Ds., but also consistently receive higher amounts of Vinnova funding. This underlines their status as innovation leaders compared to the other four regions, Upper Norrland, Central Norrland, North Central Sweden, and Småland and the Islands. These regions only started to receive more funding in recent years but continue to produce an overall lower average of doctorates.

An interesting case is Upper Norrland, which is a site of strategic investment for several Vinnova-funded initiatives (Vinnova, 2022a). Compared to the other two regions in northern Sweden, Upper Norrland benefited from more public R&D to the private sector. An example of a company supported in the region is Northvolt, which located its gigafactory in Upper Norrland to produce sustainable batteries and was repeatedly funded by Vinnova (Vinnova, 2022a). Simultaneously, Upper Norrland also has the highest average number of doctoral degrees among the regions classified as strong innovators.

6.2 A Nuanced Picture: Funding Allocation and Doctoral Degrees across Research Areas

Subsequently, the second part of the analysis examined whether the research area in which doctoral degrees are awarded impacts the amount of public R&D funding companies in a region receive. The second hypothesis, the relationship between the amount of public R&D funding received by firms and doctoral degrees awarded, varies depending on the six different research fields, humanities and arts, agricultural and veterinary sciences, medicine and health sciences, natural sciences, social sciences, and technical sciences, is also accepted. However, the statistical analysis conducted to examine differences across the research areas yielded mixed results which depend strongly on the model choice.

The field of medicine and health sciences was the only research area to produce significant results across the board. This is likely due to the higher number of degrees issued in this field of study. Table 14 summarizes the significant results. Since degrees in agricultural and veterinary sciences are limited to two regions, results in this research area were not significant in any of the models. Yet, no parameter estimate for the natural sciences was significant either. This contradicts previous findings that emphasize the strong university-industry linkages in applied research areas such as engineering by Thune (2009).

Table 14 - Significant Beta Coefficients across Research Areas and Models

Field of Research	Model	Beta Coefficient
Humanities & Arts	Pooled OLS	0.0171***
Medicine & Health Sciences	Pooled OLS	0.00617**

	FE RE	0.00421** 0.00737***
Social Sciences	Pooled OLS RE	0.0130** 0.0138**
Technical Sciences	Pooled OLS RE	0.0122*** 0.0103***

Two significant results to highlight, matching the model recommendation of the Hausman test, are the RE parameter estimates in medicine and health sciences and in social sciences. An additional Ph.D. in medicine and health sciences and the social sciences is associated with 0.74% and 1.38% increase funding to the private sector, respectively. Results, nevertheless, need to be interpreted with caution given the region-specific effect.

6.2.1 The Region-Specific Effect and Choice of Model

For all results, the careful consideration of the region-specific effect is crucial. Because of the region-specific effect, parameter estimates of the pooled OLS cannot be trusted, despite providing more significant results across the research areas. Whether the RE or FE model produces more consistent results depends on the relationship between the explanatory variables and the error component. Moreover, insufficient variation among the numbers of doctoral degrees awarded can prevent FE estimator to produce efficient results.

Therefore, although both hypotheses are accepted, results need to be interpreted with caution. More advanced econometric analysis, beyond the scope of this study, is necessary to be able to identify potential trends amongst research areas. Because no previous literature specifically considered the six different research areas in terms of their impact of R&D funding allocation to the private sector, theoretical guidance is also limited. A potential point of departure, to gain better understanding of the unobserved, region-specific effect, is to scrutinize the time-specific effect in more detail.

6.3 Structural Differences associated with the Allocation of Funding

All models included the structural indicator variables GRP and population density. The relationship between GRP and R&D funding allocation was significant in all but one of the models, underscoring the positive correlation of the variables. Although a small effect, it can multiply swiftly as GRP fluctuates. The importance of GRP in the relationship with funding allocations is consistent with the RIS, which emphasized the impact of high economic activity on innovation activity.

Conversely, all parameter estimates of population density were negative and significant in most models. This suggests a decrease in funding if population density increases. A possible explanation could be the recent increase in funds to densely populated regions, such as Upper Norrland. Again, a more detailed analysis of the unobserved region-, and time specific effect could shed light on this.

6.4 Contextualizing Patterns across Research Areas and Regions

To answer the research question, the inquiry of a casual effect of doctorates in different research areas on public R&D funding allocations to the private sector remains. Causality cannot be confirmed by the results of this study; however, it is possible to contextualize the findings with previous literature to search for explanations of patterns.

This study's results allow for an extension of the picture painted by the EU's RIS (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2021). The findings are broadly consistent with the classification of the Swedish regions, however, the dataset compiled in this study provides more nuanced insights into the relationship between doctoral degrees in different research areas and public R&D expenditures. Literature on university-industry relations attributes an important role to doctoral degree holders in producing, and transferring knowledge, and cultivating networks (Thune, 2009). This opens the possibility to further investigate the interplay between the various other indicators included in the RIS.

In conjunction with the findings of Gustafsson et. al. (2020) that firms seeking grants are often characterized by a higher stock of skilled human capital, a higher number of graduates moving to industry increases the propensity of their employers to seek and receive public R&D grants. The results of this study show a correlation between higher numbers of Ph.Ds. and an increase in funds by Vinnova to the private sector, supporting the argument of this chain of events. Nevertheless, findings by Lundh (2022) show that 44% of doctoral graduates in Sweden continue to be employed in HEIs, pointing towards their role in network facilitation.

Literature does not provide a differentiated picture regarding the role of doctorates in the six different research areas. Thune (2009) states that applied research in recent years increased, but the author does not mention specifically in which fields. Commonly, applied research is found in fields such as medicine and health sciences, natural sciences, and technical sciences, and it is often conducted in collaboration with the private sector.

The significant results in the research area of medicine and health sciences are an indicator of support for this, but are counter played by the non-significant results for the natural sciences. Some significant results of a positive relationship between funding allocations and the technical sciences, along with an increase in the number of degrees in this field can point towards the growing importance of this research area. Nevertheless, results of this study do not allow for concrete conclusions regarding this.

This study complements an earlier analysis of the regional impact of Vinnova programs by Engberg et. al. (2020). The first hypothesis, that regions with more Ph.Ds. will also receive more public R&D funding for the private sector, supports the findings of Engberg et. al. (2020) regarding the importance of pre-existing regional capabilities, such as knowledge and skills.

Conclusively, the attempt to answer the research question goes as follows: A larger pooled of highly skilled human capital, measured by the number of doctoral degrees issued within that region, has a positive relationship with the amount of public R&D funding allocated by the government agency Vinnova. The precise effect an additional doctorate has on funding flows varies by econometric model and depends on other regional-specific characteristics. Likewise, the ambiguous results across different research areas point towards the importance of the region-specific effect. Although findings varied, only the field of medicine and health sciences produced significant results across different models.

7 Concluding Remarks

Contemporary challenges, such as climate change, urgently require profound changes in the economy and technological innovations to facilitate them. Economic theory emphasizes the importance of public R&D funding for the private sector to drive the development of innovations. In parallel, it is well established that human capital plays a vital role in fostering innovation and R&D. Driven by the need to utilize government resources effectively (Becker, 2015), the study answered the research question as follows:

A larger pooled of highly skilled human capital, measured by the number of doctoral degrees issued within that region, has a positive relationship with the amount of public R&D funding allocated by the government agency Vinnova. The precise effect an additional doctorate has on funding flows varies by econometric models and depends on other regional-specific characteristics. Utilizing a random effects model, this study found a significant effect indicating a 0.218 % increase in funding when an additional Ph.D. is awarded in any research area. At the same time, varying results across the six research areas emphasize the importance of the region-specific effect. Primarily, the field of medicine and health sciences produced significant results across different models, indicating an increase in funding by 0.74% if an additional doctorate was awarded.

Innovation policy must consider a range of actors within the innovation system. In particular, the allocation of funding is important to enable effective R&D across the academic, public, and private sectors. Beyond this, regional differences in the conditions that support R&D and innovation require nuance in policy.

Therefore, this study provides guidance through new insights into the interplay between human capital and R&D funding allocations on a regional basis, enabling policymakers to consider one aspect of university-industry relations, doctoral degree holders, and their influence on the allocation of R&D funds to the private sector. Furthermore, the study complements previous research evaluating Vinnova's funding programs.

It is vital to emphasize that Vinnova funds represent only a small portion of total government R&D funding, preventing the generalization of results across broader funding flows. Ultimately, this study opens further research opportunities, particularly regarding the impact of doctorates awarded in different research areas, their relation to region-specific characteristics, as well as extended investigations of the interplay between other indicators which influence a region's innovative capacity.

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Appendices

Appendix A - Background

Table A.1 – NUTS2 Regions and their respective counties

NUTS2 Region	**County**
SE11- Stockholm	SE110 – Stockholm County
SE12 – East-Central Sweden (Östra Mellansverige)	SE121 – Uppsala County SE122 – Södermanlands County SE123 - Östergötlands County SE124 – Örebro County SE125 – Västmanlands County
SE21- Småland and the Islands (Småland med Öarna)	SE211 – Jönköpings County SE212 – Kronobergs County

	SE213 – Kalmar County SE214 – Gotlands County
SE22 – South Sweden (Sydsverige)	SE221 – Blekinge County SE224 – Skåne County
SE23- West Sweden (Västsverige)	SE231 – Hallands County SE232 -Västra Götlands County
SE31- North-Central Sweden (Norra Mellansverige)	SE311 – Värmlands County SE312 – Dalarnas County SE313 – Gävleborgs County
SE32 – Central Norrland (Mellersta Norrland)	SE321 – Västernorrlands County SE322 – Jämtlands County
SE33 – Upper Norrland (Övre Norrland)	SE331 – Västerbottens County SE332 – Norrbottens County

Table A.2 HEIs which awarded Doctoral Degrees between 2003 – 2021, by NUTS2 region

NUTS2 Region	HEI
Mellersta Norrland	Mittuniversitetet
North Central Sweden	Högskolan Dalarna Högskolan i Gävle Karlstads universitet
Småland and Islands	Högskolan i Jönköping Linnéuniversitetet (Växjö University merged with Kalmar University on January 1, 2010, to form Linné University)
Stockholm	Enskilda Högskolan Stockholm Ersta Sköndal Bräcke Högskola Gymnastik- och idrottshögskolan Handelshögskolan i Stockholm Karolinska institutet Kungl. Tekniska högskolan Södertörns Högskola

	Stockholms Konstnärliga Högskola Stockholms Universitet
South Sweden	Blekinge tekniska högskola Lunds universitet Malmö universitet /Malmö högskola
Wesr Sweden	Chalmers tekniska högskola Göteborgs universitet Högskolan i Borås Högskolan i Halmstad Högskolan i Skövde Högskolan Väst
East-Central Sweden	Linköpings universitet Mälardalens högskola Örebro universitet Sveriges lantbruksuniversitet Uppsala universitet
Upper Norrland	Umeå universitet Luleå tekniska universitet

Appendix B – Statistical Assumption

This section of the appendix outlines the statistical assumptions of the FE and RE models. These are assumptions extended based on the Gauss-Markov assumptions which determine if the parameter estimates of the OLS model are unbiased, consistent, and efficient (Wooldrigde, 2013). The assumptions outlined below, which underly the statistical models used in this study, are all outlined based on theory by Wooldridge (2013, pp.509-511). For the RE model assumptions 1,2,4,5, 6, and 7 must hold, and two other assumptions, 8 and 9, must be added (Wooldridge, 2013).

1) The model of each observation i, includes the parameters β_j , α_i, the unobserved effect and μ_{it}, the error term. It looks as follows

$$y_{it} = \beta_1 x_{it1} + \cdots + \beta_k x_{itk} + \alpha_i + \mu_{it} \text{ , } t = 1, \ldots, T$$

2) The cross section of the panel data represents a random sample.
3) The explanatory variables change over time for some of the observations and the explanatory variables are not perfectly correlated with each other.
4) Strict exogeneity must hold in all time periods t, meaning, the expected value of the error and the independent variables across all periods and the unobserved individual-specific effect are zero:

$$E(\mu_{it} | x_i \alpha_i) = 0$$

5) Homoscedasticity must hold, translating to the aspect that the expected variance of the error term μ_{it} ,given the explanatory variables, and the unobserved individual-specific effect equals the variance of the error term in all time periods:

$$Var(\mu_{it} | x_i, \alpha_i) = Var(\mu_{it}) = \sigma_\mu^2, for\ all\ t = 1, \ldots, T$$

6) The error terms are uncorrelated over all time periods, conditional on the explanatory variables, meaning no autocorrelation.

Because the assumption of autocorrelation in the case of the data set of this study was violated, robust, clustered standard errors were applied in all models. A Born and Breitung Test was performed, with the null hypothesis that no first-order autocorrelation can be found. The H0 was rejected at p=0.024.

7) Conditional on the explanatory variable and the unobserved individual specific effect, the error terms are independent and identically distributed (IID).

8) The expected value of α_i, given all explanatory variables, is constant. Hence, the unobserved effect and the explanatory variables cannot be correlated.

$$E(\alpha_i | x_i) = \beta_0$$

9) The variance of the unobserved, individual specific effect $\alpha_i$is constant in relation to all explanatory variables.

Table B.1 Multicollinearity between the explanatory variables of different research areas

	Funding	Total Degrees	Humanities & Arts	Agricultural & Veterinary Sciences	Medicine & Health Sciences	Natural Sciences	Social Sciences	Technical Sciences
Total	0.6605	1.0000						
Humanities & Arts		0.8971	1.0000					
Agricultural & Veterinary Sciences	0.5058	0.4209	0.4350	1.0000				
Medicine & Health Sciences	0.0436	0.9702	0.8190	0.2632	1.0000			
Natural Sciences	0.5542	0.9597	0.8835	0.6143	0.8882	1.0000		
Social Sciences	0.6022	0.9554	0.8866	0.5022	0.8864	0.9345	1.0000	
Technical Sciences	0.7927	0.8748	0.7468	0.0162	0.8830	0.7316	0.7915	1.0000

Appendix C –Data Set

Funding Data by Vinnova was received on request by the author on the 5th of April and the 10th of May 2023.

year	NUTS_ID	funding	total	humart	agrivet	medhealth	natural	social	technical	popdensity	grp
2003	SE32	200000,00	0	0	0	0	0	0	0	5	100169
2004	SE32	1000000,00	1	0	0	0	1	0	0	5	104718
2005	SE32	650000,00	2	0	0	0	1	0	1	5	108978
2006	SE32	211240,00	9	0	0	3	4	0	2	5	112686
2007	SE32	4432000,00	13	1	0	0	8	1	3	5	113442
2008	SE32	1150000,00	30	0	0	2	9	4	15	5	120749
2009	SE32	2257000,00	16	0	0	1	4	3	8	5	119612
2010	SE32	7700046,00	20	0	0	6	3	3	8	5	131306
2011	SE32	4218600,00	24	2	0	2	10	5	5	5	129704
2012	SE32	6818750,00	14	1	0	3	3	3	4	5	128323
2013	SE32	7702478,00	39	1	0	11	2	7	18	5	128383
2014	SE32	8712624,00	33	0	0	6	10	6	11	5	131883
2015	SE32	10162786,00	17	1	0	1	3	6	6	5	135703
2016	SE32	7936116,00	23	1	0	5	3	8	6	5	139048
2017	SE32	10894466,00	16	1	0	3	1	5	6	5	145438
2018	SE32	20415493,06	22	1	0	6	3	8	4	5	151764
2019	SE32	5141730,00	15	0	0	3	1	3	8	5	156391
2020	SE32	25892003,54	26	0	0	3	10	10	3	5	152737
2021	SE32	73132647,48	19	1	0	2	3	7	6	5	171493
2003	SE31	1430000,00	11	3	0	0	0	6	2	13	207978
2004	SE31	1259945,00	19	2	0	0	2	9	6	13	216801
2005	SE31	1994022,00	27	2	0	0	7	10	8	13	222976
2006	SE31	9314205,00	36	4	0	6	6	12	8	13	235816
2007	SE31	6678000,00	34	2	0	1	8	18	5	13	242665
2008	SE31	30971613,00	28	4	0	5	8	7	4	13	247468
2009	SE31	32536424,00	30	2	0	5	7	13	3	13	234403
2010	SE31	3941160,00	25	2	0	3	3	13	4	13	255563
2011	SE31	15049091,00	26	0	0	1	5	15	5	13	262928
2012	SE31	37314592,00	25	1	0	4	7	11	2	13	264120
2013	SE31	15994800,00	24	2	0	3	5	9	5	13	266014
2014	SE31	33020542,91	42	5	0	7	7	18	5	13	273803
2015	SE31	36845852,00	33	1	0	7	9	15	1	13	284354
2016	SE31	23541124,56	26	2	0	2	11	11	0	13	297381
2017	SE31	17645239,17	36	2	0	3	9	15	7	13	308713
2018	SE31	22503221,98	30	1	0	4	8	15	2	13	324379

2019	SE31	15306111,94	33	1	0	5	9	14	4	13	335043
2020	SE31	12318405,04	39	4	0	5	20	7	3	13	332521
2021	SE31	14930514,34	34	2	0	3	6	19	4	13	359864
2003	SE21	6834000,00	10	3	0	1	1	4	1	24	212815
2004	SE21	4128300,00	29	8	0	2	6	11	2	24	221582
2005	SE21	7105000,00	38	3	0	3	14	15	3	24	220403
2006	SE21	12120600,00	33	4	0	2	13	11	3	24	240338
2007	SE21	3484800,00	33	5	0	5	10	11	2	24	254697
2008	SE21	16569223,00	55	4	0	10	12	24	5	24	264039
2009	SE21	6359099,00	51	4	0	4	20	21	2	24	241792
2010	SE21	7388320,00	52	5	3	12	12	19	1	24	261893
2011	SE21	15324292,00	56	4	1	13	17	19	2	25	275022
2012	SE21	13745386,00	59	6	0	16	11	23	3	25	272780
2013	SE21	29893382,00	74	4	1	19	26	20	4	25	277850
2014	SE21	24435269,00	72	2	2	17	14	33	4	25	287639
2015	SE21	18842035,84	49	2	0	9	11	23	4	25	304701
2016	SE21	27115046,32	52	0	2	12	11	25	2	25	319834
2017	SE21	21656499,81	53	4	2	17	10	17	3	26	337472
2018	SE21	20226056,79	65	6	0	9	11	27	12	26	350302
2019	SE21	5648950,00	47	0	3	8	11	18	7	26	357799
2020	SE21	23496081,21	46	2	2	4	14	18	6	26	358024
2021	SE21	31378356,40	48	5	0	10	11	14	8	26	383326
2003	SE11	42994248,00	827	70	0	305	168	126	158	285	773751
2004	SE11	58806168,00	886	62	0	364	182	110	168	287	825779
2005	SE11	70334603,00	867	60	0	378	165	100	164	290	864942
2006	SE11	137173612,00	856	51	0	382	152	118	153	294	907604
2007	SE11	109596399,00	803	60	0	350	146	103	144	298	982306
2008	SE11	194115029,00	883	57	0	358	182	125	161	303	1012921
2009	SE11	207880424,00	881	51	0	401	178	104	147	309	1050112
2010	SE11	114687615,00	837	47	0	379	166	105	140	314	1086884
2011	SE11	121629995,00	835	35	0	351	179	94	176	320	1150719
2012	SE11	190938053,00	803	56	0	329	171	80	167	325	1164432
2013	SE11	227194580,19	824	32	0	350	151	95	196	331	1198463
2014	SE11	247630416,64	886	38	0	346	197	114	191	337	1271466
2015	SE11	278393597,77	942	36	0	369	220	97	220	341	1372451
2016	SE11	286248968,18	870	58	0	336	213	79	184	347	1412238

2017	SE11	418217528,73	877	42	0	337	181	112	205	353	1451421
2018	SE11	358798674,17	967	59	0	390	230	116	172	359	1528979
2019	SE11	286069343,78	831	30	0	363	179	87	172	365	1623493
2020	SE11	360702448,75	823	42	0	346	179	100	156	367	1628133
2021	SE11	420614795,25	835	45	0	363	163	98	166	370	1763960
2003	SE22	9599000,00	490	67	0	146	129	72	76	93	353331
2004	SE22	11540923,00	472	63	0	134	121	67	87	94	368283
2005	SE22	23528500,00	467	44	0	159	106	57	101	94	382219
2006	SE22	34772494,00	440	40	0	158	105	50	87	95	405770
2007	SE22	22434000,00	528	48	0	183	145	73	79	97	450657
2008	SE22	51208293,00	451	47	0	141	119	58	86	98	441487
2009	SE22	69048057,33	395	42	0	135	86	64	68	99	425221
2010	SE22	28985365,00	367	43	0	136	102	47	39	100	459791
2011	SE22	45334694,00	365	27	0	128	79	48	83	101	471351
2012	SE22	42135806,00	357	28	0	110	96	53	70	102	472103
2013	SE22	83980695,14	389	27	0	153	80	52	77	103	484588
2014	SE22	86591874,98	446	27	0	168	103	53	95	104	508626
2015	SE22	115750596,30	414	24	0	151	110	46	83	105	539519
2016	SE22	81162781,46	487	36	0	168	127	62	94	106	556877
2017	SE22	132726236,93	479	41	0	201	94	66	77	108	592119
2018	SE22	120231237,32	437	40	0	170	110	55	62	109	613867
2019	SE22	96623533,08	427	19	0	145	110	61	92	111	644010
2020	SE22	183702484,27	401	28	0	154	98	45	76	111	653831
2021	SE22	151938588,89	436	20	0	164	120	59	73	112	693074
2003	SE23	123803163,00	463	55	0	116	109	91	92	61	530778
2004	SE23	45370057,00	464	53	0	109	101	84	117	61	543640
2005	SE23	248710761,00	456	43	0	124	107	70	112	62	562473
2006	SE23	327875061,00	444	36	0	123	106	75	104	62	607441
2007	SE23	175385072,00	459	48	0	117	101	68	125	62	637813
2008	SE23	43318797,00	448	51	0	129	69	78	121	63	664107
2009	SE23	236847732,00	438	51	0	144	77	75	91	63	637597
2010	SE23	149262722,00	423	39	0	148	76	75	85	64	678842
2011	SE23	157709395,00	412	43	0	110	82	74	103	65	709897
2012	SE23	209803657,00	410	30	0	104	84	57	135	65	707202
2013	SE23	261035276,00	442	36	0	118	98	71	119	66	726679
2014	SE23	342583621,17	482	27	0	163	87	64	141	66	761224

2015	SE23	322484593,62	469	30	0	139	82	73	145	67	827405
2016	SE23	215037306,54	470	37	0	126	80	67	160	68	861777
2017	SE23	278667464,11	403	36	0	124	68	64	111	69	909224
2018	SE23	306748289,95	429	26	0	116	75	74	138	70	935348
2019	SE23	233776993,10	478	36	0	165	65	74	138	70	975266
2020	SE23	307255732,19	477	30	0	143	83	62	159	71	956581
2021	SE23	315802865,38	463	32	0	143	84	59	145	71	1028818
2003	SE12	6914400,00	711	64	70	214	216	94	53	39	390825
2004	SE12	17612461,00	661	52	71	156	216	117	49	39	406245
2005	SE12	16972198,00	694	61	78	183	234	72	66	39	419267
2006	SE12	141494307,00	707	73	66	190	201	110	67	39	448133
2007	SE12	113347340,00	726	68	73	183	229	110	63	40	474639
2008	SE12	53399348,00	735	60	58	209	219	125	64	40	485258
2009	SE12	98039913,00	664	56	63	219	187	95	44	40	472424
2010	SE12	46344174,00	649	50	62	205	187	94	51	41	508218
2011	SE12	53306546,00	651	50	62	215	180	86	58	41	531045
2012	SE12	91372043,00	677	47	61	210	191	86	82	41	539147
2013	SE12	119488639,00	619	32	55	209	169	105	49	42	547258
2014	SE12	80425797,57	679	41	62	173	195	127	81	42	563523
2015	SE12	166071485,30	670	44	66	197	187	94	82	43	596825
2016	SE12	124278118,42	807	33	79	242	240	137	76	43	622123
2017	SE12	282009995,94	713	43	61	206	208	109	86	44	658876
2018	SE12	114963199,37	645	42	40	208	186	95	74	44	688078
2019	SE12	117531501,27	693	38	52	217	201	98	87	45	707207
2020	SE12	148670230,72	575	35	38	181	171	85	65	45	711066
2021	SE12	177270899,96	636	37	40	178	194	120	67	46	765650
2003	SE33	4718085,00	189	24	0	49	59	32	25	3	133173
2004	SE33	562400,00	231	18	0	70	49	39	55	3	142408
2005	SE33	8453945,00	207	20	0	69	38	44	36	3	149065
2006	SE33	25994400,00	243	8	0	75	57	60	43	3	163102
2007	SE33	10627000,00	257	15	0	77	59	60	46	3	163270
2008	SE33	14199880,00	284	20	0	94	55	65	50	3	175434
2009	SE33	13581480,00	247	18	0	86	42	53	48	3	159103
2010	SE33	7338324,00	242	17	0	88	42	56	39	3	190111
2011	SE33	5126130,00	250	8	0	87	60	50	45	3	196210
2012	SE33	12709949,00	233	9	0	86	53	49	36	3	194113

2013	SE33	21603635,00	239	12	0	87	46	41	53	3	192545
2014	SE33	37372666,00	211	8	0	73	42	31	57	3	193678
2015	SE33	59431786,85	261	17	0	86	47	43	68	3	198634
2016	SE33	46592859,93	255	12	0	90	47	41	65	3	204848
2017	SE33	36281111,34	261	15	0	89	41	53	63	3	220898
2018	SE33	31499245,43	194	9	0	67	47	33	38	3	234692
2019	SE33	33558813,74	223	7	0	80	36	36	64	3	249480
2020	SE33	45901624,21	185	7	0	52	37	37	52	3	244765
2021	SE33	45175605,02	196	8	0	58	42	33	55	3	282423