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Geographic Concentration of Industry 4.0 patents in Sweden: 2010-2017

by

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In the age of ever-growing technological advancements, delegating some of the inherently human tasks to smart machines is becoming more and more common. The possibly new wave of industrialization – Industry 4.0 – is comprised of interconnected smart technologies that could automate parts of the production and decentralize the decision-making process. The associated efficiency has prompted businesses to invent and perfect the related technologies, and governments – to support their development. However, the concept is not easily defined and studied, which could result in ineffective policymaking activities. The thesis strives to construct the first dataset on Swedish smart technology patents, map them and analyze the geographic patterns based on the previously observed developments. For instance, two main questions were posed: Does the Industry 4.0 innovation output, as measured by patents, follow the previously observed geographical patterns of patenting behavior in Sweden? Are the current Swedish Industry 4.0 patents concentrated to metropolitan areas? After the data on all related smart-tech patents invented in Sweden (2010-2017) was collected, it was shown that the innovative activity follows the expected geographic distribution, both based on the previous overall patenting activity and the development of ICT sector from the evidence of previous technology shifts. The patents were found to concentrate to metropolitan areas, although the city size cannot be directly linked to the number of patents in the rest of the regions.

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1 Introduction

As known nowadays, the invention of the first commercial mainframe computer in the 1950s marked an important time in history from both economic and social perspectives. As a consequence of this important innovation, the digital revolution took place and restructured the way we live, work and even communicate in our societies. Currently, the Industry 4.0, which could eventually lead businesses to fully digitize their activities, is ongoing. The new wave of industrialization – or, as currently debated in the academic circles, the advanced stage of development within the third industrial revolution (defined by the development of ICT and Internet, to name a few) (Alcácer, Cantwell & Piscitello, 2016; Riffkin, 2013), – is based on the transformation of manufacturing process by integrating cyber physical systems, IoT (Internet of Things), artificial intelligence and cloud computing (Zhong et al, 2017). Due to its relative novelty, there is still a lot of uncertainties when it comes to the exact Industry 4.0 definition. Alcácer and Cruz-Machado (2019) claim that the concept originated, or at least first named, in Germany in 2011, with the main idea of connecting the physical and virtual worlds to achieve automation and efficiency.
While a more detailed explanation is provided further in the thesis (chapter 2.1), the simplest description of a fully-integrated smart manufacturing site involves data transfers between sensors, equipment, and people (Zhong et al, 2017; Hermann, Pentek & Otto, 2016), providing not only efficient, but also flexible response, with potential for decentralized decision-making. Companies in such advanced stages of integration are frequently referred to as smart factories.

Given the promising future for the productivity levels, mass customization, efficiency (Brettel et al, 2014), and even sustainable manufacturing (Stock & Seliger, 2016), the concept gained worldwide attention from governmental agencies, researchers and businesses. With the ability to revolutionize the current state of manufacturing industry, and the associated implications it has on the social (labor redistribution), economic (potential productivity growth), and environmental (resource efficiency) outcomes, it is essential to understand whether the mechanisms behind such technological advancement and its integration are similar to those previously observed before.

1.1 Research Questions

For the lack of a strict definition of Industry 4.0, there is no exact classification manual for companies and production sites, making it difficult to estimate the market size and constructively analyze the effectiveness of national innovation programs targeting its growth. In Sweden specifically, such industrial development initiatives as Produktion2030, IoT Sweden, AI Innovation of Sweden and many more are funded to increase the industrial competitiveness of the local portfolio (Vinnova, 2020). However, the innovation databases and surveys (e.g. Community Innovation Survey) are currently not equipped to identify companies undergoing the transition and implementing elements of smart production, which results in a gap of understanding of the mechanisms and drivers in their development – crucial elements for result-oriented policymaking activities. While the research suggests a way to identify such companies, it is more concerned with the geographical distribution of knowledge in particular, assessed by analyzing the patenting behavior in Industry 4.0-related technologies as explained further in the thesis. As such, the spatial dimension helps illustrate some of the key factors behind innovation and technological change (Audretsch & Feldman, 2004), providing unique insights on the smart technology knowledge hubs in Sweden. Moreover, considering that the knowledge itself attracts future smart factories (Götz & Jankowska, 2017), the thesis can illustrate Swedish cities with the largest potential of attracting the novel production sites.

The aim of this paper is to understand the distribution of Industry 4.0 knowledge and concentration in Sweden, as measured by the count of granted patents. As for the main objectives, the thesis strives to construct the first dataset on Swedish smart technology patents, map them and analyze the geographic patterns based on the previously observed developments.
Consequently, the thesis attempts to answer the following questions by using a mixed approach:

- *Does the Industry 4.0 innovation activity, as measured by patents, follow the previously observed geographical patterns of patenting behavior in Sweden?*

- *Are the current Swedish Industry 4.0 patents concentrated to metropolitan areas?*

The first question is mainly answered by conducting a descriptive analysis; the results are then compared the geographic distribution of the overall patenting activity and the patterns observed in the previous technology shifts. While the second question is complimented with maps of Industry 4.0 patenting activity, various measures of concentration are used as the primary means of analysis.
By creating a rough dataset of the local inventors and analyzing the mechanisms of knowledge distribution for yet abstract Industry 4.0 in Sweden, this paper strives to contribute to the ongoing development programs, which could be of interest for both researchers and legislators.

1.2 Outline of the Thesis

In order to provide a comprehensive background for data analysis, Chapter 2 starts with a deeper insight into the concept of Industry 4.0 by analyzing the associated technology, potential benefits and issues, and deriving the approximate characteristics of the main contributors to its development to consolidate the theory. Considering that Sweden has encompassed the previous waves of industrialization, the next subchapter provides an overview of the country's experience from the third industrial revolution. Further analysis and potential hypotheses can be derived from such historical outline, in addition to providing a better explanation of the debate and potentially clarifying the strong link between the trends in the third and fourth industrial revolutions. A short background on the technology shifts and the development of ICT in particular is described in the following subchapter, for further comparison of the geographical trends.

Nevertheless, the sole explanation of the patterns observed in past transitions cannot provide enough solid background for analyzing the behavior and mechanisms behind Industry 4.0. Thus, the chapter continues with an in-depth analysis of the Swedish regional innovation systems, currently existing knowledge hubs and their geographic location. Essentially, the understanding of where innovation normally originates is one of the key factors in forming hypotheses with regards to the main centers of Industry 4.0 and the location of the respective inventors.

In the section with empirical analysis, these insights are further used to analyze whether the representatives of smart industry follow the previously observed behavior of other innovations or form a new pattern that has to be closely examined. The concluding subchapters of the theoretical background are set to illustrate the previous research on Industry 4.0 in Sweden and trends within the overall patenting activity in the country.

The thesis continues with Data and Method chapters, describing both the logic behind the approach and chosen databases, and their limitations. Afterwards, the data is analyzed and reflected upon the theoretical approach and evidence from the existing research. Finally, the work is concluded with the discussion of the research questions and aim of the thesis, as well as suggestions for further research and potential advice for the future of Swedish policymaking activities.

2 Theoretical Approach

In the following chapter, the key processes of Industry 4.0 are described. Importantly, the key technologies described in section 2.1.1 set the criteria for the data collection process. The chapter continues with the rest of the theoretical framework used for the analysis of the empirical results.

2.1 Industry 4.0

As has been previously mentioned, the use of Industry 4.0 definition differs, depending on the research focus and area of implementation. For instance, the scope is ranging from smart homes and city planning to the industrial processes analyzed in this thesis. Essentially, Industry 4.0 covers a wide array of technologies that are capable of providing almost fully automated operations, if used together. The main goal is to leverage the current "technological and economic potential through a systematic innovation process" (Kagermann, Wahlster & Helbig, 2013).
Importantly, Weyer et al (2015) specifies three main ideas behind the technological side of the transition: smart product (transition from a separate work piece to the active part of one system), smart machine (decentralized self-configuration enabled by cyber-physical systems) and augmented operator (user-focused assistance systems to smooth the adaptation in the workforce). Such division serves as an introduction into the role of each distinguished technology in the process.

2.1.1 Key technologies

To explain the invisible but essential tools behind most of the processes involved in smart factory production, one must understand the role of cloud computing (CC). According to the definition of the US National Institute of Standards and Technology, "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell, P., Grace, T., 2011). It is mentioned that the technology is evolving and, thus, extending its applications over time. Nowadays, service-oriented cloud architecture is used in the manufacturing context, enabling users to store and request information and services from all stages of a product's lifecycle (Alácer & Cruz-Machado, 2019). Another essential process – Big Data analytics – is set to aggregate the data flows from the communication protocols, process it into useful information with the use of predictive analytics, and visualize it if needed (Lee, Bagheri & Jin, 2013). In a way, it is a tool that provides enough computational power to analyze large amounts of raw data collected from the devices at every point and step of the production process.

As one of the central technologies in the current wave of industrialization, and the component empowering the capabilities of the Cyber-Physical Systems (Weyer et al, 2015), Internet of Things (IoT) is responsible for the communication signals between different parts of production, along with tracing and tracking with the use of in-built sensors (Monostori et al 2016). One of its main values in the production process is the ability to translate the raw data into usable information and perform predictive analysis, providing unique insights for the management team (Lee et al, 2016). A different but largely similar concept, Internet of Services (IoS), collects the data from products to use it for further development and quality control, enabling the service-oriented shift within the manufacturing industry (Alácer, Cruz-Machado, 2019; Andulkar, Le & Berger, 2018). Importantly, the logic behind both IoT and IoS relies on the previously discussed cloud computing and is largely empowered by big data analytics that identifies and solves the bottlenecks found in the data (Alácer & Cruz-Machado, 2019).

Afterwards, in order to "enable users to comprehend the invisible causal relationships and make optimized decisions" (Lee et al, 2016), artificial intelligence and machine learning are integrated into intelligent manufacturing systems. With the primary goal of predicting and tackling the unforeseen problems, AI observes the patterns and is able to solve the disturbances with the increasing precision through machine learning, even with otherwise incomplete information flows (Monostori et al, 2016; Hatvani, 2013). To perfect the decision-making processes, cognitive computing is set to unite the benefits provided by the exceedingly powerful intelligence systems and the traits unique to the human mind, bridging the gap between the theoretically beneficial solutions and creativity, judgment and intuition previously not programmable with the algorithms (Stanley, 2016). In a way, the latter technology ensures that the moral compass and decision-making processes of the artificial intelligence work in ways natural to humans.

Apart from the tools contributing to the data collection and analysis, a few other technologies are frequently associated with Industry 4.0. For instance, additive manufacturing – or, as commonly referred to, 3D printing – is transforming the manufacturing process by rapid prototyping and customization that can be applied from nano- to large-scale projects (Alácer & Cruz-Machado, 2019). As the authors refer to Kim et al (2018), additive manufacturing will ultimately replace the currently used technologies, given its scope and flexibility of operations.
As the final standalone technology analyzed in this chapter, augmented reality was popularized in the entertainment industry and social media (e.g. Pokemon-go, Snapchat, Instagram, Facebook) by integrating the elements of the virtual world into reality with the use

of common devices, such as smartphones that have camera access. Currently, the AR is expected to revolutionize the process and act as the augmented operator (Weyer et al, 2015) in smart manufacturing by providing workers with virtual instructions on tablets, projectors or smart glasses. Both by visualizing the steps for the real-time operations and by providing AR-based training programs, companies are able to overcome one of the main widely-discussed obstacles on the way to cyber manufacturing – labor requalification (Weyer et al. 2015; Werrlich, 2016). Thus, augmented reality is treated as a crucial component of Industry 4.0 transitions and will be further analyzed as one in the empirical analysis.

Now that the separate technologies were briefly described, it is important to understand them on the broader level. Despite the complexity and seemingly impeccable process improvements, they must be embedded into one system to act autonomously. As explained by Alácer and Cruz-Machado (2019), Industry 4.0 is best described as a Cyber-Physical Production System (CPPS) that creates a virtual copy of the physical systems and serves as a control unit for 'networking' between all other smart technologies embedded in the process. Depending on the production scale, multiple Cyber Physical Systems are interacted to create CPPS – the bedrock of smart factories and design foundation for the real-time management in production scenarios (Rojas et al, 2017; Alácer & Cruz-Machado, 2019). In the advanced stages of its development, the technology is able to navigate all operations on the factory level: equipment settings, production peculiarities, and even logistics; its intelligence allows for autonomous decisions and problem-solving, while connectedness and responsiveness allows for quick adjustments to the changes and needs identified in the system (Monostori et al, 2016). To put it simply, the capacity and precision of CPPS is directly linked to the capacities of the technologies it captures in the process, bridging the flows of data between IoT, artificial intelligence and other previously described smart production tools, acting as the control node.

The integration of such technology does not make the process easier to imitate for the competitors: since each production possesses unique characteristics, the technological advancements of Industry 4.0 are applied to the needs of a particular company but do not standardize the production process of all companies undergoing the transition. If CPPS is thought of as the mind behind the factory, its components and decision-making patterns are solely dependent on the requirements of the particular production.

When applied in other contexts than factory production, researchers claim that CPPSs possess the transformative potential for infrastructure, residential areas, as well as entertainment and even medical industries (Monostori et al, 2016). If the explanation by Alácer and Cruz-Machado (2019) holds true, and CPPS is indeed at the core of Industry 4.0 transformations, it would mean that the production-related definitions of the current industrialization wave largely diminish its scope and potential. These issues are further discussed in chapter 2.2.1, where the conflicting opinions of authors are juxtaposed with the in-depth analysis of the development blocks. The insights are further used to enrich the theoretical framework in terms of similarities between the third and (possibly) fourth waves of industrial revolution, which could explain their geographical distribution and benefits associated with the existing infrastructure in different regions.

2.1.2 Business Rationale and Associated Gains

According to Brettel el al (2014), the three main concepts behind all production-related Industry 4.0 technologies are individualization of production, end-to-end digital integration and horizontal integration in collaborative networks, with the main goal to unite the virtual and physical world (Leyh, Martin & Schäffer, 2017). The relationship between these notions as well as the related outcomes and processes can be observed in Table 1.

Table 1. Industry 4.0 related research streams. Adopted from Brettel, M., Friederichsen, N., Keller, M. & Rosenberg, M. (2014). How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective

Individualization of Production	End-to-end Digital Integration	Horizontal Integration in Collaborative Networks
Cloud Computing	Virtualization of the Process Chain	Internet of Things and Services
Modularization	Individualized Traced Data	Collaborative Networks
Rapid Manufacturing	Real-time Operating Systems	Distributed Manufacturing
Mass Customization	Value Added Services	Supply Chain Visibility
Flexible and Reconfigurable Manufacturing Systems	Simulation and Modeling of Products and Processes	Supply Chain Flexibility
Distributed Control	Simultaneous Planning of Products and Production Processes	
Self-optimization		

The authors found that the research articles on Industry 4.0 are predominantly focused on its ability to individualize the production across the analyzed science journals, with horizontal integration in collaborative networks only slightly less regarded in the academic circles. Indeed, some of the articles analyzed for this thesis stress mass customization as one of the main ideas behind the transition (e.g. Alácer & Cruz-Machado, 2019); for instance, the efficiency and flexibility provided by the established smart systems creates an opportunity for a fast response and modularization, with little intervention required from the human operator to produce even the smallest customized batches in the large-scale production (Monostori et al, 2016). Moreover, by improving resource efficiency, Industry 4.0 integration boosts the company’s chances to achieve the objectives within Kanban (Abbadi et al, 2018) and lean management in general (Sony, 2018), supporting sustainable strategies at the same time (Stock & Seliger, 2016). Due to the levels of transparency achieved by operating in a CPPS, supply chain visibility is further enhanced, yielding not only increased levels of trust, but also accountability and traceability of the products.

Since Industry 4.0 is characterized by a mix of process innovations, the pioneers are expected to have excelled in the stage of product innovation when revolutionizing their production systems: while in the initial stages of market growth, the product innovation serves as the key focus, process innovation becomes increasingly important when the industry expands, the number of firms entering the market decreases, and the output growth slows down (Klepper, 1997). Despite the expected increase in productivity and profitability over time (as further analyzed in section 2.3), Industry 4.0 requires large financial investments and long learning period before the technology can be absorbed and exploited to its full potential (Lundquist, Olander & Martynovich, 2017). The financial and time resources would then be used to develop or purchase the new technology, the related system updates and software, as well as invested into training and labor re-qualification processes, to name a few. Thus, the companies expected to undergo the transition are not only in the mature stage of their development with enough financial resources, but also resilient to change. Based on the same assumption, a strong share of the inventors is likely to represent several large Swedish companies and concentrate in the areas of their R&D departments, where a high number of Industry 4.0-related patents would then be expected.

2.2 Third Industrial Revolution

In order to briefly analyze the existing debate within the academic community – whether or not Industry 4.0 is the new wave of industrial revolution – and to consequently use the insights to explain the geographic location of the Industry 4.0 inventors in Sweden, this chapter takes a deeper look at the development blocks of the industrial revolution. Essentially, the notion evolves around the central innovation (or group of interrelated innovations), around which supplementary activities tend to form throughout the defined timeframe (Enflo, Kander & Schön, 2006). As Kander et al (2013) refers to Bell (1980), the third industrial revolution is defined by the ICT development block, in which the theoretical knowledge is codified and applied for innovation in technology. Hence, it can be argued that Industry 4.0 is merely a more advanced stage of the third industrial revolution (Rifkin, 2014).

On the other hand, the velocity, scope and impact, along with the pace of current breakthroughs within Industry 4.0 are very distinctive, making many treat it as a distinct phenomenon (Schwab, K., 2016). According to Monostori et al (2016), cyber-physical production systems indeed rely on the developments of the third industrial revolution, however, they also represent unforeseeable improvements and growing amount of innovations in bridging the virtual and physical world. Brettel et al (2013) add that, in fact, the current development block is largely characterized by the Internet, not ICT. The statement can be supported by analyzing the previously described smart technologies shaping the transition: cloud computing, big data analytics, and IoT are impossible without the internet access. Considering that CC and BD are essential throughout different stages of the production, many capabilities of other smart factory components would be diminished without their ability to connect. At the same time, as Taalbi (2017) refers to Schön (2006; 2010), factory automation falls directly into the main description of the third development block (1970s - ongoing), with internet as one of the defining general purpose technologies of the transition. Some other historical evidence, however, suggests that the mechanisms and changes associated with Industry 4.0 make it clearly distinct from the previous developments. For instance, Popkova, Ragulina & Bogoviz (2019) carried out an extensive research, concluding that the saturation of industrial innovations and systemic transformations resulted in the change of technological mode, affecting both the production and logistics stages of manufacturing – a common feature for all previously observed waves of industrial revolution.

With the amount of opposing perspectives and the continuous growth of Industry 4.0, it is difficult to reach a definitive conclusion oh how transformative the effect can be, and whether the upcoming advancements are going to add more clarity onto the ongoing dispute. As further analyzed in the chapter 2.4, following the third wave of industrialization, the main knowledge hubs in Sweden are located in and around large metropolitan areas, as could be expected based on the historical evidence of regional development in other countries. Therefore, Industry 4.0 inventions are most likely to occur around the regions that pioneered the third industrial revolution, but might have a slight geographical re-distribution, depending on the R&D locations of the biggest local innovators, regional development programs, as well as Industry 4.0 – specific research institutions.

2.3 Technology Shifts

According to Bresnahan and Trajtenberg (1994), the technological change is defined by the developments in General Purpose Technologies (GPTs) that enable and provide opportunities, rather than finished solutions. As specified by Taalbi (2017) and was briefly mentioned in the previous section, the third industrial revolution is characterized by the following GPTs: computer, Internet, lean production, and biotechnology. It is claimed that even some of the most prominent GPTs nowadays (e.g. ICT) were initially deemed unproductive and unstable due to the long diffusion process (David, 1990). It is a process of continuous incremental adaptation of the technology in both economic and social contexts (Cantwell & Santangelo, 2003). In the long run however, the diffusion and assimilation of any technological revolution is followed by surges in productivity and overall economic development (Perez, 2009).

Geographically-speaking, the diffusion of GPTs during a new technology shift first settles in the metropolitan areas, slowly spreading to other regions as they mature (Svensson Henning, 2009; Lundquist & Olander, 2007). It is explained that the early adopters of new technological opportunities benefit from locating in the most developed markets that provide economies of scale when the transaction costs are still high (Lundquist, Olander & Martynovich, 2017). Consequently, the Industry 4.0 patents are expected to arise mainly in the metropolitan areas at this point of time, with some of the innovation output becoming more prominent in other nearby regions, considering that the concept is not entirely new. At the same time, the adoption of ICTs exhibited slower convergence patterns than the previous GPTs, since the respective companies are in need of highly skilled workforce found in the metropolitan area (Kolko, 2002). Considering that Industry 4.0 is built on the advancements and knowledge infrastructure of ICT and Internet, the smart technologies might follow a similar geographic distribution trend, reluctant to relocate even in the more mature stages of its development. Apart from the mentioned factors, the great technological proximity to the ICT sectors highly concentrated in the metropolitan areas would provide a basis for smoother diffusion process (Andergassen, Nardini & Riccottili, 2017).

2.4 Innovation landscape in Sweden

As of 2019, Sweden was ranked second on the aggregate Global Innovation Index, consistent with many years of excellence and high innovation output (WIPO, 2019). Ever since the third industrial revolution begun, the country has been positioned as one of the leaders (Schön, 2009). In addition to the world-renowned national innovation system and high education expenditures (almost double the world average) (World Bank, 2016), Sweden is ranked 7th in the world with regards to its R&D spending relative to GDP, 67% of which stems from the business sector (UNESCO Institute for Statistics, 2020). Considering that R&D investments are crucial in the production function of ideas, and the number of patents is one of the simplest ways to measure their output (Jones, 2002), it comes with no surprise that Sweden was one of the top-ten countries in the number of patent applications per unit of GDP in 2018 (WIPO, 2018).

Indeed, as a form of investment, R&D expenditures greatly affect the scale of inventions (or improvements and new ways of utilizing the past inventions, which can be compared to the process of lateral thinking) for both the private enterprises and research institutes. Importantly, the two are intertwined: the quality of academic R&D initiatives affects the number of patents granted to the nearby companies, largely due to the knowledge spillovers (Jaffe, 1989; Agrawal & Cockburn, 2003). Sequentially, the knowledge reaches other firms through various mechanisms, including but not limited to patent information disclosure, spillovers through licensing, reverse engineering, and joint research initiatives aimed at merging the capacities and knowledge of a set of different companies to complement each other's product development stage (Jaffe, 1998; Granstrand, 2005). The proximity becomes even more important for the exchange of tacit knowledge, which mostly requires a face-to-face interaction and a particular level of trust, amplifying the concept of cultural closeness (Chaminade, Lundvall & Haneef, 2018). Thus, geographically-speaking, innovations tend to cluster together, and depending on the regional specialization, a particular type of cluster can be expected. Apart from the benefits of agglomeration, where a lot of human capital and knowledge is available, other regions might attract lesser-scale niche innovations, affected by the local industries and possibly separate strong programs at otherwise less renown universities, whose graduates decide to stay in the region. That is why it is crucial to analyze the regional innovation systems and their capacity to fuel the growth of innovation output (patents) in different parts of Sweden. By doing so, this thesis attempts to identify the existing knowledge hubs that could potentially attract Industry 4.0 inventors, based on the existing evidence.

When the concept of regional innovation systems (RIS) first emerged, a group of economic geographers intended to link innovation processes to the geographical space (Chaminade, Lundvall & Haneef, 2018). The RIS not only assesses the interactions between different actors on the regional level (firms, R&D facilities, institutions, research centers etc.), but also helps understand the distribution of knowledge in various locations across the country, if different regions are analyzed and compared. For instance, Sweden is divided into 21 separate counties (*län*) and 290 municipalities (*kommuner*), each of them with a name and a code assigned. Each county elects the administrative board and the governor, whose goals are to introduce and sustain programs for the local development. There are three largest agglomerations in Sweden: Stockholm, Gothenburg and Malmö located in Stockholm, Västra Götaland, and Skåne counties respectively. Multiple sources show that the three cities are responsible for a large share of the country's innovation output (Ejermo, 2009; Ejermo, 2004), compatible with the well-established phenomenon of innovation clusters in large metropolitan areas (Capello, 2001; Bettencourt et al, 2007). In other words, the three biggest cities are at the core of the knowledge infrastructure.

Based on Curaj et al (2015), there is a certain link between the location of the university and its share of research expenditure, which, as has been established, plays an important role in stimulating innovative activities in the nearby firms. For instance, most of the significantly research-intense universities originate in the two most innovative counties, with the exception of LTU (Luleå University of Technology) and UmU (Umeå University) located in the Northern Sweden: GU (Gothenburg University) and CTH (Charlmers University of Technology) from Västra Götaland, UU (Uppsala University), SLU (Swedish University of Agricultural Sciences), SU (Stockholm University), KTH (Royal Institute of Technology), and KI (Karolinska Institute) from Stockholm county. In Skåne, only Lund University is considered to be research-intense, but the abundance of independent research institutes and innovation facilities as well as R&D departments of multiple firms facilitate the growth of local innovation.
To understand how exactly the innovation activity is distributed across other parts of the country, this chapter looks deeper into the RISs of different parts of Sweden.

2.4.1 Southern Sweden

Importantly, the region is specialized in the knowledge-intensive services, with manufacturing facilities mainly located elsewhere (OECD, 2012). As previously mentioned, the innovation activities in the Southern Sweden are predominantly centered in Skåne County which significantly stands out from most of the other administrative regions in the area by high amount of intramural R&D expenditures and the number of employees engaged in R&D activities (SCB, 2018). Out of the total of 39 Swedish universities, the Southern Sweden accommodates 6 institutions: Malmö University (Skåne county), Lund University (Skåne county), Kristianstad University (Skåne county), Blekinge University of Technology (Blekinge county), Halmstad University (Halland county) and Linnaeus University (Kronoberg, Kalmar and Småland counties). In total, the listed universities have approximately 100,000 students and thousands of academic staff (Swedish Higher Education Authority, 2018), many of whom are involved in the generation of science-based knowledge that spreads to the local industries and beyond, sustaining favorable conditions for high innovation output.

Apart from the higher education institutions, the Southern region accommodates multiple research and innovation centers, as well as facilities of firms that tend to invest more in R&D, than their counterparts in most of the other Swedish regions (Ligenzowska, 2016). According to OECD (2012), the levels of R&D employment in the region are very high, strongly represented in both business sector and universities. Consequently, the two factors - strong R&D efforts combined with knowledge spillovers between the academic and private entities – shape the positive innovation environment and provide opportunities for creating knowledge hubs for the most advanced and yet unfamiliar fields, including Industry 4.0.

Despite the high number of patents, the region's innovation output is driven by a few large firms, who tend to commercialize the research and patent more than smaller actors, which may lead to a rather exaggerated representation of the innovation activity (especially the number of applications) in Southern Sweden (OECD, 2012; Ligenzowska, 2016). Such dependence on the employment opportunities and innovation activities provided by a few companies makes the region's innovation environment and knowledge generation function more vulnerable to the market shocks affecting even one of the few main innovators.

2.4.2 Northern Sweden

Scarcely populated and dominated by the traditional capital-intensive industries (Ligenzowska, 2016), Northern Sweden accommodates only two of the country's universities - Luleå University of Technology in Norrbotten County and Umeå University in Västerbotten County – on the East coast of the two northernmost Swedish regions. According to Curaj et al (2015), both of the institutions are characterized by high shares of R&D expenditures, while businesses in the area under-invest in the R&D compared to the national and European average (Ligenzowska, 2016). In contrast to the Southern Sweden, the employment levels in knowledge-intensive services is low and, while there are many potential users of the smart innovation, there are not enough producers. Even though the applied research in the local companies could yield some innovation output, the low level of private R&D expenditures is not likely to result in the vast number of patents. However, given the respectable status of the local universities, some innovation activity is expected in the nearby municipalities, stimulated by knowledge spillovers in the area.

Based on the local demographics, the Norrbotten County has one of the highest levels for average age of population in the whole country (SCB, 2017). As can be hypothesized, the lack of entrepreneurial activity, over-specialization in mature industries undergoing decline, and high levels of unemployment (Coenen, Moodysson & Martin, 2015) cause the graduates to seek better opportunities through internal migration, thus perpetuating the lock-in observed in the Northern regions. Given the lack of industrial diversification, the region is more susceptible to the market shocks, which results in high economic vulnerability (Neffke, Henning & Boschma, 2011). As a consequence of path-dependence in the declining forest industry (Coenen, Moodysson & Martin, 2015), the Northern Swedish counties exacerbate the employment opportunities and, consequently, further affect the number of young specialists who decide to leave the region. With such volatile conditions surrounding the local RIS, the local administration should not only facilitate research, but also diversify the regional industrial portfolio: attracting technologically related yet different industries would result in overall cohesion, make the region more resilient and stimulate knowledge spillovers (Neffke, Henning & Boschma, 2011). However, according to Coenen, Moodysson & Martin (2015), these measures cannot work, unless combined with institutional innovation, change of the obsolete routines and adaptation to the modern modes of production and development. While both of the factors are important, Koo (2005) suggests that knowledge-based industry clustering (when both of the other conditions hold true) is also crucial for stimulating and sustaining the corporate innovativeness and knowledge production in the region.

As of now, the Northern regions are not expected to produce high innovation output in the smart-tech development, due to the previously mentioned institutional challenges and path dependence. However, Vinnova in collaboration with Lindholmen Science Park commissioned the Luleå Science Park to establish a northern node for the AI research, as a part of the national initiative. According to AI Innovation of Sweden (2020), the program is expected to start this year and cover the Kiruna-Sundsvall area, which could yield the creation of a new Industry 4.0-related knowledge hub in the previously unexplored geographical location. Thus, the results of this study could be largely different in years to come, with more smart-tech patent applications originating in the Northern Sweden as a consequence of the research initiative.

2.4.3 Western Sweden

The Western Sweden accommodates two well-funded universities: Gothenburg University and Chalmers University of Technology. With the presence of a technical higher education institution and low level of unemployment (Göterborgs Stad, 2016), it is likely that the educated young people frequently stay in the region instead of migrating, likely resulting in significant innovation output for smart-tech. The region has also been a case study for the Triple Helix innovation, where the actors are expected to collaborate in facilitating the innovation activity (Fogelberg & Thorpenberg, 2012). According to the authors, two large science parks were established in the region to facilitate the collaboration between different parties involved in the local innovation process: Open Arena Lindholmen (founded by the local universities, the City of Gothenburg, Volvo AB and Ericsson) and Innovatum Technology. As further discussed in the thesis, Volvo and Ericsson are some of the most active companies in Industry 4.0 patenting activities, which in collaboration with other actors can result in large spillovers and high-quality research results in the area.

According to the European Commission (2020), the region was ranked as one of the most innovative places in Europe, side by side with the Swedish capital. Specialized in knowledge-intense services, along with automotive manufacturing and trade (Ligenzowska, 2016), the Western Sweden is highly interested in attracting Industry 4.0 to the region. Since both business and academic actors have a strong orientation towards the research in technology, the area has a strong potential to generate the knowledge and even pioneer the country's smart factory landscape.

2.4.4 Eastern Sweden

With the Swedish capital located on the Eastern coast of the country, most of the well-funded (Curaj et al, 2015) and world-renown universities are located in the Stockholm area or in close proximity: Stockholm University, KTH Royal Institute of Technology, Karolinska Institute, Swedish University of Agricultural Sciences and Uppsala University. Given the highest rates of educational attainment in the country (SCB, 2018), Stockholm is well-endowed with human capital and continuously exhibits high labor productivity and levels of employment (Paschou & Metaxas, 2013). According to Chatterji et al (2014), the education levels are closely linked to entrepreneurial activity, which could explain the strongest performance of startup environment in the country, with 16.1 new companies per 1000 inhabitants in 2016 (European Commission, 2020), and the growing number of tech startups in the area. The strong presence of technological startups is explained by Audretsch and Lehmann (2005), who claim that universities in knowledge-intense regions tend to accommodate clusters of entrepreneurs in the technology sectors. While entrepreneurship is an important variable in the knowledge production function (Quian & Acs, 2013), most of such companies do not commercialize their inventions and are, thus, unlikely to have a considerable effect on the innovation output if measured by patents. As Svensson (2007) refers to Kaplan and Strömberg (2001), this phenomenon is partly explained by the inadequate external financing for R&D departments of smaller firms "due to the information asymmetries and high transaction costs between inventors and external financers".

Strong human capital and large research investments combined with the multicultural environment and the abundance of local and international firms located in the area result in one of the highest rates of innovation output in the country (Andersson, Andersson & Mellander, 2011). Indeed, the ubiquitous presence of small- to large- scale enterprises which, as had been mentioned, are responsible for most of the country's R&D spending relative to GDP (UNESCO Institute of Statistics, 2020), and the strong cooperation with the local academic institutions continuously foster the growth of the knowledge infrastructure in the capital region. Its international orientation and presence of large MNEs (multinational enterprises) allows Stockholm to access global knowledge networks and, consequently, the know-how possessed by companies overseas. It is therefore hypothesized that the capital region has one of the largest concentration levels for Industry 4.0-related inventors in the country.

2.5 Previous Research

The following section describes the existing research on the geography of Industry 4.0 knowledge. Afterwards, the previous patterns of the patenting activity observed in the country and the possible agglomeration externalities are discussed, to provide a point of comparison for the upcoming empirical analysis.

2.5.1 Spatial distribution of Industry 4.0 knowledge

As of now, the number of articles analyzing the Industry 4.0-related patents and the geographical distribution of the associated knowledge is rather scarce. However, some closely linked concepts had been researched. For instance, Ciffolilli and Muscio (2018) mapped the regional distribution of Industry 4.0 investments from the FP7 funding program by the European Commission (2007-2013). The research indicates that most of the Swedish regions have received "low" to "medium-low" funding, with exception of Stockholm County, where it was high by international standards. The authors illustrate that Stockholm has advantages for Industry 4.0 knowledge creation. Given the results of the research, Stockholm is likely to exhibit more patents in the empirical analysis than previously expected. Conversely, the Western Sweden might have less impressive results than initially thought, due to some of the lowest funding levels in the country, although other sources of funding were not included in the research.

Apart from the funding distribution, the authors compiled a clustering coefficient to identify the level of Industry 4.0 concentration across the European regions. The results were ranging from 0.992 to 3.029, where the higher number indicated stronger clusters prompting easier knowledge diffusion and exchange within the network of actors. While the paper does not indicate the coefficient for each of the regions, it supports the assumption that Industry 4.0 knowledge concentrates in the well-connected knowledge-intense regions. The statement is complemented by Jankowska and Götz (2017), who add that Industry 4.0 is drawn to the smart tech knowledge concentrated in regions where private entities and scholars cooperate, creating potential for further research: if there are distinctive knowledge hubs in Sweden, can the first smart factories be expected there in years to come?

2.5.2 Patenting behavior and Concentration

In order to fully grasp the behavior of Industry 4.0-related patents in Sweden, it is crucial to understand the previously observed patterns of their regional distribution. As analyzed by Ejermo (2009), the geographic properties of the patenting activity in the country were highly skewed between 1982 and 1999. The author found that the three metropolitan regions – Stockholm, Gothenburg and Malmo – were granted the highest mean number of patents per year, compared to the rest of the country. However, while patterns of patent concentration have been discussed in multiple studies (e.g. Ó hUallacháin, 1999; Lim, 2003), the results observed in Sweden indicate that, on average, the capital region had almost 2.4 times more granted patents than the two 'runner-ups' (Ejermo, 2009). Consequently, even if the behavior managed to slightly change between 1982-1999 and the timeframe of this thesis, it is expected that Stockholm will exhibit considerably higher innovation output both in the analysis of the overall and the Industry 4.0-specific distribution of patents.

Additionally, according to the OECD (2008), Sweden was ranked first in patent intensity (number of applications per million inhabitants) in metropolitan areas, with two-thirds of all applications originating in one of the three regions. Considering that the smart technology development requires strong knowledge infrastructure and human capital, it is likely that the variance between patent counts in metropolitan regions and the rest of the country will be even more so contrasting. These hypotheses are further tested in the empirical section of the thesis.

2.5.3 Agglomeration externalities

In general, benefits of agglomeration have been studied in multiple fields, including innovation. There are three types of externalities classified in the literature: Marshall–Arrow–Romer's (MAR), Jacobs', and urbanization (Neffke et al, 2018). According to the authors, the MAR externalities are frequently contrasted to those presented in studies by Jacobs (1969). In the first statement, companies benefit more from a strong specialization in the region and exploit the advantages of labor market pooling, supplier proximity and intra-industry knowledge spillovers (Neffke et al, 2018). On the other hand, according to Jacobs' externalities, the local industrial diversification leads to highly valuable inter-industry knowledge spillovers (Neffke et al, 2018). Finally, the benefits of urbanization arise by the proximity to large markets, well-educated workforce and strong networks with other innovation actors (Neffke et al, 2018). Henning et al (2016) argue that, depending on the type of firm and its level of maturity, different externalities might be more attractive to the firm's development. hUallacháin (1999) adds that some of the most important externalities are related to the concentrations of technologically intense manufacturing, which is especially applicable in the case of this thesis. Combined with the benefits of economies of scale, "the most advanced regional receiver and development competence is found in the large regions" (Lundquist, Olander & Martynovich, 2017). If all of different statements are examined, it can be assumed that Industry 4.0 would largely benefit from the urban locations where both the benefits of established ICT sector and the diverse knowledge spilling over from other industries can be exploited.

3 Data

As Koo (2005) refers to Acs et al (2002) and Acs & Audertsch (1989, 1991), patent data has been validated as a way to measure technological change by multiple researchers throughout the years. As had been previously mentioned, this thesis relies on patent data from both the Swedish and international companies whose patent applications were published between 01/01/2010 and 31/12/2017. Even though the timeframe of the research would ideally include all data up to 2020 to capture the current developments in rapidly advancing Industry 4.0 technologies, the bureaucratic process can take several years for the patent to be granted since the application date. Consequently, the most recent data would be largely scarce due to the ongoing patenting process.

3.1 Sources

In the first step of the research, the patent data is collected from the European Patent Office (EPO) by performing a keyword search in the Espacenet database. Essentially, it is an intergovernmental organization – a regional patent office – that processes applications for 38 member countries (EPO, 2020). Apart from the EU states, it covers operations in North Macedonia, Iceland, Albania, Monaco, Norway, Liechtenstein, Serbia, Switzerland, Turkey, and San Marino. Importantly, the chosen database filters solely based on the publication date of the application, which does not necessarily mean that the patents were granted. However, this thesis looks at the approved applications by identifying them in the next step of the process, since the dataset used for mapping contains information on granted patents only, simply leaving the unapproved applications without matching data.

All of the obtained observations were matched to the locations recorded in the OECD REGPAT 2019 dataset, additionally capturing the unique inventor ID and roughly estimated weight of their contribution (1 divided by the total number of inventors per given patent). While the location data is available if the original document is examined on EPO, it does not indicate the inventor ID, making it difficult to draw the line between the number of patents and the actual number of their developers in the area, resulting in a potential bias for the results of the research. Such insights can be further used to analyze whether there is a main group of inventors leading the innovation process in Sweden, in the brief description of the main actors in chapter 5.1.3.

Lastly, the dataset is complemented by the population data collected from the Statistics Sweden 2019 that is used to determine whether there is a relationship between the city size and the number of Industry 4.0 patents produced in the municipality.

3.2 Collection

At first, the keyword search is performed in the Espacenet database. While Industry 4.0 has a largely scope-dependent definition, the following keywords for performing the search query were formed after extensive literature analysis, as specified in chapter 2.1: “Internet of Things” and IoT, “Additive Manufacturing” and “3D Printing”, as well as “Machine Learning”, “Cognitive Computing”, “Augmented Reality”, “Big Data”, “Artificial Intelligence” and “Cloud Computing”. Considering that most of the technology patents use internationally adopted English terms, the Swedish translation did not yield any results for most of the keywords. As can be further noticed from the list, synonymous terms were used to ensure thorough coverage of the chosen technologies and related processes, in which case the duplicates were dropped after a check. Importantly, the use of abbreviations in any case but IoT was inconclusive. For instance, the EPO database does not show any results for a widely adopted term AI for Artificial Intelligence, which can possibly suggest the restrictions of its use to avoid ambiguity. While there have been mentions of Internet of Services in the literature (Alácer & Cruz-Machado, 2019; Andulkar, Le & Berger, 2018), the query did not give any results, and its widely adopted abbreviation IoS was confused for iOS in the case-insensitive search engines of both databases.

After the duplicates were dropped, a total of 1848 patents were available for the next steps. Out of those, 28 were deemed to be wrongly-linked to the keyword search, which required a separate analysis of ‘suspicious’ titles in the dataset (i.e. biological compounds, consumer product designs): 7 in the search query for “Additive Manufacturing”, 7 – for ‘3D Printing’, 3 – for IoT, and 11 – for ‘Machine Learning’.

When the data is exported, it only indicates the main publication number: if many different numbers are assigned, the one with the most extensive coverage is included in the results (WO over EP, but EP over state-specific patent names etc.). As previously mentioned, the OECD REGPAT dataset contains information for the EP-titled inventions only, which requires additional search for alternative publication numbers on the Espacenet database. The observations that do not have such numbers are described in the analysis of the main actors but not mapped for the lack of location data. For instance, a simple graph will be constructed to see whether a few separate organizations drive the overall patent count for the inventions in question.

Together with the patents recorded multiple times, depending on the number of inventors, 3417 observations are used; out of those, 819 separate patents are missing the location data either because they have not been granted at the time the REGPAT dataset was updated, or because they were not published with the EP number, following the institutional changes that took place in 2016. Moreover, two municipalities were not recognized during the mapping process in Tableau: Habo (2 patents) and Håbo (1 patent). In general, the data collection process has been by far one of the most challenging and time-consuming parts of the thesis, due to the number of steps required to match the patents in the databases and the meticulous process of cleaning the dataset by the end of its construction.

3.3 Limitations

One of the first limitations stems from the institutional changes within the patenting bodies, which resulted in the restated procedure for assigning publication numbers. To start with, the first two letters of the publication number indicate the country or region of its validity, ranging from individual states to ‘EP’ (coverage in all member countries), to ‘WO’ (international). The latter one is frequently found across the database, as a result of the Patent Cooperation Treaty (PCT) between the World Intellectual Property Organization (WIPO) and the main patenting offices around the globe. Given that WIPO itself is not a body accredited to grant patents, the applicant is expected to apply through the respective national office or to the WIPO directly, in which case the organization itself notifies the patent office, to protect the invention internationally (WIPO, 2020). The data from WIPO is then loaded into the EPO databases, resulting in patent information on inventions that do not necessarily originate in one of the member states, but are legally protected in the area. However, since 2016, the WO-type patents documented in other than the official EPO languages (i.e. English, German and French) are not intellectually classified in the system (WIPO, 2018). It is an important factor, given that the patenting behavior, particularly in larger firms, has shifted towards obtaining an international patent, which used to be published predominantly as both EP and WO. As in the further stages the data is linked to the OECD REGPAT 2019 dataset by matching the EP publication number, the later WO patents not published in one of the official languages (i.e. no EP equivalent) cannot be matched to the location even if the rest of the criteria is met. Consequently, some of the observations and inventors are not captured during the mapping process. Considering that a lot of these patents were developed in the same companies, whose locations are frequently centered around their R&D departments, it can be assumed but not implied that the remaining patents of such companies would follow the same geographical trend.

There are several issues associated with patent data, which have to be considered while drawing conclusions of the research. Perhaps the most significant disadvantage is that some industries are known for widely using trade secrecy over formal intellectual property rights and patents in particular (Granstrand, 2005). For instance, the author claims that “patents are most likely to support the growth of knowledge-intensive industries in fields characterized by low ratios of imitation to innovation costs" (2005, 267), but be less effective for the others. Thus, while Industry 4.0 technologies can be adopted across various different industries, some of them might be under-represented due to the disadvantages associated with intellectual property rights. Levin et al (1987) add that the decision-making process is case-dependent, claiming that the extent to which the publicly disclosed patent information could prompt the development of related inventions in other companies affects the final decision between patenting and secrecy. Furthermore, patents for the main focus of this thesis – process innovations – are thought to be generally less effective (Levin et al, 1987), possibly affecting the final decision of firms. Seeing that, it can be assumed that the real number of Industry 4.0 inventors in Sweden is higher than represented in the official data. At the same time, the recorded data can also over-represent particular regions: a patent developed by multiple inventors will be mapped as many times, as many inventors are listed in the process. Moreover, the areas with departments of large R&D firms will be affected the most, since a group of inventors might be specialized in a particular type of technology or process innovation that is of interest for this thesis. Thus, a map adjusted for the number of inventors per area will be produced additionally to illustrate the difference.

4 Methods

In this section, the approach to data analysis is described, attempting to present a clear step-by-step plan for answering the stated research questions.

4.1 The Approach

After the dataset is constructed, the number of patents per municipality are calculated in the Excel sheet and imported separately into the Tableau visualization tool for mapping. Moreover, all of the Swedish patent data recorded in the REGPAT dataset is mapped for further comparison. To complement the visual representation, the share (%) of patents per metropolitan area is calculated for both the overall and the Industry 4.0-specific patenting behavior. Further graphs will be provided to see whether particular regions are prevalent throughout the whole period of observation or the smart-tech sector spreads beyond the limits of metropolitan areas. These steps help understand whether the geographical aspect follows the previously observed patterns or exhibits unique behavior, answering the first research question:

- *Does the Industry 4.0 knowledge, as measured by patents, follow the previously observed geographical patterns of patenting behavior in Sweden?*

The maps and shares of patents for the three metropolitan regions also provide some explanations to the second research question:

- *Are the current Swedish Industry 4.0 patents concentrated to metropolitan areas?*

Additionally, to provide deeper insights into the behavior of Industry 4.0-related patents, the population data from the Statistics Sweden 2019 is regressed against the number of patents per municipality. This step helps understand whether the activity is dependent on the size of the region, as observed in the previous research. Essentially, the following exponential model (as constructed in Bettencourt et al, 2007) is used to test the hypothesis:

$$Y(t) = Y_0 \, N(t)^{\beta},$$

where Y is the number of patents, Y_0 – normalization constant, and $N(t)$ – the size of population at the time t. The given model can be simpler represented as:

$$ln(Y+1) = \beta * ln(N+1) + ln(Y_0)$$

Importantly, the agglomeration externalities are present if the coefficient is higher or equal to 1. By analyzing the regression and significance of the results, the thesis can answer whether the knowledge infrastructure, superior human capital and economies of scale are the determinants for Industry 4.0 patent generation in the region.

To quantify the concentration ratio of Industry 4.0 in Sweden and supplement more insights for the main research question, the thesis looks into the Herfindahl–Hirschman Index (HHI). The following formula is used for calculations:

$$HHI=\sum_i s_i^2,$$

where s_i is the share of Industry 4.0 patents generated in the county *i*, expressed as a decimal. Essentially, squaring the values gives much more weight to the counties with larger market shares (Rhoades, S.A., 1993). The results can take any value in the range between 0 and 1, where 1 would indicate low competition between the regions. It is considered that $HHI \leq 0.15$ indicates unconcentrated markets, $0.15<HHI<0.25$ – moderately concentrated, and $HHI \geq 0.25$ – highly concentrated (US Department of Justice, 2010). If interpreted, the higher concentration of innovation output would mean that a few counties are responsible for most of the Industry 4.0 patents, indicating that the competition between the regions in this field is likely to be weak (Rhoades, S.A., 1993). The same measure will be used to compare the level of concentration between the overall and smart-tech-specific innovation activity.

Lastly, to account for the possible limitations, the thesis looks at the number of Industry 4.0 inventors per city, to understand whether there is a particular group of specialists responsible for a high patent count in a given municipality. The number of all patents assigned to an inventor is calculated in the Excel sheet and matched to the respective location. Afterwards, the number of entries per city is analyzed and mapped in Tableau for further visual comparison with the distribution of Industry 4.0 patents.

4.2 Limitations

First of all, while the thesis works with the quantity of patents, it does not address their quality in any of the empirical parts. According to Trappey et al (2012), “High quality patents contain wide claims, refer to few prior art designs, and are highly applicable”. Even though it seems non-essential for the scope of this research, using one of the most commonly adopted quality measures – citation count – could enrich the thesis on understanding the links for knowledge spillovers within Industry 4.0 patents. For instance, it could additionally capture whether their geographical proximity is linked to larger spillovers and innovation output in

the area. Moreover, such insights could also assess the quality of regional knowledge bases for their development in general.
The method is also limited in a way that the dynamics of patents growth and regional distribution is not analyzed. For instance, if the patents were mapped by different time segments, the pattern of knowledge distribution could be analyzed and contrasted to the diffusion of the ICT technologies in Sweden. Thus, both of the limitations give potential to provide an extended analysis in the works of other researchers.

5 Empirical Analysis

In this part of the thesis, the results are presented and extensively examined, with the further discussion relating them to the theoretical framework.

5.1 Results

The following sections present and analyze the data, as well as compare the current overall distribution of patents in Sweden with the distribution of Industry 4.0-specific patents. Both are also examined on the concentration of innovation output to metropolitan areas, with a separate section (5.1.3) dedicated to the analysis of the main limitation of the performed research.

5.1.1 Overall patenting activity in Sweden

To establish a point of comparison, the thesis first examines the geographical distribution of all patenting activity in Sweden. Generally, the innovation output is the highest in the following municipalities: Stockholm (21,314), Gothenburg (11,418), Lund (9,877), Linköping (4,853), Västerås (4,849), Malmö (4,873) and Uppsala (6,191). In the descriptive statistics found below, it can be noticed that all of the indicated regions represent patent counts way above the average, with Lund, Gothenburg, Uppsala and Stockholm going over three standard deviations from the mean. As can be further examined from Appendix A, the phenomenon described by Ejermo (2009) – highly skewed patenting activity throughout the country – holds true in the timeframe of used database. In fact, 250 out of 290 recorded locations exhibit low - to slightly above the mean levels of innovation output, with 236 of them falling below the mean value.

Variable	Obs.	Mean	Std.Dev.	Min	Max
All: Patent Count	290	504.934	1680.568	1	21,314

For instance, the three metropolitan areas account for 62.6% of all observations on Swedish patents, based on the REGPAT dataset: 33.3% from Stockholm area, 14% - in Malmö, and 15.3% - in Gothenburg. In contrast to the results obtained by the OECD (as described in the section 2.4.2), the concentration of patents in the metropolitan regions has fallen by 12.4%.

To further describe the concentration of overall patenting activity and provide a point of comparison for Industry 4.0 innovation output, the Herfindahl–Hirschman Index (HHI) was calculated. The result of 0.18 (0.15<HHI<0.25) indicates that the patenting behavior is moderately concentrated, meaning that many counties are actively involved in the innovation process. In other words, there is a healthy competition across the Swedish regions in terms of innovation output, with no areas exhibiting significantly higher shares and driving the overall number of patents. The results have been further visualized in the Figure 1 (represented on the next page due to the large size).

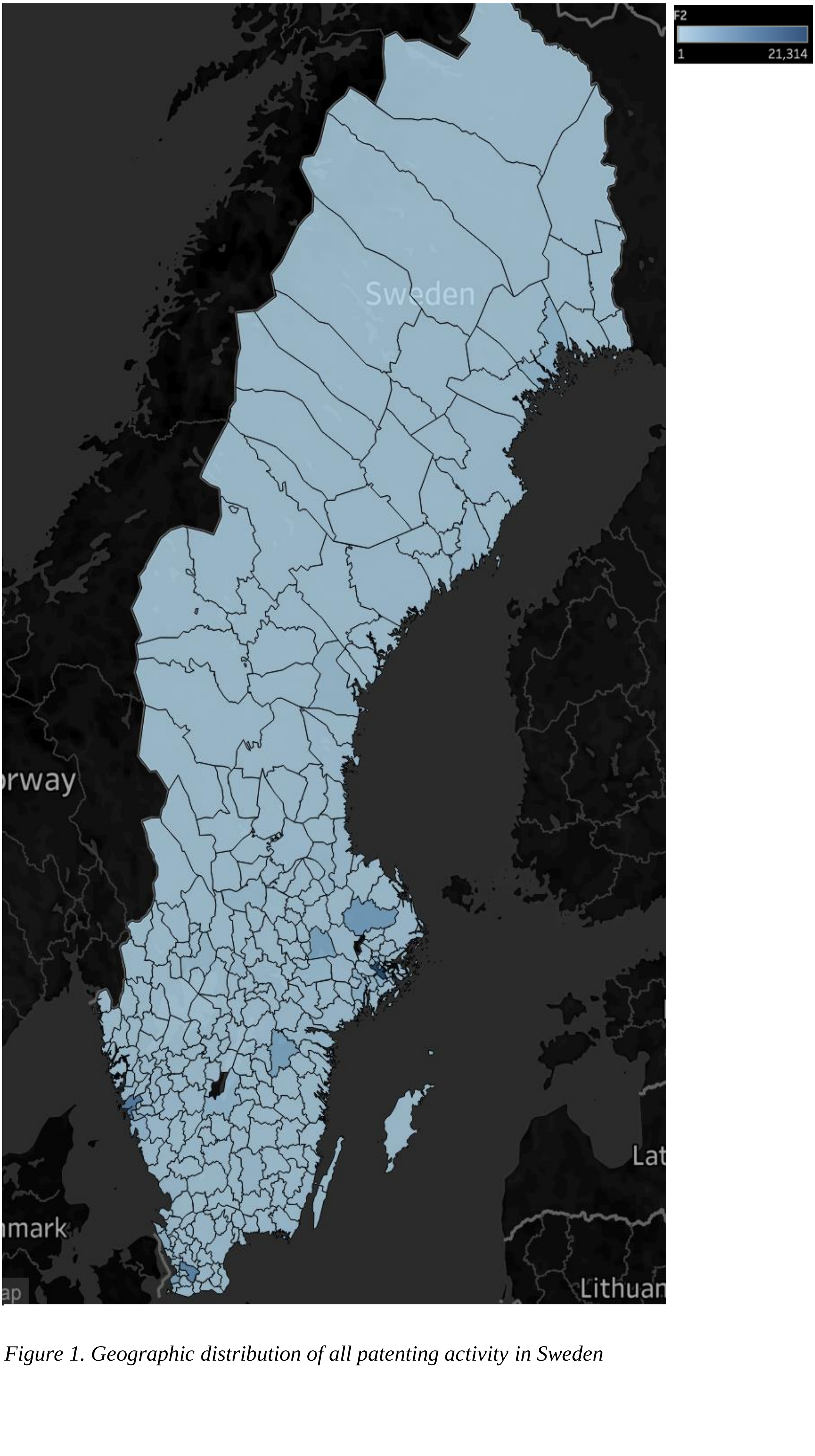

Figure 1. Geographic distribution of all patenting activity in Sweden

5.1.2 Industry 4.0-specific patents

Apart from a few cities with a relatively intense patenting activity, the results are homogenous in less research-oriented regions. As described below, with the total of 113 different locations where Industry 4.0 patenting activity had been recorded, the innovation output reaches almost 23 patents on average. Similarly to the overall patenting activity in Sweden, the standard deviation is high. For instance, the frequency distribution histogram illustrated in Appendix A, represents a nearly identical pattern to the results obtained from the general distribution of patents in Sweden.

Variable	Obs	Mean	Std.Dev.	Min	Max
4.0: Patent Count	113	22.938	65.258	1	556

Particularly, Stockholm is characterized by the highest patent count (556), followed by Lund (304) and Malmö (162) from Skåne County, Gothenburg (159) from Västra Götaland, and Linköping (154) from Östergötland County. Based on the previous research and analysis in section 5.1.1, it is hypothesized that the Industry 4.0 patents are concentrated to metropolitan regions. To test whether the agglomeration externalities indeed result in smart-tech patent concentration, the following simple model is regressed:

$$ln(Y+1) = \beta * ln(N+1) + ln\ (Y_0)$$

where population *N* is used to denote the municipality size. Based on the regression observed below, it can be claimed that the size of population does not have a strong effect on the outcome of the Industry 4.0 patent counts in the given municipality. The results are significant under 0.01 confidence level, with the coefficient of 0.931. Considering that the 95% confidence interval is between 0.827 and 1.035, the agglomeration externalities cannot be excluded as a potential factor behind higher Industry 4.0 innovation activity.

As can be found in the Appendix B, the residuals are normally distributed. Overall, the model fit is relatively strong, estimated at almost 52%, which could be improved by adding other possible determinants.

ln_PatentCount	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ln_Population	0.931	0.053	17.61	0.000	0.827	1.035	***
Constant	-8.410	0.524	-16.05	0.000	-9.442	-7.379	***

Mean dependent var	0.777	SD dependent var	1.270
R-squared	0.519	Number of obs	290.000
F-test	310.274	Prob > F	0.000
Akaike crit. (AIC)	752.741	Bayesian crit. (BIC)	760.081

*** *p<0.01*, ** *p<0.05*, * *p<0.1*

The relationship can be closer examined in Figure 2, represented below. While not perfectly linear, the values for the logged number of patents and population represent a positive relationship. While agglomeration externalities might not be the main reason behind Industry 4.0 development in the region, it could be one of the lesser determinants.

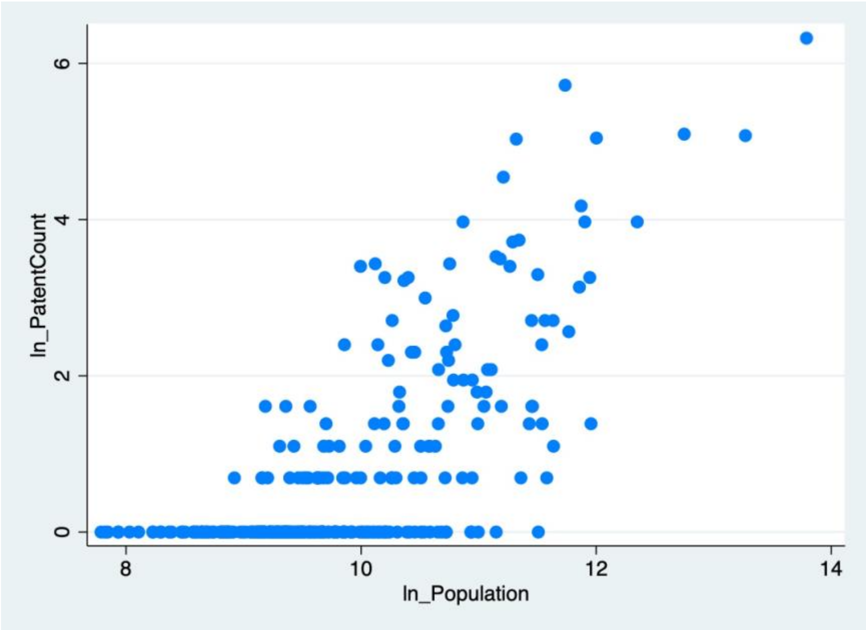

Figure 2. Relationship between logged Population data and the Industry 4.0 Patent Count

Nevertheless, it is evident that the smart technology is mainly patented in the biggest metropolitan areas. If the analysis is to be extended further, the concentration of Industry 4.0 patents in the metropolitan areas can be contrasted to the rest of the country. For instance, Stockholm metropolitan area is responsible for 43% (1112) of all entries, Malmö – 21.2% (550), and Gothenburg – only 10.8% (280). Altogether, the three metropolitan areas account for 75% of all Industry 4.0-related patents in the country, precisely following the overall concentration of patents in Sweden based on the OECD 2008 report but higher concentration than the more recent calculations presented in section 5.1.1 (62.5%). Consequently, the Industry 4.0 actors and patentees do exploit the benefits of agglomeration in the three most significant regions but have more location determinants otherwise: municipality size does not entirely predefine the pace of smart tech development in the region.

As means of further analyzing concentration, Herfindahl–Hirschman Index was calculated for all Swedish counties based on the output of Industry 4.0 innovations. The result of 0.271, as previously described in the section 4.1, indicates that the patents are highly concentrated to some regions. Considering that the index squares the shares of output for every region, those with a higher initial Industry 4.0 patent count have a heavier weigh in the index. As metropolitan areas were found to produce larger outputs, it can be claimed that the output is highly concentrated to counties around them, with the exception of Östergötland County that produced nearly the same output as Västra Götaland County (i.e. primarily, Gothenburg metropolitan area). It can be explained by the fact that Linköping (Östergötland County) experienced a lot of exits in the traditional textile and wood industries during the 1970s, followed by the entries of more technologically advanced computer and communication industries that have been growing in the region since then (Neffke, Henning & Boschma, 2011).

When compared to the results obtained in section 5.1.1, the HHI is significantly higher for Industry 4.0 patents than the overall patenting behavior (0.18), where the activity is moderately concentrated. The phenomenon can be further observed in Figure 4, where shares of smart-tech innovation output of a given municipality are compared to its total share of patents. Interestingly, there are 38 municipalities (mainly from the metropolitan areas) in which the share of Industry 4.0 patents outweighs the total share of patents, conversely to 177 municipalities (61%) that have not produced any smart tech output during the chosen timeframe at all. The higher concentration of Industry 4.0 patents to the metropolitan areas is compatible with the evidence presented in the Technology Shifts chapter, in which the geographical distribution of GPTs was skewed towards larger or more knowledge-intense areas, at least throughout the initial stages of their development.

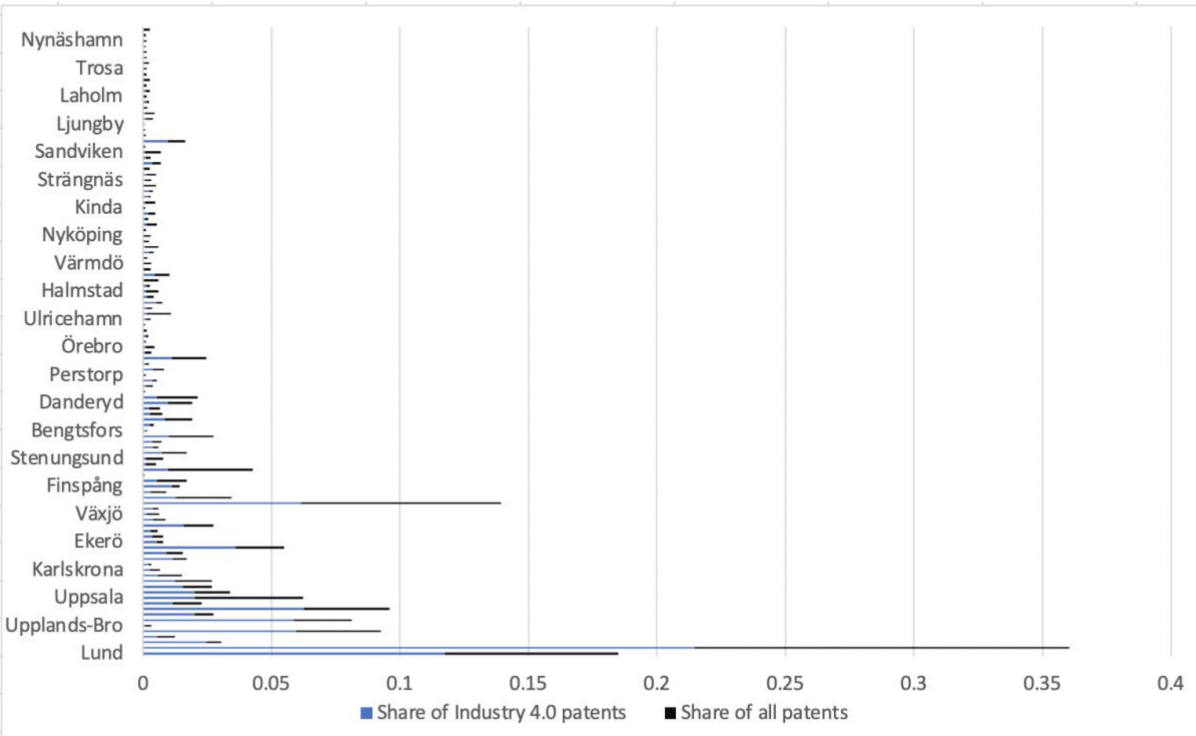

Figure 3. Comparison for shares of Industry 4.0 patents and shares of all patents per municipality

As has been previously mentioned, it is common for a technology (or set of connected technologies) to originate in the metropolitan areas before slowly spreading to other regions in the given country (Svensson Henning, S., 2009; Lundquist, K-J., Olander, L-O., 2007). In order to examine whether the high shares of patents in the three regions were driven by the first years of observation, Figure 4 was compiled. Although a slight increase in the share of outside regions took place during 2010-2011, they were never predominant in Industry 4.0 patent generation if compared to the three metropolitan areas altogether. Despite fluctuating between 2011 and 2014, the shares of metropolitan regions were following the initially discussed behavior (with the exception of Malmö metropolitan area, which almost caught up to the pace of Stockholm in 2012). From 2014 onwards the shares were relatively stable. While there is a gap between the percentage of metropolitan regions in the beginning (81%) and end (73%) of the selected timeframe, so far there was no clear trend indicating that Industry 4.0 has been actively spreading to other regions due to the volatility in the middle years of observation.

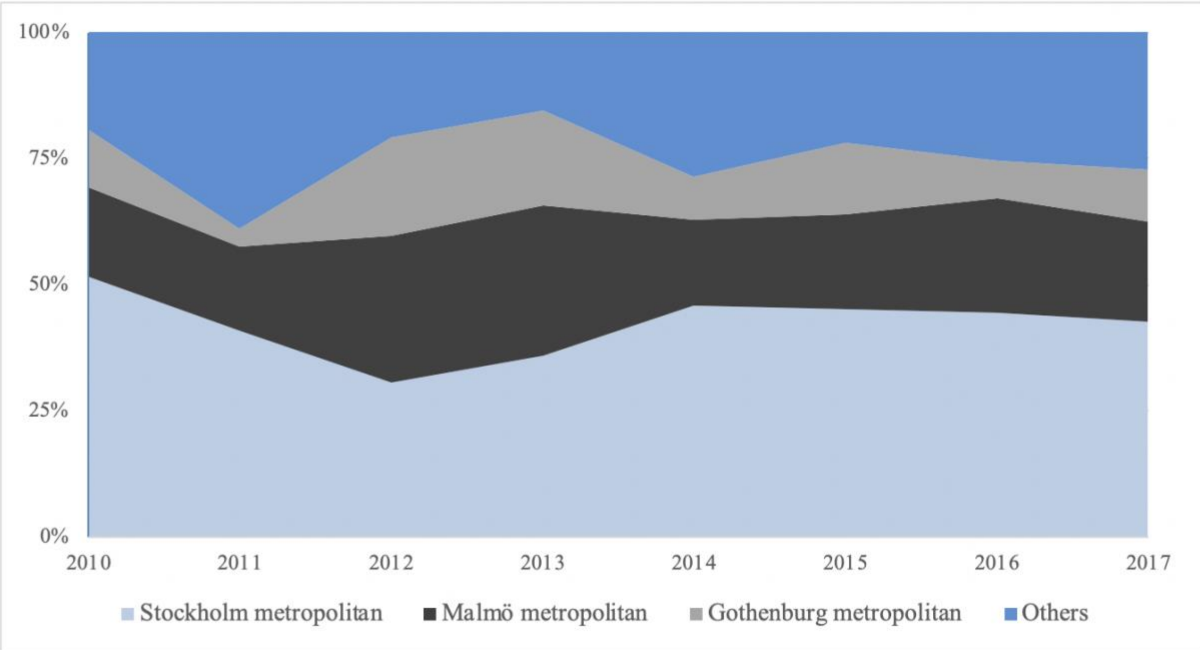

Figure 4. Share of patents by year and location

As can be observed from Figure 5 (represented on page 32 due to the large size), most of the other recorded activity originates in the Southern part of the country with significantly larger coverage than further in the North. Interestingly, the patenting activity within Industry 4.0 is not only strongly concentrated to metropolitan regions, as proven above, but is also largely undistributed across the country, covering only 113 out of 290 municipalities. Such results can indicate that the smart-tech development is highly dependent on the knowledge infrastructure and overall connectedness of the nearby regions. Moreover, as can be further analyzed in the Appendices C-G, the farther away a municipality is from the local 'knowledge hub', the more their patent counts seem to decrease. While not tested in the thesis, this observation can serve as a basis for further research.

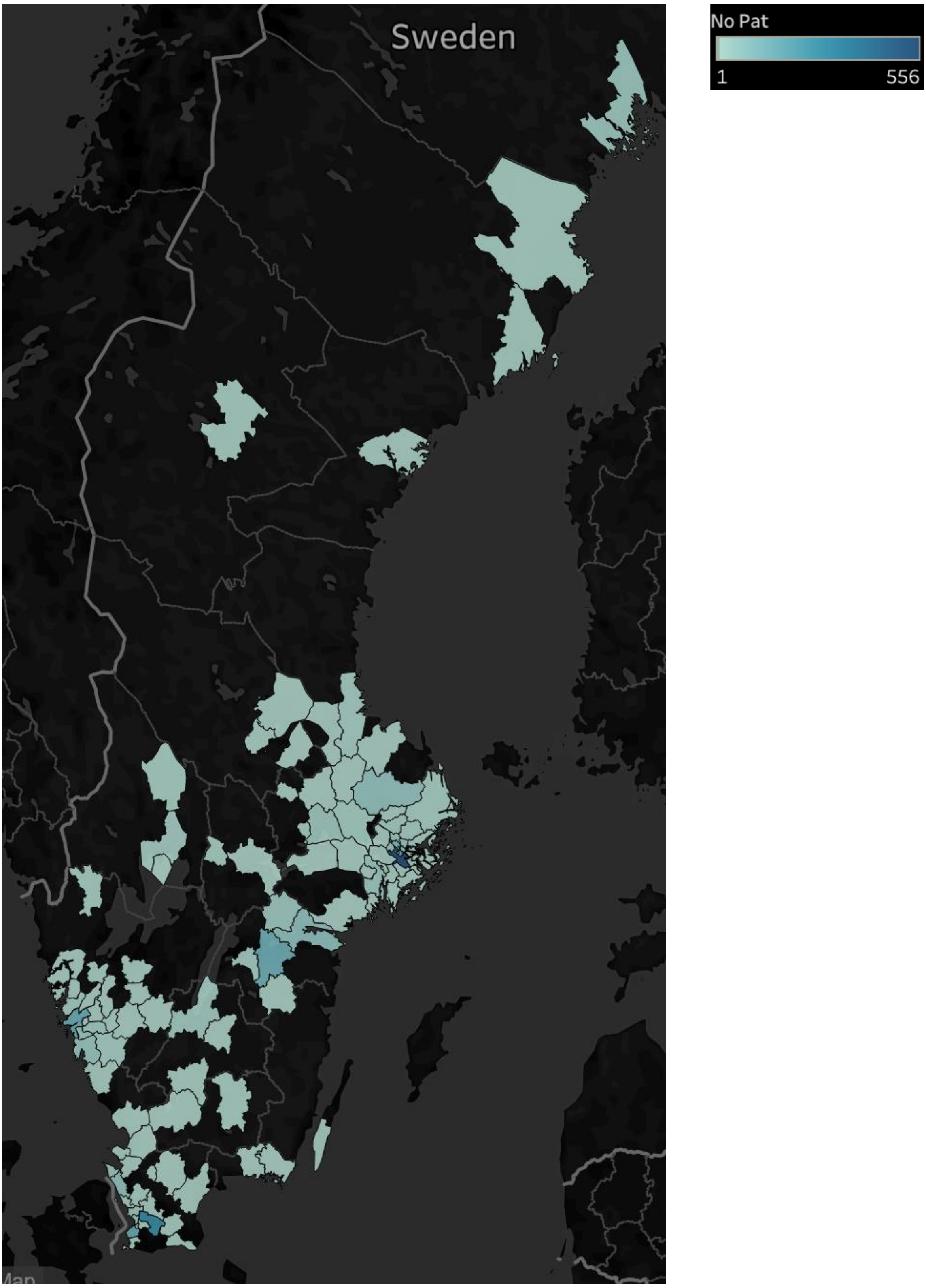

Figure 5. The number of Industry 4.0-related patents per Swedish municipality

5.1.3 Industry 4.0 Inventors

Despite the expected distribution of patent activity, a few companies might be driving most of the output. Therefore, this sub-chapter strives to examine whether it is the case in the observed dataset to understand if it should be treated as a limitation.
As illustrated in Figure 5, Ericsson alone is responsible for almost half of all observations, with a lot of research activity in Lund and Stockholm areas. The observation supports (although further research is required) some assumptions made earlier in the thesis: (1) large companies in the mature stage of development are expected to pioneer the Industry 4.0 innovation process (2) a few large companies are likely to be responsible for a high number of the recorded observations.

While it is widely known that R&D facilities are located in the vicinity of knowledge-intense regions if possible and that innovation tends to attract more innovations in a sort of vicious circle, the results can be biased if no further analysis is performed. Moreover, if there is a particular group of inventors specialized in a given technology, they will be mapped multiple times. Since bigger companies tend to not only patent more actively (Mariani, M., Romanelli, M., 2007), but also involve more inventors per patent, it is crucial to map the number of inventors per municipality to understand whether the current results were driven by strong RIS and knowledge generation activity in the whole area or simply by accommodating some of the largest R&D facilities in the country.

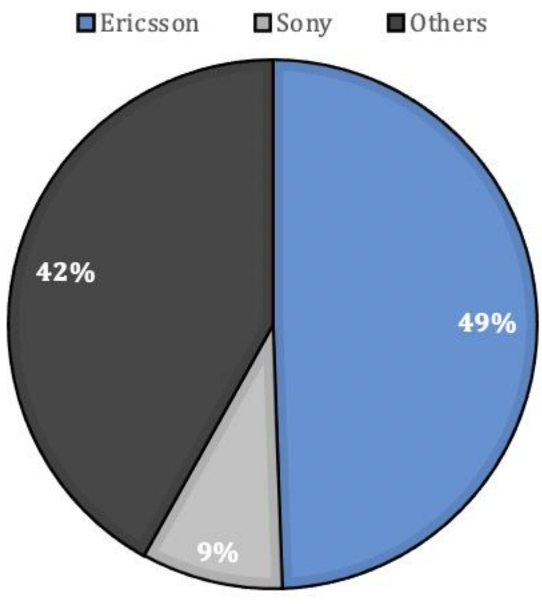

Figure 6. Percentage of patents by company out of the total number of observations

To briefly examine the data, a descriptive statistic is presented below. With the mean of rounded 15 inventors and the previously discussed 23 patents per municipality, it can be claimed that each of the recorded inventors is assigned to 1.53 patents on average. Given a high standard deviation, the actual number of patents per inventor is largely different depending on the locality, meaning that highly innovative regions could indeed be over-represented in the previous sections due to multiple entries of the same patent.

Variable	Obs	Mean	Std.Dev.	Min	Max
4.0: Inventors	113	15.097	42.155	1	361

While a big share of the inventors can still be employed by bigger companies in the represented sample, the results illustrated in Figure 5 indicate that there are no abnormalities in the patenting activity, since the regions that exhibited the highest numbers of patents also represent the highest numbers of inventors. To provide some further explanation (Appendix H), when the number of inventors is divided by the number of patents, anything close to 0 would mean that a few inventors are driving the innovation output in question. In this case, the only municipality with a noticeably low index is Mark, with 2 inventors responsible for 9 patents (represented by Ericsson). However, as mapped in Figure 6 (presented on the next page, due to the large size of the map), it has no impact on the outcome for identifying the Industry 4.0 knowledge hubs and concentration of patenting activity in Sweden and is thus not considered to be a significant limitation. It can be further observed in Appendices I-M where the regions are zoomed in.

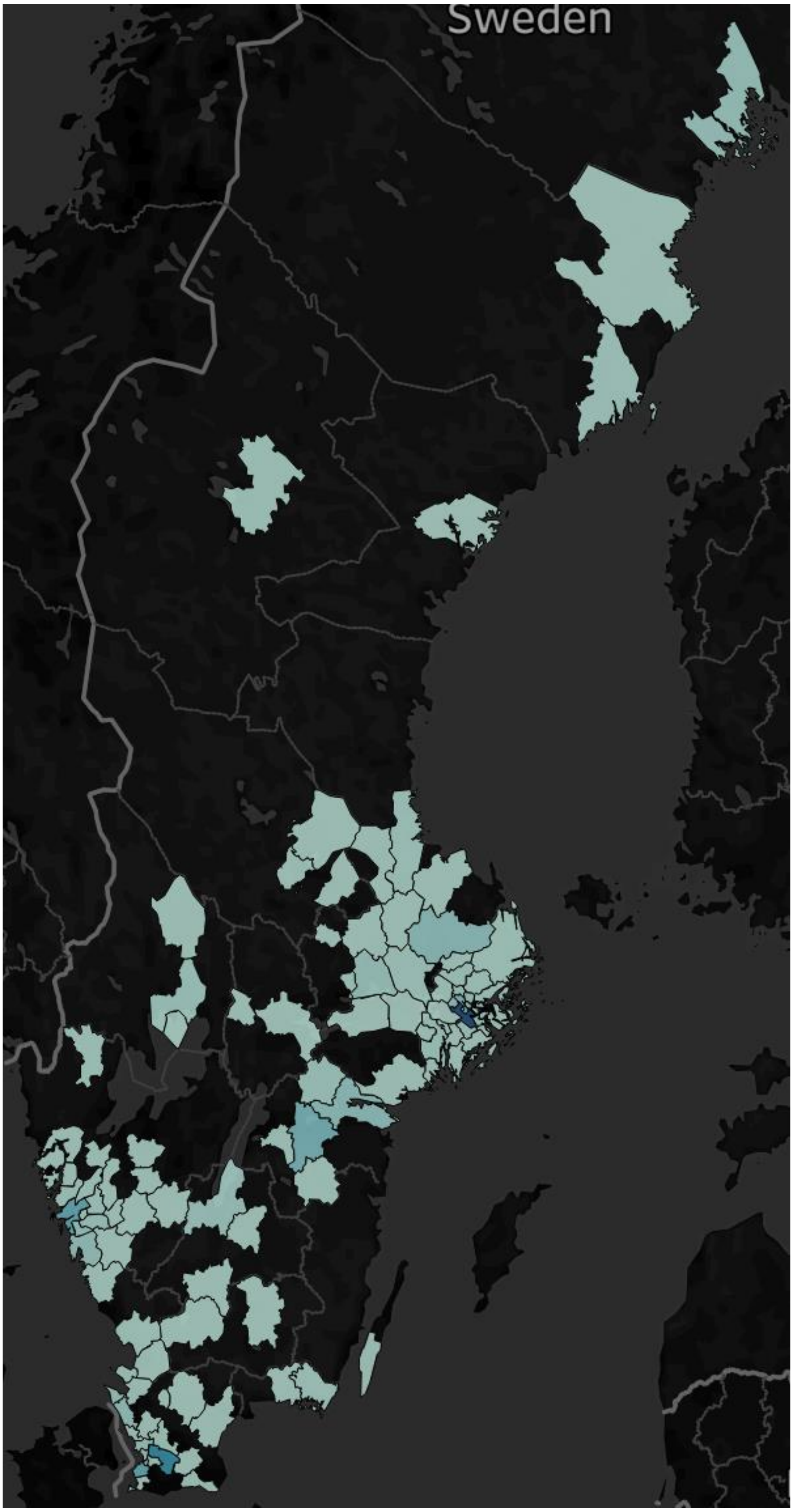

Figure 7. Number of Industry 4.0 inventors per municipality.

5.2 Discussion

As observed in the maps, and can be examined regionally in the Appendices, the geographic distribution of Industry 4.0-reated patents and inventors follows the expected pattern. For instance, although further research is required to examine the causality, the presence of well-funded universities in the area is connected to a larger patent count. It supports one of the statements mentioned earlier, where higher education institutions with strong academic R&D performance are said to create large knowledge spillovers to the private sector (Jaffe, 1989; Agrawal, & Cockburn, 2003). On the other hand, companies tend to exploit this privilege by locating their R&D facilities to the nearby areas for both the educated workforce and spillovers, perpetuating the entrance of new firms and the consequent flow of knowledge in the region. Thus, while universities are important for the knowledge production function and establishment of strong human force, they cannot be the sole explanation of innovative activity. Moreover, as indicated by the results, Industry 4.0 patents are concentrated to metropolitan areas, and the presence of strong networks and actors, including universities and research institutions, is a part of the agglomeration externalities. While the agglomeration externalities themselves, if measured solely by the population size, were shown to be an important factor for generation of smart tech patents, the results indicate that other determinants need to be studied.

Importantly, the three biggest metropolitan areas – Stockholm, Gothenburg and Malmö – exhibit strong Industry 4.0 innovation output. All of the mentioned pioneering cities are specialized in knowledge-intense services, also exhibiting the highest levels of concentration for the ICT sector, as discussed in the section 2.3. Compatible with the evidence from the early development of ICT in Sweden, Industry 4.0 patents are found in a particular set of municipalities in the metropolitan areas where they are concentrated. While the knowledge of associated technologies is expected to eventually reach other regions, similarly to ICT, it is likely that the patenting activity will still be concentrated to metropolitan areas due to the superior labor force. As the currently available data indicates, the Industry 4.0 patenting activity has not spread much around the country during the selected timeframe. Thus, compatible to the evidence of the Technology Shifts chapter, the potentially new GPTs are building on the established digital infrastructure, large ICT sector, and the superior technological knowledge.

At the same time, more patents were expected to originate in Gothenburg, with only 11% of all smart-tech developments recorded in the area. While it exhibits a slightly higher overall patenting activity (15.3%) than Malmö (14%), it is significantly behind on Industry 4.0 patents, with 11% against 21.2% respectively. Seeing that the previous research has identified strong concentration of ICT sector in the region, the smart technology was expected to build on the existing infrastructure either by utilizing the local knowledge or by prompting incremental innovations from ICT to smart tech.
On one hand, it could indicate lack of technology specialization in the academic society, given that otherwise the region has a strong agglomeration economy. On the other hand, it is

even more curious, considering that it accommodates one of the few well-funded technology universities in Sweden (Chalmers University of Technology). It could be expected that the amount of human capital in the technology-related fields and research would produce more innovation output. Moreover, with the local focus on cooperation between the industrial, governmental and academic actors, the knowledge spillovers were expected to drive a higher patenting activity. At the same time, the region received the least financial support compared to the rest of the Swedish regions during the EU funding process for Industry 4.0 in Europe, partly explaining the lack of such developments. Interestingly, the areas in its vicinity did not produce much output, possibly indicating the lack of proper spillover mechanisms in the area. Thus, the discovered phenomenon prompts more questions for further research.

6 Conclusion

This chapter provides a summary of the research and concludes the thesis with the reflections on aims and objectives, as well as further questions that the research can pose in the future extensions of the analysis.

6.1 Aims and Objectives

Essentially, the aim of this paper was to describe the concentration of Industry 4.0 innovation activity in the Swedish regions, as measured by the count of granted patents. The objectives were to construct and map the dataset for Industry 4.0 patent activity in the country as well as to compare it to the previously observed technology developments and geographical distribution of patents. As represented in both the theoretical and empirical sections, the thesis attempted to link the patenting activity to the strength of regional innovation systems and geographic characteristics within the current set of the General Purpose Technologies, on which smart technology is expected to build. In the empirical section, it was found that the development of Industry 4.0 patents follows almost all of the expected patterns: the innovation output is concentrated to the metropolitan areas; moreover, the smart-technology-specific patents are significantly more concentrated than the overall innovation output, similarly to the distribution of ICT – the defining GPT of the third industrial revolution.
All of the metropolitan areas in the country have strong regional innovation systems, although the relationship was not tested for causality. However, it was found that the agglomeration externalities and benefits associated with larger Swedish regions play a role in the consequent development on Industry 4.0 in the area. Based on the course of the thesis, the aims and objectives were fulfilled, although a more in-depth analysis of the empirical results could be carried out to provide further explanations.

6.2 Practical Implications

Primarily, the results of this work can be further used by the policymakers, considering the abundance of development programs and lack of previous region-specific research for Industry 4.0 patent distribution in Sweden. It is of utmost importance to understand how the knowledge and number of inventors evolve, in order to introduce effective policies for the local development and allocate adequate funds to meet the established goals and benchmarks. Additionally, understanding the geographic behavior of Industry 4.0 patents can help the officials predict the development of smart factories in the country, since it was mentioned that they are likely to form around the specialized knowledge hubs. Furthermore, the thesis can be of interest for other researchers looking into the development of smart technologies in Sweden.

For instance, there is a lot of potential for further research and extensions. The scientific community could further look into the geographic distribution of patents by year and compare the results to the existing studies on distribution of ICT. Such research would set the narrative for the regional convergence/divergence patterns of Industry 4.0 innovation activity and predict its distribution over the upcoming span of time.
Another potentially interesting issue is extending on the phenomenon observed in the Gothenburg area, where the Industry 4.0 patenting activity did not follow the results expected based on the previous research and the examination of general patenting practices in Sweden. For example, the patent citation analysis could be performed to partly explain the spillover mechanisms within the research topic in the area.
Finally, more can be studied about the most active Industry 4.0 patentees, their respective industries, as well as groups of inventors associated with their R&D activities.

6.3 Chapter Summary

All in all, Industry 4.0 behavior can be studied for various purposes. Importantly, the shift towards automated production has already started, while the studies on mechanisms behind the knowledge generation and distribution of patenting activity are rather scarce. While the Industry 4.0-related innovation output followed the expected behavior by highly concentrating to metropolitan areas, the extended studies might examine a myriad of other research angles with the similar data, in which the patenting activity could act differently to what was observed in the thesis.

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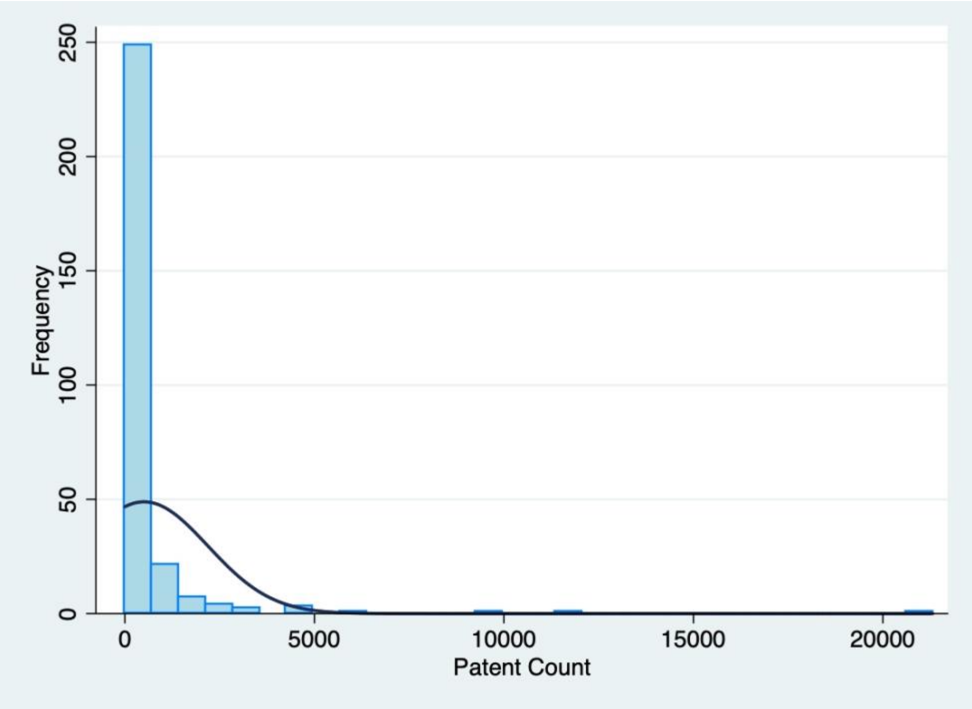
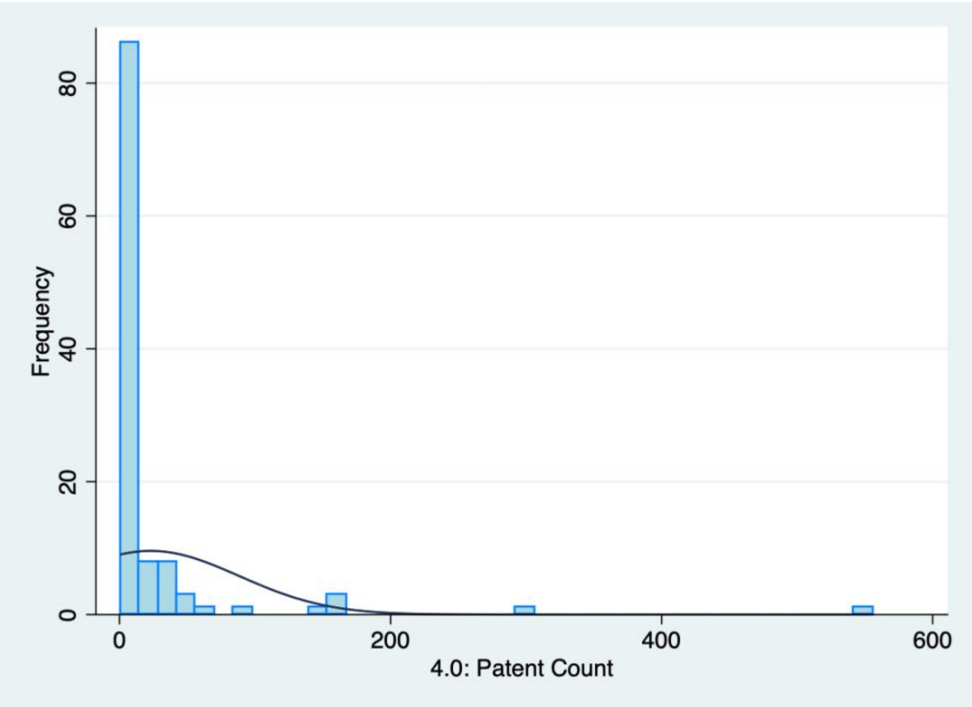
Appendix A

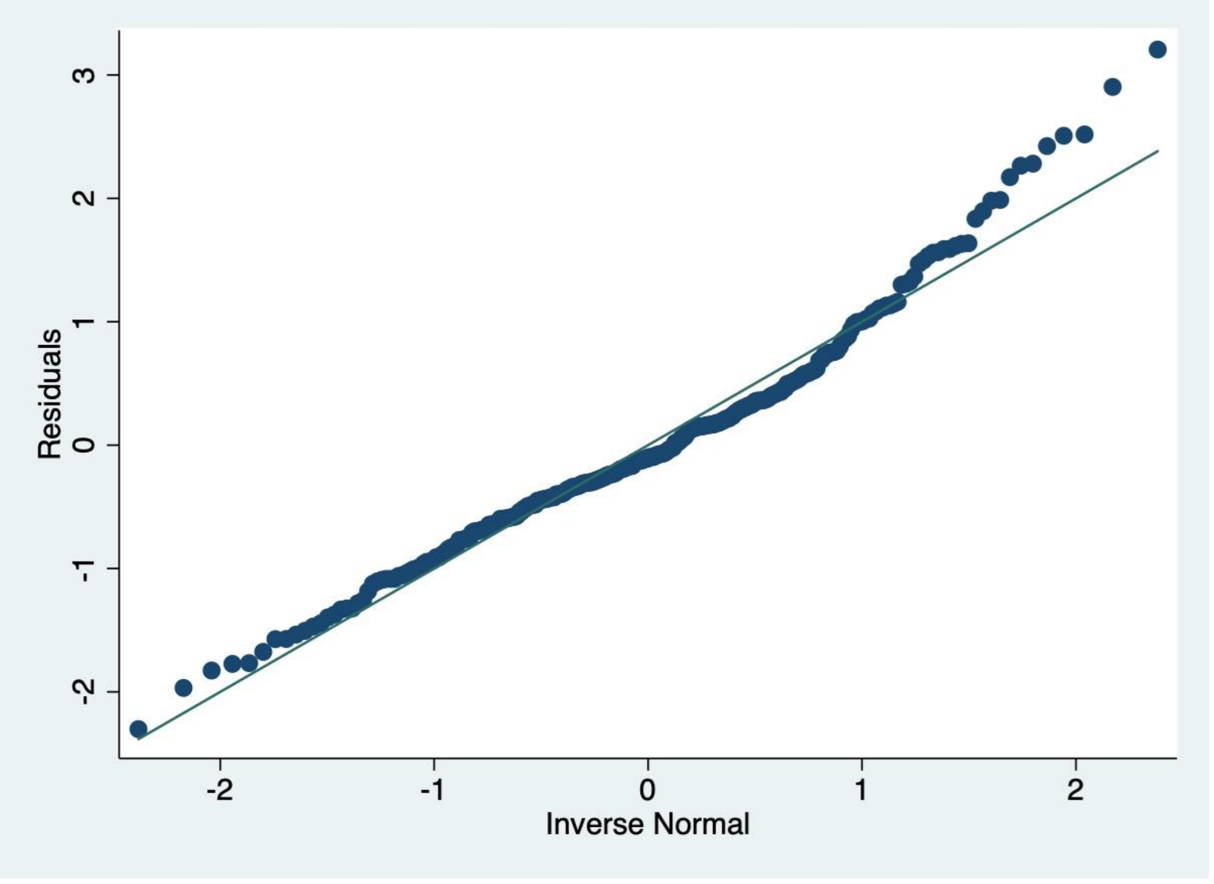


Note: overall patenting activity.



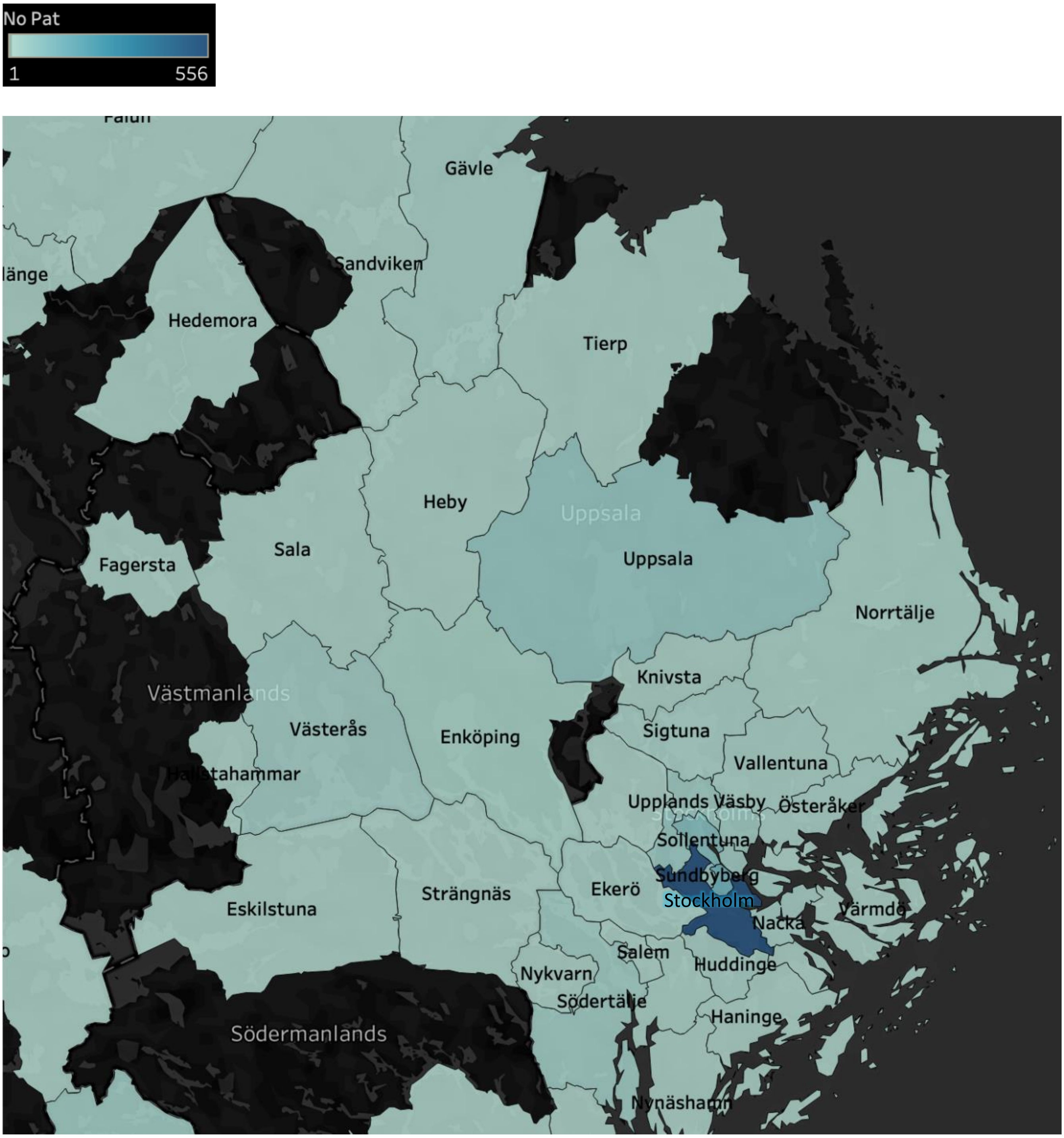
Note: Industry 4.0 patenting activity.

Appendix B



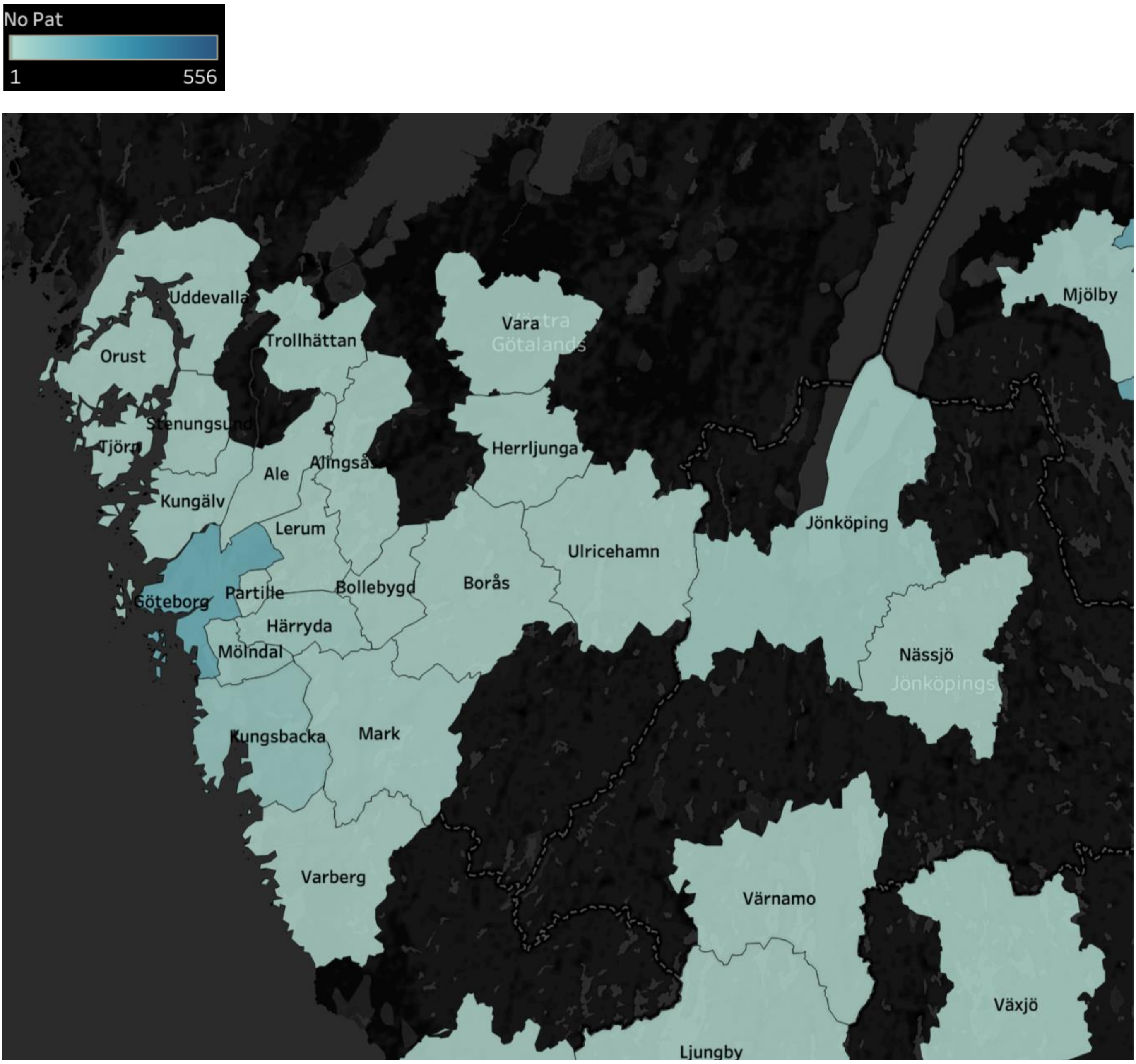
Note: distribution of residuals when ln_Population is regressed against ln_PatentCount.

Appendix C



Note: Industry 4.0 patents in the Eastern Sweden (around Stockholm)

Appendix D

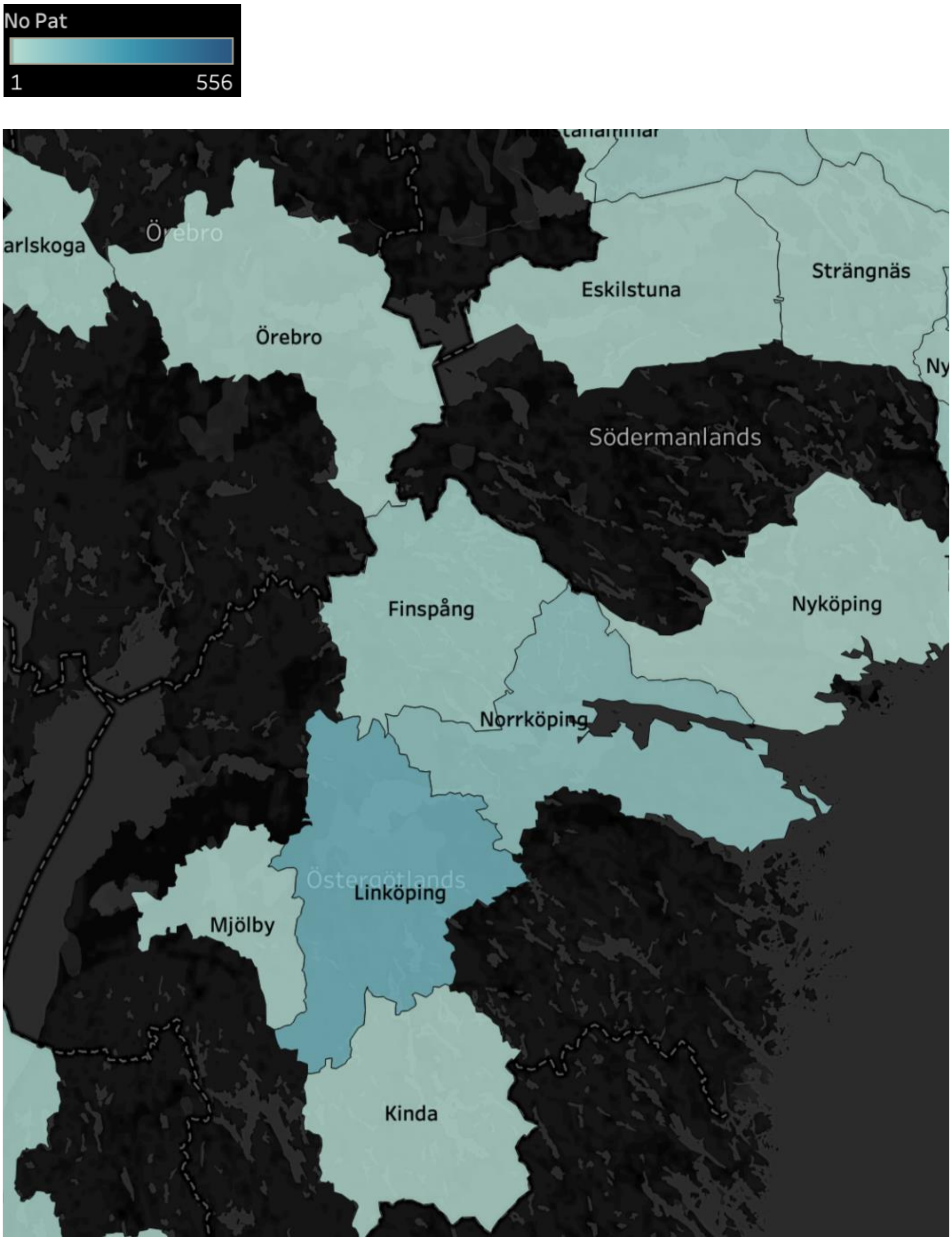


Note: Industry 4.0 patents in the Western Sweden (around Gothenburg)

Appendix E

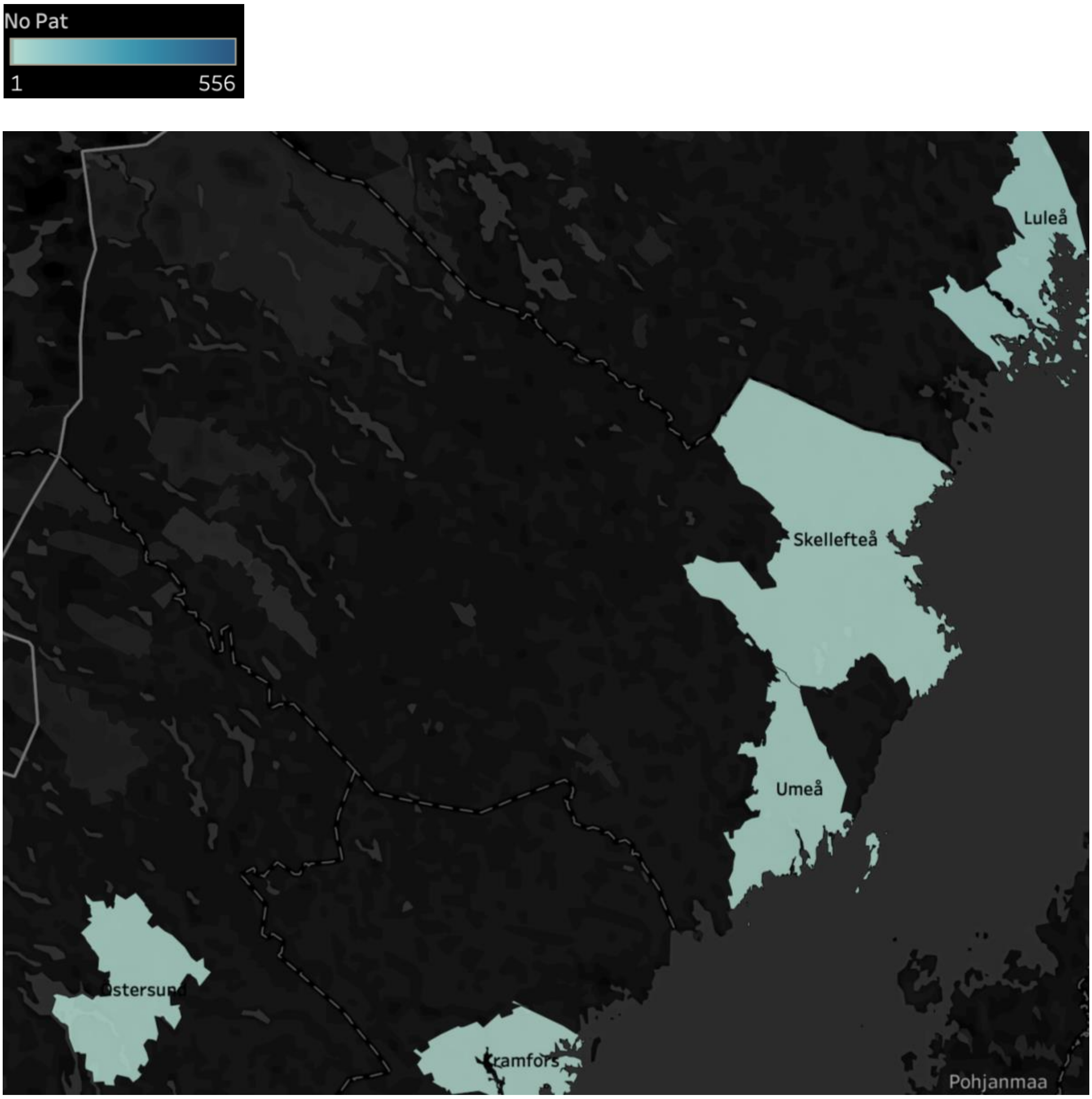
Note: Industry 4.0 patents in the Southern Sweden (around Malmö)

Appendix F



Note: Industry 4.0 patents around Linköping

Appendix G



Note: Industry 4.0 patents in the Northern Sweden

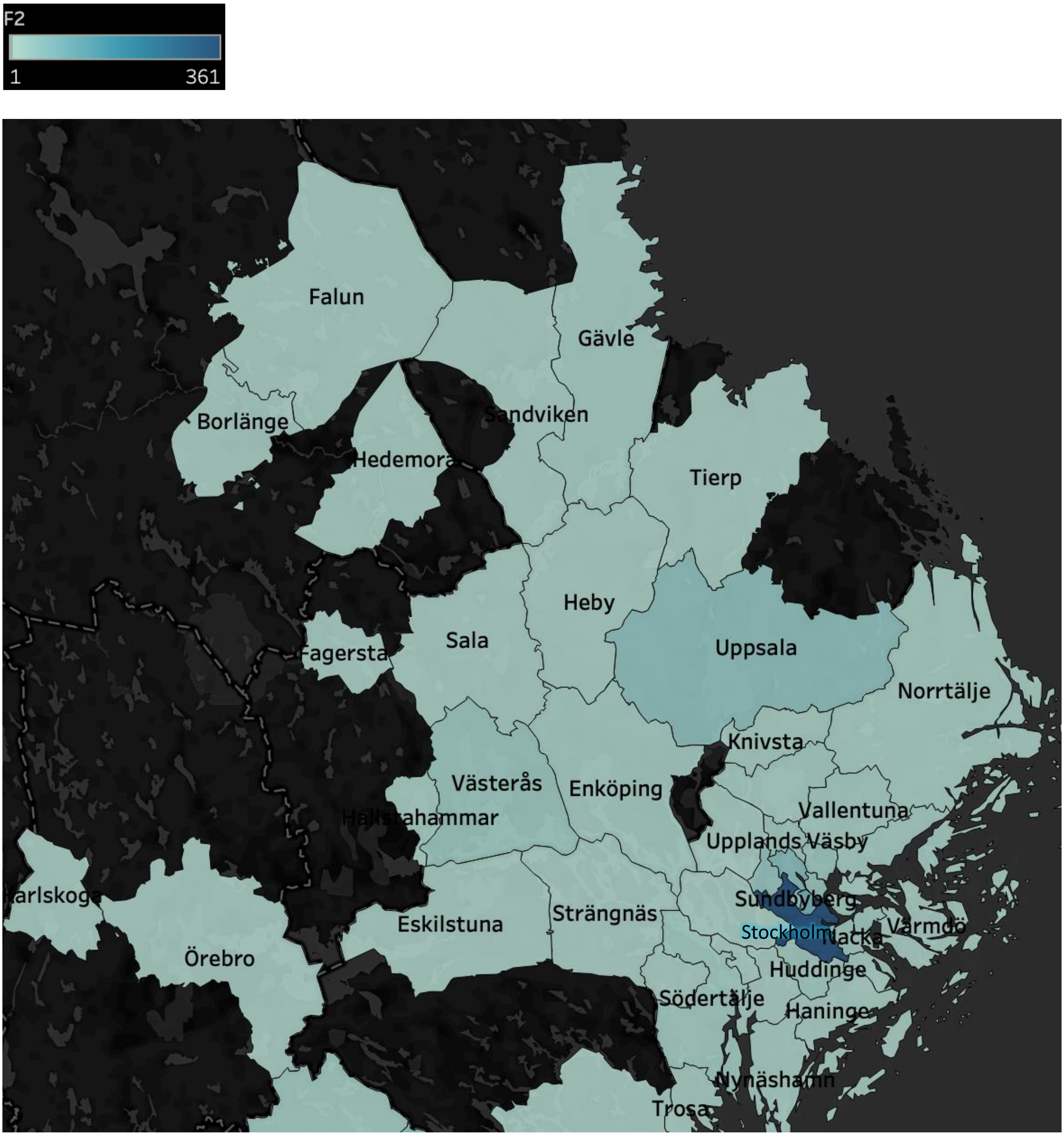
Appendix H

Inv/Pat	City	Inv/Pat	City	Inv/Pat	City
0.65	Lund	0.60	Sigtuna	1.00	Kristianstad
0.65	Stockholm	0.89	Eslöv	1.00	Nyköping
0.59	Norrköping	0.42	Södertälje	1.00	Orust
0.71	Karlstad	0.75	Bengtsfors	1.00	Skellefteå
0.51	Linköping	0.71	Varberg	0.50	Nykvarn
1.00	Upplands-Bro	0.73	Jönköping	1.00	Trollhättan
0.61	Solna	1.00	Lerum	1.00	Kinda
0.62	Sundbyberg	0.50	Tyresö	1.00	Borås
0.67	Malmö	0.96	Danderyd	0.60	Östersund
0.57	Lomma	0.91	Huddinge	0.83	Uddevalla
0.79	Uppsala	1.00	Bollebygd	1.00	Vellinge
0.48	Helsingborg	1.00	Ale	1.00	Strängnäs
0.78	Järfälla	0.22	Mark	0.50	Karlskoga
0.66	Täby	1.00	Perstorp	1.00	Hässleholm
0.73	Lidingö	1.00	Staffanstorp	0.67	Vallentuna
1.00	Karlskrona	0.50	Tjörn	0.67	Falun
0.80	Ystad	0.72	Luleå	0.50	Sandviken
0.47	Upplands Väsby	1.00	Salem	1.00	Tierp
0.67	Kävlinge	0.67	Örebro	0.72	Höganäs
0.62	Sollentuna	0.50	Habo	1.00	Herrljunga
0.36	Ekerö	0.67	Nässjö	1.00	Heby
0.67	Österåker	1.00	Ronneby	1.00	Ljungby
0.25	Mjölby	1.00	Mörbylånga	0.67	Ängelholm
0.68	Kungsbacka	0.67	Ulricehamn	1.00	Alingsås
0.60	Gävle	1.00	Botkyrka	1.00	Hammarö
1.00	Växjö	0.75	Norrtälje	1.00	Hagfors
0.80	Burlöv	0.46	Enköping	1.00	Laholm
0.72	Göteborg	1.00	Landskrona	1.00	Hallstahammar
0.73	Mölndal	1.00	Halmstad	1.00	Hedemora
0.75	Kungälv	0.50	Svalöv	1.00	Fagersta
0.48	Finspång	1.00	Eskilstuna	1.00	Öckerö
0.79	Nacka	0.58	Umeå	1.00	Trosa
1.00	Vara	1.00	Värnamo	1.00	Vaxholm
0.88	Västerås	1.00	Värmdö	1.00	Sala
0.67	Haninge	1.00	Sjöbo	1.00	Håbo
1.00	Stenungsund	0.67	Borlänge	1.00	Kramfors
0.74	Härryda	1.00	Partille	1.00	Nynäshamn

				1.00	Båstad
				1.00	Knivsta

Note: number of inventors divided by patent count in the region

Appendix I



Note: number of Industry 4.0 inventors in the Eastern Sweden (around Stockholm)

Appendix J

Note: number of Industry 4.0 inventors in the Western Sweden (around Gothenburg)

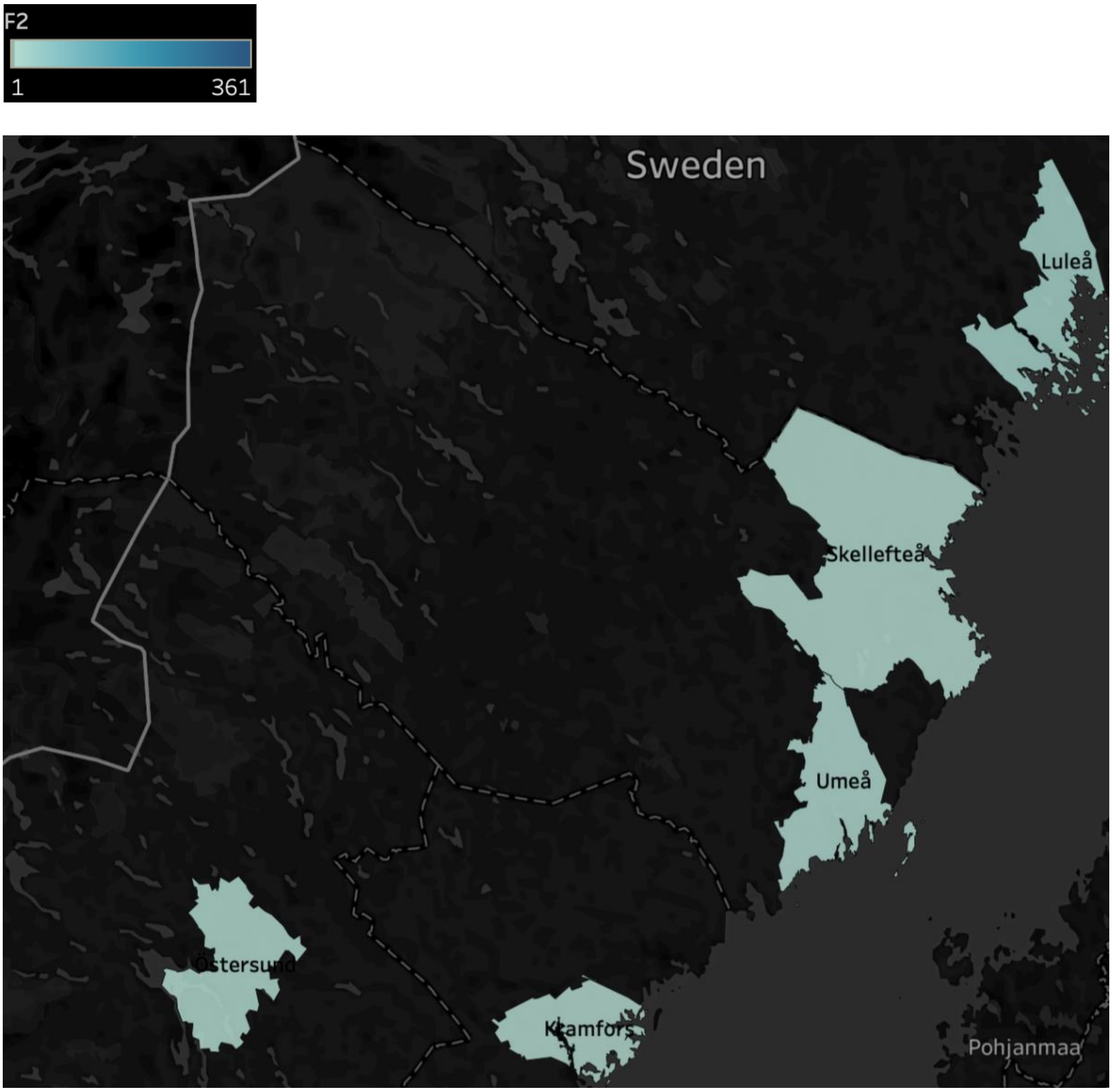
Appendix K

Note: number of Industry 4.0 inventors in the Southern Sweden (around Malmö)

Appendix L

Note: number of Industry 4.0 inventors around Linköping

Appendix M



Note: number of Industry 4.0 inventors in the Northern Sweden