Universiteit Utrecht – Master Thesis – Human Geography - Economic Geography: Regional Development & Policy

How far does the influence of innovation in North-Rhine Westphalia reach?

A quantitative approach on how influential innovation in Germany's highest populated Bundesland is on socio economic endowments of the region.

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Abstract

In this thesis the influence of innovation in North-Rhine Westphalia on socio economic endowments is tested. North-Rhine Westphalia is a highly diverse region as has an old industrial region (Ruhrgebiet), modern service minded cities Cologne and Düsseldorf are located in the region and it has big agricultural areas. The thesis provides insight on how innovation (measured by quantity and quality of patents) influences the regional GDP per capita (purchasing power standards) and unemployment rates. It is tested if innovation alone influences these socio economic endowments or if other factors play a more eminent role. First an overview of North-Rhine Westphalia's innovation is given. Secondly, the role of innovation in improving the socio economic endowments was tested. According to this research human capital and the creative class play a more vital role in improving the socio economic endowments than innovation alone. Policy makers in a diverse region as North-Rhine Westphalia should be careful when implementing policy, as a one size fits all policy is missing.

Introduction

Differences between regions have existed for a long time, these regional disparities are ever increasing in a time of globalisation. In the era of globalisation innovation plays a major role, regions that innovate are in the lead and are competing with regions on an international scale (Drabenstott, 2008). Since the industrial revolution regional differences have been increasing, especially between urban and rural regions. In a time where innovation plays a more vital role in which regions prosper and which regions decline an ever increasing gap between those regions is present.

Nowadays differences between urban regions are visible too. Regions with industry as its core activity struggle to find new core activities by a lack of innovation. This lack of innovation is attributed to strong specialisation in the region’s industry, which is in decline. This stresses the danger of being dependent on one type of industry. Furthermore, the knowledge that is created by the industry is too much specialized in this single industry. This stems from the first point and emphasizes the danger of being a mono-industrial region. Thirdly, the industrial region is locked in, in multiple facets. The region is functionally locked in, interfirm relations are very strong which makes it difficult to break these relations or start relations with other firms. Cognitively the region is locked in, the people in the region have no other conception of what their region could look like. Lastly, the region is politically locked in, public and private actors are so intertwined that major change/innovating is being blocked (Trippl & Otto, 2008, 1219). The old industrial region thus are locked in old industries and paradigms, which makes declining the gap with more prosperous regions difficult.

This thesis focuses such an old industrial region: North-Rhine Westphalia in Germany. Industrial regions in Europe, and North Rhine-Westphalia is no exception have faced economic decline. No other mass employment industry substituted the old industries. The old industrial regions are left with big social problems like unemployment, poverty etc. (Müller, 2005, 82) Within North Rhine Westphalia (a NUTS-1 region in the European Union regional division) big differences exist. The region is overall economically strong in Germany. It is the most populated Bundesland of the federal nation with approximately 17 million inhabitants, yet it has one of the highest unemployment rates of all German Bundesländer: 7.9% in January 2021 (Bundesagentur für Arbeit). This region was once dominated by heavy industry, mostly by coal and steel. In the second half of the twentieth century slowly but steady North-Rhine Westphalia started to decline economically due to structural changes in the economy. One of the problems for North-Rhine Westphalia was the high wage bill for workers. Strong unions in West-Germany ensured workers received high wages. This made coal and steel of North-Rhine Westphalia (Ruhrgebiet) more expensive than coal from abroad, which lead to a decline in demand of coal and steel from North-Rhine Westphalia. Secondly, the region’s identity as a mining region haltered the development of entrepreneurial spirit in the region. As multiple generations worked in the mines the urge to create, invent something new was absent. Alongside the economic decline, this old industrial region declined socially too. The old industrial region has difficulty adapting to the new knowledge based economy and lack financial and human capital to regain strength. The regional government has undergone action in the past to tackle social problems in the Ruhrgebiet, although this has not lead to substantial beneficial change to cities in the region (Müller, 2005).

During the industrial period North-Rhine Westphalia was economically the most powerful region of Germany. In the post-industrial era the region has been surpassed by Baden-

Wurttemberg and Bavaria. North-Rhine Westphalia still has the highest absolute GDP of all German Bundesländer, but this is due to the highest population rate of the region. Per capita North-Rhine Westphalia ranks seventh on GDP per capita compared to the other Bundesländer. Although it must be noted that the three city states (Berlin, Bremen and Hamburg) rank higher as well (Produktionswert, Bruttowertschöpfung der Landwirtschaft, 2021).

The new regions that thrive are regions with a relative highly educated population with an emphasis on the service sector. These regions do possess high financial- and human capital. Cities are attractive places for highly educated people as they offer a certain lifestyle which is attractive to these people. Regions with high human and financial capital seem most able to innovate, hence these sort of regions should perform well on socio economic circumstances. The thesis will look at the influence of innovation in North-Rhine Westphalia on socio economic circumstances in the region.

North-Rhine Westphalia offers an interesting case as differences within the region exist. Cities like Dortmund and Duisburg are old industrial cities with relatively high unemployment rates. The two biggest cities Cologne and Düsseldorf are attractive for highly educated people and fit more in to the knowledge based economy of the twenty-first century (Takkinen, 2012). The region also has a rural/agricultural side outside the cities. The thesis hopes to provide insight into how a strong economic region tries to cope in a new era of economics and how differences within the region play a role. Previous research has mainly focused on differences in regions on a national scale, whilst regions internally are not homogenous. This thesis is relevant for policymakers of regional development to know what kind of development can be fruitful for the future.

The aim of the thesis is to research the influence of innovation on socio economic endowments (regional GDP per capita (PPS) and unemployment) in North-Rhine Westphalia. It does so by using data on patents for North-Rhine Westphalia and using other variables: human capital in a region, the creative class in a region and population density. The aim is to research what influences the socio economic endowments more, thereafter distinguish which regions can be more successful socio economically and what possible policy implications could be. The region is divided into five NUTS-2 regions, namely: Arnsberg, Cologne, Detmold, Düsseldorf and Münster. The research questions are:

To what extent does North-Rhine Westphalia's innovation contribute to improving the socio economic position of North-Rhine Westphalia in Germany?

1. What is the position of North-Rhine Westphalia's innovation compared to other Bundesländer of Germany?
2. Which NUTS-2 region in NRW is the most innovative and has the best socio economic endowments?
3. How do human capital, creative class and population density contribute to improving the socio economic standards in NRW?

The thesis is structured as follows: first a theoretical framework with current theories on innovation and regional convergence is presented. This is followed by an introduction of North-Rhine Westphalia, then the methodology is presented. Next is the results of the analysis, the thesis is concluded by a conclusion and critical reflection.

Theoretical framework

In the theoretical framework different theories of innovation and how innovation can be influenced will be discussed. Firstly it is explained what knowledge and innovation entail to have a good understanding. Then the role of innovation in regional convergence is being discussed to establish an image on how regions can use innovation in their advantage. Thirdly, the use of patents as a way of measuring innovation is introduced and its influence on socio economic endowments. Lastly, other factors that might influence the socio economic endowments are introduced.

What is knowledge?

In order to understand innovation and knowledge it is necessary to understand the broad definition that these words hold. Malecki (2010) describes what different types of knowledge exists and the subtle differences that exist in knowledge based on an extensive literature research. Furthermore he describes the geographical differences in knowledge, which are ever present. First he describes the production of knowledge and how it can be measured. Using patents as a means of measuring knowledge and innovation is the most common way of measuring knowledge. The quantity and availability of the data is what makes patents so suitable for measuring knowledge and makes researching knowledge relatively uncomplicated. However, with the rise of the quantity of patents, issues with quality of patents have risen over time (Hall and Ziedonis, 2001 cited in Malecki, 2010, 494). A second problem with using patents is that it measures only codified knowledge. *Tacit* knowledge is not captured by patents. Tacit knowledge is "*central to innovation as a learning process"* (Nonaka and Takeuchi (1995), cited in Malecki, 2010, 495). Knowledge can also be produced by spillovers. Institutions that have invested and are active in R&D can spill knowledge over to other institutions that have not been investing in R&D. Knowledge that has been produced by universities has been spilled over to private businesses. Nonetheless, the bigger the distance from the university the less knowledge is being spilled over to private businesses. Spillover of knowledge is measured by patent citations but the citations cannot grasp all the spillovers and therefore measuring all spillovers is impossible. Hence, a realm of informality is required by transforming knowledge, tacit knowledge in particular, which makes measuring this tacit knowledge difficult. Another example of the immeasurability is measuring knowledge that is inside people. Mostly this is done by using education attainment levels of geographical entities. At first glance this seems perfect, but graduates of universities don't stop learning once they leave their campus. Within firms, people learn new things that they would never learn at a university. Combining the people, informality in a dense environment has led to the theory that dense urban areas (big cities) are more able to innovate than less dense areas (smaller cities and rural areas). Hence why the impact of population density will be used in the continuation of this research.

Secondly Malecki describes how knowledge transforms into knowledge systems. The accumulation of knowledge leads to the formation of knowledge systems. These can form on a national- and regional scale. Knowledge economies are economies that have *"localized and regionalized, clustered collective learning systems"* (Cooke, 2002, cited in Malecki, 2010, 498). Opposite of knowledge economies are innovation averse regions. Yet, just accumulation of knowledge isn't enough to form knowledge systems. It is necessary for firms to learn new things (through R&D) and maintain this new knowledge to grow their competences. These new competences should lead to more competitiveness but also the incentive to keep learning new things to tackle future challenges. By keep learning these new competences, companies are able to create tacit knowledge, this is formed by internal and external knowledge. Which is sometimes hard to measure as stated before. When looking at the geography of innovation systems and the transfer of knowledge a sticky pattern is visual. The knowledge is not evenly spread over geographical entities and companies. A small amount of big companies have great competences and absorptive capacities of knowledge. The big players contribute most to the creation and spreading of knowledge. With tacit knowledge this holds even more truth. A stickier pattern is visual due to the difficulty with transferring this tacit knowledge. Thus, knowledge systems that are have a high knowledge integration between firms (or regions) and the more worldwide the competitive firms and regions (other specialized, "sticky" regions) operate the better economic output such an innovation system (region) can produce.

Thirdly, Malecki elaborates on spillovers of knowledge. When studying spillovers, distance, fluctuation of firms and their sizes, differences in spillovers, absorptive capacity are important aspects. When looking from a perspective of competence, a firm can be seen as a 'warehouse' of skill and knowledge that is gained by learning and doing. Especially in the cultural sector the stream of knowledge is crucial for creating creative and new products. When looking at where knowledge spills over on a global scale the image is spiky. This confirms the idea that knowledge is sticky and concentrated in few spaces. Growing economically in a knowledge economy means gaining more knowledge and sits on the basis of regions being able to catch up other regions with knowledge. Furthermore spillovers are dependent on which sector the knowledge is in. For example, the biotech sector is not as clustered as the telecommunication sector. Also, as time passes one cluster in a sector can specify its knowledge even more due to workers being geographically stiff. A cluster can thus become very specialized in one type of knowledge. In spillovers and clusters once again dense urban areas have benefits over more rural areas. They are able to transfer tacit knowledge better and are relatively close to other clusters elsewhere on the global scale (Malecki, 2010, 503). Measuring spillovers by looking at patent data in Europe has given several explanations for the spilling over of knowledge. By looking at autocorrelation of patents the location of input factors plays a major role. But once again social capital also plays a vital role in the knowledge spillovers, alongside the tightness of R&D and the accessibility to human capital in its diverse forms.

Regional Convergence

The matter of regional convergence is discussed because knowledge of these theories helps to understand how lagging regions are able to catch up with prospering regions. What factors play a major role in converging regions? Regional convergence has been discussed widely in the academic debate. Solow (1956) stated that a region will grow when there is an accumulation of capital, growth of population and improvement in technology. If multiple regions are able to follow this path of economic growth, regional disparities will decrease. This view is supported by neoclassical equilibrium economics. If the national market is not obstructed by barriers and is integrated, the market will solve disparities that exist between regions. As the market will regulate differences in wages, production, capital etc. On the other hand there is the notion in the academic world that market forces will lead to regional divergence, given a barrier-free internal market. Prosperous regions thrive in expense of regions that decay. "*Economies of scale and agglomeration lead to the cumulative concentration of capital, labour, and output in certain regions at the expense of others.*" (Martin & Surley, 1998, 201). This process of uneven regional development is re-enforcing. Barriers and government action is needed to foster equal regional growth.

In the theory of regional convergence the image of divergence and convergence isn't accurate according to Marxist geographers this can vary over time. In period X region X will thrive whilst in period Y region Y will thrive and region X will decay. In the capitalist society we live from crisis to crisis. The capitalist market solves these problems by shifting economic activity to new places to ensure the accumulation of capital according to Marxist geographers. This then leads to convergence and divergence of regions, which is not a linear process. (Martin & Surley, 1998). After the Marxist-geographic paradigm in the 1970's-1980's was followed by a period of extra attention to the type of regions that exist, mainly the focus lied on old industrial regions and post-Fordism regions. Yet the focus of was still on particular growth in particular regions instead of looking at long term changes in regional development, the economic evolution.

In the academic debate about the economic development of regions academics write about the evolutionary economic geography (EEG). Thinking of economic growth in an evolutional manner started in the 1950's. "*Uneven spatial development through the concept of cumulative causation and regional economic development was viewed as a cumulatively unfolding process.*" (MacKinnon et al, 2007, 3). Regions that were growing economically would establish and expand their lead over regions that didn't prosper. On the long term the economic advantages would be reinforcing and the lead of this regions would only grow further. In later years the spatial aspect of economic development of regions started playing a more prominent role. Path dependence of a region is an important element in EEG. The (economic) history of the region is determined for the success or failure of the region thus can determine regional convergence or divergence. Boschma & Frenken (2006) state that economic geographers put emphasis on the exchange of knowledge between firms and institutions to determine the success of a region (MacKinnon et al., 2007).

In the 1990's the impact of institutional impacts entered the debate about evolution in economic geography. "*In particular, inherited institutional frameworks and routines were viewed as critical in shaping how particular regions responded to the pressures of globalisation*" (MacKinnon et al, 2007, 3). The institutional frameworks of the region can thus influence the business climate and the economic performance of the region. Given the uniqueness of every regions these institutional frameworks have different impacts on every region, definitely when comparing regions at an international scale. Furthermore geographers look at the way how some technologies and the implementation of this technology became dominant in regions, the evolution of this dominant technology. After the focus on the implementation of a technology evolutionary economic geographers looked at the daily routines within the regions and looking at decisions in the past to analyse the trajectory of regions (MacKinnon et al., 2007).

Boschma & Martin (2007) state that knowledge and innovation play a vital role in the evolution economies (of regions). Especially the ability to create new knowledge within the region can contribute to production and lead to a thriving economy. In their view the evolution economic geography is divided in four sub streams. The geography of new economic activities, where does innovation take place. Two: the spatial structures of the behaviour of individuals, firms and institutions. The third is how economic regions are self-organizing in absence of a controlling mechanism or governing body. Lastly, the processes of path creation/dependence which form economic development and transformation and why these processes are geographically constrained (Boschma & Martin, 2007, 540).

Innovation in regions

As Boschma and Martin (2007) stress, innovation is important in the realm of converging regions. This section aims to dive deeper in to what innovation means for regions and how it can be encouraged. For regions to be innovative it is not only important to be specialized in one type of technology or sector. Being innovative in a diverse set of sectors and or technologies is essential. The speed of technological development nowadays is so high and inventions follow quick sequentially that 'betting' on one horse is not enough. A diverse set of innovative technologies is thus necessary in the competition between regions and to come out as a top region. Regions that have diverse innovation patterns will then produce a diverse set of products. Diverse economies can easily transition in to producing different products. In contrary, specialized regions have more difficulty transitioning into a diverse economy that can lead to a lack of diversification (Kogler et al., 2013). Specialized regions have high levels of relatedness, relatedness of knowledge. The knowledge that they produce is concentrated in a small amount of sectors, highly related knowledge is mostly situated in smaller cities/regions. Whereas big metropolitan areas show a more diverse level of knowledge. As Kogler et al. (2013) prove in their research on relatedness in American cities, relatedness and therefor specialization can evolve over time and over geographical entities.

According to Broekel (2013) innovation in regions can thrive when a strong R&D subsidy is present in the region. These subsidises can come from companies but also from innovation programmes of government bodies of multiple geographical scales. Innovation can be more successful if actors join forces and innovate together. Subsidizing innovation is especially fruitful for smaller businesses. As they have less capital of their own to invest in innovation. With innovating their products they can increase their productivity which leads to further employment growth (Broekel, 2013, 1089). Gumbau Albert (2016) discusses the role of entrepreneurship in regions and its influence on innovation of Spanish regions. His research confirms that innovation plays a vital role in the economic growth of regions. Regions with innovative start-ups that require much knowledge have higher economic growth than regions that lack these kind of start-ups. What further derives from this is that regions with better socio-economic endowments are more likely to thrive economically. Examples of these endowments are low unemployment rates and a relative high share of highly educated people. Sternberg (2011) further dives in differences between regions in countries. He researched the relation between entrepreneurship and regional development in Germany and Spain. Urban regions have a higher rates of entrepreneurship and highly educated people, which leads to more innovating start-ups. However, these rural/peripheral areas in countries receive more subsidies from governing bodies, in this case the European Union to enhance innovation and entrepreneurship. Sternberg (2011) states this supranational support is not always working as innovation and entrepreneurship is embedded within regions itself and it is difficult to create this artificially by subsidizing certain regions. These regions must adapt from within to become more attractive. It should be questioned if some regions are ever qualified to become attractive for people capable to innovate.

To measure innovation in this research not only the quantity and different technology fields are used. Frietsch et al. (2014) looked at the impact of the quality of patents on a nation's export. Their viewpoint was that technologically advanced countries have greater innovative capacities with higher value of export as a consequence. In line with this starting point the authors state: patents with higher citations numbers create a positive effect on the country's export. By using data of patents from over two decades of eighteen countries their research confirmed their view from the starting points. First the quantity of patents has a positive effect on the nation's export. Furthermore some quality indicators seem to have a positive effect on a nation's export. Not all measured indicators of quality influence the export directly, but the amount of forward citations adds significantly to the export of a country/region (Frietsch et al., 2014, 557). Hence in this research quality indicators of patents based on citations will be used, additionally to the quantity of patents per NUTS-3 region.

Creative sector and innovation

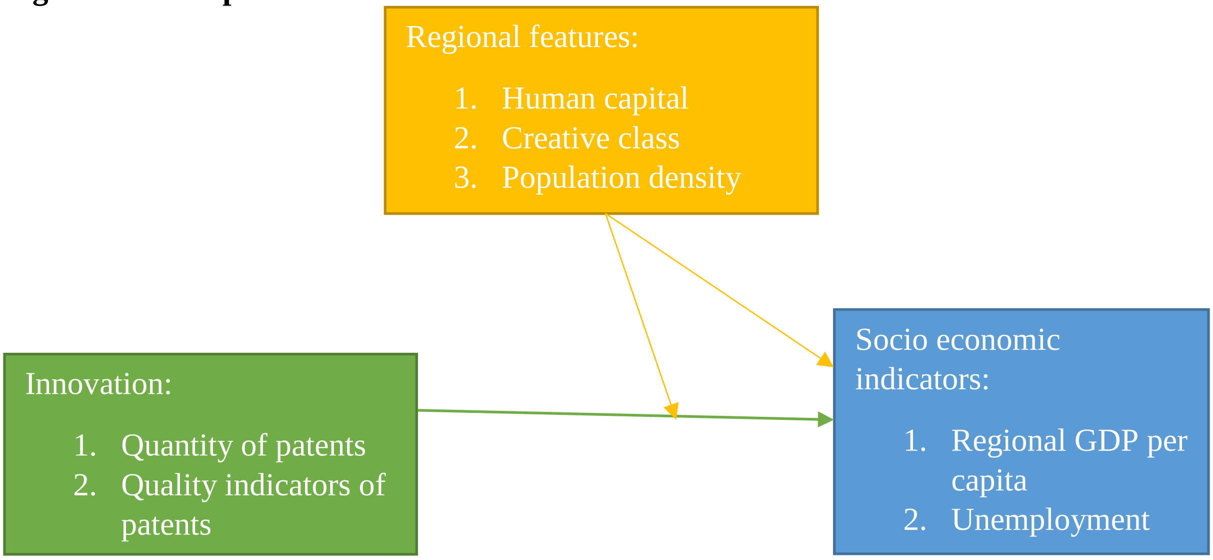
Not only patents and their quality indicators can help predict a region's socio economic endowments. In this research the role of the creative class and highly educated people is tested too. It is used due to the fundaments that Florida (2003) laid, which is briefly explained in this paragraph. Creative people help shape the form of innovation in companies and regions. With their creative minds they go off the beaten track and come up with new ideas. The benchmark work on the importance of the creative class is the theory of Richard Florida (2003). Florida confirms the importance of cities in nowadays economy. In cities people come together and industries cluster together. Not only in the manufacturing industries (car cluster Detroit), but also in the creative industries (film industry in Hollywood). According to Florida; "*The ability to rapidly mobilize talent from such a concentration of people is a tremendous source of competitive advantage for companies in our time-driven economy of the creative age*" (Florida, 2003, 5). A starting point for his theory on creative class is the presence of human capital for regional development. The need for a region to have highly educated people (human capital) is necessary to increase the economic output. Glaeser regards human capital and the lifestyle that cities offer as the roots for city/regions to be successful (Gleaser, cited in Florida, 2003, 3). The network of customers and producers that develop because of human capital further strengthen the advantages such a city/region already has. A strong labour pool is another beneficial consequence of human capital in a city that is closely related to the aforementioned benefit. The problem with the human capital theory is that is to narrow, it only considers educational attainment as an important contributor to economic output. According to Florida creativity plays an even bigger role. His research concludes that people not migrate solely for jobs but to places that are inclusive and diverse. These creative people are key drivers for economic growth of the city/region. Creative people are researches, scientists, architects, designers, directors and so on. Furthermore, Florida singles out creative professionals in knowledge based jobs in the financial and high tech sector for example. These creative professionals require a higher education, thus have high human capital. The cities that attract the creative class rank high on innovation scores. What kind of cities attracts the creative class? Florida explains this along technology, talent and tolerance. If a city has these three assets a city can become successful. Examples in the USA are Seattle and San Francisco. An example of a less successful city according to Florida is Miami, it has talent and tolerance, yet existing technology lacks to become a successful city according to Florida's theory (Florida, 2003).

Müller, Rammer and Trüby (2008) conducted research on innovation within the creative industries in Austria. In general, companies in the creative industries tend to be more innovative than in other knowledge intensive companies. Furthermore, creative industries can contribute to innovation in the industry. Mainly larger companies try to innovate products and processes within their company. As they have more resources to innovate than smaller companies. Other companies can than benefit from the newly required knowledge. The creative industry doesn't only have companies in different sizes, the creative industry houses multiple sectors and thus makes it one of the most heterogeneous sectors. Policy towards it can be very difficult as a one-size-fits all solution is absent. One pattern seems to be clearly visible. Smaller companies as aforementioned lack resources, financial and human capital to innovate. Daily tasks have priority over innovating and creating new ideas. If policymakers seek to support in their region it is best to do it by supporting small firms as they need it more than bigger companies do (Müller et al, 2008).

Florida's theory has been widely adopted and critically acclaimed. However his paradigm has been criticized too. For instance, when is something or someone creative? The wide definition from musicians and actors to knowledge professionals has made the definition of the word creativity somewhat indistinct. In line with the problems of defining creativity it can also be difficult to measure and its contribution to the innovation and economy of a region. A creative idea can be thought of by an artist but can be used by a company in a different sector, this is an example of how difficult it can be to trace back the original idea or person who came up with the idea. It can be criticized too that creativity is now seen as a way to make money and create innovation. For artists, their first priority is to make something they like, or to be provocative. Florida's adage is in sharp contrast of what creativity and art should be like. Furthermore, creativity is used an instrument to solve problems and achieve new goals. By instrumentalizing creativity to solve problems creativity and free thoughts are being further discouraged. In addition the role of creativity and creative arts in society should be critically looked at. In times of crises the cultural sector is one of the first sectors that faces budget cuts by governments. But, simultaneously this sector should be creative, innovative to help fight the crises. This paradox relationship that governments and societies have with culture will remain an issue (Oakley, 2009).

This research adds to theories as it combines all theoretical aspects on the role of innovation for regions. First only the influence of patents on socio economic endowments is tested, in a later stage the regional features are added to test which is more important. The research hopes to shine a light for policy makers what kind of policy is fruitful on improving life for the citizens of their region. The conceptual framework is in figure 1.

Figure 1: Conceptual framework of the research



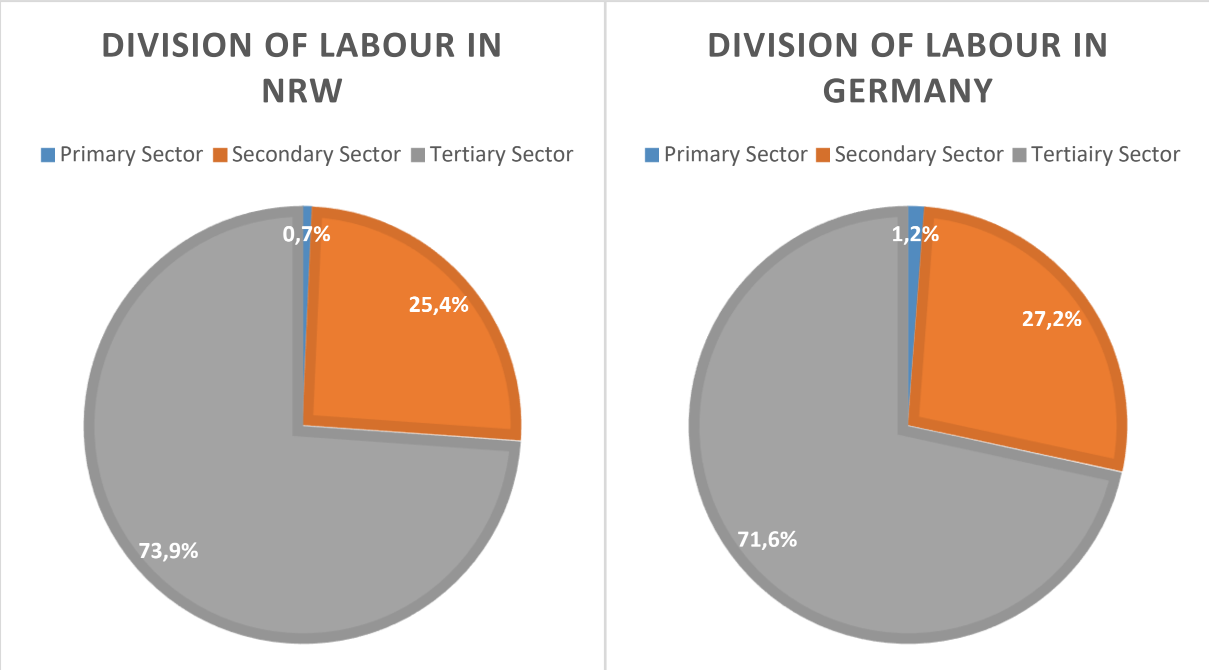
Introduction regions of North-Rhine Westphalia

North Rhine Westphalia

Figure 2: location of NRW in Germany (KFZ, 2021) and administrative division of NRW (On the World Map, 2021)

In 2018 North-Rhine Westphalia contributed the most of all sixteen German Bundesländer (NUTS-1 region) to the German economy. The region had a GDP of €697 billion. This accounted to more than one fifth of the total GDP of Germany. It should be noted that North-Rhine Westphalia has circa one fifth share of population of Germany. In that regard, this strong economic position should not come as a surprise. The state is also one of the leading exporting states of the country, only the two southern most states (Baden Wurttemberg and Bavaria) contributed more to the nation's export in 2019. On the other hand socio economically is amongst the weaker states in the country with purchasing power being below national average. In 2019 the unemployment rate was 3.6%, slightly higher than the national average at 3.2%. The working force of the region comprised of nine million people in 2019, the service sector is strongly represented and compared to the national average very service minded as is visible in Figure 3.

Figure 3: Division of Labour in three labour sectors in NRW and Germany in 2019.



Small-medium enterprises are the backbone of the region of the economy. 80% of the working population are employed with a SME. Next to the importance of SME there, Germany's biggest companies are located in the region. Examples are Bayer, Thyssen Krupp and Deutsche Telekom. The region also attracts the most Foreign Direct Investments of all German Bundesländer. 28.5% of all FDIs was invested in 2016 in North Rhine Westphalia, the equivalent of €189.9 billion (European Commission, 2020).

Arnsberg

Arnsberg is a region in the eastern part of North-Rhine Westphalia, Dortmund and Bochum are the two biggest cities in Arnsberg. In 2018 the regional GDP per capita was €34.800 and unemployment was 4% (Eurostat, 2020). Dortmund is economically the most important city of Arnsberg, the city adapts to the post-industrial era and frames itself as a city where innovation can thrive. The amount of tech companies is on the rise and together with the technical university that is based in Dortmund the city is creating a hub for tech start-ups. Next to the technology hub the city also has a lively finance- and insurance sector. More over the city sees itself as a transport hub, in car-, rail and air transport, furthermore the city has the Europe's largest canal harbour. To establish itself even more as a research and innovation city the city also has a university of applied science and art and the 'Technologie Zenter Dortmund'. The latter employs 8500 people and aims to incorporate research, development and implementation in the real world (Dortmund, 2021). East of Dortmund the region becomes more rural smaller urban settlements. The city of Arnsberg has 70.000 inhabitants, is famous of its paper industry due to the surrounding forests. In the far east of the region the town of Winterberg is a famous tourist destination, especially catering to skiers.

Cologne

The Cologne region encompasses the south-western part of the region with Colognes as biggest and most important city. Bonn, Aachen and Leverkusen are other cities within the region. In 2018 the regional GDP per capita was €42.800 and unemployment was 3.6% (Eurostat, 2020). The city of Cologne has a very diverse economy. Located on the Rhine the city is an important hub for water way transport. The city is well connected to the industrial Ruhr Area, the rest of Germany and to neighbouring countries: the Netherlands, Belgium and Luxemburg. The city is a transport hub in rail and road transport. In Germany the city is known as a media city, large national television networks are based in the city as well as television studios where the shows are recorded. In 2017 the metropolitan area of the city accounted for 40% of all revenue in the cultural sector of North Rhine Westphalia (Köln, 2017). Furthermore the city tries to attract start-ups in a diverse set of branches and sees itself as a digital hub (Köln, 2021). East and west of the Cologne/Bonn area the region becomes more rural. In the west next to the Dutch and Belgian border is the city of Aachen. This city has a university that works together with local businesses. Aachen also works together with cities in the Netherlands and Belgium, it truly acts as an international city (Begaß, 2021).

Detmold

Detmold is located in the north east of North-Rhine Westphalia and Bielefeld is the biggest city in the region. In 2018 the regional GDP per capita was €37.800 and the unemployment rate was 3.2% (Eurostat, 2020). The city of Bielefeld is a smaller city compared to aforementioned Dortmund and Cologne. Yet it tries to be as attractive to young entrepreneurs as Dortmund and Cologne. The city has a science council that works together with the local higher education facilities and companies (WEGE, 2021). The second biggest city in Detmold is Paderborn. This city has developed a relatively strong IT-sector within the city. The city is attractive to young bright minds due to prospect on the job market, moreover the city is attractive to young bright minds because of lower living costs compared to bigger cities (Stadt Paderborn, 2021). The region furthermore has smaller cities and more rural regions. The economy of the region is diverse and offers leisure activities to visitors and its residents (Regieringsbezirk Detmold, 2021).

Düsseldorf

Düsseldorf is in the west of North-Rhine Westphalia, Düsseldorf is the most important city and the capital of the whole of North-Rhine Westphalia. Other important cities are Duisburg and Monchengladbach. In 2018 the regional GDP per capita was €41.500 and unemployment was 4.3% (Eurostat, 2020). Düsseldorf city is the political heart of the Düsseldorf region and North Rhine Westphalia. Furthermore the city is an important financial hub, with a large banking centre but also a stock market. Next to the financial importance of the city, Düsseldorf is a telecom and marketing centre in the region. Fashion and haute couture is relatively well represented in the city's economy. The city's airport is one of Germany's busiest airports and the city host large conventions in 'Messe Düsseldorf'. It is the most internationally connected city of the region, and a truly service minded city (Düsseldorf Wirtschaft, 2016). West of the city Düsseldorf is a more rural area of the region, directly east and north of the city are the cities: Duisburg, Essen and Wüppertal. These cities are in the Ruhr area and have an industrial history. Duisburg and Essen are cities that are finding back their economic prominence, especially Essen is developing in to modern service sector city. Yet unemployment remains high compared to standards of North Rhine Westphalia and Germany, namely 10%. (Bundesagentur für Arbeit, 2021). Mönchengladbach is a city west of Düsseldorf, historically this city was a textile city. Nowadays the economy is more diversified, yet unemployment rates are equally high as in Duisburg and Essen.

Münster

Münster is the northern region of North-Rhine Westphalia. Münster and Gelsenkirchen are the most important cities. The south of this region is part of the industrial Ruhrgebiet whilst the countryside around Münster offers lush green landscapes. In 2018 the regional GDP per capita was €33.600 and the unemployment was 3.6% (Eurostat, 2020). The city of Münster is a university city. More than 20% of the residents of Münster is a student. The Westfälische Wilhemls-Universität is one of the leading universities in the country. Moreover the city has a university of applied sciences, an art academy, a music academy and an academy where police students are trained. Science and innovation are thus important in the city (Stadt Münster, 2021). The university and the government are the city's biggest employer, large industries or large companies (headquarters) are absent in the city. The city of Gelsenkirchen is in the south of the region. It is one of the poorest cities in Germany, as of March 2021 the unemployment rate exceeds 15.1% (Bundesagentur für Arbeit, 2021). The city has problems coping with the structural economic changes in the post-industrial era. Besides these two bigger cities the region has smaller urban centres and mainly smaller settlements. This region relatively rural compared to the other four regions.

Methodology

To measure to what extent innovation in North-Rhine Westphalia contributes to strong socio economic endowments a quantitative research is conducted. This thesis uses a deductive approach were general theories on the relation of innovation and socio economic endowments are tested by using hypotheses (Bryman, 2012, 160). Measuring innovation can be done in many ways, in this thesis patents will be used as an indicator of innovation. Data on patents have large quantities, furthermore do they contain rich information on technology fields, location of filing and various quality indicators (Petralia et al., 2017, 959). The latter three will be used in the remainder of the thesis. The data on patents comes from the REGPAT dataset that is constructed by the OECD. From this database the following two databases have been used: 'OECD REGPAT Database' and 'OECD Patent Quality Indicators Database' (OECD, 2021). The first dataset entails information on patents per region from the EPO and USPTO. The second dataset offers information on indicators of quality of the patents from EPO and USPTO. Both datasets contain information on patents from 1978 to 2020. The datasets were combined to generate a complete dataset of all the patents and their respective indicators of quality. After the combination of the two datasets the patents of Germany were filtered out to fit the research. All the calculations in the thesis have been done by using R.

First stage of the analysis: EconGeo Package

The research in the thesis is done in two stages. The first stage of the research uses the EconGeo package in R, developed by Pierre Alexandre Balland. The EconGeo package is ideal in analysing spatial distribution of economic activities (Balland, 2017). Within this first stage of the analysis only the quantity of patents per technology field region is used, the quality indicators are neglected in this stage of the thesis. The aim of this stage of the research is to establish North-Rhine Westphalia's innovation position in Germany and to establish which region within North-Rhine Westphalia is most innovative. Within the EconGeo, the following calculations have been executed:

1. Get a matrix before calculating
2. Location quotient (RCA)
3. Herfindahl index
4. Shannon index
5. Relatedness (co-occurrence)
6. Knowledge complexity
7. Ubiquity

Location quotient (revealed comparative advantage) can calculate if a certain region has advantages in certain industries. In that manner it becomes clear if a region is a sort of specialist in that industry. The Herfindahl index goes even a step further. This index can show if an industry holds a monopoly position in one of the regions. The exact opposite of the Herfindahl index is the Shannon index. This index measures the diversity between the patents. The higher the score of the Shannon index is, the more diverse and rich the region's patents applications are. "*Shannon index increases with richness and evenness, and it puts more weight on the richness than on evenness*" (Zeleny, 2021). Relatedness (co-occurrence) will calculate the relatedness between the industries present in Germany. Going a step further, knowledge complexity is calculated. This calculation will show how complex the knowledge is that is being produced in the region. It does so by referring to the number of interdependent technologies in the regions. The last calculation of the first part of the analysis is ubiquity. Calculating ubiquity can be related to knowledge complexity. If a region makes non-ubiquitous products it means the products are difficult to make, there is not much interest in the product from the consumer side or the product is linked to the geography of the respective region (Balland, 2017).

To start analysing the data needs to be prepared. The different technology fields are shown in table 1 in appendix 1. The first step was to add a variable 'count number' to every patent with value '1', this enables to count patents in a desired manner. Once this was completed the next step was to distinguish the different regional codes from each other. The region code in the dataset was at NUTS-3 level. For the analysis of all Bundesländer (NUTS-1 level) all the NUTS-3 level regions were attributed to the corresponding NUTS-1 level region via a separate data file. The dataset was aggregated to show the amount of patents per NUTS-1 region per technology per year. In the analysis two decades (2000-2009) and (2010-2019) will be analysed. This is done to see if changes in innovation have occurred in the two decades. A lack of data in data prior to 2000 in the second stage of the analysis is the main reason behind this choice. Subsetting the data to the two respective decades was the next step. After completion the dataset was subsetted once more to eradicate the filing year. The final data file looked as follows:

Region	Technology field	Patent count
Baden Württemberg	1	xx
Baden Württemberg	2	xx
Bavaria	1	xx

The multiple calculations from the EconGeo package by Balland could be run now.

The second part of the first analysis followed a similar pattern as the first part of the first analysis. The national dataset was subsetted to all patents of North-Rhine Westphalia (NUTS-1 region), the NUTS-3 regional code was aggregated to their five corresponding (NUTS-2) regions of North-Rhine Westphalia via the same separate data file. This data file was subsetted to the two decades too. In the first stage of the analysis two hypotheses are tested:

Hypothesis 1: North-Rhine Westphalia is the most innovative Bundesland of all German Bundesländer

Hypothesis 2: The regions Cologne and Düsseldorf (regions with the highest GDP per capita) are the most innovative regions of North-Rhine Westphalia

Second stage of the analysis: regression analyses

The second analysis stage of the thesis is a regression analyses to research if innovation influences the socio economic standards in North-Rhine Westphalia. The socio economic standards are regional GDP per capita purchasing power standards (PPS) and unemployment. Regional GDP per capita (PPS) is an indicator of economic output of a region. Using PPS eradicates differences between countries (Eurostat, 2021). Although this research is done at a national scale using PPS is still fruitful as it uses index numbers and differences between regions can be grasped easily, 100 is the EU average per respective year. The lowest score is 99 for Münster in 2019. Cologne has the highest rate of 134 in 2014. Unemployment rates show the share of unemployed people in the economically active population (Eurostat, 2021). The highest unemployment rate is recorded in 2009 in Arnsberg: 9.2%. The lowest unemployment rate is 3% in Detmold in 2019. The regional GDP per capita (PPS) ranges from 2008 to 2019, the data on unemployment rates ranges from 2009 to 2020. To complete regression analyses the Y variables in R cannot have empty values (NA) in their columns, hence only the patents from 2008 to 2019 and 2009 to 2020 are used in the analyses.

Figure 4: Descriptive statistics of dependent and explanatory variables

N = 634					
Variables	**Indicator**	**Minimum**	**Maximum**	**Mean**	**SD**
GDP per capita (PPS)	Regional (NUTS-2) GDP (purchasing power standards per inhabitant). 100 is European average	99	134	118.89	11.80
Unemployment	Unemployment percentage per (NUTS-2) region per year	3	9.2	5.47	1.44

Patents	Patents per (NUTS-3) region per year	1	610	82.53	101.7
Quality of patents	Average quality scores of patents per year per (NUTS-3) region	0.085	0.717	0.273	0.051
Originality of patents	Average of all originality scores from patents in a year in a (NUTS-3) region	0.412	0.914	0.687	0.069
Radicalness of patents	Average radicalness scores from patents in a year in a (NUTS-3) region	0.054	0.727	0.345	0.076
Human capital	Percentage of higher educated people per (NUTS-2) region	20.9	30.9	24.9	2.76
Creative class	Percentage of cultural employers per year (NUTS-2) region	2,7	5.0	3,62	0,72
Population density	Population density of (NUTS-2) regions of NRW in km^2 per year	310	1007	602,73	254,7

The independent variables are quantity of patents and three quality indicators of the patents: quality-, originality- and radicalness of patents. The amount of patents per year per NUTS-3 region differs very much. Euskirchen (Cologne) in 2016 and Gelsenkirchen, Kreisfreie Stadt (Münster) in 2019 had only one patent. The most patents per year that a NUTS-3 region filed was Mettmann (Düsseldorf) in 2011: 610. The NUTS-2 region Düsseldorf has most NUTS-3 regions that have the most patent files per year. NUTS-3 regions that have the least patents per year are more evenly divided between the five NUTS-2 regions, yet Münster and Arnsberg are overrepresented.

The quality index uses four components to measure the quality of patents: number of forward citations (up to five years of publication), patent family size, number of claims and the generality index of the patents (Squicciarini et al., 2013, 59). The quality indicator entails the technological and economic value of innovations, a higher quality index of a patent means more technological and economic value. In the regression analysis the mean quality of patents per year per NUTS-3 region is used. The highest score on quality of patents is an outlier and is Oberbergischer Kreis (0.717) (Cologne) in 2019. The second best score is significantly lower with 0.511 is Hamm, Kreisfreie Stadt in Arnsberg. At the lower end are scores of lower than 0.1, regions in Cologne and Düsseldorf have the lowest quality scores. The originality index refers to the breadth of technologies on which a patent relies (Squicciarini et al., 2013, 49). A higher originality score per patent is reached when this patent depends on a broad range of different technologies. A more diverse set of knowledge leads to a more original patent/innovation. Like the quality indicator, the originality index of patent per year per NUTS-3 region is calculated. Originality scores are generally higher than quality scores. Regions with lower originality scores are divided evenly over the five NUTS-2 regions. Thirdly, the radicalness index is based on the idea that the more a patent cites previous patents in technologies other than the ones it is in, the more radical this invention is (Squicciarini et al., 2013, 53). This index is similar to originality index due to the wide arrange of different technologies it relies on. But it is different because the radicalness index values using this knowledge outside the paradigm of these technologies. The radicalness index is also measured as mean per year per NUTS-3 region in North-Rhine Westphalia. Geographically radicalness scores are evenly divided over the NUTS-2 regions. All five regions have NUTS-3 regions with low and high average radicalness scores. These three indicators give a good and diverse overview of the patent quality in the respective years per NUTS-3 region. Radicalness of patents has similar minimum and maximum values as quality of patents. Regions with the lowest scores are located in Arnsberg, on the other end of the spectrum the regions with the highest average radicalness scores are regions with less than five patents in a respective year. The quality index shows how the patents are perceived in the years after and the latter two on the basis on which the patens rely on, with both their unique facets. By using the quantity of patents and the three different quality indicators a broad base is set to measure innovation in North-Rhine Westphalia.

The three control variables are the human capital -, creative class- the population density per NUTS-2 region. The share of higher educated people is the indicator of the human capital variable. The share of higher educated people is calculated as people whom have a tertiary education degree in the age group of 25 to 64. The higher the share of higher educated people, the more human capital a region has. In multiple years Arnsberg has the lowest share of higher educated people of all regions, Detmold also has a low relative share of higher educated people. Cologne and Düsseldorf have the highest share of higher educated people. The creative class variable uses the percentage of cultural employers per region as an indicator. This is calculated as the share of workers in cultural employment of the total employment. This data specifically tells how many people are occupied within the cultural sector as a main job (Eurostat, 2021). In this indicator the lowest score is 2.7%, which represents Münster in 2017. Alongside Münster Arnsberg also has a relatively low share of employers in the cultural sector. The region with the highest share of cultural employers is Cologne with 5% in 2015. The final control variable is population density of the five NUTS-2 regions of North-Rhine Westphalia and is measured by people per square kilometre per year. The most densely populated region is Düsseldorf with a population of 1007 per km^2 in 2019. This has steadily increased over the years that the research is conducted. In second place is Cologne with around 600 people per km^2 on average, a big difference compared to Düsseldorf. The least populated NUTS-2 region of North-Rhine Westphalia is Detmold. The eastern region only has approximately 300 people per km^2 on average. Based on the work of Frietsch et al (2014) and Florida (2003) the following hypotheses have been created and will be tested in the analysis:

Hypothesis 3: Innovation plays a major role in maintaining high socio economic standards in North-Rhine Westphalia

Hypothesis 4: The creative class has more influence on maintaining high socio economic standards than human capital

Why use patents to measure innovation?

Innovation is hard to measure and in the academic debate consensus on how to measure innovation is still absent. Indicators such as R&D expenditure or personnel in working in R&D are commonly used to measure innovation. These indicators give an image of the input of innovation not the output, furthermore is the public expenditure on R&D not a unifying indicator as some governments can choose to invest more whilst in other nations R&D is more funded by private enterprises. Another way of measuring innovation is measuring the amount of scientific papers from a geographical entity. The amount of scientific papers doesn't capture all the new innovations that are done because not all articles describe new inventions. The value of export of high tech products is a different means of measuring innovation, yet it can be possible that a product that is exported from region A is invented in region B. Therefore this indicator is flawed too when trying to measure innovation. Patents are most suitable to measure innovation, firstly because of the great quantity, secondly because of its uniformity worldwide. The data that is used in this thesis comes from a dataset that has information on patents worldwide. The amount of granted patents can thus be compared easily between geographic entities. The indicators of quality per patent give an extra dimension to this indicator as it gives more opportunities to compare innovation standards than solely quantity of patents (Fan, 2014).

Using patents as indicator for innovation ensures high validity with the great quantity and richness of the data, whilst still regarding that measuring innovation with patents is not perfect. Measuring the share of higher educated people with people that have tertiary education between the age of 25 and 64 ensures a complete image of the people in the region's workforce that are highly educated. The use of cultural employers statistics is valid in measuring the creative class because it measures "*people working in economic activities that are deemed cultural, irrespective of whether the person is employed in a cultural occupation. It also covers persons with a cultural occupation, irrespective of whether they are employed in a cultural economic activity."* (Eurostat, 2021). Furthermore it takes the large amount of self-employment in account that is present in this sector. Taking data on population density from the NUTS-2 regions is done to test Malecki's statement that dense regions are more innovative than less urban regions. The dependent variables have been chosen to not only highlight the regional's economic performance (regional GDP (PPS) per capita) but to also to measure if more people benefit from this economic welfare (unemployment rates). The data form Eurostat to measure these variables completely represent the values of these variables. In terms of reliability the data that has been used comes from reliable sources that are frequently updated. This ensures that the concept are measured stably (Bryman, 2012, 715). In line with the reliability of the data, the data is suitable too. The data is rich, frequently updated and comes from reliable sources. In most cases the data represents the chosen variables in a direct manner.

Analysis

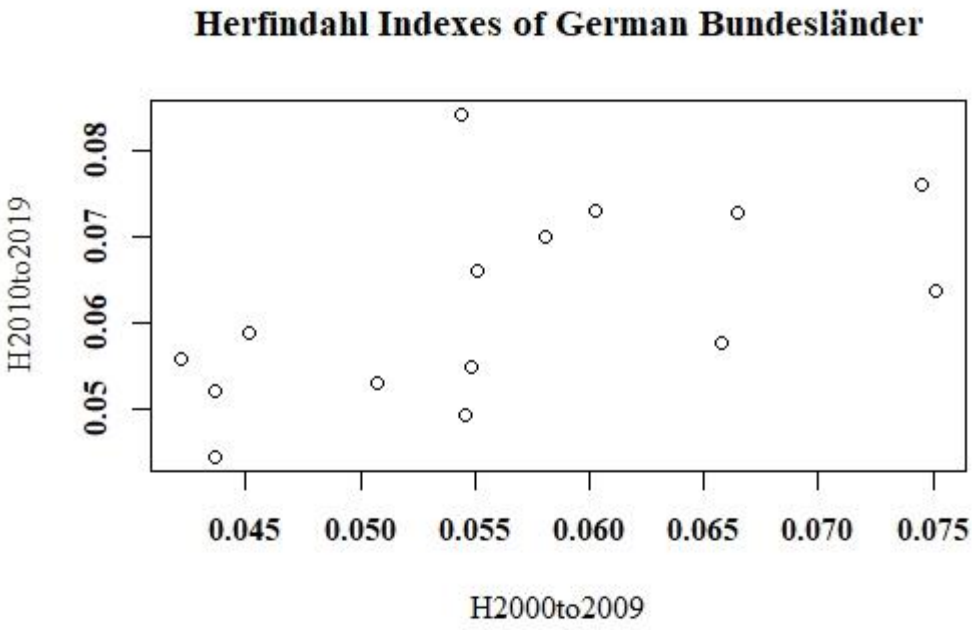
Analysis 1: EconGeo package

Location Quotient (Revealed Comparative advantage) (North-Rhine Westphalia in Germany)

The EconGeo package by Balland (2017) will give information on where North-Rhine Westphalia is positioned on innovation in Germany. Which technologies are present, which are absent and if other regions are performing better or worse than North-Rhine Westphalia. The analysis is done in two timeframes (2000-2009 & 2010-2019). The location quotient (Revealed Comparative Advantage) shows in which industry a respective region has an advantage. Between 2000 and 2009 North-Rhine Westphalia had a revealed comparative advantage in patenting in mainly chemistry industries as divided by the OECD, organic fine chemistry and basic materials chemistry are examples of the chemical industries. Mechanical engineering is an overarching industry where North-Rhine Westphalia performs well too. On the other hand North-Rhine Westphalia underperforms in the electrical engineering sectors such as telecommunications and computer technology. In the fields of electrical engineering North-Rhine Westphalia underperforms comparing to Baden-Württemberg, Bavaria and Berlin as these states show a revealed comparative advantage. An interesting visible pattern is the revealed comparative advantage of chemistry in Germany. North-Rhine Westphalia, its neighbours Hesse and Rhineland-Palatinate and former East German region Saxony-Anhalt all show a positive image in patenting in chemistry, whilst top economic regions Baden-Württemberg and Bavaria underperform in this industry. Between 2010 and 2019 the industries in which North-Rhine Westphalia had a revealed comparative advantage stayed primarily equal. In the most recent decade North-Rhine Westphalia gained revealed comparative advantage in the field of digital communications and IT methods for management. The region was able to expand its knowledge in some electrical engineering fields compared to the other German Bundesländer. Simultaneously North-Rhine Westphalia kept its presence in the field of knowledge on chemistry. Comparing North-Rhine Westphalia's development in some technology fields with Hesse's development shows that North-Rhine Westphalia was able to develop better and in more industries. Hesse shows little changes in revealed comparative advantage scores in the two decades compared. The same pattern is visible in Rhineland-Palatinate, the southern neighbour of North-Rhine Westphalia showed no almost no changes in revealed comparative advantages in technology fields. Another striking pattern is the decrease in revealed comparative advantages in electrical engineering fields of Berlin. The capital region still performs better than North-Rhine Westphalia in this field yet the region seems to catch up with Berlin. Results are visible in figures 2 to 4 in appendix 1.

Herfindahl index (North-Rhine Westphalia in Germany)

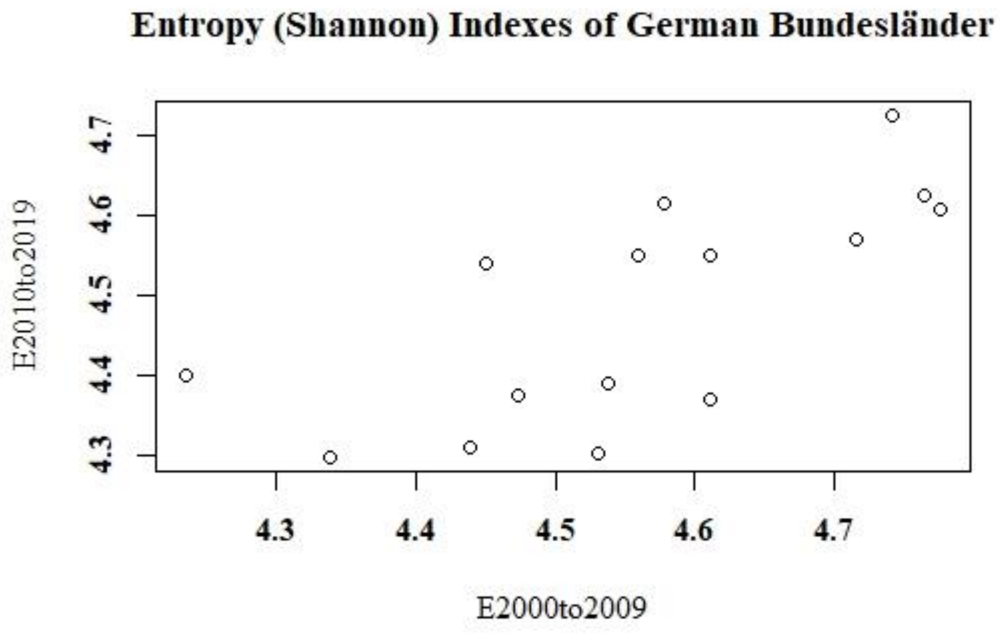
Figure 5: Herfindahl indexes of German Bundesländer 2000-2009 & 2010-2019.



The Herfindahl indexes of the Bundesländer of Germany are all small in sizes. The figures are small and therefore show the diversity in technology fields of patents that the regions have. None of the regions comes close to dependence on one certain industry in patents. As is visible figure 5, some Bundesländer had relatively high Herfindahl indexes in the 2000's, and they remain relatively high in the 2010's. It shows how diverse the economy is of the regions. Some regions show small change, albeit positive or negative in the two timeframes, yet the changes are so small that the significance of these changes miniscule. Thus, North-Rhine Westphalia is no exception compared to the other Bundesländer.

Entropy (Shannon) Index (North-Rhine Westphalia in Germany)

Figure 6: Entropy (Shannon) indexes of German Bundesländer 2000-2009 & 2010-2019.



Entropy Shannon indexes of the German Bundesländer are all quite similar. None of the scores is an outlier. Regions with higher entropy scores in the 2000's have higher entropy scores in the 2010's as well, showing consistency as a diverse economy in figure 6. The small differences in scores indicate small differences between the regions considering entropy. The scores of over 4 indicate a high richness in a diverse set of technology fields. It also shows that the regions not only have a diverse set of technologies, these technologies also are significantly prevalent in the respective regions. No significant differences between the two decades exist showing consistency over time in the German regions. Equal to the Herfindahl index, the entropy (Shannon) index for North-Rhine Westphalia is not very different from the other Bundesländer.

Co-occurrence, relatedness and relatedness density (North-Rhine Westphalia in Germany)

With the relatedness function from the EconGeo package the relatedness between industries in Germany is calculated. The first step is to measure co-occurrence of industries, this calculates the number of co-occurrences between industry pairs (Balland, 2017, 3). This is necessary to measure relatedness, which measures the relatedness of industries in Germany. Then it is possible to measure the relatedness density of regions. A high relatedness density could indicate the presence of a cluster in the region. In the 2000's North-Rhine Westphalia ranks in the top-3 of all the technology fields. This signals the all-round presence of all technologies in the region. Consistently ranked in the top-3 of every technology field are the two southern regions of Bavaria and Baden-Württemberg. This confirms the strong position of innovation according to patenting of the three regions that was revealed by revealed comparative advantage. North-Rhine Westphalia has the highest related density in most of the chemistry industries. Furthermore the region has the highest related density in some mechanical engineering technology fields. In the 2010's the same geographical record is visible in regions that have the highest relatedness density of Germany. North-Rhine Westphalia, Bavaria and Baden-Württemberg reign supreme. North-Rhine Westphalia is the number one in almost all of the chemistry technology fields. Furthermore, North-Rhine Westphalia now has the highest related density is in more technology fields outside the realm of the chemistry industry. An increase that shows that North-Rhine Westphalia is gaining more knowledge outside of the chemistry industry. Results are visible in figures 5 and 6 in appendix 1.

Knowledge complexity (North-Rhine Westphalia in Germany)

Knowledge complexity measures how relative complex the knowledge is per technology field. The complexity of knowledge is calculated by the EconGeo package too. The knowledge complexity scores vary differently. North-Rhine Westphalia is a relatively strong region in knowledge on chemistry in the 2000's. The knowledge complexity of the chemistry industry is relatively low. The individual technology fields of chemistry rank at the bottom half of the knowledge complexity. It must be noted that this is relatively complex compared to the other technology fields. The individual fields of the electrical engineering score highest on knowledge complexity. In these fields other Bundesländer have better revealed comparative advantage than North-Rhine Westphalia. In the 2010's the chemistry industries created relatively the least complex knowledge. Notwithstanding the fact that their scores have improved slightly. The electrical engineering technology fields are not the ones who relatively create the most complex knowledge in Germany, mechanical engineering produces relatively more complex knowledge then in the 2000's. North-Rhine Westphalia thus produces in both decades the most knowledge in chemistry yet this is not the most complex knowledge in Germany. The fields that create the most complex knowledge are also well represented in North-Rhine Westphalia, yet other regions create more complex knowledge in those fields. Results are visible in figure 7 in appendix 1.

Ubiquity (North-Rhine Westphalia in Germany)

Technology fields that are ubiquitous are technology fields that are very common. If a region produces knowledge that is very ubiquitous it means the region produces knowledge that is less diverse and probably less complex. In the 2000's the industries with the highest ubiquity scores are mainly within the chemistry sector. A confirmation that these industries create the least complex knowledge. A confirmation that North-Rhine Westphalia is a region with the best revealed comparative advantage in industries that produce knowledge that are ubiquitous and less complex knowledge. Mainly Bavaria, Baden-Württemberg and Berlin produce complex knowledge from electrical engineering industries in the 2000's. In the 2010's a mutual impression of the chemistry industries is present. The technology fields in this sector produce the most ubiquitous knowledge. Although electrical engineering is still well represented at the top of least ubiquitous technology fields, mechanical engineering performs better in the latter decade. The image is corresponding to the knowledge complexity calculations. North-Rhine Westphalia performs best in industries that are less complex and more ubiquitous, nonetheless it should be noted that North-Rhine Westphalia still ranks high in regards to relatedness density in industries that produce more complex and less ubiquitous knowledge. Results are visible in figure 8 in appendix 1.

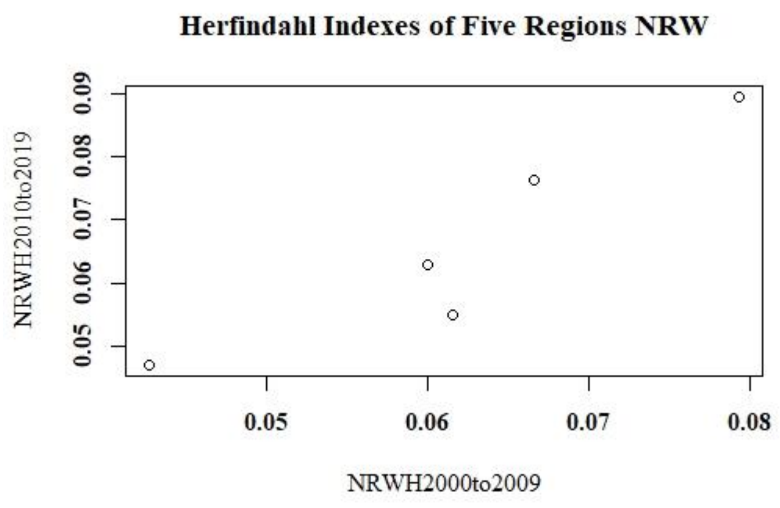
Location Quotient (Revealed Comparative advantage) (Five regions North-Rhine Westphalia)

In the first stage of the first part of the analysis the position of innovation of North-Rhine Westphalia in Germany has been researched. In the second stage an internal research of North-rhine Westphalia will be conducted. A similar analysis will be done to research what kind of innovation takes place within the five regions (Arnsberg, Cologne, Detmold, Düsseldorf and Münster) of North-Rhine Westphalia and how they compare to another.

North-Rhine Westphalia has a revealed comparative advantage in the technology fields of chemistry. In the 2000's the two regions Cologne and Düsseldorf are the two regions within North-Rhine Westphalia that mainly have a revealed comparative advantage in the chemistry technology fields. It seems as if these two regions therefore play an important role in North-Rhine Westphalia's innovation on a national scale. In electrical engineering Cologne plays a major role as well, Arnsberg and Detmold have revealed comparative advantage in some of the technologies too. Düsseldorf and Munster have no revealed comparative advantage in electrical engineering. In the instrument technology fields Düsseldorf doesn't have any revealed comparative advantage, the other four regions have some, with Cologne having the most technology fields with revealed comparative advantage. In mechanical engineering Arnsberg and Detmold have the most technology fields with revealed comparative advantage, Münster plays a significant role too. Düsseldorf and Cologne have a revealed comparative disadvantage, with this being Cologne's worst performance. In 2010's no big changes occurred in the fields of electrical engineering. Cologne, Arnsberg and Detmold remain the best performers whilst Düsseldorf and Münster have a revealed comparative disadvantage. In the instruments technology fields no real changes occurred over time too. Cologne and Düsseldorf remain the regions with a revealed comparative advantage in chemistry in the 2010's, although Münster has some more technology fields with revealed comparative advantage than in the decade before. In mechanical engineering the regions Detmold and Münster perform the best of the five regions in North-Rhine Westphalia, whilst Düsseldorf and Cologne are again underperforming in these technology fields. Results are shown in figures 9 to 11 in appendix 1.

Herfindahl index (Five regions of North-Rhine Westphalia)

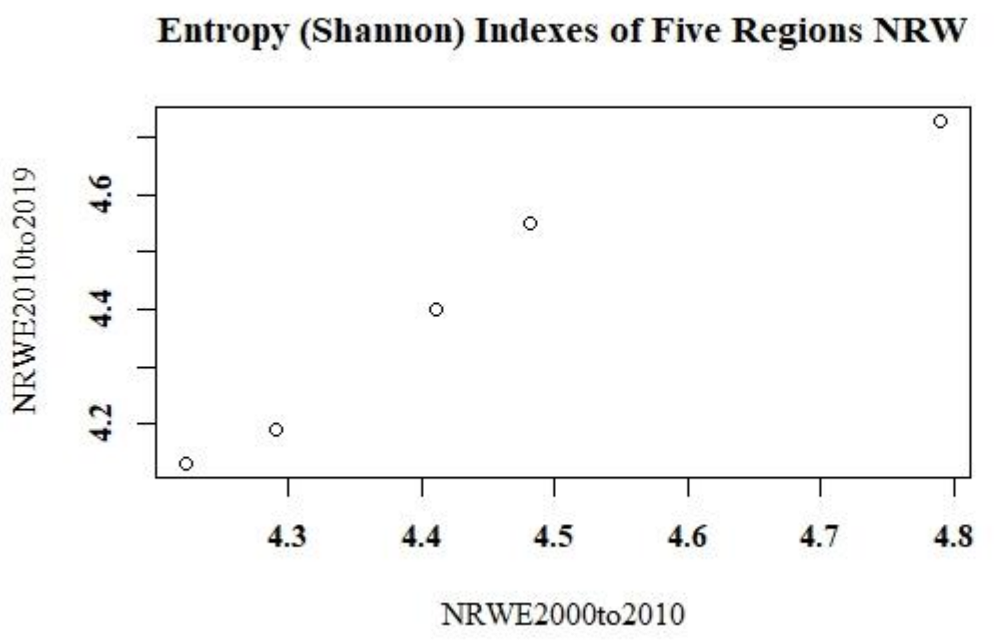
Figure 7: Herfindahl indexes of North-Rhine Westphalia regions 2000's & 2010's.



The Herfindahl indexes of the five regions of North-Rhine Westphalia are all very small. It shows that not one technology field in the case of innovation is dominant in one of the regions. In figure 7, the region with the lowest scores (Cologne) shows lowest scores both decades and is the least dependent on one technology fields, yet differences are so small that significant differences between the regions are absent. Furthermore, none of the regions undergone major changes in the two decades.

Entropy (Shannon) Index (Five regions of North-Rhine Westphalia)

Figure 8: Entropy (Shannon) indexes of North-Rhine Westphalia regions 2000's & 2010's



In figure 8 a clear line is visible, the region with the lowest entropy index in the 2000's has the lowest entropy index in the 2010's too. This consistency is also visible in the region with the highest entropy score. Between the two decades the values for the regions stay approximately equal, signalling no big differences in diversity over time the Shannon entropy- and Herfindahl index of the regions indicate that the same pattern. The scores are similar to those of all German Bundesländer and confirms the diversity of the economy of all the regions. The regions are not dependent on one single technology in innovation and all have diverse set of technologies in innovation.

Co-occurrence, relatedness and relatedness density (Five regions of North-Rhine Westphalia)

With these calculations potential clusters of industries in North-Rhine Westphalia could be spotted. Industries that have high relatedness densities could be a cluster. Prior to the relatedness density co-occurrence and relatedness have been calculated. In the decade 2000-2009 Düsseldorf had the highest relatedness density in electrical engineering. Cologne had the second highest scores, Münster had the lowest scores in all technology fields of electrical engineering. A synonymous pattern is visible in the instruments technology fields. Münster has the lowest relatedness density whilst Düsseldorf and Cologne have the highest relatedness densities in these technology fields. The chemistry technology fields show highest relatedness densities in Cologne and Düsseldorf too, the other three regions lagging behind. Mechanical engineering clusters could be found in Düsseldorf as the region consistently has the highest relatedness density in this sector. From 2010-2019 no dramatic changes have been found. Düsseldorf and Cologne remain the regions with the highest relatedness density in all sectors. Münster is often ranked lowest in regards to relatedness density per technology field. Arnsberg and Detmold remain consistently behind Cologne and Düsseldorf, occasionally having more relatedness density than the two aforementioned regions, whilst sometimes having lower relatedness density than Münster. Results are visible in figures 12 and 13 in appendix 1.

Knowledge complexity (Five regions of North-Rhine Westphalia)

In the 2000's the technology fields with the highest relative complex knowledge were mainly in the chemistry and electrical engineering sector. Six technologies had maximum relative complexity. Considering Cologne and mainly Düsseldorf have the highest relatedness density it seems that these regions innovate the most in these sectors and also produce relatively the most complex knowledge. On the other hand in the 2000's two technology fields have a minimum relative complex knowledge. These are organic fine chemistry and materials, metallurgy. Both these fields are in the chemistry sector and also in these regions Düsseldorf and Cologne have the highest relatedness density and revealed comparative advantage. From 2010 to 2019 even more technology fields have maximum relative complexity. Electrical engineering is the main contributor with four technology fields. Once more confirming the strong position Düsseldorf and Cologne play in North-Rhine Westphalia's innovation. It should be noted that these two regions also have a revealed comparative advantage and high relatedness density in the technologies that have minimum relative complexity. Results are visible in figure 14 in appendix 1.

Ubiquity (Five regions of North-Rhine Westphalia)

The ubiquity figures from the five regions in North-Rhine Westphalia completely differs from that of all German Bundesländer. Differences in values are far smaller and the maximum ubiquity value is 4. The values suggest that all patents in all technology fields are not ubiquitous. In the first decade mainly electrical engineering- and chemistry technology fields create knowledge that is non-ubiquitous. At the same time these two sectors have technology fields in the ubiquitous realm too. In the following decade more technology fields produced relatively less ubiquitous knowledge (13>11). It is remarkable that the most of the technology fields with non-ubiquitous knowledge in the 2000's remain producing non-ubiquitous knowledge in the 2010's. Examples of these technology fields are: telecommunications, digital communication and IT methods form management. Furthermore, more technologies in the 2010's became more ubiquitous (12>11). Two of the twelve technology fields, namely: analysis of biological materials and transport are more ubiquitous than the most ubiquitous technology fields in the 2000's. The pattern that is visible is that differences between technology fields is expanding. In the first decade the ubiquity rates were more equally divided. In the second decade technology fields that produced more non-ubiquitous knowledge became further apart from technology fields that created more ubiquitous knowledge. This image is in line with the findings from the complex knowledge calculations that more complex knowledge is being produced in the 2010's. Results are visible in figure 15 in appendix 1.

Analysis 2: Regression analysis of North-Rhine Westphalia

Regression analysis: Regional GDP per capita (PPS) as dependent variable

Figure 9: Regression output, dependent variable: regional GDP per capita (PPS)

Independent variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Patents	0.030^{***} (0.004)	0.025^{***} (0.005)	0.021^{***} (0.004)	0.014^{***} (0.004)	0.011^{***} (0.003)	0.002 (0.002)
Quality of patents		1.067 (9.111)	-3.366 (6.991)	-4.810 (6.346)	7.118 (6.326)	2.676 (2.373)
Originality of patents		15.733^{*} (9.390)	-6.610 (7.946)	10.320 (8.331)	-6.128 (6.573)	-2.723 (3.174)
Radicalness of patents		13.784 (8.427)	10.447 (6.761)	6.247 (6.871)	-6.128 (6.573)	0.762 (2.563)
Human capital			2.706^{***} (0.141)			-1.237^{***} (0.101)
Creative class				12.244^{***} (0.560)		14.858^{***} (0.378)
Population density					0.033^{***} (0.001)	0.027^{***} (0.001)
Constant	116.416^{***} (0.583)	101.307^{***} (5.401)	52.753^{***} (5.341)	65.472^{***} (5.224)	97.960^{***} (3.750)	80.085^{***} (2.148)
N	634	592	434	277	592	277
(Adjusted) R^2	0.067	0.079	0.501	0.660	0.557	0.953
$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$						

The first regression analysis has regional GDP per capita (PPS) as dependent variable. This variable ranges from 2008 to 2019. The first model is the single linear regression on the influence of the amount of patents on regional GDP (PPS). The variance in GDP is only mildly explained by the amount of patents in the regions given the low R-square value (0.067). Furthermore is the influence on the amount of patents very small, with the increase of one patent, the regional GDP (PPS) will rise with 0.030. Using the amount of patents as an explanatory variable for regional GDP (PPS) is significant with a p value < 0.001. In the second model of the regression analyses the three quality indicators (quality, originality and radicalness) of patents are added. In this model only the adjusted R-square is low indicating a low influence on the variance of regional GDP (PPS) by the intrinsic value of patents. The second model is significant, yet not all variables are, the quality- and radicalness of patents influence on regional GDP (PPS) are not significant. 42 observations are lost because the quality of patents indicator is not as complete the quantity of patents. Mainly in more recent years some NUTS-3 regions don't have an average quality indicator as not all patents are cited or forwarded and some NUTS-3 regions had very little patents in the respective years. The relationship between originality of patens and GDP (PPS) is unlikely due to chance and the amount of patents likewise. Both patents and their average originality per region per year have a positive influence on the regional GDP (PPS), albeit their values differing greatly. The intrinsic values influence on the regional GDP (PPS) is hard to establish considering the different values and the inconsistency in significance among these explanatory variables. Hence, control variables are added individually in the model. First human capital is added in to the model. In this third model more observations have dropped because data on human capital only ranges from 2011 to 2019. What is striking is the much higher adjusted R-square value, the discrepancy in regional GDP (PPS) can for 50% be explained by the differences in human capital per NUTS-2 region. The intrinsic values of patents are all three not significant anymore. Simultaneously the amount of patents and the human capital are very significant. A one percent increase in share of higher educated people raises the regional GDP (PPS) with 2.7. The second control variable is the creative class in the region. Removing the human capital and adding the creative class gives an even greater adjusted R-square value. In the fourth model more observations have dropped as data on the share of cultural employers only was available in the years 2014 to 2019. The same figure as with the share of higher educated people is established. The intrinsic patent values become insignificant whilst the patents themselves and the newly added variable, cultural class in the region are very significant. The influence of the share of cultural employers on regional GDP (PPS) is even greater than the influence of the share of higher educated people. This could be because the relative differences between the values of cultural employers between the regions is bigger. The last value that is added to check the influence of innovation on regional GDP (PPS) is population density. The adjusted R-square value with is comparable to those of the prior to analyses. The influence of population density on regional GDP (PPS) is smaller than that of the prior two variables, yet its presence makes the intrinsic values of the patents insignificant. The influence of the amount of patents remains consistent throughout all the analyses. The final model has all independent variable put together. The amount of observations is equal to the fourth model. This is because R uses only observations where all variables are complete, in this case from 2014 to 2019. In this final model it becomes clear that the influence of innovation alone is not significant. The three control variables have significant influence on the regional GDP per capita (PPS). The influence of population density of a NUTS-2 region is small, a positive influence just above zero. It is interesting to see that human capital has a negative influence on the regional GDP per capita (PPS) whilst the cultural class influences the regional GDP per capita (PPS) in a positive manner. The general pattern that comes from these analyses is the amount of patterns has a small positive influence regional GDP (PPS), the intrinsic values of these patents have a very small influence on regional GDP (PPS). Once they are checked with a control variable that is linked to the regions their influence is only based on chance.

Regression analysis: Unemployment as dependent variable

Figure 10: Regression output, dependent variable: Unemployment rates

Independent variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Patents	0.001^{**} (0.001)	0.001 (0.001)	0.001^{*} (0.0005)	0.001 (0.0005)	0.0005 (0.001)	-0.0005 (0.0004)
Quality of patents		-0.711 (1.161)	0.329 (0.852)	-0.278 (0.790)	-0.581 (1.145)	0.623 (0.547)
Originality of patents		-2.847^{**} (1.236)	0.461 (0.968)	-0.388 (1.037)	-3.465^{***} (1.229)	0.476 (0.732)
Radicalness of patents		1.079 (1.092)	1.250 (0.825)	0.943 (0.856)	0.909 (1.077)	0.303 (0.591)
Human capital			-0.132^{***} (0.017)			-0.364^{***} (0.023)
Creative class				-0.209^{***} (0.070)		0.864^{***} (0.087)
Population density					0.001^{***} (0.0002)	0.002^{***} (0.0002)
Constant	5.347^{***} (0.077)	7.302^{***} (0.708)	7.485^{***} (0.650)	5.324^{***} (0.650)	7.195^{***} (0.698)	8.747^{***} (0.495)
N	581	539	434	277	539	277
(Adjusted) R^2	0.011	0.007	0.122	0.023	0.034	0.535
$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$						

The second regression analysis will test the influence of the intrinsic values of patents and the three control variables on unemployment rates in North-Rhine Westphalia. This dependent ranges from 2009 to 2020. All other drops in observations per model have the same explanation as in the prior regression analysis. The first model in this analysis represents the influence of patents on unemployment in North-Rhine Westphalia. The R-square is very low, just one percent of the variance in unemployment rates can be explained by the amount of patents in North-Rhine Westphalia. Given the independent variable score is almost equal to zero (yet significant) the influence of patents on unemployment rates is very minimal. In the second model the intrinsic values of the patents are added. In this model the variation in unemployment rates can almost not be explained by these intrinsic values. The influence of patents only becomes insignificant, whilst the originality of patents does have a significant effect on unemployment rates. The more original patens are in a region, the lower the unemployment rates are. In model 3, the first control variable is added. The human capital per NUTS-2 region influences the unemployment rates significantly. If the share of higher educated people increases, unemployment rates will decrease. The differences in unemployment rates can be explained by the regression for 12%. The influence of the quantity of patents is significant, but the rate is very close to zero. None of the intrinsic values of patents has influence on the unemployment rates anymore. To see if this pattern holds true with other control variables the creative class per NUTS-2 region is added to the regression, whilst the human capital is removed. In this fourth model an equal image is visible. If the share of cultural employers rises in a NUTS-2 region the unemployment rate will descent. The influence of the quantity of patents is insignificant. The variance in unemployment rates can only be explained by the regression for 2.3%. The final control variable is population density. For model 5 this independent variable is added and the share of cultural employers in a NUTS 2-region is removed. The outcome of this remarkably different than the two regression analyses with other control variables. Whereas the first two control variables had a significant effect on unemployment rates - they fostered a decline in unemployment -, population density has a significant but very small influence on unemployment rates. The originality of patents has a more prevalent influence on unemployment rates. A far stronger effect than the human capital and creative class. The low adjusted R-square score indicates a low influence of the independent variables on the unemployment rates. The difference in outcomes of the models with the control variables makes it interesting to see what happens if all the independent variables are combined in one model. The outcome of this model makes the quantity- and intrinsic values of the patents insignificant. The three control variables are significant but show different directions. Population density has an effect that is very close to zero. The human capital of a NUTS-2 region of North-Rhine Westphalia has a negative influence. If the share of higher educated people increases, the unemployment rates decrease. The effect of the creative class of a region is contra wise. If their share rises, unemployment rates will rise too. The variation in unemployment rates can explained by all the variables combined in this model better than in the previous analyses, given the adjusted R-square of 53.5%.

Conclusion

The aim of the thesis was to research the influence of innovation on socio economic endowments (regional GDP per capita (PPS) and unemployment) in North-Rhine Westphalia. It did so by using data on patents for North-Rhine Westphalia and using other variables: human capital in a region, the creative class in a region and population density. The goal was to establish policy implications for regional policymakers who seek to improve socio economic endowments in their region, the research question was: *To what extent does North-Rhine Westphalia's innovation contribute to improving the socio economic position of North-Rhine Westphalia in Germany?*

To answer the main question first the state of North-Rhine Westphalia's innovation has been established using the EconGeo package by Balland (2017), in a second stage the influence of this innovation on the region's GDP and unemployment has been tested. The state of North-Rhine Westphalia's innovation shows that this Bundesland is one of the most innovative in Germany. The region is alongside Bavaria and Baden-Württemberg one of the most innovative regions in the country given these regions have highly revealed comparative advantage in all different technology fields in this research. To state that it is the most innovative region is exaggerated, but it is a key player in the nation. Furthermore the innovation in the regions is very diverse, yet all other German regions have diverse set of patents too. What was striking when looking at the complexity of knowledge is that North-Rhine Westphalia was strong in technology fields that created the least complex knowledge, the chemistry technology fields. To test the second hypothesis an internal research of North-Rhine Westphalia was done in a similar manner. Cologne and Düsseldorf showed great revealed comparative advantage in the chemistry fields. It could be stated that these two NUTS-2 regions play a major role for North-Rhine Westphalia on a national scale. Overall, Düsseldorf and Cologne show signs of being the most innovative but they are not complete outliers in North-Rhine Westphalia, it is remarkable that the most innovative regions create the most knowledge in a technology field with the least complex knowledge (chemistry).

The second stage of the analysis was the regression analysis to test the third and fourth hypotheses. This stage of the analysis was done in two phases, a regression analysis with regional GDP per capita (PPS) as dependent variable and a regression analysis with unemployment rates as a dependent variable. In both analyses the influence of patents (innovation) was very limited on the socio economic standards. The quantity of patents had more influence than their intrinsic quality indicators. Only the originality of patents, the more diverse the patents on average are in a NUTS-3 region only has a small positive influence on the regional GDP per capita (PPS) and unemployment when looking only at quantity- and quality of patents. But once the control variables were added the intrinsic quality indicators influence on the dependent variables became insignificant. The influence of population density of the NUTS-2 regions is very small but the share of higher educated people and share of cultural employers play a major role. Regions that have a relative high portion of cultural employers have a higher regional GDP per capita (PPS) and generally lower unemployment rates. The same statement goes for regions with a relatively high portion of higher educated people. The influence of the creative class is greater when all variables are combined. This confirms the fourth hypothesis and supports Florida’s (2003) theory that the cultural class has bigger influence on the welfare of a region than human capital alone. Additionally the regression analyses show innovation is not a major player in keeping North-Rhine Westphalia’s living conditions at a high level. The more constant variables have a more eminent function in North-Rhine Westphalia.

What are the policy implications for regions whom want to improve their regional GDP per capita and decrease their unemployment and want to look at innovation as a solution? Boschma & Martin (2007) have stated that innovation and the creation of new knowledge is vital for regions to thrive socio economically. The importance of original innovation has come up in the analysis. It is therefore important for regions to have a diverse economy and not being reliant on just one technology. Once there is a diverse set of technologies and companies present, these companies can learn from each other and spark innovation. Tacit knowledge can be transferred, something that is not visible analysing patents. For policymakers providing an open business climate is essential, ensure a diverse set of industries can thrive in the region. The analyses also showed the importance of human- and creative capital, what Sternberg (2011) and Florida (2003) already claimed. The relatively high presence of these factors contributes most to good socio economic endowments, although their relationship is not a one way direction. Regions with a high regional GDP and low unemployment also attract these people and these regions offer attractive jobs for this demographic. Hence it is vital for regions to attract his demographic, because they are capable to innovate. Is it then fruitful for national or regional governments to directly invest in innovation? In this research the influence of direct investment is not tested but given the smaller influence of patents on socio economic endowments policy makers need to think carefully about where they invest money in innovation. Small businesses whom lack sufficient financial funds to innovate should be supported because they can increase productivity and possibly hire more people, which is in line with Broekel (2013). Furthermore funding universities and cultural facilities is important to stay attractive to young (bright) people. As the analysis has shown, this is more important than to invest into innovation directly. At times policy makers should adapt to reality and face that their region doesn't have all the potential to develop into a successful region that is innovative and attracts many highly educated people instead they should adapt to reality and make most of other opportunities. Future research could look into the role of funding of innovation as this was part of the initial plan of this research. How much money do some of the regions spend on innovation in time and did it help to improve innovation and or socio economic endowments for its residents. Another aspect that didn't come out of the research is what type of residents of a region benefit from innovation in the region. Does an innovation technically advance a region that manual labour is no longer needed, or does innovation bring more jobs to a region? More detailed future research on one region could look at this.

Reflection

The methodological approach was to give an extensive image on innovation in North-Rhine Westphalia and how it influences the regions' socio economic endowments. The first stage of the analysis (EconGeo) was overall a good method for setting the basis of North-Rhine Westphalia's positon on innovation. Al the calculations were relative to one another. What was missing is how important certain industries are in the region in terms of patenting. A positive result in region A could also mean that it has just a little bit more patents than all the other regions. Furthermore it didn't say anything about employment for the region or who benefits from the respective revealed comparative advantage in an industry in a respective region. Hence, the image that came from the analysis was one dimensional and perhaps looking at economic output or employment per industry could have been a valuable addition.

Using the two different decades in the EconGeo analysis has shown little differences over time. This method didn't have the perceived outcome of showing big differences in time. Adding to this using the EconGeo package for the internal comparison of North-Rhine Westphalia with only five different regions gave deceiving images. For example, some technologies had maximum scores of relative complex knowledge. To translate these outcomes to reality and stating that one technology has all the complex knowledge is not a translation that holds truth. Furthermore, the low variance in Herfindahl and Shannon indexes could have been expected with 35 different technologies being represented in all regions, having one outlier between all these technologies would have been exceptional in a country with such a diverse economy.

During the process of analysing the data the output data of the calculations was done by personal observations. Everything has been done to avoid missing some values, but the risk is still present that some values haven been overlooked. As mentioned before the internal comparisons of North-Rhine Westphalia gave strange results, another option could be to look at innovation surveys in the region to achieve an image of the region's innovation. Furthermore the research only looked at knowledge that is codified. Patents can't measure tacit knowledge, as mentioned by Malecki (2013). This tacit knowledge is vital for regions to innovate, but direct measurement of this type of knowledge is lacking in the research.

In the second stage of the analysis the initial plan was to add funding of innovation as an explanatory variable, yet consistent available data wasn't found. Another problem was the different scales of measuring that was used. The patens on data was on NUTS-3 level, while the data on higher educated people, cultural employers and population density was at a NUTS-2 level. If the latter data all would have been available on NUTS-3 level the results would have been more precise. Switching between scales could have been hard to follow for the reader. In line with this approaching the analysis form a city perspective within North-Rhine Westphalia was more fruitful. In that case differences between rural and urban regions stand out more and the population density variable comes out stronger as regional population density can give deceiving images due to large surfaces or big rural areas in the region. The indicator for creative class was cultural employers per NUTS-2 region. The cultural employers don't overlap completely with the definition of Florida (2003) as professions like architects are defined as creative class too by Florida (2003). A lack of a more accurate indicator was the reason for using this indicator in regards to its drawbacks. Yet, the indicator is still a very good and diverse indicator for measuring the employment of the creative class in a region. Furthermore, what is in line with the missing variable of funding of innovation is a lack of institutional background of the different regions. A difference in institutional frameworks per region can influence the entrepreneurial climate and innovation of a region. Future research should incorporate the different regional institutional frameworks in a perhaps more qualitative- in-depth oriented research.

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Appendix 1: Tables from EconGeo analyses

Figure 1: Table of different technologies, division of OECD REGPAT (Squicciarini et al.,2013, 65).

1. Electrical engineering	**2. Instruments**	**3. Chemistry**	**4. Mechanical engineering**	**5. Other fields**
1. Electrical machinery, apparatus, energy	9. Optics	14. Organic fine chemistry	25. Handling	33. Furniture, games
2. Audio-visual technology	10. Measurement	15. Biotechnology	26. Machine tools	34. Other consumer goods
3. Telecommunications	11. Analysis of biological materials	16. Pharmaceuticals	27. Engines, pumps, turbines	35. Civil engineering
4. Digital communication	12. Control	17. Macromolecular chemistry, polymers	28. Textile and paper machines	
5. Basic communication processes	13. Medical technology	18. Food chemistry	29. Other special machines	
6. Computer technology		19. Basic materials chemistry	30. Thermal processes and apparatus	
7. IT methods for management		20. Materials, metallurgy	31. Mechanical elements	
8. Semiconductors		21. Surface technology, coating	32. Transport	
		22. Micro-structural and nano-technology		
		23. Chemical engineering		
		24. Environmental technology		

Figure 2: Revealed Comparative Advantage 2000-2009 German Bundesländer

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Baden-Württemberg	1	1	0	0	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	1	1	1	0	0	0
Bayern	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	1	1	1	0
Berlin	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Brandenburg	0	0	0	0	1	1	0	1	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0
Bremen	0	0	0	0	0	1	1	0	0	1	1	0	1	0	1	0	0	1	0	1	0	0	1	1	1	0	0	0	1	0	0	1	1	0	1
Hamburg	1	1	0	1	0	1	0	0	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0
Hesse	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0
Lower Saxony	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	1	0	1	0	1	1	0	0	0
Mecklenburg-Vorpommern	0	1	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1
North Rhine-Westphalia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1
Rhineland-Palatinate	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Saxony	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0
Saxony-Anhalt	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1
Schleswig-Holstein	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	1	1	0	0	0	1	0	1	1	1	0	1	0	0	0	1	1	1
Thuringia	1	1	0	0	0	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0

Figure 3: Revealed Comparative Advantage 2019-2019 German Bundesländer

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Baden-Württemberg	1	1	0	0	1	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1	0	0	0
Bayern	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1	1	1	0
Berlin	0	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Brandenburg	0	0	1	0	1	0	0	1	0	0	1	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Bremen	1	1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	0	1
Hamburg	0	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	1	0	1	0
Hesse	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0	1	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lower Saxony	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0
Mecklenburg-Vorpommern	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0	1	0	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	0
North Rhine-Westphalia	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	0	1	0	0	1	0	1
Rhineland-Palatinate	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Saxony	1	0	1	0	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0	0
Saxony-Anhalt	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	0	1	1	1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	1
Schleswig-Holstein	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	1	0	1	1	0	1	1	0	1	0	0	0	0	0	1
Thuringia	0	1	1	0	0	0	0	1	1	1	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4: comparison of revealed comparative advantage of German Bundesländer (F indicates change)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Baden-Württemberg	T	T	T	T	T	**F**	**F**	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T
Bayern	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	**F**	**F**	T	T	**F**	T	T	T	**F**	T	**F**	T	T	T	T
Berlin	T	T	**F**	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T
Brandenburg	T	T	**F**	T	T	**F**	T	T	T	T	T	**F**	T	T	T	T	T	**F**	T	T	**F**	T	T	T	T	**F**	T	**F**	T	**F**	T	T	T	T	T
Bremen	**F**	**F**	T	T	T	**F**	**F**	T	T	T	T	**F**	**F**	T	T	T	T	T	T	**F**	T	T	**F**	**F**	T	T	**F**	T	T	T	T	T	**F**	T	T
Hamburg	**F**	**F**	T	**F**	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	**F**	T	**F**	T	T	T	T	T	T
Hesse	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	**F**	T	T	**F**	T	T	T	T	T	T	**F**	T	T	**F**	**F**	T	T	T	T	T	T
Lower Saxony	T	**F**	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	**F**	T	T	T	T	**F**	T	T	T	T	T	**F**	T	T	T	T
Mecklenburg-Vorpommern	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	**F**	T	**F**	T	T	T	T	T	T	**F**
North Rhine-Westphalia	T	T	T	**F**	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T
Rhineland-Palatinate	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T
Saxony	**F**	T	**F**	T	**F**	T	T	T	**F**	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T
Saxony-Anhalt	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	**F**	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Schleswig-Holstein	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	**F**	T	T	**F**	T	T	**F**	**F**	T	T	T	T	T	T	T	**F**	**F**	T
Thuringia	**F**	T	**F**	T	T	T	T	T	T	T	**F**	T	T	T	**F**	**F**	T	T	T	T	T	T	**F**	T	T	T	T	T	**F**	T	T	T	T	T	T

Figure 5: Relatedness density of technologies in Germany 2010 - 2019

	1	2	3	4	5	6	7	8	9	10	11	12
Baden-Württemberg	134747.23	150926.03	148829.03	144889.97	152507.48	147806.09	147151.31	149388.84	151880.49	140693.86	150776.22	146158.57
Bayern	170969.28	194078.77	194063.85	187615.89	197066.59	189272.84	191345.13	191590.41	192500.05	183646.58	189240.04	188876.72
Berlin	15335.04	16042.31	15931.32	15358.22	16158.38	14967.21	15787.92	16251.17	16339.95	15500.37	16126.93	15537.74
Brandenburg	4579.34	5005.75	4863.55	4810.67	5005.21	4919.55	4849.81	4913.31	5031.09	4816.21	4690.33	4871.61
Bremen	2009.08	2248.11	2231.71	2158.22	2283.2	2233.41	2208.81	2239.32	2254.61	1898.64	2188.54	2184.28
Hamburg	17887.84	19016.55	19035.85	18765.97	19126.91	18632.14	18819.92	19073.38	18999.19	17879.2	18875.33	18832.16
Hesse	44421.5	47544.07	46867.19	46607.54	47338.09	46292.04	47505.58	47707.43	48748.01	45948.18	49767.83	46881.7
Lower Saxony	34639.56	36777.09	36837.87	36178	37220.91	36379.44	36382.07	36488.98	36526.6	35133.66	36022.99	36045
Mecklenburg-Vorpommern	1678.61	1737.95	1684.94	1666.82	1726.91	1697.79	1698.89	1736.96	1769.86	1653.04	1687.1	1680.38
North Rhine-Westphalia	113888.37	120822.36	122548.01	123082.92	121275.34	118833.63	124787.76	121754.05	121124.92	117540.49	124178.47	121965.11
Rhineland-Palatinate	28817.38	29075.89	29944.29	31452.21	28745.62	28271.36	31395.33	29861.8	29512.4	28597.07	31469.89	30551.29
Saxony	7418.03	8736.62	8649.21	8563.59	8765.48	8549.73	8630.76	7919.44	8750.96	8029.58	8631.21	8561.72
Saxony-Anhalt	1744.04	1794.62	1772.94	1785.34	1786.76	1739.3	1809.56	1756.87	1834.03	1756.72	1850.85	1786.81
Schleswig-Holstein	8104.83	8367.48	8311.03	8265.07	8390.94	8261.36	8365.11	8398.3	8487.17	8086.96	8381.82	8225.51
Thuringia	5317.51	5885.57	5584.41	5511.63	5914.37	5719.15	5706.13	5876.63	5108.36	5411.56	6014.66	5690.42

	13	14	15	16	17	18	19	20	21	22	23	24
Baden-Württemberg	141032.07	128697.08	141968.7	140706.33	128209.97	142521.19	129840.39	138300.47	140325.15	157156.75	140962.9	145736.46
Bayern	182443.94	164852.62	181652.98	178832.43	165119.26	185010.36	166182.8	179028.93	181367.77	197175.44	181077.24	186356.14
Berlin	14239.72	14527.78	15200.77	14634.4	15132.71	15747.03	15514.07	15517.63	15121.18	16451.57	15762.23	15920.72
Brandenburg	4691.24	4177.4	4613.15	4597.73	4168.31	4714.89	4238.34	4546.17	4556.54	5150.25	4672.87	4812.84
Bremen	2178.9	1937.73	2054.3	2087.97	1933.05	2108.83	1937.79	2064.92	2098.35	2322.39	2101.71	2193.08
Hamburg	17086.7	15973.67	18378.88	18391.05	17889.97	18873.52	17529.3	18433.66	18435.8	19131.09	18195	18579.66
Hesse	40879.21	47738.92	48713.43	49009.12	49802.56	48865.79	47876.09	47660.5	47764.32	48887.31	47806.49	48453.09
Lower Saxony	35113.17	32212.3	34828.14	34282.33	32504.42	35845.65	32885.12	34579.37	34949.14	37113.9	34863.36	35338.85
Mecklenburg-Vorpommern	1532.76	1710.24	1645.37	1707.73	1681.95	1676.28	1618.94	1649.21	1647.51	1789.17	1643.35	1720.62
North Rhine-Westphalia	120880.81	136541.54	127006.03	128679.81	136911.52	132099.11	135980.84	130150.29	128464.58	121374.82	125171.2	126126.12
Rhineland-Palatinate	30935.2	39148.35	33342.79	34478.77	39316.94	35817.7	39101.53	35604.19	34812.85	28680.26	32484.62	32786.17
Saxony	8517.77	7887.12	8172.88	8425.34	8229.58	8490.02	8142.32	8222.87	8260.34	8878.06	8314.23	8480.97
Saxony-Anhalt	1712.93	1964.91	1683.88	1802.58	2013.17	1860.54	1872.74	1792.56	1828.2	1830.29	1810.88	1811.3
Schleswig-Holstein	7792.11	8736.27	8367.26	8322.62	8472.95	8561.95	7479.77	8331.44	8247.48	8565.79	8222.79	8259.86
Thuringia	5169.07	5132.24	5595.26	5650.51	4913.1	5496.49	5072.33	5308.76	5460.31	6158.17	5578.81	5723.44

	25	26	27	28	29	30	31	32	33	34	35
Baden-Württemberg	140897.49	139781.78	143900.76	143406.8	141230.6	144889.55	139702.8	137843.21	140395.75	146877.88	133528.99
Bayern	181252.75	183408.22	184735.46	183368.42	181105.33	186750.8	181790.04	176433.79	181345.78	188978.15	173684.48
Berlin	15690.67	15918.25	16042.56	15743.57	15692.17	15778.02	15896.69	14676.18	15354.97	15332.07	15194.08
Brandenburg	4771.98	4757.87	3755.01	4761.07	4675.53	4782.6	4780.9	4918.44	4663.32	4853.39	4417.78
Bremen	2064.98	2180.26	2120.4	2167.71	2039.42	2190.87	2137.89	2050.3	2128.66	2222.97	1953.16
Hamburg	17587.08	18487.91	18032.21	18544.09	17760.49	18785.9	18496.62	15952.38	18316.54	17716.24	17948.18
Hesse	46739.44	47447.87	46263.09	48505.16	46249.54	46966.66	46146.79	45399.16	47666.05	46320.95	47606.73
Lower Saxony	34751.34	35108.61	33784.91	35166.88	32037	35791.48	34755.92	30503	35026.86	36881.82	33378.06
Mecklenburg-Vorpommern	1400.56	1676.26	1635.34	1705.04	1645.66	1690.64	1709.39	1647.72	1683.64	1667.54	1623.44
North Rhine-Westphalia	122422.93	120103.22	117577.06	126886.58	121944.29	122397.92	117919.72	115914.32	126567.53	121475.44	122226.51
Rhineland-Palatinate	32308.84	31193.72	27813.31	33673.97	31528.33	30980.91	29725.83	28674.15	34488.37	29968.54	36119.34
Saxony	8314.53	8277.42	8661.75	8390.18	8090.53	8405.5	8537.77	8417.16	8380.76	8621.43	8066.52
Saxony-Anhalt	1790.76	1800.16	1772.52	1870.22	1762.17	1719.41	1735.36	1745.85	1830.3	1751.43	1769.16
Schleswig-Holstein	8136.25	8094.56	7503.07	8381.41	7658.12	8309.22	8117.16	7860.27	8257.23	8173.47	7943.03
Thuringia	5542.05	5772.62	5826.09	5676.98	5374.38	5615.77	5842.77	5645.37	5462.88	5677.24	5146.8

Figure 6: Relatedness density of technologies in Germany 2010 - 2019

	1	2	3	4	5	6	7	8	9	10	11	12
Baden-Württemberg	134747.23	150926.03	148829.03	144889.97	152507.48	147806.09	147151.31	149388.84	151880.49	140693.86	150776.22	146158.57
Bayern	170969.28	194078.77	194063.85	187615.89	197066.59	189272.84	191345.13	191590.41	192500.05	183646.58	189240.04	188876.72
Berlin	15335.04	16042.31	15931.32	15358.22	16158.38	14967.21	15787.92	16251.17	16339.95	15500.37	16126.93	15537.74
Brandenburg	4579.34	5005.75	4863.55	4810.67	5005.21	4919.55	4849.81	4913.31	5031.09	4816.21	4690.33	4871.61
Bremen	2009.08	2248.11	2231.71	2158.22	2283.2	2233.41	2208.81	2239.32	2254.61	1898.64	2188.54	2184.28
Hamburg	17887.84	19016.55	19035.85	18765.97	19126.91	18632.14	18819.92	19073.38	18999.19	17879.2	18875.33	18832.16
Hesse	44421.5	47544.07	46867.19	46607.54	47338.09	46292.04	47505.58	47707.43	48748.01	45948.18	49767.83	46881.7
Lower Saxony	34639.56	36777.09	36837.87	36178	37220.91	36379.44	36382.07	36488.98	36526.6	35133.66	36022.99	36045
Mecklenburg-Vorpommern	1678.61	1737.95	1684.94	1666.82	1726.91	1697.79	1698.89	1736.96	1769.86	1653.04	1687.1	1680.38
North Rhine-Westphalia	113888.37	120822.36	122548.01	123082.92	121275.34	118833.63	124787.76	121754.05	121124.92	117540.49	124178.47	121965.11
Rhineland-Palatinate	28817.38	29075.89	29944.29	31452.21	28745.62	28271.36	31395.33	29861.8	29512.4	28597.07	31469.89	30551.29
Saxony	7418.03	8736.62	8649.21	8563.59	8765.48	8549.73	8630.76	7919.44	8750.96	8029.58	8631.21	8561.72
Saxony-Anhalt	1744.04	1794.62	1772.94	1785.34	1786.76	1739.3	1809.56	1756.87	1834.03	1756.72	1850.85	1786.81
Schleswig-Holstein	8104.83	8367.48	8311.03	8265.07	8390.94	8261.36	8365.11	8398.3	8487.17	8086.96	8381.82	8225.51
Thuringia	5317.51	5885.57	5584.41	5511.63	5914.37	5719.15	5706.13	5876.63	5108.36	5411.56	6014.66	5690.42

	13	14	15	16	17	18	19	20	21	22	23	24
Baden-Württemberg	141032.07	128697.08	141968.7	140706.33	128209.97	142521.19	129840.39	138300.47	140325.15	157156.75	140962.9	145736.46
Bayern	182443.94	164852.62	181652.98	178832.43	165119.26	185010.36	166182.8	179028.93	181367.77	197175.44	181077.24	186356.14
Berlin	14239.72	14527.78	15200.77	14634.4	15132.71	15747.03	15514.07	15517.63	15121.18	16451.57	15762.23	15920.72
Brandenburg	4691.24	4177.4	4613.15	4597.73	4168.31	4714.89	4238.34	4546.17	4556.54	5150.25	4672.87	4812.84
Bremen	2178.9	1937.73	2054.3	2087.97	1933.05	2108.83	1937.79	2064.92	2098.35	2322.39	2101.71	2193.08
Hamburg	17086.7	15973.67	18378.88	18391.05	17889.97	18873.52	17529.3	18433.66	18435.8	19131.09	18195	18579.66
Hesse	40879.21	47738.92	48713.43	49009.12	49802.56	48865.79	47876.09	47660.5	47764.32	48887.31	47806.49	48453.09
Lower Saxony	35113.17	32212.3	34828.14	34282.33	32504.42	35845.65	32885.12	34579.37	34949.14	37113.9	34863.36	35338.85
Mecklenburg-Vorpommern	1532.76	1710.24	1645.37	1707.73	1681.95	1676.28	1618.94	1649.21	1647.51	1789.17	1643.35	1720.62
North Rhine-Westphalia	120880.81	136541.54	127006.03	128679.81	136911.52	132099.11	135980.84	130150.29	128464.58	121374.82	125171.2	126126.12
Rhineland-Palatinate	30935.2	39148.35	33342.79	34478.77	39316.94	35817.7	39101.53	35604.19	34812.85	28680.26	32484.62	32786.17
Saxony	8517.77	7887.12	8172.88	8425.34	8229.58	8490.02	8142.32	8222.87	8260.34	8878.06	8314.23	8480.97
Saxony-Anhalt	1712.93	1964.91	1683.88	1802.58	2013.17	1860.54	1872.74	1792.56	1828.2	1830.29	1810.88	1811.3
Schleswig-Holstein	7792.11	8736.27	8367.26	8322.62	8472.95	8561.95	7479.77	8331.44	8247.48	8565.79	8222.79	8259.86
Thuringia	5169.07	5132.24	5595.26	5650.51	4913.1	5496.49	5072.33	5308.76	5460.31	6158.17	5578.81	5723.44

	25	26	27	28	29	30	31	32	33	34	35
Baden-Württemberg	140897.49	139781.78	143900.76	143406.8	141230.6	144889.55	139702.8	137843.21	140395.75	146877.88	133528.99
Bayern	181252.75	183408.22	184735.46	183368.42	181105.33	186750.8	181790.04	176433.79	181345.78	188978.15	173684.48
Berlin	15690.67	15918.25	16042.56	15743.57	15692.17	15778.02	15896.69	14676.18	15354.97	15332.07	15194.08
Brandenburg	4771.98	4757.87	3755.01	4761.07	4675.53	4782.6	4780.9	4918.44	4663.32	4853.39	4417.78
Bremen	2064.98	2180.26	2120.4	2167.71	2039.42	2190.87	2137.89	2050.3	2128.66	2222.97	1953.16
Hamburg	17587.08	18487.91	18032.21	18544.09	17760.49	18785.9	18496.62	15952.38	18316.54	17716.24	17948.18
Hesse	46739.44	47447.87	46263.09	48505.16	46249.54	46966.66	46146.79	45399.16	47666.05	46320.95	47606.73
Lower Saxony	34751.34	35108.61	33784.91	35166.88	32037	35791.48	34755.92	30503	35026.86	36881.82	33378.06
Mecklenburg-Vorpommern	1400.56	1676.26	1635.34	1705.04	1645.66	1690.64	1709.39	1647.72	1683.64	1667.54	1623.44
North Rhine-Westphalia	122422.93	120103.22	117577.06	126886.58	121944.29	122397.92	117919.72	115914.32	126567.53	121475.44	122226.51
Rhineland-Palatinate	32308.84	31193.72	27813.31	33673.97	31528.33	30980.91	29725.83	28674.15	34488.37	29968.54	36119.34
Saxony	8314.53	8277.42	8661.75	8390.18	8090.53	8405.5	8537.77	8417.16	8380.76	8621.43	8066.52
Saxony-Anhalt	1790.76	1800.16	1772.52	1870.22	1762.17	1719.41	1735.36	1745.85	1830.3	1751.43	1769.16
Schleswig-Holstein	8136.25	8094.56	7503.07	8381.41	7658.12	8309.22	8117.16	7860.27	8257.23	8173.47	7943.03
Thuringia	5542.05	5772.62	5826.09	5676.98	5374.38	5615.77	5842.77	5645.37	5462.88	5677.24	5146.8

Figure 7: Knowledge complexity of technologies in Germany

2000-2009		**2010-2019**	
Technology field	*Knowledge complexity*	*Technology field*	*Knowledge complexity*
1	85,63	1	87,69
2	72,43	2	86,92
3	100,00	3	72,49
4	92,67	4	70,99
5	90,92	5	75,96
6	79,77	6	95,88
7	81,97	7	78,35
8	62,53	8	52,56
9	60,68	9	55,16
10	63,47	10	80,43
11	44,09	11	50,02
12	90,92	12	96,08
13	55,76	13	49,99
14	28,19	14	30,57
15	33,23	15	40,81
16	31,94	16	30,58
17	0,00	17	0
18	17,33	18	46,61
19	17,73	19	8,21
20	16	20	13,88
21	38,46	21	28,65
22	63,31	22	82
23	21,87	23	28,07
24	41,13	24	59,02
25	32,6	25	75,33
26	45,97	26	47,73
27	62,38	27	76,83
28	41,57	28	52,3
29	25,21	29	83,43
30	52,29	30	59,03
31	65,89	31	100
32	71,11	32	94,81
33	44,42	33	70,81
34	76,59	34	95,88
35	20,96	35	39,96

Figure 8: Ubiquity of technologies in Germany

2000-2009		2010-2019	
Technology Fields	Ubiquity	Technology Fields	Ubiquity
1	4	1	4
2	7	2	5
3	2	3	4
4	3	4	3
5	4	5	4
6	6	6	3
7	4	7	4
8	6	8	7
9	7	9	4
10	7	10	7
11	9	11	10
12	4	12	4
13	9	13	9
14	6	14	6
15	10	15	8
16	8	16	8
17	4	17	3
18	8	18	8
19	6	19	5
20	7	20	5
21	6	21	9
22	3	22	4
23	9	23	8
24	7	24	7
25	8	25	5
26	5	26	5
27	6	27	8
28	5	28	4
29	8	29	6
30	6	30	5
31	2	31	2
32	5	32	6
33	4	33	2
34	4	34	3
35	5	35	4

Figure 9: Revealed Comparative Advantage Five NUTS-2 Regions NRW 2009-2019

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Arnsberg	1	1	0	0	1	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	1	1	0	0	1
Detmold	1	1	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1	1	1	0	1	1	1	1
Düsseldorf	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0
Köln	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0
Münster	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	1	0	1	0	0	1	1	1	0	0	1	0	1

Figure 10: Revealed Comparative Advantage Five NUTS-2 Regions NRW 2010-2019

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Arnsberg	1	1	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	1	1	0	0	1
Detmold	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0
Düsseldorf	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	0	1	0	0	0	0	0
Köln	0	1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1	0	0	0
Münster	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	1	1	1	1	1	0	0	1

Figure 11: Comparison of revealed comparative advantage in two decades of Five NUTS-2 Regions NRW (F indicates change)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Arnsberg	T	T	T	T	T	T	T	**F**	**F**	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T
Detmold	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	**F**	T	T	T	T	T	**F**	T	T	T	**F**
Düsseldorf	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	**F**	**F**	T	T	**F**	T	T	T	T	T	T	T	T
Köln	T	T	T	T	**F**	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	**F**	T	T	**F**	T	T	T
Münster	T	T	T	T	T	T	T	T	T	T	T	T	**F**	T	T	T	T	T	**F**	T	T	T	T	**F**	T	T	T	T	T	T	**F**	**F**	**F**	T	T

Figure 12: Relatedness Density of technologies in five NUTS-2 regions of North-Rhine Westphalia 2000-2009

	1	2	3	4	5	6	7	8	9	10	11	12
Arnsberg	22978.95	17163.16	7250	8283.33	17322.22	11900	8347.06	17883.33	16965	16576.47	17505	27025
Detmold	18452.63	12984.21	4762.5	7855.56	11416.67	10326.32	7223.53	12566.67	12780	10223.53	12130	25466.67
Düsseldorf	29626.32	28173.68	26925	26927.78	28000	27773.68	28205.88	28788.89	28965	26100	30915	30408.33
Köln	29068.42	41500	38362.5	37505.56	41866.67	39200	40117.65	43138.89	41380	40429.41	42885	30033.33
Münster	9326.32	6673.68	4756.25	6061.11	5450	6242.11	6317.65	7050	6870	5276.47	8095	9900

	13	14	15	16	17	18	19	20	21	22	23	24
Arnsberg	16768.42	21290.91	7718.18	8694.44	8857.89	25611.11	22880	24275	7633.33	46988.89	18488.89	16963.16
Detmold	11773.68	13281.82	4427.27	7338.89	7042.11	23255.56	14360	15887.5	4513.33	39122.22	10511.11	11910.53
Düsseldorf	28163.16	81890.91	76236.36	28200	36484.21	100911.11	82750	106525	57513.33	48800	96888.89	28284.21
Köln	41289.47	41900	50190.91	36711.11	36031.58	31833.33	36690	36325	45533.33	39600	54977.78	41652.63
Münster	6826.32	16727.27	9645.45	7177.78	6915.79	16588.89	15740	17537.5	8113.33	16833.33	16922.22	7005.26

	25	26	27	28	29	30	31	32	33	34	35
Arnsberg	43655.56	25480	16673.68	24600	22181.82	26437.5	27325	25066.67	35446.15	36363.64	24594.12
Detmold	36277.78	21480	12121.05	22400	17559.09	21637.5	20006.25	20288.89	27792.31	32063.64	22052.94
Düsseldorf	50300	88580	28273.68	87772.73	33445.45	107312.5	30206.25	29394.44	47761.54	48209.09	66264.71
Köln	37566.67	28890	41289.47	33418.18	36518.18	32637.5	30775	28883.33	32907.69	32281.82	34447.06
Münster	15388.89	16360	6931.58	16672.73	9031.82	17625	10481.25	9700	14638.46	15936.36	13258.82

Figure 13: Relatedness Density of technologies in five NUTS-2 regions of North-Rhine Westphalia 2010-2019

	1	2	3	4	5	6	7	8	9	10	11	12
Arnsberg	26541.18	24400	8021.43	12600	35388.89	17222.22	10186.67	6515.38	16670.59	21860	12011.76	38290
Detmold	27958.82	28772.22	8735.71	11875	40722.22	25211.11	10926.67	5515.38	18076.47	17360	11670.59	46460
Düsseldorf	40688.24	33433.33	28800	32375	93022.22	33038.89	32166.67	42184.62	31970.59	31866.67	31676.47	48650
Köln	24017.65	29494.44	35307.14	33612.5	24777.78	33883.33	36273.33	36607.69	35882.35	32720	34982.35	29770
Münster	10405.88	8155.56	5364.29	6637.5	11044.44	6572.22	6093.33	3892.31	6476.47	6740	6164.71	13250

	13	14	15	16	17	18	19	20	21	22	23	24
Arnsberg	15416.67	9793.33	7440	8427.78	8538.1	7425	10238.46	22227.27	7457.14	38469.23	18854.55	5707.69
Detmold	16744.44	8460	5080	8511.11	8633.33	22850	9230.77	13363.64	3928.57	36061.54	10545.45	3969.23
Düsseldorf	31805.56	55986.67	57800	41400	45838.1	134250	63192.31	88254.55	102800	48707.69	84909.09	55476.92
Köln	33711.11	27100	33866.67	32644.44	27171.43	49800	28138.46	33318.18	44442.86	30753.85	36100	35607.69
Münster	6011.11	7873.33	6200	6172.22	6380.95	9850	7853.85	12009.09	8942.86	12953.85	11063.64	5523.08

	25	26	27	28	29	30	31	32	33	34	35
Arnsberg	48912.5	33120	7457.14	11037.5	23010	29454.55	27362.5	26700	30006.25	32916.67	25406.25
Detmold	50737.5	32210	3928.57	26887.5	25455	36454.55	31962.5	30718.75	31081.25	39583.33	32456.25
Düsseldorf	60437.5	80540	102800	90062.5	36745	78181.82	35993.75	32200	42425	45175	45506.25
Köln	32462.5	22550	44442.86	38312.5	30735	22163.64	28412.5	26475	23368.75	26916.67	24606.25
Münster	15600	11500	8942.86	12175	8705	9790.91	9675	9306.25	11287.5	12216.67	9700

Figure 14: Knowledge complexity of technologies in Five NUTS-2 regions in NRW

2000-2009		**2010-2019**	
Technology fields	Knowledge complexity	Technology fields	Knowledge complexity
1	66,01	1	9,66
2	77,34	2	39,77
3	100	3	100
4	100	4	100
5	77,34	5	20,79
6	75,37	6	50
7	100	7	100
8	90,63	8	100
9	75,37	9	59,66
10	90,63	10	59,66
11	72,31	11	47,27
12	50,74	12	0
13	72,32	13	100
14	0	14	43,04
15	50	15	71,52
16	100	16	100
17	100	17	71,52
18	28,81	18	21,85
19	17,84	19	43,04
20	0	20	43,04
21	45,22	21	55,18
22	66,01	22	19,31
23	67,84	23	32,77
24	100	24	55,18
25	55,9	25	20,9
26	44	26	20,78
27	90,63	27	71,52
28	28,81	28	21,85
29	43,21	29	40,83
30	28,81	30	21,85
31	81,27	31	13,94
32	66,01	32	35,45
33	43,21	33	0
34	50,75	34	0
35	55,9	35	20,91

Figure 15: Ubiquity of technologies in five NUTS-2 regions in NRW

2000-2009		**2010-2019**	
Technology Fields	Ubiquity	Technology Fields	Ubiquity
1	2	1	2
2	3	2	3
3	1	3	1
4	1	4	1
5	3	5	3
6	2	6	2
7	1	7	1
8	2	8	1
9	2	9	2
10	2	10	2
11	3	11	4
12	1	12	1
13	3	13	1
14	1	14	1
15	2	15	2
16	1	16	1
17	1	17	2
18	3	18	3
19	2	19	1
20	1	20	1
21	3	21	3
22	2	22	1
23	2	23	2
24	1	24	3
25	3	25	2
26	3	26	3
27	2	27	2
28	3	28	3
29	2	29	3
30	3	30	3
31	1	31	3
32	2	32	4
33	2	33	1
34	1	34	1
35	3	35	2