Methods and Techniques for Business and Economics

Business Intelligence for Business Networks

Automotive Industry Network Analysis

Hassanat Oluwatobi Awodipe - 280020

Muhammad Ahmed - 287068

Academic Year 2023-24

Table of Contents

Chapter 1 Introduction.. 3

Chapter 2 Overview of the Dataset.. 5

Chapter 3 Statistical Analysis... 6

3.1 Propulsion Segment.. 6

3.1.1 Distribution of Actors in Propulsion... 6

3.1.2 Countries…………………………………………………………………………7

3.1.3 Operating Revenue……………………………………………………………8

3.1.4 Employees………………………………………………………………………8

3.1.4 Industry…………………………………………………………………………10

3.2 Tyres Segment.. 11

3.2.1 Distribution of Actors in Tyres... 11

3.2.2 Countries………………………………………………………………………..12

3.2.3 Operating Revenue…………………………………………………………...13

3.2.4 Employees………………………………………………………………………13

3.2.5 Industry…………………………………………………………………………15

Chapter 4 Major Companies Focus...16

4.1 Distribution of Patents in Propulsion..16

4.1.1 Major Companies in Focus in Propulsion..17

4.2 Distribution of Patents in Tyres...20

4.2.1 Major Companies in Focus in Tyres...21

Chapter 5 Patents Network Analysis..25

5.1 Propulsion or Transmission Segment..25

5.1.1 Group Level……………………………………………………………………27

5.1.2 Node level………………………………………………………………………31

5.1.3 Scale Free Property…………………………………………………………..37

5.2 Tyres Segment..38

5.2.1 Group Level……………………………………………………………………39

5.2.3 Node Level………………………………………………………….…………42

5.2.4 Scale Free Property…………………………………………………………46

Chapter 6 Inter-country Network....47
6.1 Propulsion Segment....47
6.2 Tyres Segment....49
Chapter 7 Inter-industry Network....52
7.1 Propulsion Segment....52
7.2 Tyres Segment....54
Chapter 8 Hypotheses Test....57
Conclusion....61
Reference List....63
Appendix....64

Chapter 1

Introduction

This report analyses the European automotive industry, with a focus on patents. The automotive industry is renowned for its technological innovation and intense competition, where product differentiation plays a crucial role in driving sales. The industry is a key driver of economic activity contributing over 6% to the region's total economic activity [1]. Last year, the European Union finally adopted the law to make all new cars and vans sold in Europe zero-emission from 2035 to cut emissions. This law was reached because transport is responsible for one-quarter of all greenhouse gas emissions in the EU, and road transport makes up 70% of that amount[1].

Consequently, the dynamics in the EU automotive industry are changing, and manufacturers and consumers are moving away from diesel and petrol-powered vehicles to Battery Electric Vehicles (BEVs). Beyond the production of sustainable vehicles, there are other factors that affect the growth of the industry such as the dependence on components from other countries particularly; China, regulations and trade policies, technological innovation & research, consumer trends, etc. [2]

The first part of the report provides an overview of the statistical summary of the industry including the economic indices. It discusses the collaboration of organisations for patent production. This section gives insights into the characteristics, relevance and roles of the actors involved in the industry. Here, we also identify the countries with the highest number of actors for patent production. Within these countries, we highlight the top companies based on operating revenue and number of employees, and this will serve as the basis for the hypotheses test conducted in the last chapter.

The second part involves the network analysis of the industry, it examines how interaction and collaboration among the actors can foster growth and innovation. Here, the focus is on two segments of the industry: Propulsion or Transmission and Tyres. Propulsion or transmission relates

[1] https://climate.ec.europa.eu/news-your-voice/news/5-things-you-should-know-about-electric-cars-2024-05-14_en

to the movement of the vehicle. It describes how power is transmitted from the engines to the wheels so that the vehicle can move from one place to another [3]. Tyres are vehicle components, usually made of rubber or composite materials. They cover the wheels and provide cushion and grip on the road surface[2]. As the automotive industry revolutionizes from mechanical propulsion to electrical propulsion, it is expected that organisations will generate patents in this regard. In some cases, this may also result in a different type of tyre used for vehicles with electric propulsion. Additionally, the inter-industry and inter-country networks of the patents were also examined.

The concluding chapter discusses the relationship between certain variables. In particular, a hypothesis test is carried out to confirm or reject if these variables are linearly correlated. Based on these results, we conclude that patent production is affected by these variables.

[2] https://testbook.com/mechanical-engineering/wheels-and-tyres-definition-properties-and-types

Chapter 2

Overview of the Datasets

Our analysis uses data from four main datasets: a network dataset for the tyres segment, another for the propulsion segment, a codebook for identifying organizations, and a dataset for economic values.

Propulsion Segment: In this dataset, we have *440* Source-Target edges, each with weights, comprising 263 unique sources and a cumulative weight of *1,830*.

Tyres Segment: This dataset contains *242* Source-Target edges with assigned weights, representing 124 unique sources and a total weight sum of *4,460*.

To associate specific organizations with each node, we utilized the *auto_codebook* dataset, which includes 11,115 distinct sources and their corresponding organization names. However, we identified some inconsistencies: although the codebook's final entry is labeled *auto_11071*, both the propulsion and tyres datasets contain source values exceeding *auto_11071*. Consequently, organization names for 13 sources in the tyres dataset and 23 in the propulsion dataset were not identifiable.

After linking sources to their respective organizations, we merged this data with the *vehicles* dataset to extract economic information, matching each source with its unique *BvD ID number*. During this process, we encountered missing economic details for some organizations, such as operating revenue, NACE codes, and employee counts. To address these gaps, we supplemented missing data using Orbis, and for cases where Orbis data was unavailable, we used the average of available values to impute missing entries.

As a result, we created two refined attribute datasets—one for tyres and one for propulsion. Each dataset now contains the following fields: *source, organization name, NACE codes, ISO country codes, operating revenue, and number of employees*. These datasets will be used in the subsequent Statistical and Network Analysis sections.

Chapter 3

Statistical Analysis

In this section, we will present a detailed examination of the distribution of actors across tyres and propulsion segments. The first section will explore the distribution of actors, which represent key entities or nodes within the propulsion sector. This analysis will reveal the relationships and interactions among actors, shedding light on their roles in facilitating the flow of information and resources. By analysing the distribution of actors, we can gain insights into the participation of countries in these industries. Following this, the second section delves into a similar analysis but specifically targets the tyres sector. Here, we will uncover the varying levels of actor participation, assess their contributions to revenue generation, and highlight the competitive dynamics within this crucial industry segment. Together, these sections provide a comprehensive overview of actor distributions, underscoring their significance in fostering innovation and collaboration across the European automotive markets.

3.1. Propulsion Segment

3.1.1. Distribution of Actors

Table 3.1.1: Distribution of Actors

	Top 5	**# of Actors**
First country	**DE**	70
Second country	**FR**	26
Third country	**IT**	21
Fourth country	**US**	14
Fifth country	**JP**	12
Top 5 EU		139
Remaining EU		37
Total EU		**176**
Total non-EU		**64**
Org Details Not Available		**23**
TOTAL		**263**

Table 3.1.1 outlines that Germany (DE) leads with 70 actors, followed by France (FR) with 26, Italy (IT) with 21, the United States (US) with 14, and Japan (JP) with 12. Collectively, the top five EU countries account for 139 actors, while the remaining EU countries contribute 37, bringing the total number of EU actors to 176. Non-EU countries add 64 actors, and there are 23 actors for which organisational details are unavailable, leading to a total of 263 actors in the dataset.

3.1.2. Countries

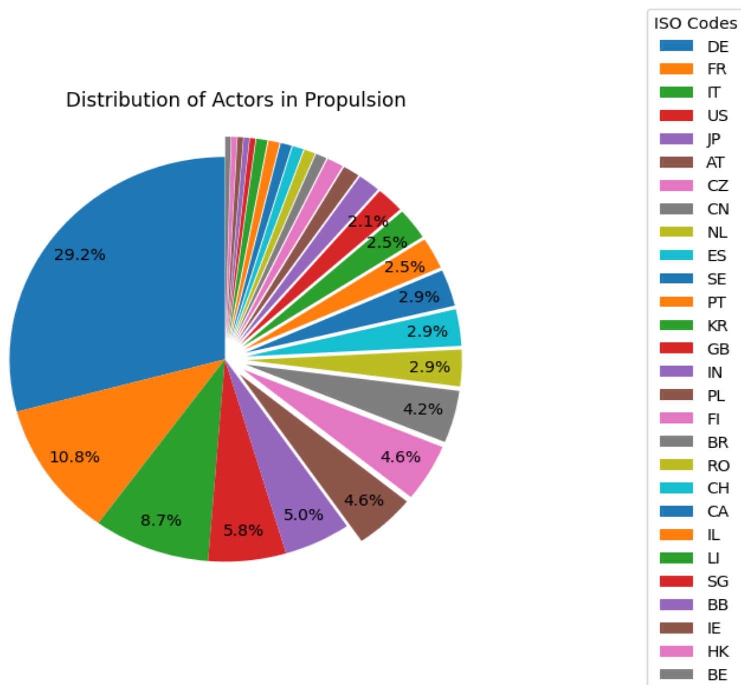


Figure 3.1.1: Distribution of Actors according to ISO codes

Figure 3.1.1 depicts that Germany (DE) holds the largest share, contributing **29.2%** to the total, making it the dominant country in this category. Following Germany, France (FR) accounts for **10.8%**, while Italy (IT) holds **8.7%**. The United States (US) contributes **5.8%**, and Japan (JP) and Austria (AT) each have a share of **5.0%**. Czech Republic (CZ) and China (CN) both contribute **4.6%**, while the Netherlands (NL) adds **4.2%**. Several other countries, including Spain (ES), Sweden (SE), Portugal (PT), South Korea (KR), and Great Britain (GB), each hold **2.9%** of the total. Other nations, such as India (IN), Poland (PL), Finland (FI), Brazil (BR), Romania (RO), Switzerland (CH), and more, contribute smaller shares, ranging from **2.1%** to **2.5%**. Overall, the chart highlights Germany's significant dominance, followed by smaller contributions from other nations.

3.1.3. Operating Revenue

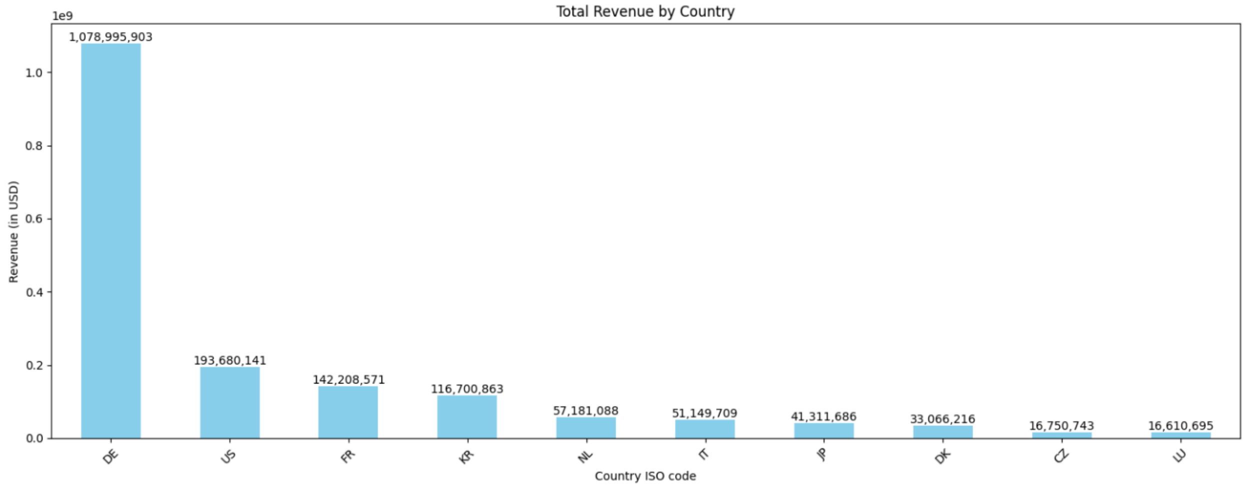


Figure 3.1.2: Total Revenue by different countries

Figure 3.1.2 highlights total revenue by country, with Germany (DE) leading by a large margin at $1.5 billion, far outpacing other nations. Japan (JP) follows with $500 million, and France (FR) ranks third with $385 million. South Korea (KR) and the United States (US) contribute $263 million and $221 million, respectively. The Netherlands (NL) adds $200 million, while Italy (IT), Spain (ES), China (CN), and Canada (CA) generate smaller revenues, ranging from $53 million to $77 million. Germany's dominance is clear, while other countries contribute significantly but on a smaller scale.

3.1.4. Employees

After a detailed assessment of operating revenue dynamics, let us consider another economically significant variable: the number of people employed in the organisations. The data shows it employs around 6.3 million people in the network. Let us examine the geographic distribution of employees of companies associated with the network, as shown in *figure 3.1.3*. Once again, the centrality of Germany (mainly) and France stands out compared to the other European countries, which also have fewer employees than the US and Japanese multinationals connected to the network. Furthermore, it is essential to note that, aside from the two major European countries mentioned earlier and the group of Italy and Czech Republic, the contribution of other countries is relatively insignificant. This finding confirms that the organisations under analysis are primarily concentrated in a handful of European countries, most of which in Central Europe.

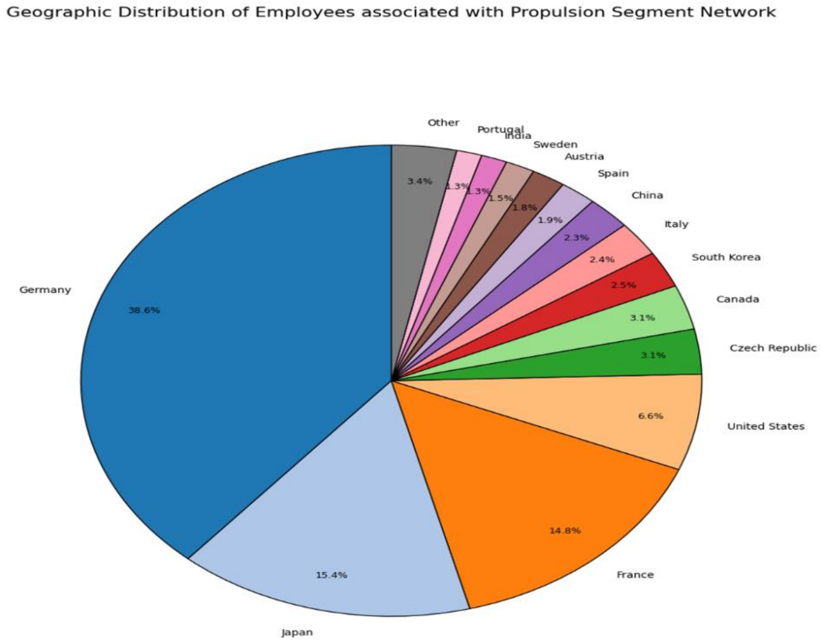


Figure 3.1.3: Geographic distribution of employees in the propulsion network

When examining the average size of firms within the network, as shown in *figure 3.1.4* below by the average number of work units per firm, some noteworthy dynamics become apparent. In Canada, firms record an average of 97,211 work units, about three times higher than the leading European country. Another significant evidence is the inverse size relationship between Germany and France. German firms invoice more overall but register a bit lower average number of employees per firm. Finally, it is essential to note the relatively small capacity of other European countries, which have a significantly smaller average firm size than France and Germany. This evidence confirms that these countries are relatively marginal in the network. These considerations are supported by a fundamental principle of industrial economics, which states that a multinational corporation with a significant budget and a dispersed workforce has greater access and, therefore, greater centrality in global innovation networks [4].

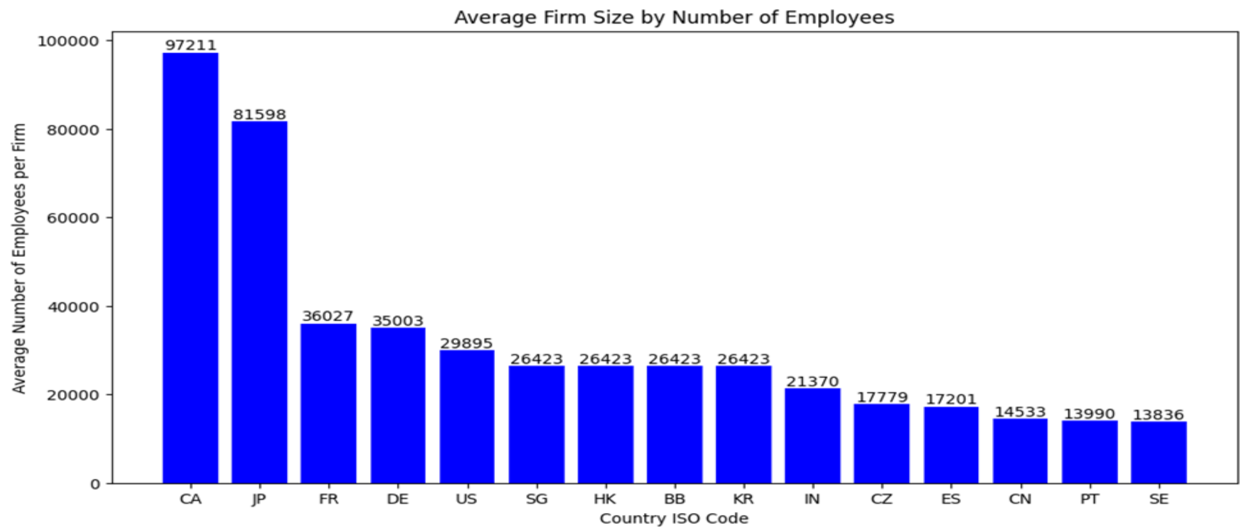


Figure 3.1.4: Average number of employees per country

3.1.5. Industry

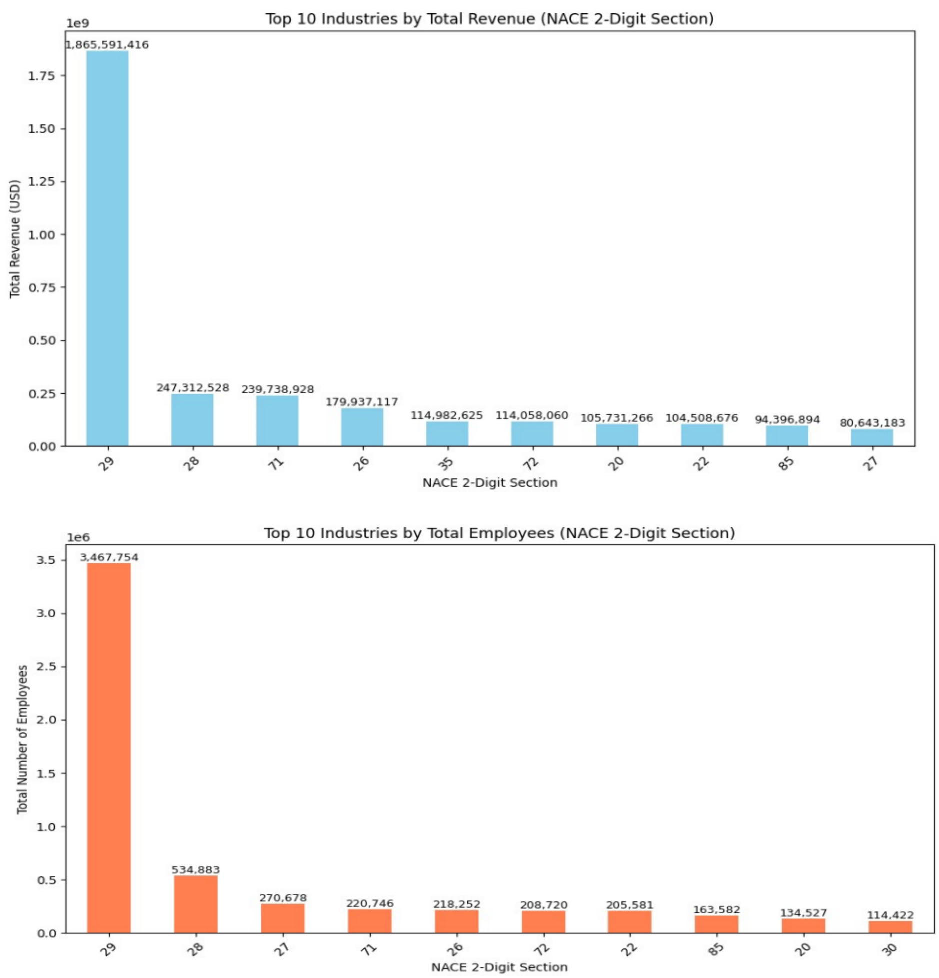


Figure 3.1.5: Top 10 industries by Revenue and Employees

The analysis of the top 10 industries (based on NACE 2-digit) by total revenue and total number of employees highlights a clear concentration of economic and workforce impact within specific sectors. NACE section 29 dominates both charts, generating around **$1.87 billion** in revenue and employing approximately **3.47 million** people, indicating its pivotal role in the economy, likely within the automotive or heavy machinery sector. Following section 29, sections 28, 71, and 26 are also notable, each contributing significant revenue and employment, though far less than section 29. These sections display revenues ranging from **$80 million to $247 million** and employee counts from **around 114,000 to 534,000**. The sharp decline in both revenue and workforce numbers after the top industry underscores the disparity in economic scale across sectors, where a few sectors hold the majority share of both financial and human resources. This pattern suggests that the economy is heavily influenced by a limited number of high-revenue, high-employment industries, with smaller contributions from other sectors.

3.2 Tyres Segment

3.2.1. Distribution of Actors

The table below shows the number of actors involved.

Table 3.2.1: Distribution of Actors

	Top 5	**# of Actors**
First country	**DE**	37
Second country	**US**	23
Third country	**IT**	11
Fourth country	**FR**	10
Fifth country	**NL**	4
Top 5 EU		64
Remaining EU		10
Total EU		**74**
Total non-EU		**37**
Org Details Not Available		**13**
TOTAL		**124**

Table 3.2.1 outlines the distribution of actors across various countries. Germany (DE) leads with 37 actors, followed by the United States (US) with 23, Italy (IT) with 11, France (FR) with 10, and the Netherlands (NL) with 4. Collectively, the top five EU countries account for 64 actors, while the remaining EU countries contribute 10, bringing the total number of EU actors to 74. Non-EU countries add 37 actors, and there are 13 actors for which organisational details are unavailable, leading to a total of 124 actors in the dataset.

3.2.2. Countries

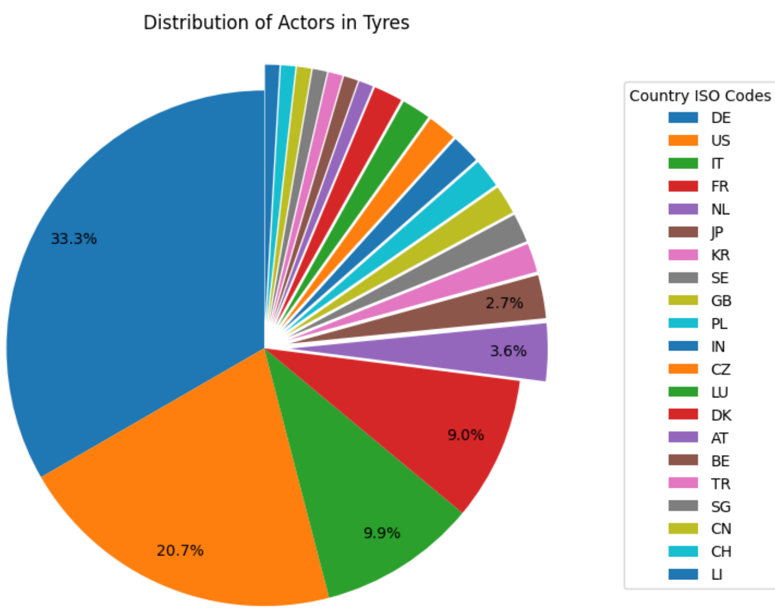


Figure 3.2.1: Distribution of Actors according to ISO codes

The pie chart in the *figure 3.2.1* visualizes the distribution of actors in the tyres segment grouped by ISO codes, representing each country's share as a percentage of the total count. Germany (DE) takes the largest portion, accounting for **33.3%** of the total, followed by the United States (US) with **20.7%**. Italy (IT) contributes **9.9%**, while France (FR) holds 9**.0%**. The Netherlands (NL) is shown with **3.6%**, and Japan (JP) has **2.7%**. Other countries occupy smaller portions of the pie, each representing a very minimal share. The chart effectively highlights that Germany, and the United States dominate the dataset, with smaller contributions from other countries.

3.2.3. Operating Revenue

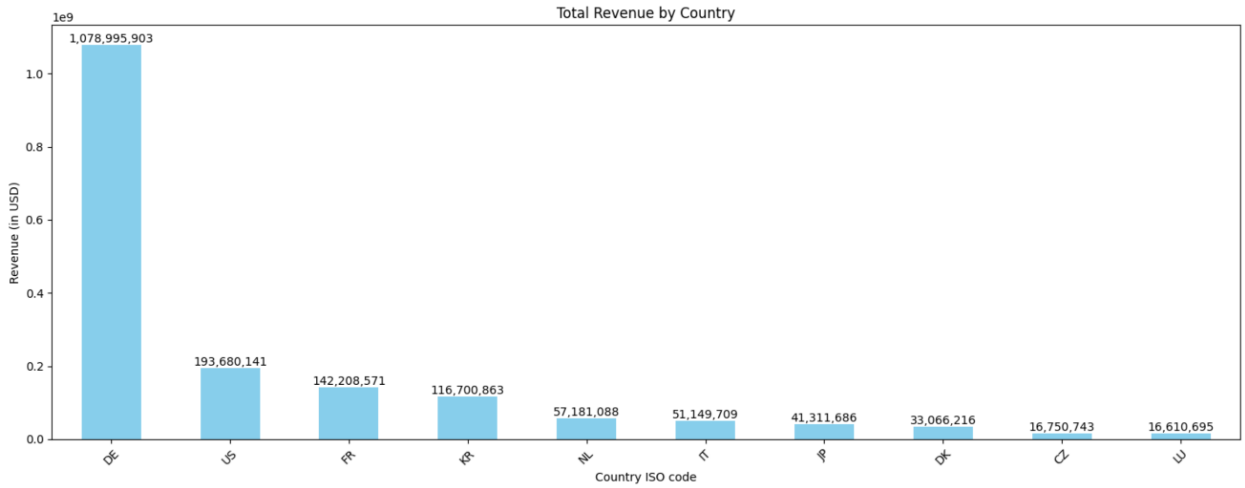


Figure 3.2.2: Total Revenue by different countries

The bar chart in *figure 3.2.2* shows that Germany (DE) dominates with a staggering $1.08 billion, far surpassing the other countries. The United States (US) follows, generating $193.7 million, and France (FR) comes in third with $142.2 million. South Korea (KR) contributes $116.7 million, while the Netherlands (NL) and Italy (IT) bring in $57.2 million and $51.1 million, respectively. Spain (ES) and Denmark (DK) follow with revenues of $41.3 million and $33.1 million. Smaller revenue figures are shown for China (CN) and Switzerland (CH), each generating around $16.7 million and $16.6 million, respectively. This chart highlights Germany's overwhelming dominance in revenue generation compared to other countries, with most others contributing significantly smaller amounts.

3.2.4. Employees

After a detailed assessment of revenue dynamics, let us consider another economically significant variable: the number of people employed in the organisations. The data shows that it employs around 3.4 million people in the network. Let us examine the geographic distribution of employees of companies associated with the network, as shown in *figure 3.2.3*. Once again, the centrality of Germany (mainly) and France stands out compared to the other European countries, which also have fewer employees than the US and Japanese multinationals connected to the network. Furthermore, it is essential to note that, aside from the two major European countries mentioned earlier and the group of Italy and Netherlands, the contribution of other countries is relatively insignificant. This finding confirms that the organisations under analysis are primarily concentrated in a handful of European countries, most of which are located in Central Europe.

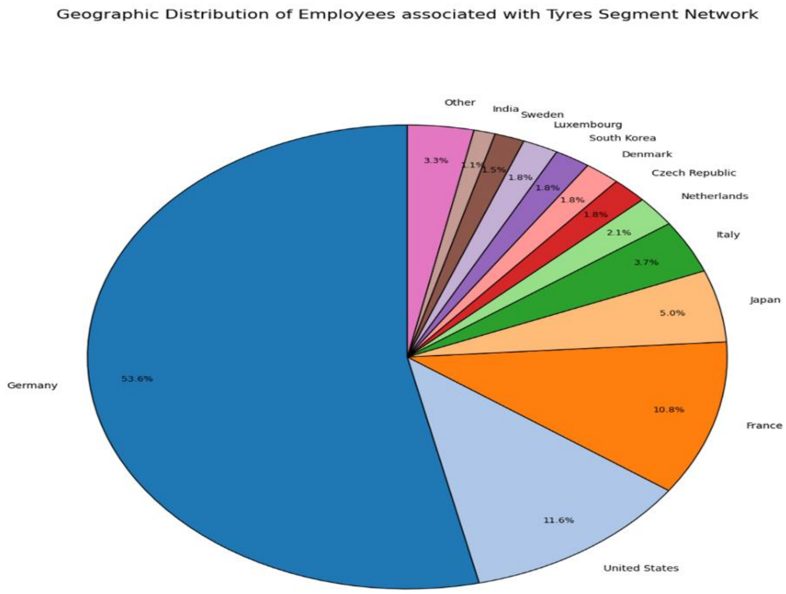


Figure 3.2.3: Geographic distribution of employees in the tyres network

When examining the average size of firms within the network, as shown in *figure 3.2.4* by the average number of work units per firm, some noteworthy dynamics become apparent. In Japan, firms record an average of 56,942 work units, about 7,500 units higher than the leading European country. It is essential to note the tie between other European countries, which have a bit smaller average firm size than France and Germany.

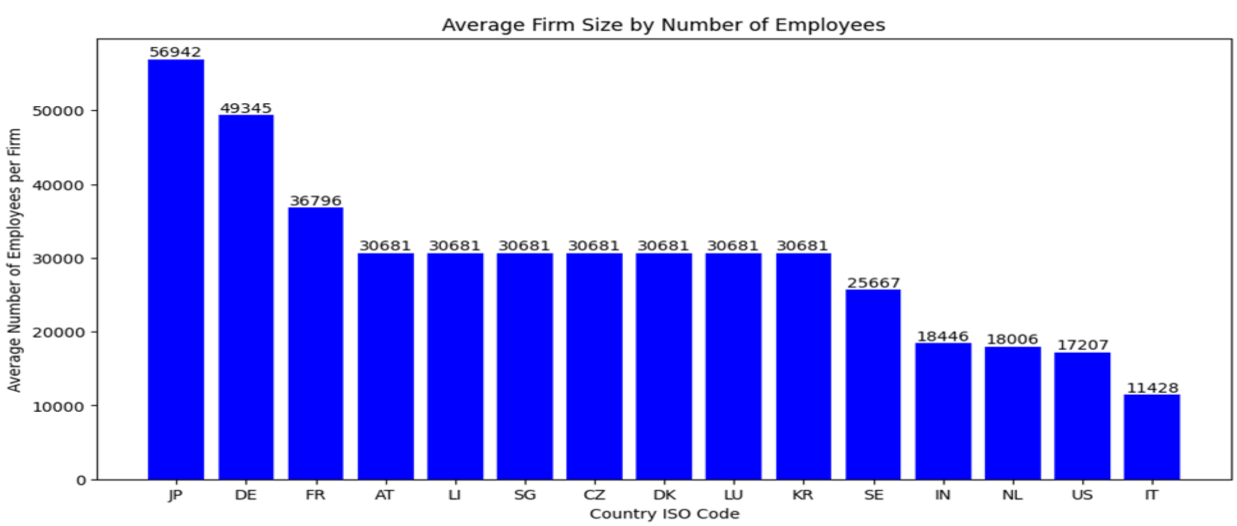
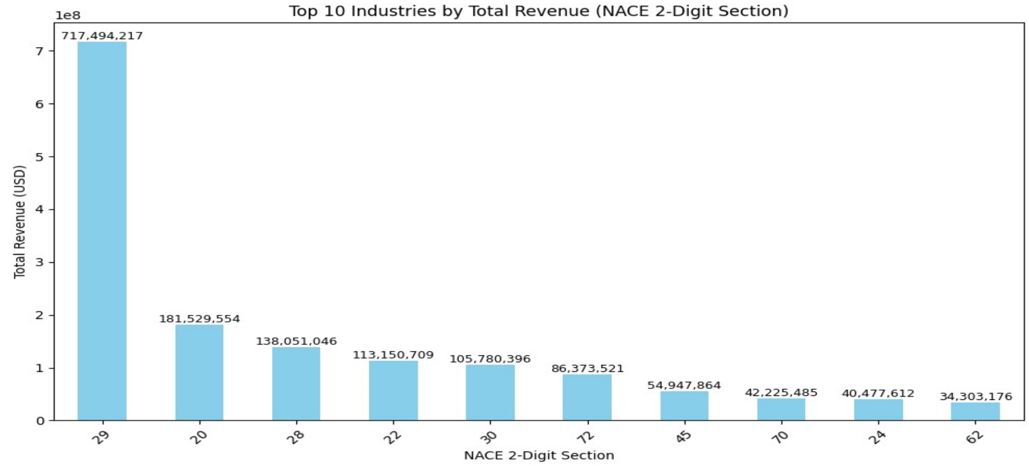


Figure 3.2.4: Average number of employees by country

3.2.5. Industry



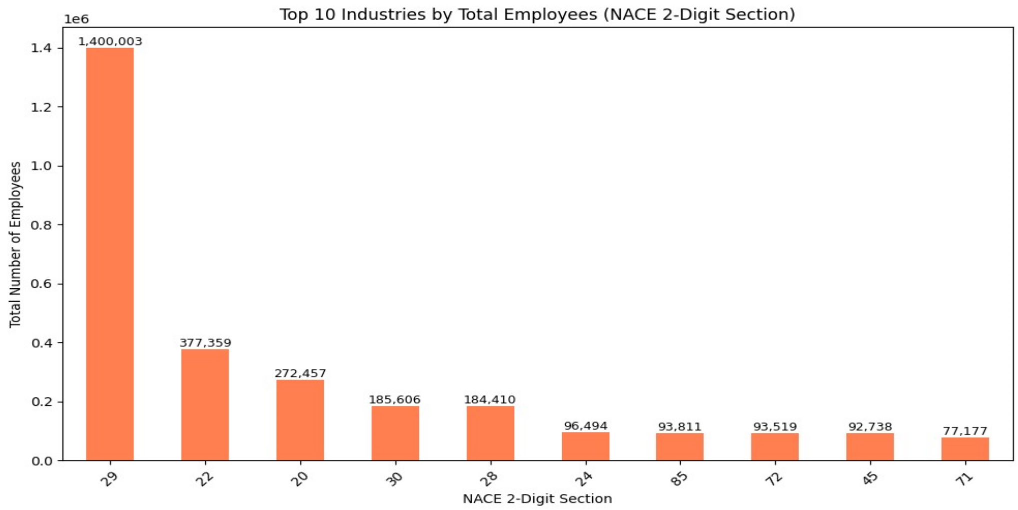


Figure 3.2.5: Top industries by Revenue and Country

The two bar charts below illustrate the top 10 industries (based on NACE 2-digit) by total revenue and total number of employees. In the first graph, *figure 3.2.5* shows the "Total Revenue by Industry" chart shows that industry code 29 dominates in revenue, reaching approximately 717 million USD, followed by codes 20, 28, and 22 with significantly lower revenues. The second graph, "Total Employees by Industry," reveals a similar trend, with industry code 29 also leading in employee count, housing over 1.4 million employees, while codes 22 and 20 follow with much smaller employee counts. Both graphs highlight the prominence of Industry Code 29 in terms of both revenue and employment, indicating its significant role in the economy compared to other industries in the top 10 list.

Chapter 4

Major Companies Focus

After identifying the countries with high concentrations of actors, this chapter provides analysis of patent distribution and key companies in the propulsion and tyre segments. Both sections highlight the geographic and corporate dynamics in innovation and revenue, underscoring how patents and business strategies vary across these two segments.

4.1 Distribution of Patents in Propulsion

Table 4.1: Distribution of Patents

	Top 5	**# of Patents**
First country	**DE**	634
Second country	**FR**	353
Third country	**JP**	214
Fourth country	**AT**	69
Fifth country	**IT**	59
Top 5 EU		1155
Remaining EU		120
Total EU		**1275**
Total non-EU		**484**
Org Details Not Available		**71**
TOTAL		**1830**

Table 4.1 presents data on the number of patents for various countries and regions in the propulsion or transmission segment. Among the top 5 countries, Germany (DE) leads with 634 patents, followed by France (FR) with 353 patents, Japan (JP) with 214 patents, Austria (AT) with 69 patents, and Italy (IT) with 59 patents. Collectively, the top five EU countries contribute 1,155 patents which is more than half of the total patents in this dataset. In addition, there are 120 patents from remaining EU countries and 484 patents from non-EU countries. Furthermore, 71 patents do not have their organisational details available, bringing the total number of patents in the dataset to 1,830.

4.1.1 Major Companies in Focus in Propulsion

Table 4.2: Top five countries based on operating revenue

Countries	Operating Revenue	# of Patents
DE	1.522523e+09	634
JP	5.008934e+08	214
FR	3.850365e+08	353
KR	2.633668e+08	48
US	2.217764e+08	59

Table 4.3: Top five EU countries based on operating revenue

Countries	Operating Revenue	# of Patents
DE	1.522523e+09	634
FR	3.850365e+08	353
NL	2.004580e+08	40
IT	7.718822e+07	59
ES	7.393521e+07	11

In *Table 4.2*, Germany (DE) leads with over $1.5 billion in revenue and 634 patents, followed by Japan (JP) with a significantly lower revenue of $500 million and 214 patents. France (FR) ranks third, generating $385 million in revenue with 353 patents. South Korea (KR) and the United States (US) contribute with smaller revenues of $263 million and $221 million, and patent counts of 48 and 59, respectively. Among the top five EU countries (*Table 4.3*), Germany and France dominate in both revenue and patent activity, while the Netherlands (NL), Italy (IT), and Spain (ES) join the list with moderate revenues and smaller patent portfolios.

Table 4.4 shows among the highest-revenue firms, only **auto_10626** and **auto_8177** appear in both the top 10 by revenue and top 10 by patent connectivity. Firms like **auto_7037**, which is third in patent connectivity, is ranked lower in terms of revenue (around $79 million). Other high-revenue firms such as **auto_9880** and **auto_6526** have relatively low connectivity weights, suggesting that they generate significant revenue but are not as heavily involved in patent creation.

Table 4.4: Top ten firms by revenue

Source	**Operating Revenue**	**# of Patents**
auto_10626	**3.10607637e+08**	63
auto_9880	**2.78351047e+08**	15
auto_6526	**1.62730017e+08**	**14**
auto_1177	**1.53039961e+08**	**26**
auto_3076	**1.14982625e+08**	**4**
auto_4749	**1.12465501e+08**	**20**
auto_8177	**9.8824709e+07**	**63**
auto_1149	**9.4690569e+07**	**1**
auto_7037	**7.9387885e+07**	**160**
auto_5630	**6.8301922e+07**	**2**

Table 4.5: Top ten firms by patent connectivity

Source	**Operating Revenue**	**# of Patents**
auto_8064	**5.085653e+07**	174
auto_7037	**7.938788e+07**	160
auto_916	**6.797438e+07**	**91**
auto_2149	**1.555860e+07**	**77**
auto_2147	**4.817130e+05**	**64**
auto_8177	**9.882471e+07**	**63**
auto_10626	**3.106076e+08**	**63**
auto_9749	**4.047761e+07**	**33**
auto_11014	**4.855054e+07**	**28**
auto_1177	**1.530400e+08**	**26**

Table 4.5 **shows t**he firms with the highest patent connectivity (e.g., **auto_8064**, **auto_7037**) are not the top revenue generators, except for **auto_10626** and **auto_8177**. **auto_8064** has the highest patent connectivity weight (174) but a relatively modest revenue of around $50 million. **auto_7037**, second in connectivity with a weight of 160, has a revenue of $79 million, far less than the top revenue earners.

Germany (DE) is the leader in both total revenue and patent connectivity, followed by France (FR) and Japan (JP). This suggests that Germany has both strong revenue generation and a robust network in patent creation. In contrast, countries like South Korea (KR) and the US have lower patent weights compared to their revenues, indicating a possible disconnect between revenue and patent participation. Organisations that generate the most revenue are not necessarily the most connected in the network or heavily involved in patent creation. The differences between the top firms by revenue and top firms by patent connectivity support this. While there are some firms (like auto_10626 and auto_8177) that perform well in both revenue and patent connectivity, many high-revenue firms do not have strong patent participation. Conversely, firms with the highest patent connectivity do not necessarily have the highest revenue. This suggests that revenue generation and patent participation (connectivity) are related, but they are not strongly coupled in this dataset. The organisations excelling in one area are not guaranteed to excel in the other.

The tables below display the top five firms for each of the top three EU countries.

1. Germany

id	Organisations	Operating Revenue
auto_10626	Volkswagen AG	3.106076e+08
auto_6526	Mercedes-Benz Group AG	1.627300e+08
auto_1177	Bayerische Motoren Werke AG	1.530400e+08
auto_8177	Robert Bosch Gesellschaft Mit Beschraenkter	9.882471e+07
auto_1149	Basf Se	9.469057e+07

2. France

id	Organisations	Operating Revenue
auto_3076	Engie	1.149826e+08
auto_7843	PSA Automobiles SA	6.442885e+07
auto_8064	Renault	5.085653e+07
auto_2067	Compagnie Generale Des Etablissements Michelin	3.051968e+07
auto_3730	Forvia SE	2.847639e+07

3. Netherlands

id	Organisations	Operating Revenue
auto_694	Aramco Overseas Company B.V.	9.919200e+08
auto_2007	CN Industrial N.V	2.347300e+07
auto_10386	V.O.F. Wenhao	1.555860e+07
auto_1121	Bakker Holding Son B.V.	1.555860e+07
auto_3600	Firma Dekker	1.555860e+07

4.2 Distribution of Patents in Tyres

Table 4.6: Distribution of Patents

	Top 5	# of Patents
First country	**FR**	2013
Second country	**CH**	1478
Third country	**DE**	532
Fourth country	**US**	144
Fifth country	**IT**	100
Top 5 EU		2700
Remaining EU		31
Total EU		**2731**
Total non-EU		**1695**
Org Details Not Available		**34**
TOTAL		**4460**

Table 4.6 presents data on the number of patents for various countries and regions in tyres segment. In the top 5 countries, France (FR) leads with 2,013 patents, followed by Switzerland (CH) with 1,478 patents, Germany (DE) with 532 patents, the United States (US) with 144 patents, and Italy (IT) with 100 patents. Collectively, the top five EU countries contribute 2,700 patents which is more than half of the total number of patents in our dataset. There are 31 patents from remaining EU countries and 1,695 patents from non-EU countries. Additionally, 34 patents have no organisational details available, bringing the total patents recorded to 4,460.

4.2.1 Major Companies in Focus in Tyres

Table 4.7: Top five countries based on operating revenue

Countries	**Operating Revenue**	**# of Patents**
DE	**1.078996e+09**	532
US	**1.936801e+08**	144
FR	**1.422086e+08**	**2013**
KR	**1.167009e+08**	**8**
NL	**5.718109e+07**	**15**

Table 4.8: Top five EU countries based on operating revenue

Countries	**Operating Revenue**	**# of Patents**
DE	**1.078996e+09**	532
FR	**1.422086e+08**	**2013**
NL	**5.718109e+07**	**15**
IT	**5.114971e+07**	**100**
DK	**3.306622e+07**	**2**

In *Table 4.7*, **Germany (DE)** leads with over $1 billion in revenue and 532 patents, followed by the **United States (US)**, which has a much lower revenue ($193 million) but a considerable number of patents (144). **France (FR)** stands out with the highest number of patents (2,013) but a relatively moderate revenue of $142 million. **South Korea (KR)** and the **Netherlands (NL)** follow with lower revenues and comparatively fewer patents. Among the **Top Five EU Countries (***Table 4.8***)**, Germany and France remain the top contributors, while **Italy (IT)** and **Denmark (DK)** join the list with smaller revenues and patent portfolios.

Table 4.9 depicts top ten firms by revenue. Among the firms with the highest revenue, auto_8177 and auto_2067 are notable for appearing in both the top 10 by revenue and the top 10 by patent connectivity. However, many of the top revenue earners do not have a particularly high number of patents. auto_10626 is the leading firm by revenue, generating over $310 million with only 10 patents. auto_1177 is the second-highest revenue earner, with approximately $153 million in revenue but only 1 patent, suggesting that its business is not heavily dependent on patent activity.

auto_2067, though ranked lower in revenue (about $30 million), stands out for having an extremely high number of patents (1,547). Firms like auto_4749, auto_1149, and auto_9749 generate substantial revenues (ranging from $40 million to $110 million) with modest patent portfolios, ranging from 1 to 10 patents each.

Table 4.9: Top ten firms by revenue

Source	**Operating Revenue**	**# of Patents**
auto_10626	**3.106076e+08**	10
auto_1177	**1.530408e+08**	1
auto_4749	**1.124655e+08**	**7**
auto_8177	**9.882471e+07**	**23**
auto_1149	**9.469857e+07**	**10**
auto_353	**5.433159e+07**	**2**
auto_2444	**5.217908e+07**	**1**
auto_9749	**4.047761e+07**	**3**
auto_2067	**3.051968e+07**	**1547**
auto_4481	**2.411581e+07**	**2**

Table 4.10: Top ten firms by patent connectivity

Source	**Operating Revenue**	**# of Patents**
auto_2067	**3.051968e+07**	1547
auto_2149	**1.653311e+07**	283
auto_2147	**4.817128e+05**	**280**
auto_5795	**1.653311e+07**	**85**
auto_4873	**1.593200e+07**	**85**
auto_8355	**1.655618e+06**	**56**
auto_8362	**2.096151e+06**	**56**
auto_8347	**2.211914e+07**	**41**
auto_369	**9.938568e+06**	**33**
auto_8177	**9.882471e+07**	**23**

Table 4.10 depicts the top ten patents. The firms with the highest patent connectivity typically have significantly fewer revenues compared to the top revenue earners. However, these firms show a stronger focus on patent creation and innovation. auto_2067 dominates the list with 1,547 patents, despite having a relatively lower revenue ($30 million) compared to top revenue-generating firms. This indicates that auto_2067 is highly innovative but does not necessarily translate its innovations into high revenue. auto_2149 and auto_2147 rank second and third in patent connectivity with 283 and 280 patents, respectively, but they both generate relatively modest revenues (around $16 million and less than $500,000). auto_8177, which appears on both the top 10 revenue and top 10 patent connectivity lists, generates significant revenue (nearly $99 million) and has a respectable number of patents (23). Firms like auto_5795 and auto_4873 have medium connectivity (85 patents each) but relatively low revenues (around $16 million).

There is a clear distinction between firms that generate high revenue and those that are highly patent-active. Only auto_2067 and auto_8177 appear on both lists, highlighting their strong positions in both revenue generation and patent innovation. However, auto_2067 is an outlier in terms of its patent activity (1,547 patents) but much lower in terms of revenue.

Firms like auto_10626 are top revenue earners but do not show high patent connectivity, suggesting that their revenue is driven by factors other than innovation, or they may be focusing on non-patent-dependent business models. Conversely, firms like auto_2149 and auto_2147, which are highly patent-active, generate much lower revenues, implying that their innovations may still be in early stages or not yet fully monetized.

The tables below display the top five firms for each of the top three EU countries.

1. Germany

id	Organisations	Operating Revenue
auto_10626	Volkswagen AG	3.106076e+08
auto_1177	Bayerische Motoren Werke AG	1.530400e+08
auto_8177	Robert Bosch Gesellschaft Mit Beschraenkter	9.882471e+07
auto_1149	Basf Se	9.469057e+07
auto_9749	Thyssenkrupp Ag	4.047761e+07

2. France

id	Organisations	Operating Revenue
auto_353	Airbus	5.433159e+07
auto_2067	Compagnie Generale Des Estanlissements Michelin	3.051968e+07
auto_8347	Safran	2.211914e+07
auto_732	Arkema	1.235336e+07
auto_368	Airbus Operations	1.232776e+07

3. Netherlands

id	Organisations	Operating Revenue
auto_2007	CNH Industrial N.V	2.347300e+07
auto_9334	Synvina C.V.	1.653311e+07
auto_1481	Bridgestone Mobility Solutions B.V.	1.653311e+07
auto_9539	Teijin Aramid B.V.	6.418721e+05

Chapter 5

Patents Network Analysis

This analysis aims to highlight the organisations that are foremost in establishing patents related to propulsion or transmission and tyres in the automotive industry. A patent is an exclusive right granted for an invention. They benefit inventors by providing them with legal protection for their inventions, and society by providing public access to technical information about these inventions[3]. The analysis examines the undirected relationship between the organisations and the countries of origin.

The patents ORG * ORG datasets for the segments were used for the analysis. The dataset shows the number of patents between two actors. Two actors are connected by a specific weight based on the number of patents they establish. In our case, the collaborations are symmetrical hence we treated it as an undirected network. Firstly, we consider the propulsion segment and then the tyres segment.

5.1 Propulsion or Transmission Segment

The table below shows the properties of the network as analysed by ASEN

Table 5.1.1: Propulsion Network main indicator

	Value
Nodes	263
Absolute Density	220
Normalized Density	0.64%
Average links value	4.159
Average path length	4.003
Connected components	74
Fragmentation	0.935
Global clustering coefficient	0.507
Degree centralization weighted normalized	0.004
Betweenness centralization weighted	0.025
Eigenvector centralization weighted	0.704

[3] World Intellectual Property Organisation: https://www.wipo.int/web/patents

The *number of nodes* is equal to the number of actors involved in patent collaboration. There are no isolated nodes, i.e. there is no mono-patent. All the nodes are connected by 220 *edges*, and their *density* is 0.64%. The density of the graph describes the ratio between the actual connections and all possible graph connections [5]. Hence, it can be said that the graph is sparsely connected, indicating that the organisations do not collaborate very closely.

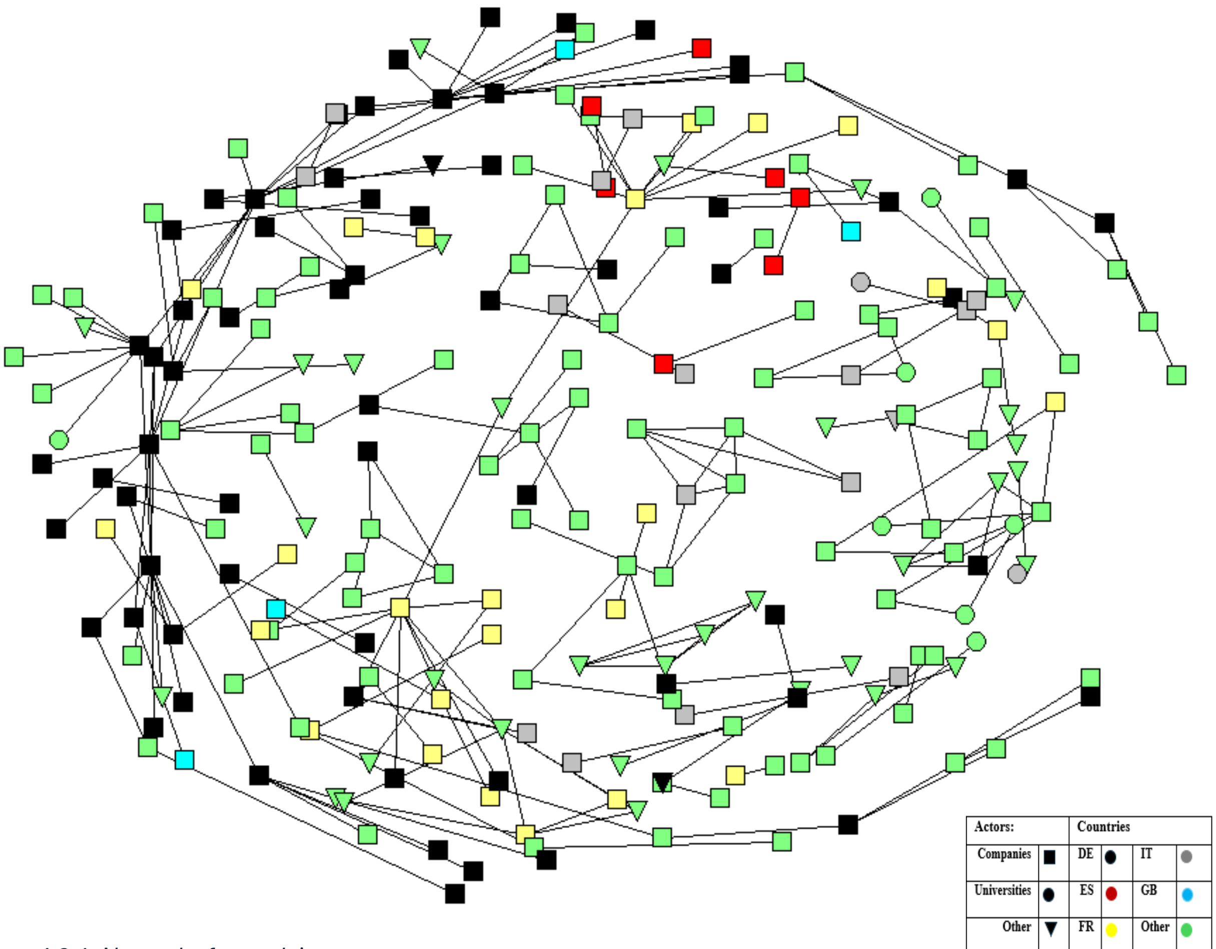


Figure 4.2.1: Network of propulsion segment

The *average links value* is the sum of the weights of the edges in the network divided by the number of edges. The weights represent the number of patents that two given actors have worked on. So, on average, an organisation has collaborated with another organisation on 4 patents. However, the *average path length* of 4 means that the number of steps along the shortest paths needed to travel between any two actors in the network is relatively high. Although not so obvious in *fig 4.1.1* above, the network is highly fragmented, meaning that a large proportion of the network exists in small, isolated components. There are 74 *components*, which are subgroups of nodes where there are connections within the subgroup but no connections to other nodes outside the group [5]. The *global clustering coefficient* of 0.507 indicates the coexistence of tightly connected clusters which implies the efficient flow of knowledge and information. The *low-weighted degree* and *betweenness centralities* mean that the network does not seem to be dominated by certain organisations that are extremely central in patent collaboration. The Eigenvector centrality is relatively high denoting that some nodes are connected to the few influential nodes present in the network.

Furthermore, this network represents only a sample of the EU automotive organisations that collaborate on patents. This sample shows that collaboration is limited to a specific group of actors.

5.1.1. Group Level

Main Component

This represents 22.8% of the entire network. Below are some of its indexes obtained from UCINET and ASEN:

Table 5.1.2: Main component indicators

	Value
Nodes	60
Absolute density	66
Normalized density	3.73%
Total links value	758
Average links value	5.742
Average path length	4.398
Small world index	2.278
Global clustering coefficient	0.183
Degree centralization weighted normalized	0.023
Betweenness centralization weighted	0.460
Eigenvector centralization weighted	0.601

Compared to the entire network, the MC consists of 60 nodes and 66 edges, making it more denser than the entire network. The total links value shows that there are 758 patents collaboration and two organisations collaborate on at least 5 patents. There are no disconnected nodes, so the fragmentation value is 0 and the software was able to compute a small world index. The small world index is greater than 1 meaning that there is high clustering and short average length paths. However, it would take on average the same effort for organisations to reach each other as it is in the main network since the average path lengths are almost the same. The GCL is significantly higher indicating that the nodes have a good amount of neighbours. Examining the centrality indexes shows that there are dominant actors in the main network that facilitate patent collaboration. Overall, the spread of information across the main component is more efficient. In the network image below, the node size represents the degree centrality binary while the link size represents the number of patents.

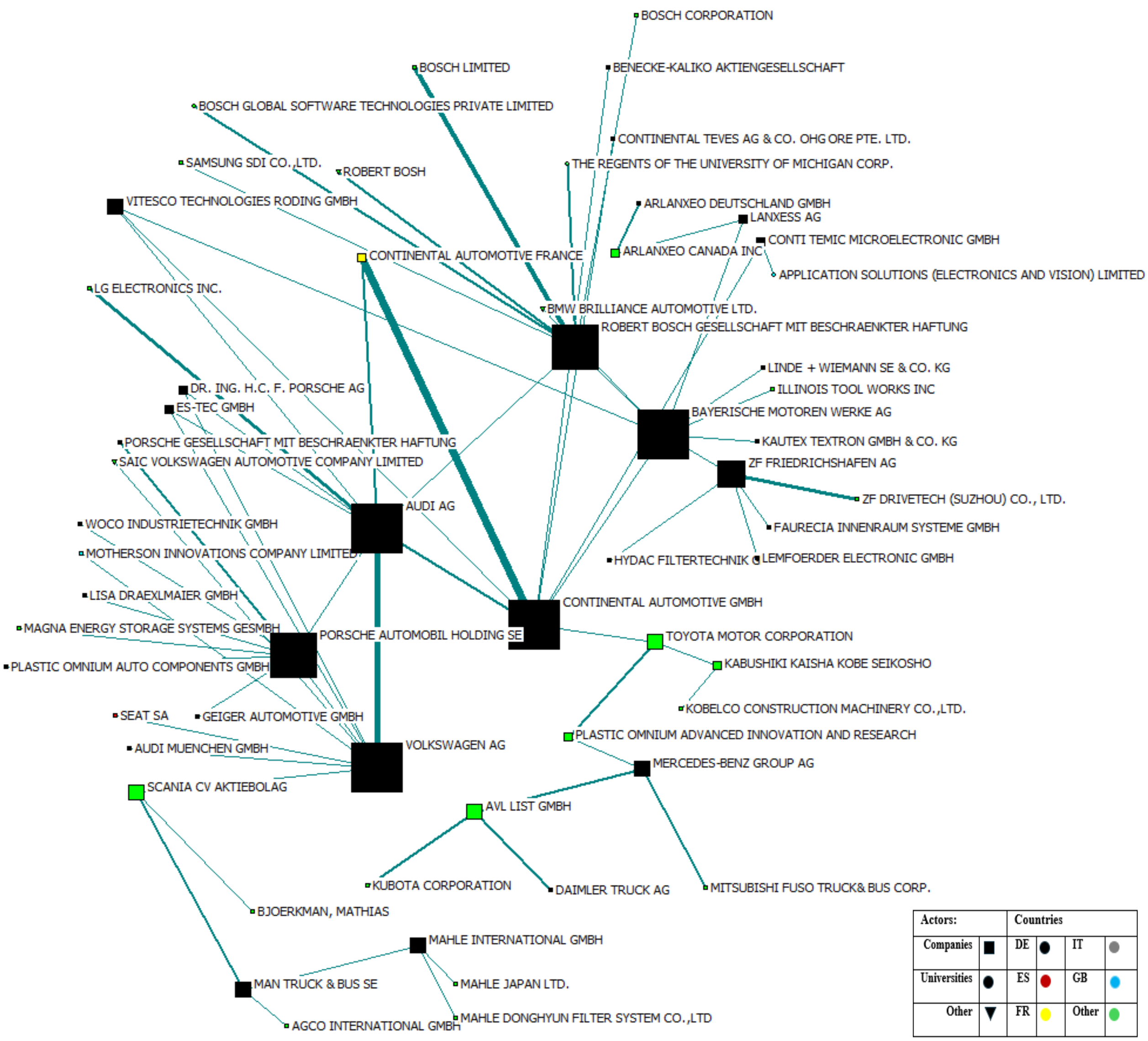


Figure 5.1.2: Propulsion main component network

K-core

A k-core is a maximal group of actors, all connected to other members of the group with at least k links [6] The value of k can be varied to observe the interconnectedness of the network and identify strong communities. Actors within the subgraph are considered an elite group that shares innovations and holds a competitive advantage over those who are not part of it [4].

Using ASEN for the analysis and UCINET for the visualization, the output indicates that the network has a maximum of 3-core with *degree centrality=3*. The k-core subgraph consists of 4 components and each component consists of a clique in which every organisation is directly connected to one another. There are a total of 16 actors but 4 actors in each clique. These actors have a high level of collaboration as they have worked on 114 patents together and share an average of 2 patents between themselves. In addition, the APL of 1 suggest that information flow is fast and the GCL value of 1 indicates a full cluster since all actors collaborate with themselves.

The table below, followed by the graph provides a partial view of the k-core graph.

Table 5.1.3.1 K-core main indicators:

	Value
Nodes	16
Edges	24
Density	0.2
Average links value	2.375
Global clustering coefficient	1
Average path length	1

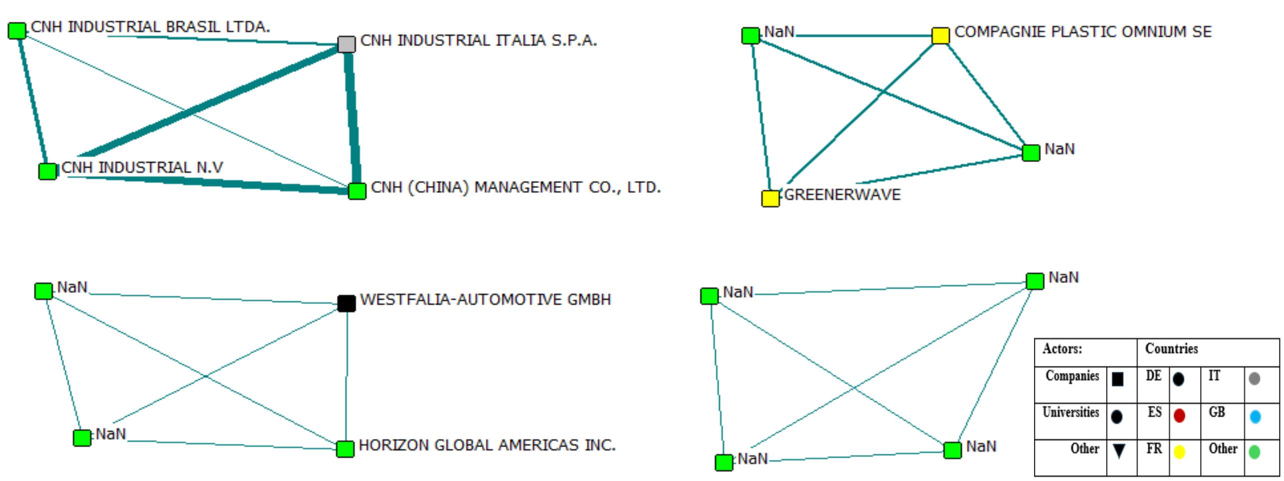


Figure 5.1.3 : Network of the Propulsaion k-core

The table below displays the list of the actors associated with the nodes.

Table 5:1.4 Organisations in the K-core

	ID	Organisation Name	# of Patents	Country
1	auto_1999	CNH (CHINA) MANAGEMENT CO., LTD.	19	CN
2	auto_2003	CNH INDUSTRIAL BRASIL LTDA.	7	BR
3	auto_2005	CNH INDUSTRIAL ITALIA S.P.A.	20	IT
4	auto_2007	CNH INDUSTRIAL N.V	20	NL
5	auto_11638	NaN	3	
6	auto_11658	NaN	3	
7	auto_4630	HORIZON GLOBAL AMERICAS INC.	3	US
8	auto_10788	WESTFALIA-AUTOMOTIVE GMBH	3	DE
9	auto_2068	COMPAGNIE PLASTIC OMNIUM SE	6	FR
10	auto_4230	GREENERWAVE	6	FR
11	auto_11343	NaN	6	
12	auto_11364	NaN	6	
13	auto_11392	NaN	3	
14	auto_11412	NaN	3	
15	auto_11417	NaN	3	
16	auto_11483	NaN	3	

Unfortunately, there are no details for half of the actors associated with the k-core. These unknown actors are present in three out of four components.

Taking a closer look at *table 5.1.4.* above, the diversity of the organisations in terms of country can be seen. Germany (DE), Italy (IT), Netherlands (NL) and France (FR) are all EU while China (CN), Brazil (BR) and US (United States) are all non-EU. Notably, the organisations in the first component appear to belong to the parent company in China while the others are subsidiaries in different parts of the world. This may explain why there are intense collaborations among the actors, the actors prefer to create patents with their subsidiaries. In the second component, the oranisations appear to be independent while the third component consists of countries in France.

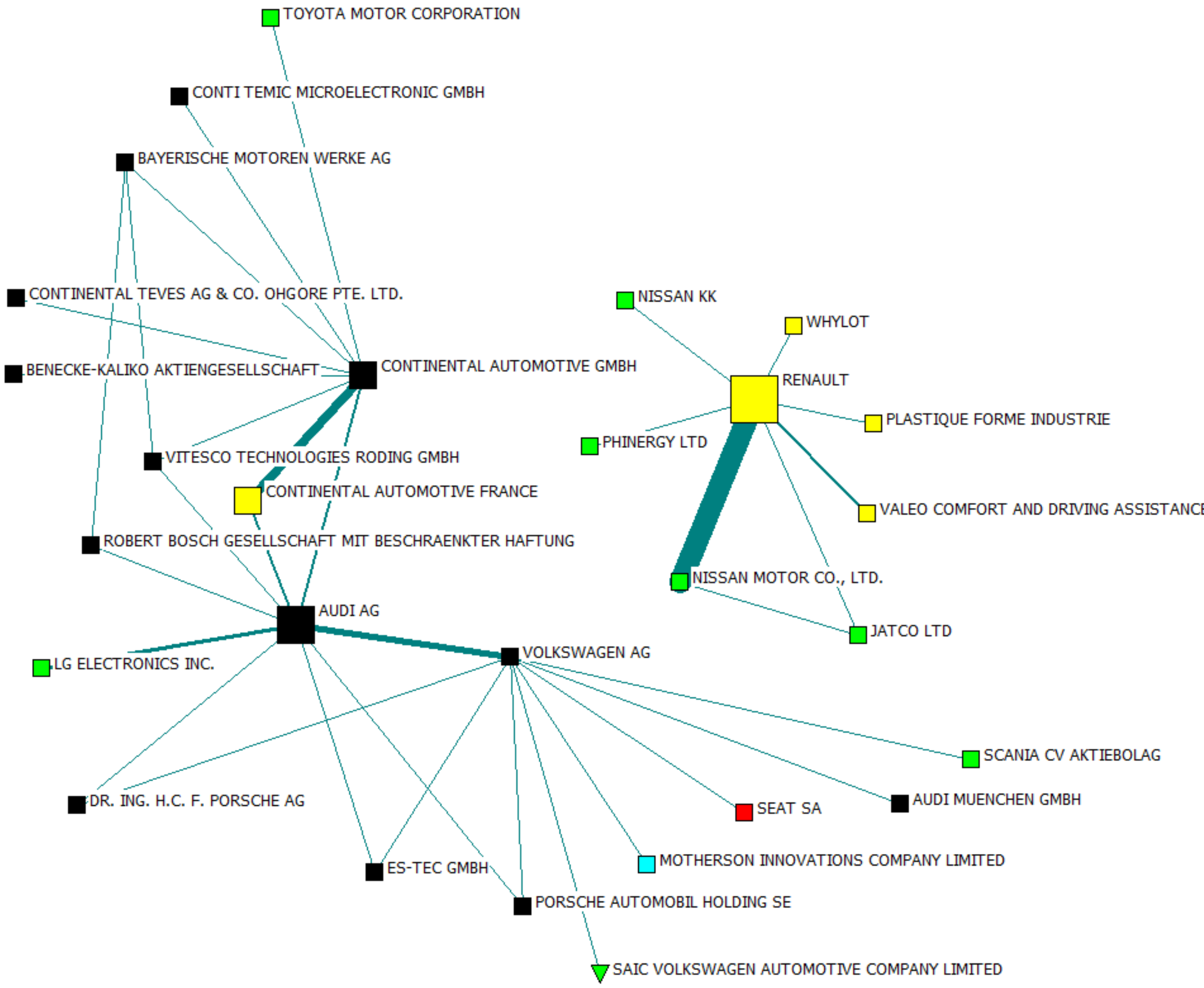
The actors in the individual components enjoy easy collaboration and flow of information however, they do not have some of the highest number of patents for a given actor in the entire network. The small size of the k-core further reflects the disconnectivity of the network and emphasizes how patent collaboration is limited to a small group of actors. In addition, it can be concluded that patent collaboration may be dependent on company's management.

5.1.2. Node Level

The table 4.5 below shows the top 5 most connected nodes. The actors are arranged in descending order of weighted normalised degree centrality. The table shows the normalised values for the centrality measures, it can be observed that Renault and Nissan Motor are highly connected compared to the rest of the actors. Notably, Nissan Motor is located in Japan and collaborates extensively with EU organisations. While the network and group levels seemed to reflect poor collaboration, the node level highlights a better rate of collaboration. The actors are from the Manufacturing (29) and Professional, scientific and technical activities (72) industries. Interestingly, out of the top 5 EU countries with a high number of patents (that was identified earlier in the research), Austria and Italy did not make it to the Ego network. The table and graph below shows the network of the top 5 Ego networks

Table 5.1.5: Top 5 most connected nodes

ID	Organisation Name	DCWN	BCWN	EIG	NACE	
auto_8064	RENAULT	0.664	0.005	0.999	2910	FR
auto_7037	NISSAN MOTOR CO., LTD.	0.611	0	0.998	2910	JP
auto_916	AUDI AG	0.347	0.026	0	2910	DE
auto_2149	CONTINENTAL AUTOMOTIVE GMBH	0.294	0.023	0	2931	DE
auto_2147	CONTINENTAL AUTOMOTIVE FRANCE	0.244	0	0	7219	FR
auto_10626	VOLKSWAGEN AG	0.24	0.017	0	2910	DE



Actors:		Countries			
Companies	■	DE	●	IT	●
Universities	●	ES	●	GB	●
Other	▼	FR	●	Other	●

Figure 5.1.4: Network of the most connected nodes for Propulsion Segment

Ego Network 1: RENAULT

Based in France, Renault claims to be at the forefront of mobility that is reinventing itself[4]. The company is involved in both traditional internal combustion engine vehicles but it is also active in the manufacture of electric vehicles. In patenting, Renault is involved in a range of different areas, including vehicle design, propulsion systems and safety features [7].

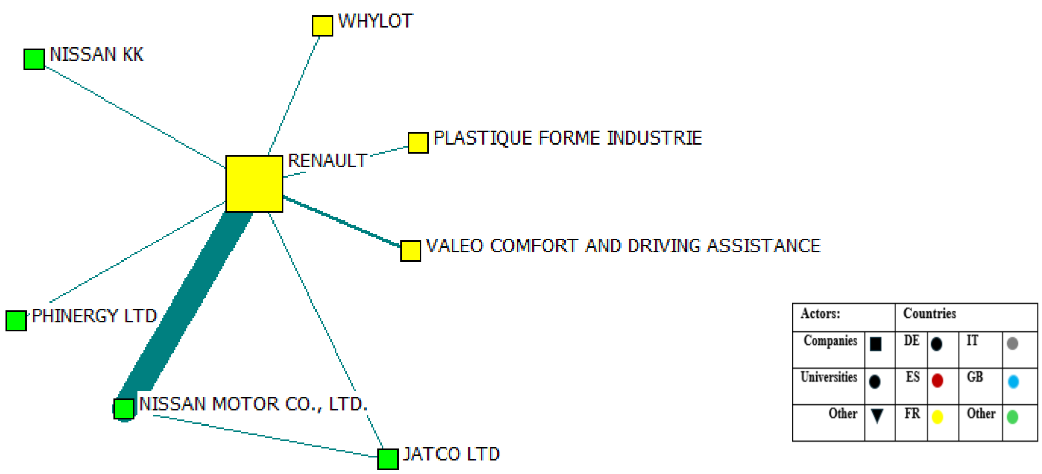


Figure 5.1.5: Network of Renault

The above network of Renault shows that it has 10 direct neighbours, two of which are unknown and are omitted in the visualisation. The geographical distribution of its neighbours is quite interesting as it does not include any country from Europe besides France where it is based. The neighbouring actors are from Japan and Isreal. Renault thrives on its alliance with Nissan and Mitsubishi Motors, and this explains why it has several direct connections with Nissan for patent collaboration. This ego network is isolated from the other ego networks.

Ego Network 2: AUDI AG

[4] https://www.renaultgroup.com/en/our-company/

Based in Germany, the history of Audi extends back to the 19th century [5]. It is known for high-quality luxury vehicles and positions itself as the sportiest supplier of racing cars in the premium sector. Like Renault, Audi prides itself on its commitment to sustainability and progressive design worldwide

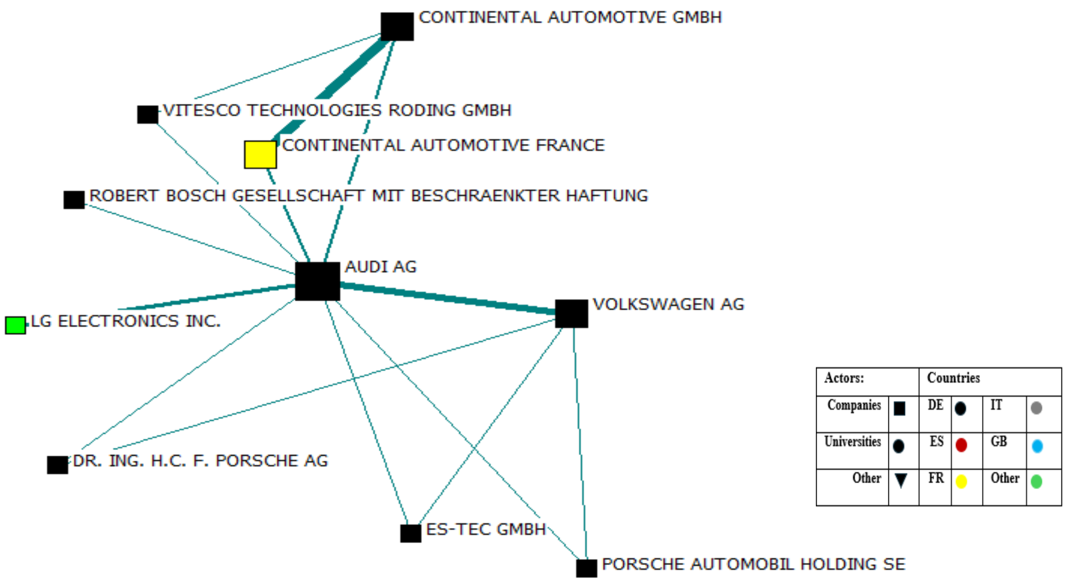


Figure 5.1.6: Network of Audi

In the network of Audi, it can be observed that it prefers to collaborate with other organisations located in Germany. On a few occasions, it collaborated with an organisation in France and another in Korea. There are also 10 nodes in this network, three of them being among the top 5 ego networks. This indicates that Audi is not just connected to a lot organisations, but it is also connected to organisations that are well connected. In reality, this means that Audi takes propulsion patent collaboration very seriously.

Ego Network 3, 4: CONTINENTAL AUTOMOTIVE

[5] https://www.audi.com/en/company/profile.html

Headquartered in Germany, Continental Automotive is a global technology solutions provider for manufacturers of vehicles, machines, traffic and transportation[6]. It offers a wide range of safe, efficient, intelligent and sustainable mobility products. The French company is a subsidiary of the German company.

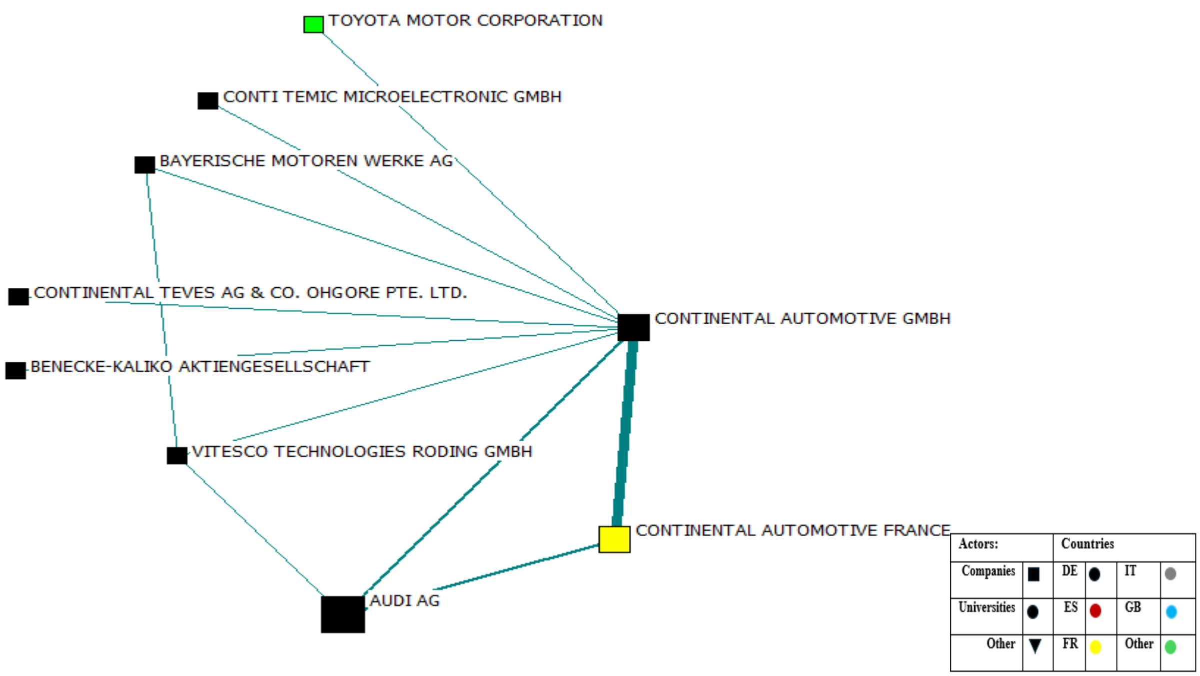


Figure 5.1.7: Networks of Continental Automotive

The duo of Continental Automotive GMBH and Continental Automotive France work hand in hand. It is imperative to study the Ego networks of both organisations together because on its own, Continental Automotive France is connected to only two organisations. One of them is Continental Automotive GMBH with which it shares a total of 58 patents. The other is Audi which makes the network include 3 actors from top 5 most nodes. The German company, on the other hand, is connected to 7 other companies including two other subsidiaries of Continental Automotive; Conti Temic Microelectronic GMBH and Continental Teves AG & Co. Continental Automotive serves as a bridge for the French company to be connected to organisations inside and outside Germany. Both Ego networks have 9 nodes, mostly actors from Germany and just one from Japan. This suggests that Continental Automotive prioritises patents collaboration within Germany.

[6] https://www.continental.com/en/

Ego Network 5: VOLKSWAGEN AG

Based in Germany, Volkswagen is a large organisation which currently has 10 strong core brands aimed to be a software-centric global leader in sustainable mobility.[7] The brands are divided into Core, Progressive and Sport Luxury and they work independently to achieve its shared success.

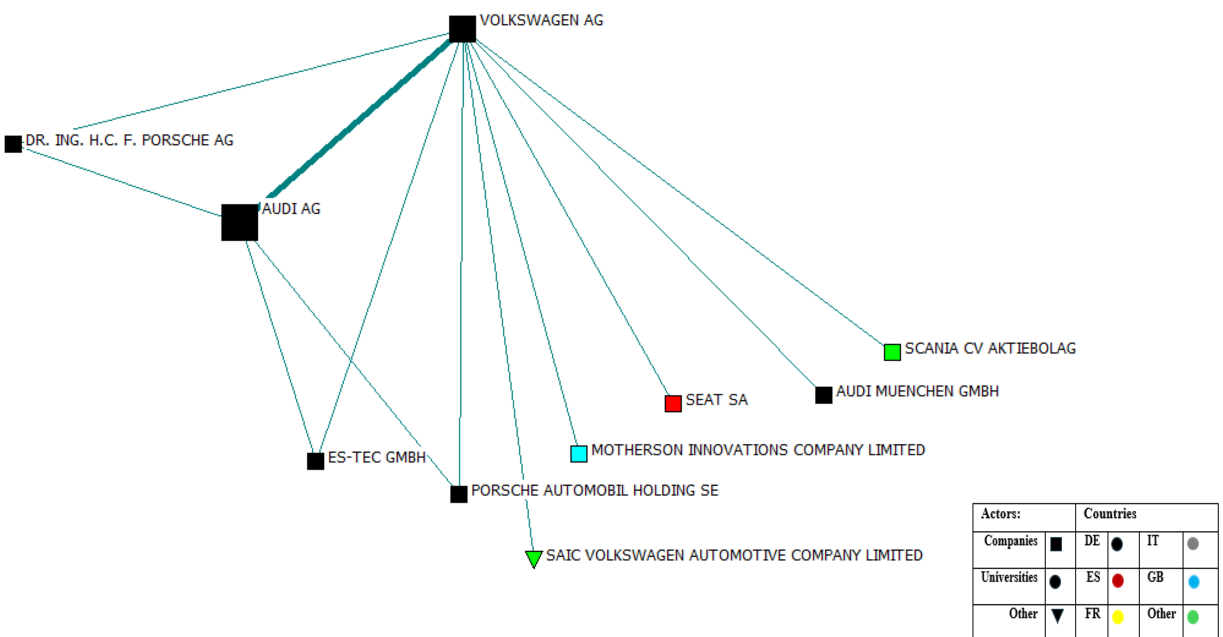


Figure 5.1.8: Network of Volkswagen

In this network, there are 10 nodes including nodes that belong to the brands of Volkswagen such as Porsche, Audi and SAIC Volkswagen. This Ego network has the most diversified geographic density, it is characterized by EU actors from Sweden, Spain and Germany and non-EU actors from China and Great Britain. There is a balance in the collaboration of propulsion patents with brands of its own and other organisations. Notably, Volkswagen AG is the only Ego network that appears in the list of top 5 organisations with the highest operating revenue.

[7] https://www.volkswagen-group.com/en/brands-and-brand-groups-15811

5.1.3. **Scale Free Property**

This is a network characteristic where the distribution of node degrees follows a power-law distribution [8]. This implies that a small number of nodes have many connections, while most nodes have relatively few. By plotting the fraction of nodes, P(k) against all possible Degree Centrality (DC) values, we observed a power-law distribution.

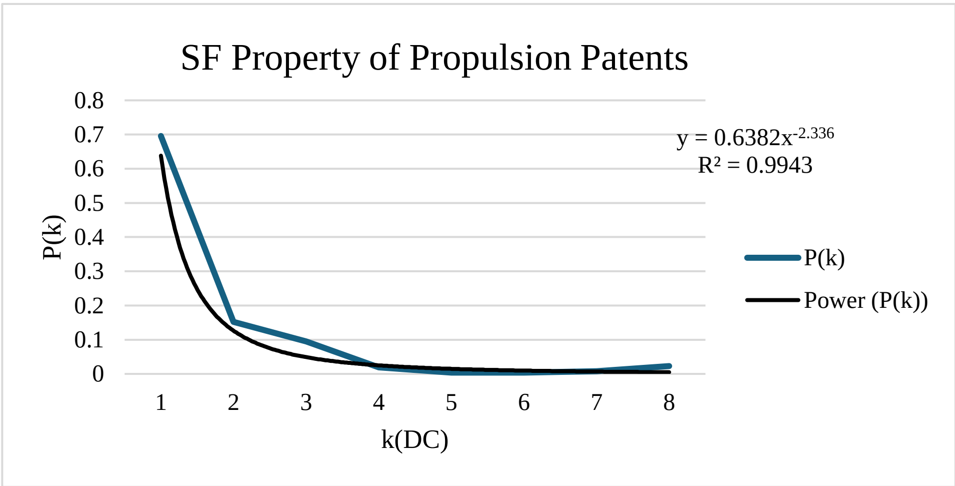


Figure 5.1.9: SF Structure of binary DC

To test the scale-free property, both axes in the initial graph were converted to a log scale and then interpolated with a linear line. The R-squared value which shows the goodness of fit indicated moderate fitness. Therefore, it can be concluded that the distribution is scale-free.

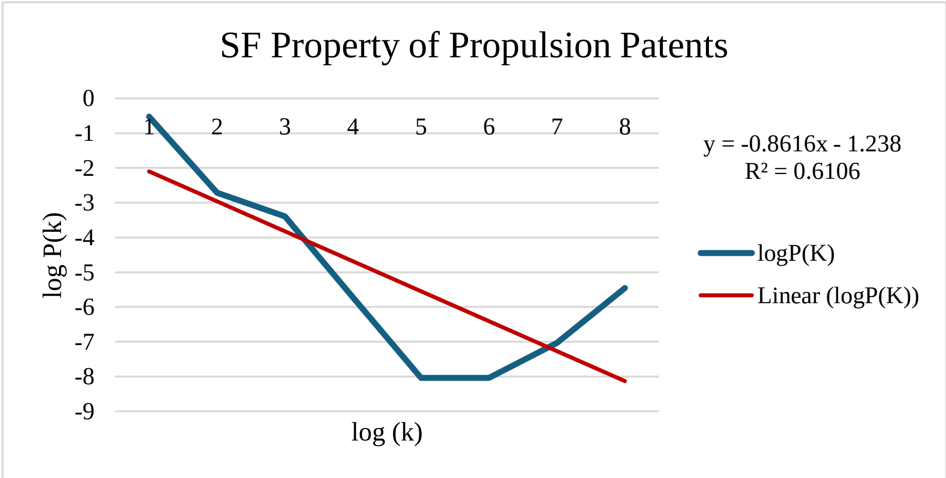


Figure 5.1.10: Log-log Transformation

5.2. Tyres Segment

The table below shows the properties of the network as analysed by ASEN

Table 5.2.1: Tyres Network main indicator

	Value
Nodes	124
Absolute Density	121
Normalized Density	1.59%
Average links value	18.43
Average path length	1.850
Fragmentation	0.926
Connected components	32
Global Clustering Coefficient	0.754
Degree centralization weighted normalized	0.008
Betweenness centralization weighted	0.044
Eigenvector centralization	0.602

All the nodes are connected by 121 edges, and the density of the graph is 1.59**%**. Despite having fewer actors compared to the propulsion network, the average number of patents shared by two organisations is 18 indicating that there are more tyre patent collaboration than there are propulsion. The short average length path shows that information flow is efficient hence explaining why there are more collaborations. Nevertheless, the work is highly fragmented and this can easily be seen in the network graph below. There are 32 connected components implying that the organisations form a sparsely connected network. Similar to the propulsion network, the low weighted degree and betweenness centralization mean that the network does not seem to be dominated by certain organisations that are extremely central in patent collaboration.

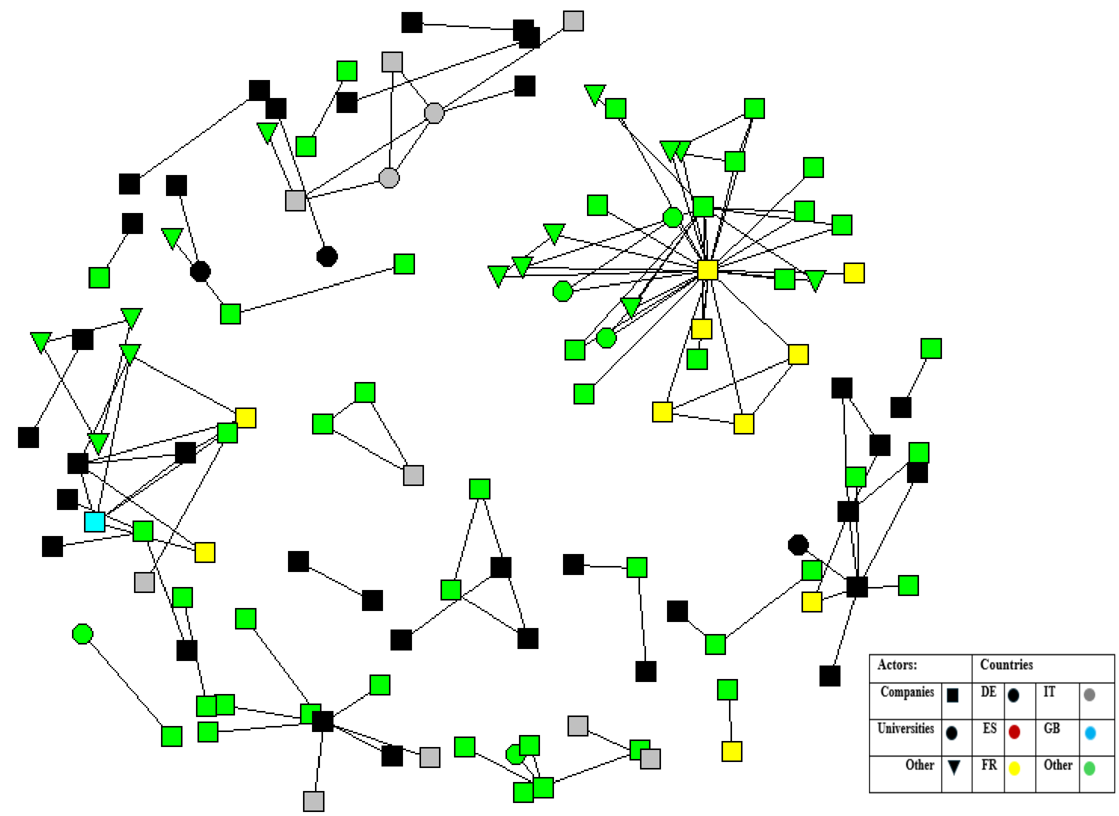


Figure 5.2.1: Network of tyres segment

5.2.1. Group Level

Main Component

This represents 23.39% of the entire network. Below are some of its indexes:

Table 5.2. 2: Main Component Indicators

	Value
Nodes	29
Absolute density	44
Normalized density	10.84%
Total links value	3250
Average links value	36.93
Average path length	1.936
Small world index	1.821
Global clustering coefficient	0.911
Degree centralization weighted normalized	0.036
Betweenness centralization weighted	0.864
Eigenvector centralization weighted	0.495

Compared to the entire network, the MC consists of just 29 nodes and 88 edges, making it a lot smaller than the entire network, albeit denser. The total links value shows that there are 3250 patents collaboration and two organisations collaborate on at least 36 patents. This value is quite significant as it explains that the actors in the main component contribute to more than half of the entire tyre patents. Although the average path length of 1.936 is not so different from that of the entire network, the actors in the MC are particularly deliberate about patent collaboration and hence generate more patents. The small world index being greater than 1 indicates that the MC is characterized by high clustering and short average length paths. This is supported by the high GCL value of 0.911. Examining the centrality indexes shows that there are dominant actors in the main component that facilitate patent collaboration. Overall, the spread of information across the main component is faster and more efficient. In the network image below, the node size represents the degree centrality binary while the link size represents the number of patents.

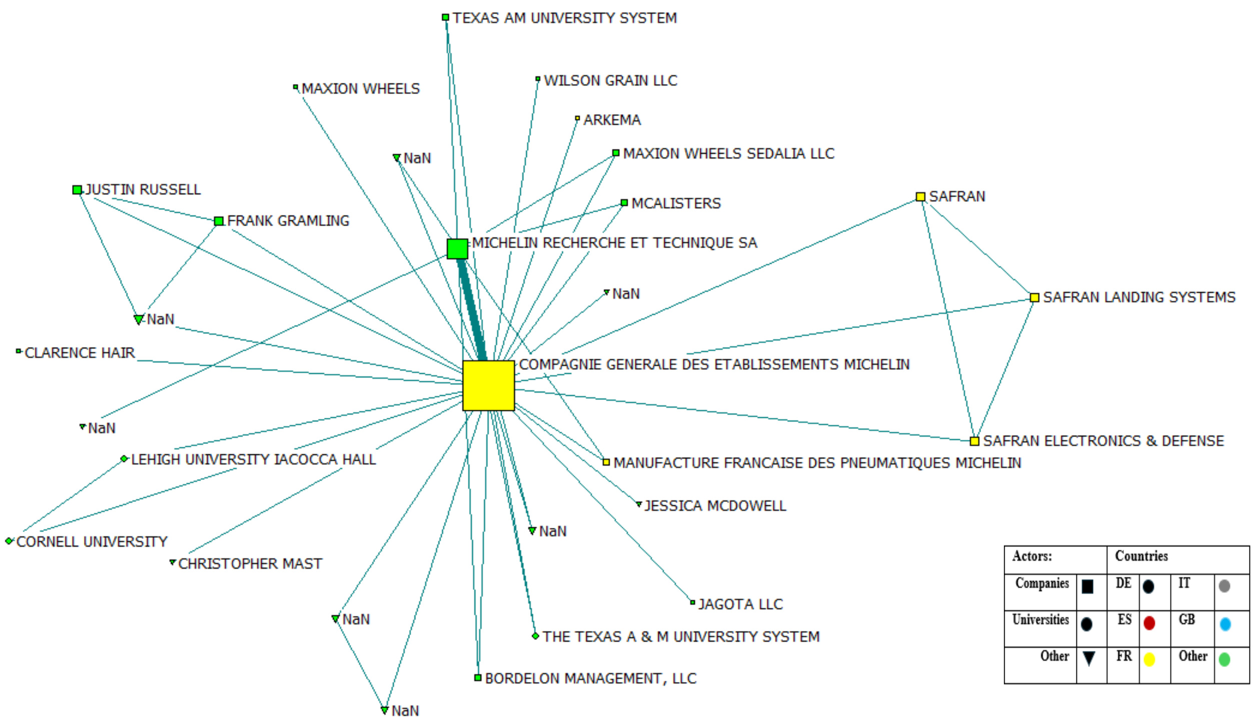


Figure 5.2.2: Network of the Tyres main component

K-core

Using ASEN for the analysis and UCINET for the visualization, the output indicates that the network has a maximum of 3-core with varying *degree centralities*. Unlike the k-core network for the propulsion segment, the tyres k-core consists of two components. The table below, followed by the graph provides a partial view of the k-core graph. Each component included an unknown actor.

Table 5.2.3.3 K-core main indicators:

	Value
Nodes	12
Edges	21
Density	31.8%
Fragmentation	0.530
Average links value	86
Global clustering coefficient	0.789
Average path length	1.323

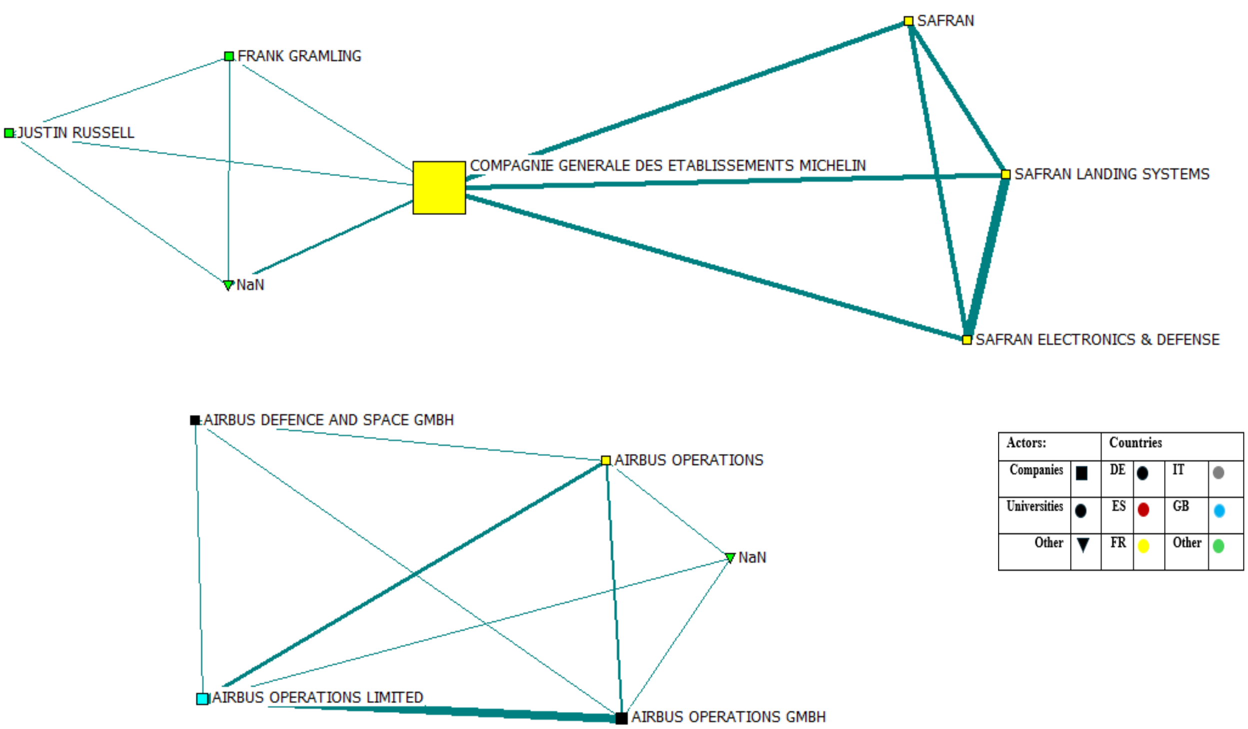


Figure 5.2.3: Network of the tyres 3-core

Similar to the k-core of the propulsion network, the k-core is made of parent companies and their subsidiaries. While the first component appears to be an Airbus network, the second component appears to be a Safran-France network. The Airbus clique includes the subsidiaries from Great Britain, Germany and France, all collaborating to form a clique. The Safran component is more diverse as it includes Michelin, also in France. However, Michelin partners with two other companies in the US that have no connection to Safran.

Table 5.2.4: Organisations in the K-core

	ID	Organisation Name	# of Patents	Country
1	auto_11094	NaN	3	NaN
2	auto_11643	NaN	5	NaN
3	auto_2067	COMPAGNIE GENERALE DES ETABLISSEMENTS MICHELIN	1547	FR
4	auto_356	AIRBUS DEFENCE AND SPACE GMBH	3	DE
5	auto_368	AIRBUS OPERATIONS	18	FR
6	auto_369	AIRBUS OPERATIONS GMBH	33	DE
7	auto_370	AIRBUS OPERATIONS LIMITED	37	GB
8	auto_3754	FRANK GRAMLING	3	US
9	auto_5506	JUSTIN RUSSELL	4	US
10	auto_8347	SAFRAN	41	FR
11	auto_8362	SAFRAN LANDING SYSTEMS	56	FR
12	auto_8355	SAFRAN ELECTRONICS & DEFENSE	56	FR

5.2.2. Node Level

The table below shows the top 6 most connected nodes, one of them located in the US. The actors are arranged in descending order of weighted normalised degree centrality.

Table 5.2.5: Top 5 most connected nodes

ID	Organisation Name	DCWN	BCWN	EIG	NACE	
auto_2067	COMPAGNIE GENERALE DES ETABLISSEMENTS MICHELIN	12.577	0.045	1	2211	FR
auto_6611	MICHELIN RECHERCHE ET TECHNIQUE SA	12.016	0.005	1	7219	CH
auto_2149	CONTINENTAL AUTOMOTIVE GMBH	2.301	0.003	0	2931	DE
auto_2147	CONTINENTAL AUTOMOTIVE FRANCE	2.276	0	0	7219	FR
auto_4873	ILLINOIS TOOL WORKS INC	0.691	0	0	2829	US
auto_5795	KT PROJEKTENTWICKLUNGS-GMBH	0.691	0	0	7112	DE

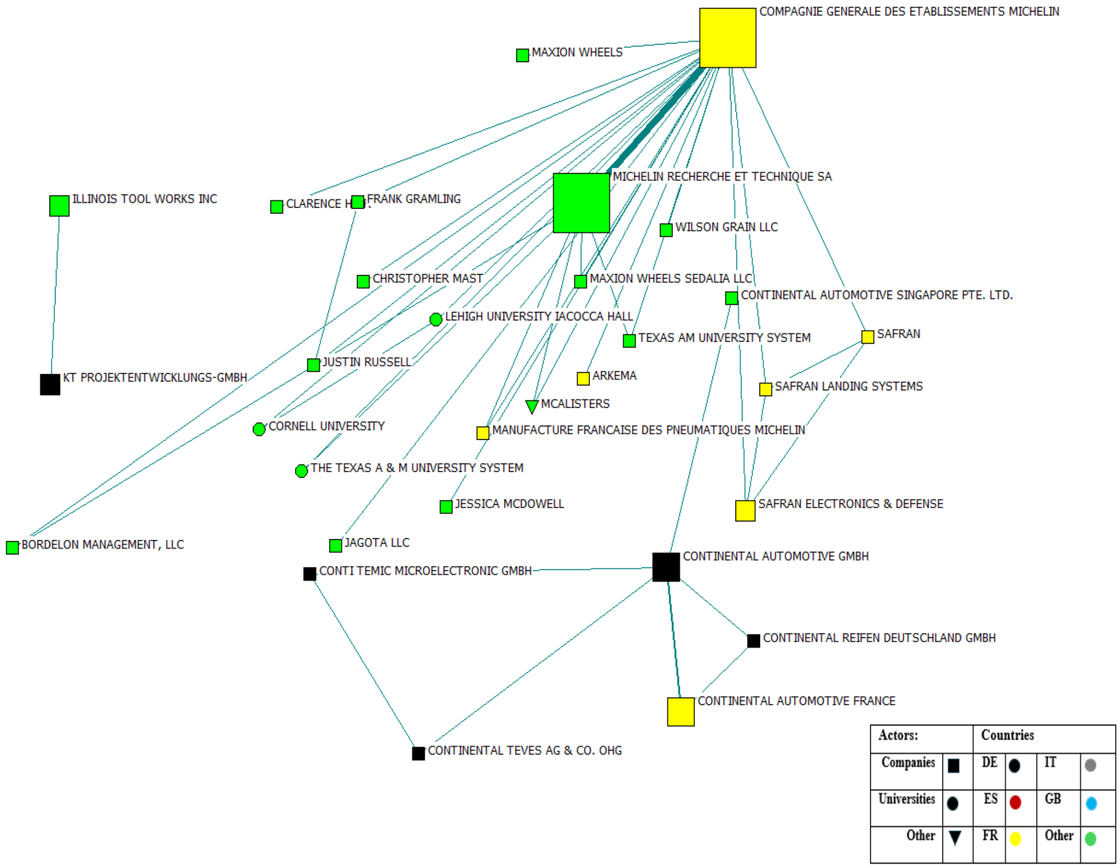


Figure 5.2.4: Network of the most connected actors

Ego Network 1, 2: MICHELIN

Michelin is one of the world's largest tyre manufacturers, known for its innovation in mobility solutions, including tyres, sustainable transportation, and road safety technologies. Michelin owns a variety of patents, which are for example related to the casing of tyres, tire tread and rubber materials. The company even has patents on services and new products that go beyond tyres [7]. The research and development arm of Michelin, Michelin Recherche et Technique SA is focused on technological innovation in the tyre and mobility sectors.

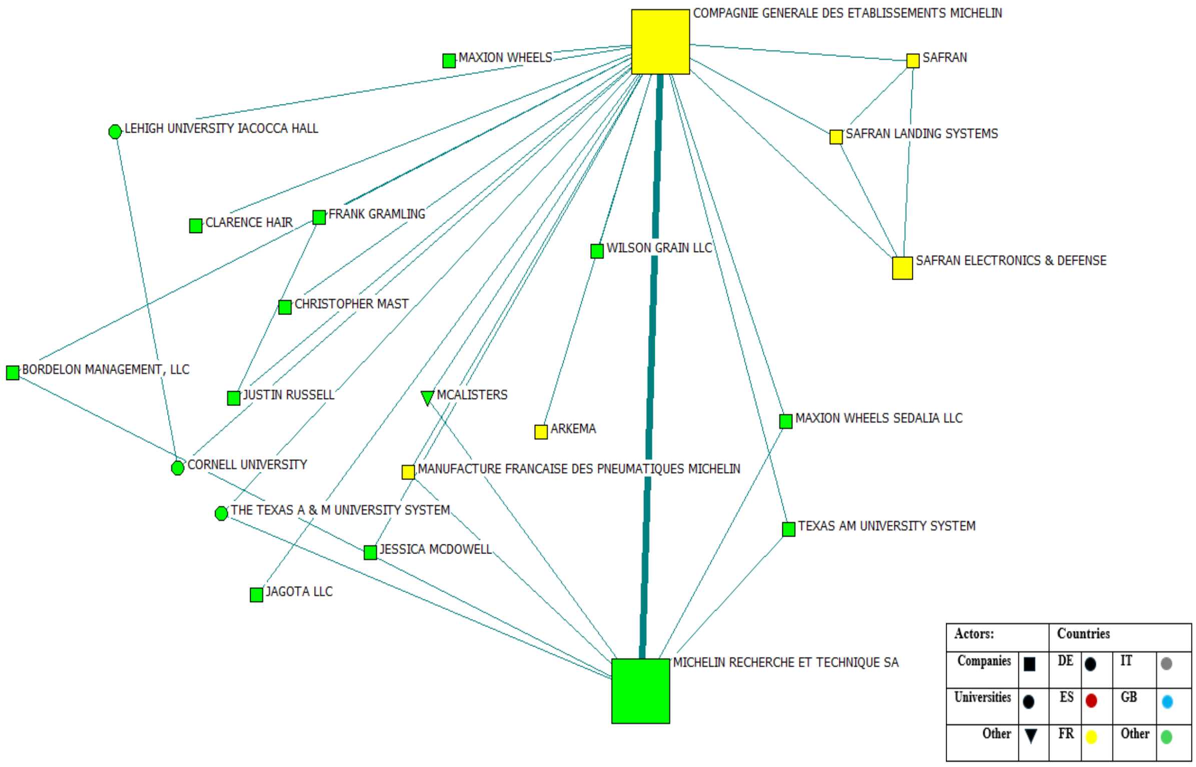


Figure 5.2.5: Network of Michelin3

The Michelin subsidiaries in France and Switzerland engage in a good amount of patent collaboration, especially with universities. They share the largest number of patent collaborations between themselves. It can be observed that both companies collaborate with the same companies for example, MCALISTERS and MAXION WHEELS. In addition, they seem to collaborate a lot with US based actors.

Ego Network 3, 4: CONTINENTAL AUTOMOTIVE

Similar to its role in the ego network of the propulsion segment, Continental Automotive once again stands out in patent collaborations within the tyre segment. This proves that they are indeed a solutions provider for the automotive industry.

In this ego network, the companies collaborate with their subsidiaries in different countries. They share the most collaboration with each other. It appears that the companies do not collaborate with universities or the other category of actors.

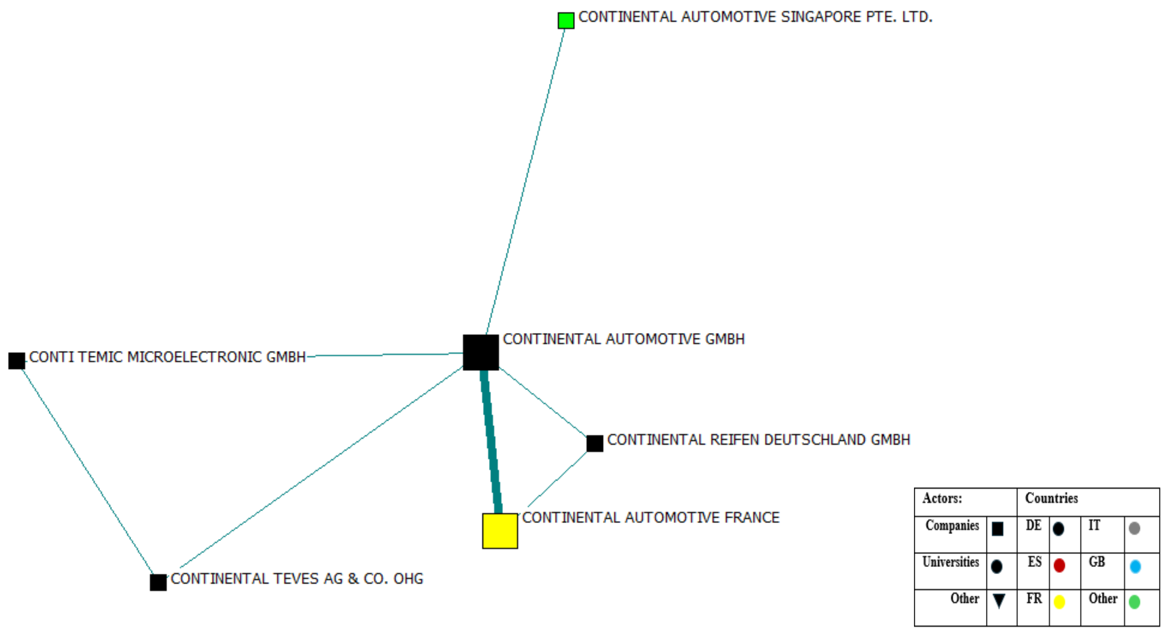


Figure 5.2.6: Network of Continental Automotive

Ego Network 5: KT PROJEKTENTWICKLUNGS-GMBH

Based in Germany, this company specialises in developing technical solution, particularly for automotive equipment, with a focus on innovations that can be patented and implemented.[8] In the entire network, this company is only connected to ILLINOIS TOOL WORKS INC based in the US. They have worked on 85 patents which makes their degree centrality weighted high and allows them to be included in the most connected ego network.

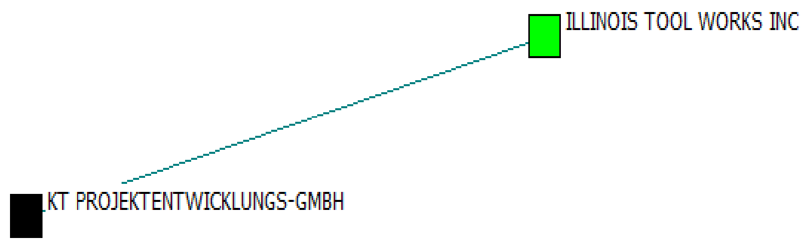


Figure 5.2.7: Network of KT PROJEKT

[8] https://www.webvalid.de/company/KT+Projektentwicklungs-GmbH,+Untergruppenbach/HRB+728656

5.2.3. **Scale Free Property**

Using the same approach as in the propulsion segment, we plotted the fraction of nodes against all possible degree centrality values. The resulting plot shown below follows a power-law distribution indicating that overall connectivity is dominated by a few highly connected nodes, while most nodes have relatively few connections.

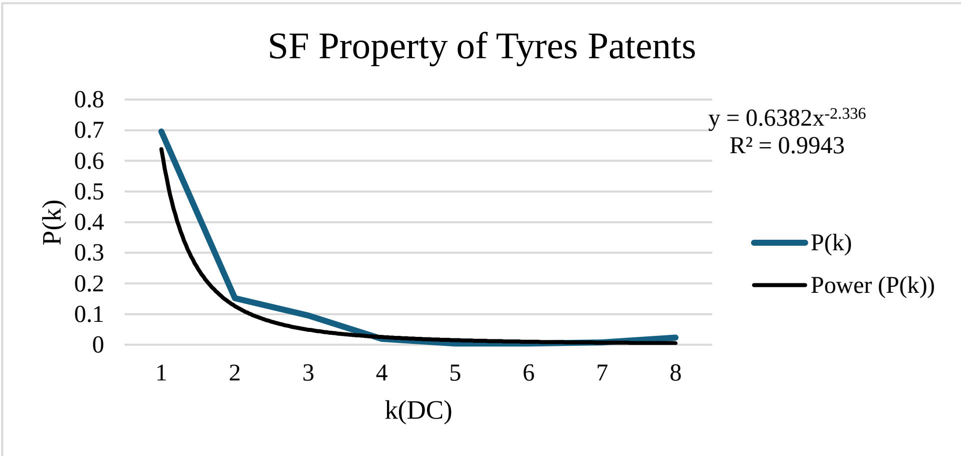


Figure 5.2.8: Scale-free property of tyres segments

Additionally, after applying a log transformation to both axes, we derived the following plot. Fitting the curve to a linear line resulted in an R-squared value of 0.7503. This value is higher than that of the propulsion network, suggesting that the tyre network has a better goodness of fit and similarly exhibits scale-free characteristics.

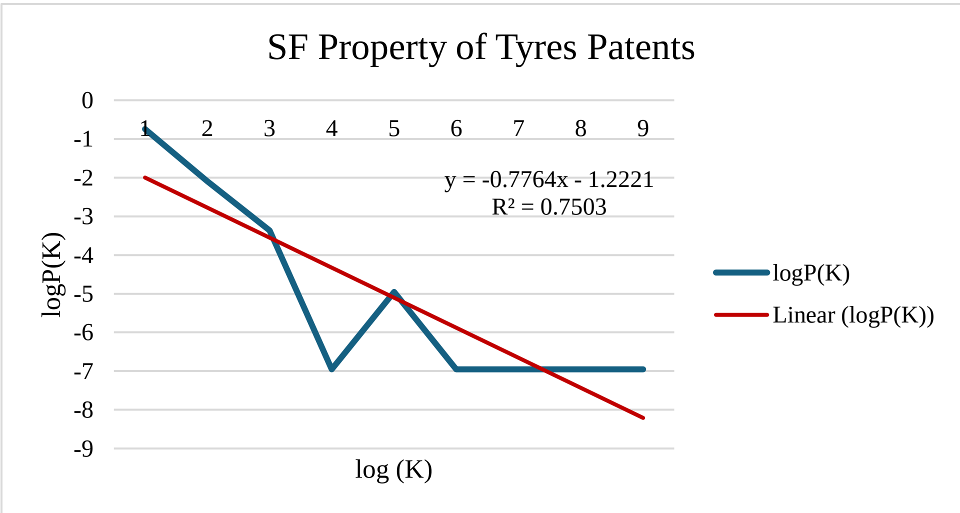


Figure 5.2.9: Log transformation

Chapter 6

Inter-Country Network Analysis

In addition to analyzing the organisations, this chapter examines the networks of the corresponding countries and industries. The goal is to explore how countries collaborate in patent production and identify which countries are most actively involved. For this analysis, the actors in the ORGxORG network for each segment were assigned to their respective countries of origin. The weights of duplicate rows (based solely on Source and Target) were summed to represent the total number of patents produced by each country pair. These pairs could consist of two different countries or the same country collaborating internally.

6.1 Propulsion Segment

In this network, there are 28 nodes with 68 edges. Using ASEN and UCINET for the analysis, the following table summarizes the network.

Table 6.1.1: Network of countries in propulsion segment

	Value
Nodes	28
Edges	68
Normalized density	17.99%
Average links value	16.603
Fragmentation	0.071
Connected components	2
Global clustering coefficient	0.498
Average path length	2.137
Degree Centralization Weighted Normalized	0.102
Betweenness Centralization Weighted	0.466
Eigenvector Centralization Weighted:	0.873

The normalized network density indicates a relatively moderate to sparse connectivity among the countries. A reduction can be seen in the total links value because the nodes with unknown actors were not considered in the analysis. Notwithstanding, the remaining known countries collaborate well and two countries share at least 16 patents. The network is slightly fragmented as there is an isolated node. This node belongs to actor(s) in Romania. For this reason, there are two components in the network: Romania (RO) and the other fully connected countries.

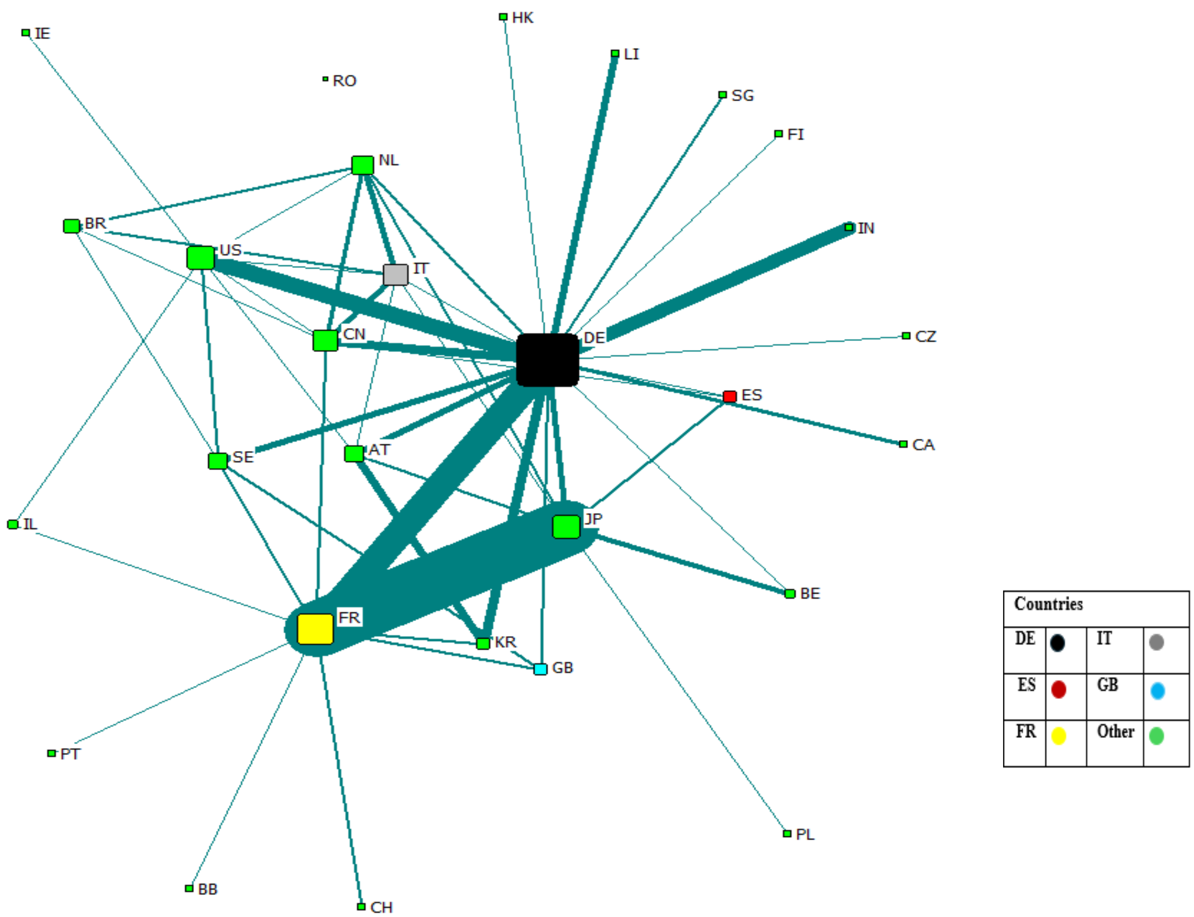


Figure 6.1.1: Inter-country network for propulsion patents

The top 5 countries with the highest number of patents can be identified by the size of the node. United States and Italy equally produced 54 patents each. Unlike the likes of Germany, France and Japan which have appeared multiple times in the analysis, Austria appeared for the first time owning 69 propulsion patents.

The diagram below shows the 10 most connected countries based on degree centrality binary absolute. Germany, France and Japan are the most connected countries and this may explain why they have the highest number of patents However, this high connection does not significantly affect their revenue as some of these connected countries do not appear in the list of countries with the highest revenue (*fig 3.1.2*)

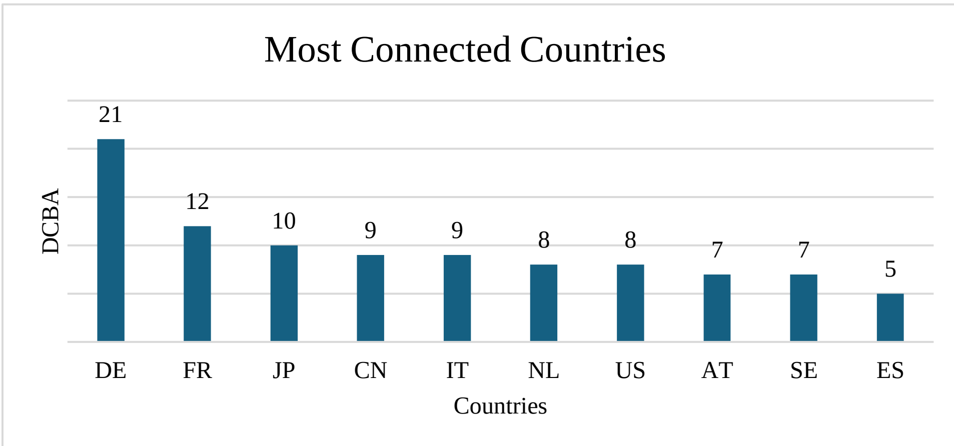


Figure 6.1.2: Top 10 most connected countries for propulsion patents.

6.2 Tyres Segment

The inter-country relation for the tyres segment is slightly smaller than that of propulsion. There are 21 unique countries which are connected by 32 edges.

Table 6.2.1: Network of countries in tyres segment

	Value
Nodes	21
Edges	32
Normalized density	15.24%
Average links value	2.688
Fragmentation	0.271
Connected components	4
Global clustering coefficient	0.533
Average path length	2.288
Degree Centralization Weighted Normalized	0.083
Betweenness Centralization Weighted	0.497
Eigenvector Centralization Weighted:	1.000

This network is sparsely connected with a high clustering coefficient, but it's fragmented into four components, suggesting isolated subgroups. The low degree centralization reflects evenly distributed connections, yet a few nodes have high betweenness, indicating their importance in linking parts of the network. Notably, the maximum eigenvector centralization shows that one or more countries have a central role, potentially holding significant influence over the network's connectivity.

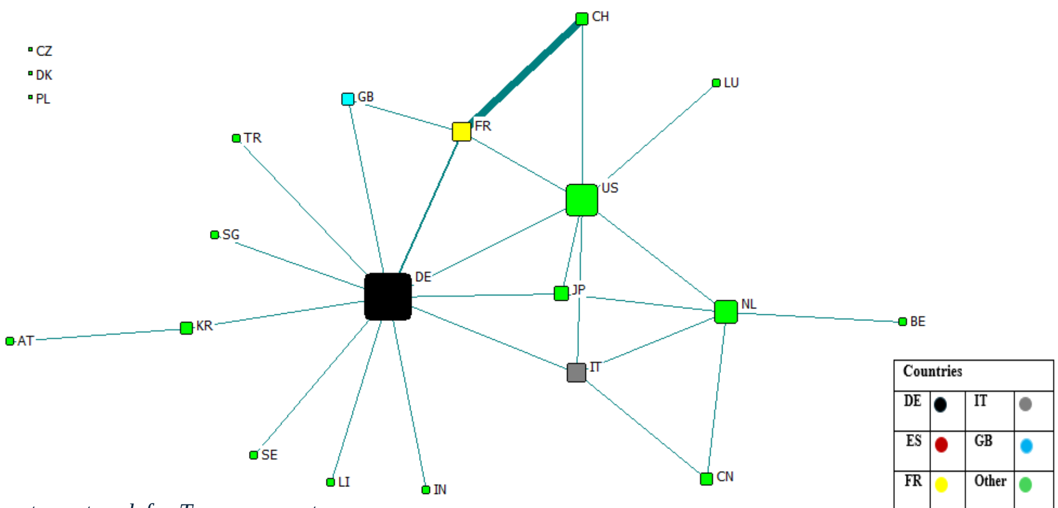


Figure 6.2.1: Inter-country network for Tyres segment

The network image above reveals that Czech Republic, Denmark, and Poland are isolated nodes, while other countries actively engage in patent collaboration. The size of each node represents its degree centrality, and the thickness of the links indicates the weight of patent collaborations. Notably, France and Switzerland share the highest number of patent collaborations, while Germany stands out for collaborating with the most countries in the network.

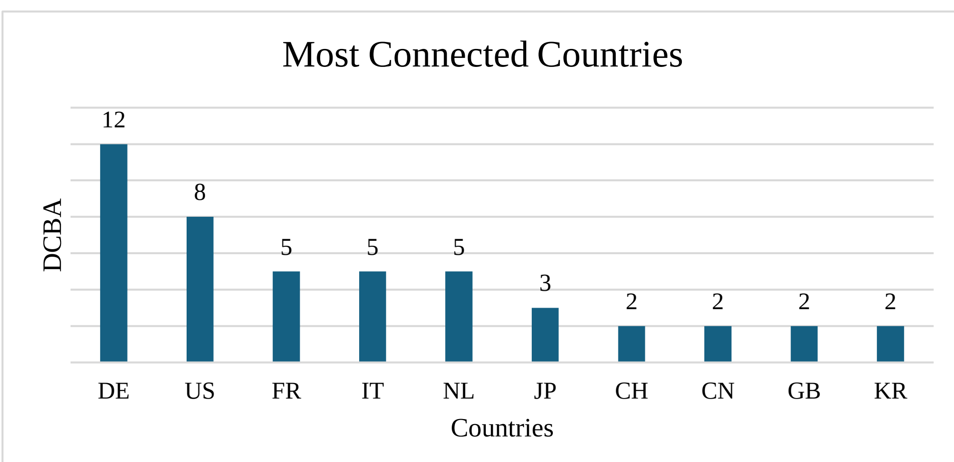


Figure 6.2.2: Most connected countries for tyres patents.

The graph above shows the top 10 most connected countries based on a degree centrality binary absolute that is greater than 1. The DCBA values here are much lower than those of propulsion segment. Some of the countries involved in propulsion are also involved in tyre patents emphasizing these countries' interest in collaboration.

Chapter 7

Inter-Industry Network Analysis

Similar to the inter-country network analysis, the inter-industry network was also conducted to explore how different industries collaborate for patent production and identify which industries are mostly involved in this process. Patent production related to propulsion and tyres is not exclusively carried out by manufacturers in the automotive industry. For this analysis, actors in the ORGxORG network for these segments were mapped to their respective industry NACE codes, considering only the first two digits. The weights of duplicate rows (based on Source and Target) were summed to represent the total number of patents produced by each industry pair. These pairs could either be within the same industry or between different industries.

7.1 Propulsion Segment

The table below followed by the graph summarizes the network for the propulsion patents. There are 35 industries collaborating on patent production. These industries are inter-connected by 73 edges and have a low density indicating a relatively sparse network. On average, each industry has collaborated on at least 3 patents.

Table 7.1.1: Network of industries in the tyres segment

	Value
Nodes	35
Edges	73
Normalized density	12.27%
Average links value	3.260
Fragmentation	0.111
Connected components	2
Global clustering coefficient	0.444
Average path length	2.386
Degree Centralization Weighted Normalized	0.085
Betweenness Centralization Weighted	0.455
Eigenvector Centralization Weighted:	0.356

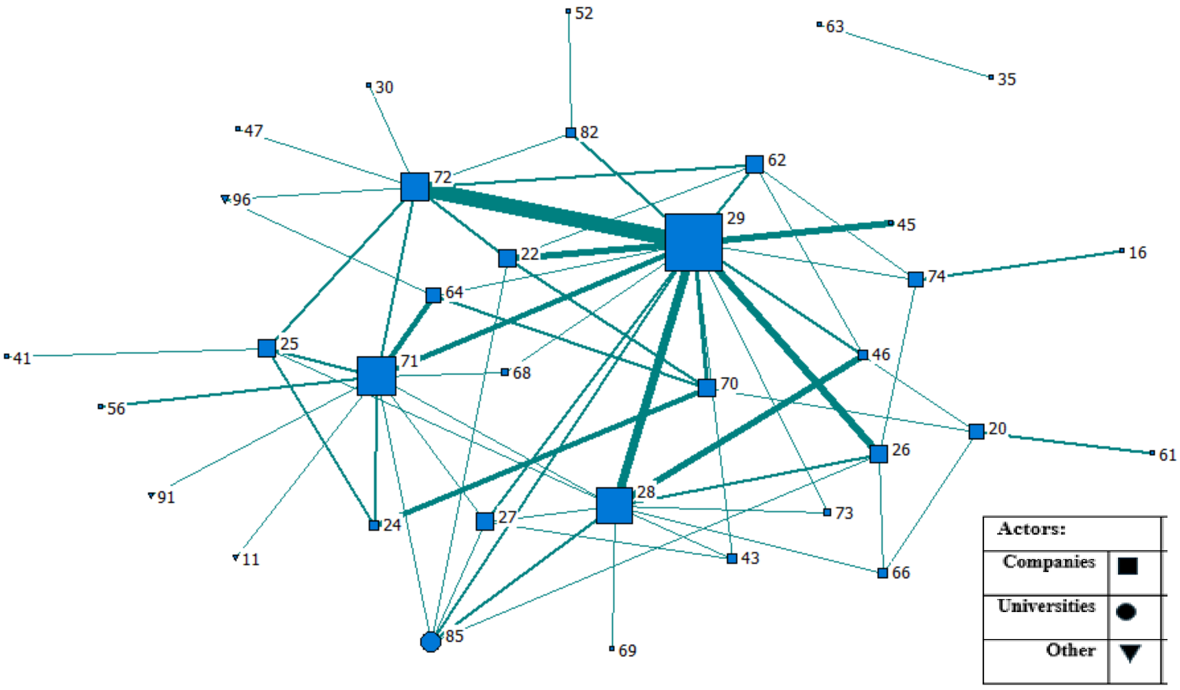


Figure 7.1.1: Propulsion inter-industry network

The network contains two connected components and so, has a low fragmentation value. In the *figure 7.1.1* above, the industry codes 63 and 35 form a component while the other nodes form the main component. The network is moderately clustered given the GCL value, with a relatively short average path length. While the network is not heavily centralized in terms of degree, there are few nodes holding influence over connectivity and information. The industries 29, 71 and 28 have larger node sizes indicating their high degree centrality. The thickness of the node size reflects the weights of the patents. A large share of the network consists of companies as indicated by the shape of the nodes. There are very few industries that are not companies and only one industry is a University.

Figure 7.1.2 below shows the industries with a DCBA greater than 5. The first three industries (29, 28 and 71) are also the top industries based on revenue (*fig 3.1.5*). The NACE codes 29, 28, 26, 22, 25 and 27 are all related to Manufacturing but differ in their type of products[9]. The code 71 belongs to the classification for Architectural and Engineering Activities. Code 72 represents

9 https://showvoc.op.europa.eu/#/datasets/ESTAT_Statistical_Classification_of_Economic_Activities_in_the_European_Community_Rev._2.1._%28NACE_2.1%29/data

Scientific Research and Development. Code 85 involves all things Education. Code 70 refers to Activities of Head Offices; Management Consultancy Activities. Code 62 refers to Computer programming, Consultancy and Related Activities. The diversity of these industries highlights the cross-disciplinary solutions produced in the EU automotive network. The high DCBA of code 72 and 85 shows that the manufacturing companies tend to collaborate with research centers and universities thereby creating a powerful ecosystem that drives innovation, efficiency, and growth. By pooling their expertise and resources, they can address complex challenges, develop new products, and enhance competitiveness in an increasingly interconnected market. This collaborative approach ultimately leads to sustainable development and increased economic value.

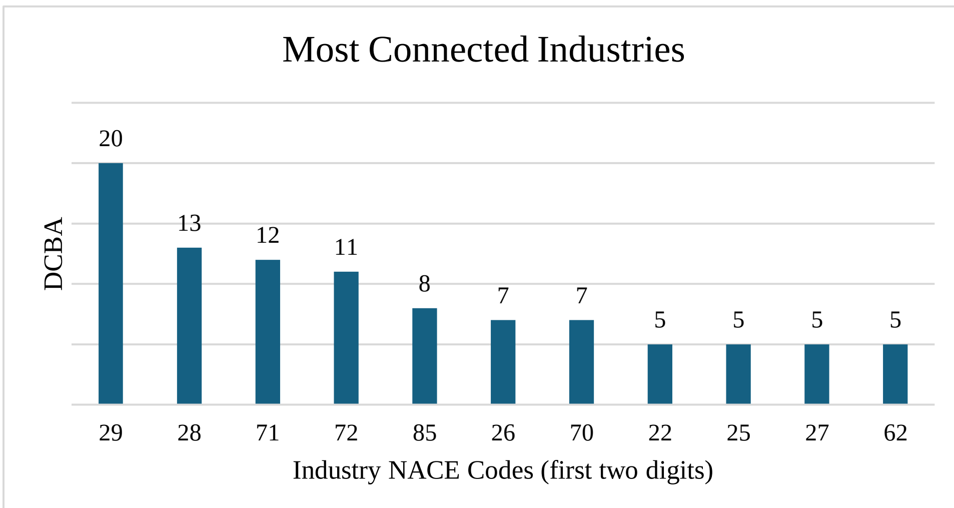


Figure 7.1.2: Most connected indutsries for propulsion patents.

7.2 Tyres Segment

In this network, there are 29 nodes with 57 edges. Despite having more patents produced, it is a smaller network than the propulsion inter-industry network.

Table 7.2.1: Network of industries in the tyres segment

	Value
Nodes	29
Edges	57
Normalized density	14.04%
Average links value	34.018
Fragmentation	0.133
Connected components	2

Global clustering coefficient	0.485
Average path length	2.449
Degree Centralization Weighted Normalized	0.036
Betweenness Centralization Weighted	0.495
Eigenvector Centralization	0.311

The network is sparsely connected indicating sparse collaboration among the different industries. The high average link value shows that collaborating industries work on a high number if patents. In the *fig 6.2.1* below, the node size shows the degree centrality while the link size represents the weights of the edges. There are just two components, causing the fragmentation score to be low. . NACE code 23 and 32 which are both under Manufacturing form one component while the other NACE codes form the main component. It can be observed that NACE code 22 is the most connected node. The global clustering coefficient is slightly high indicating the presence of clusters while the average path length shows that effort needed to collaborate is relatively moderate. The centrality indexes indicates that there are only few nodes that are extremely central in patent collaboration.

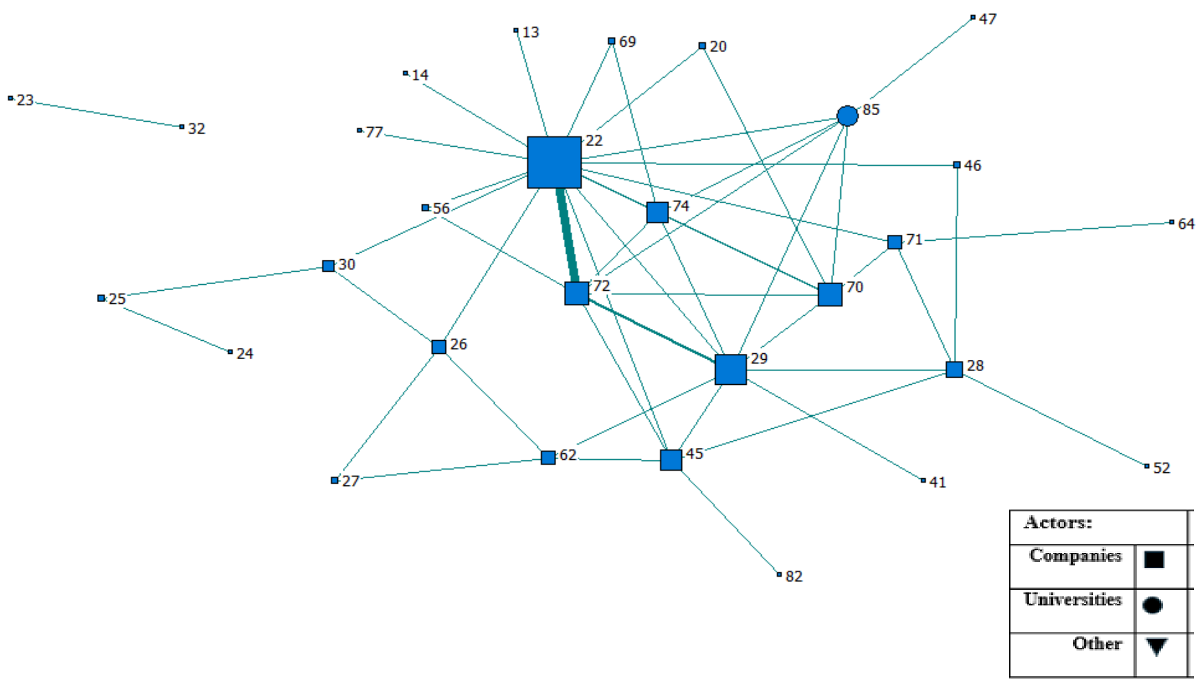


Figure 6.2.1: Tyres inter-industry network

Furthermore, we plotted the DCBA of the industries whose values were 5 and above. Unlike the propulsion network, the connected industries seem to share no relation with the top industries based on revenue. Out of the 10 industries with high revenue, only 5 of them are among the most connected. Similar to the propulsion inter-industry network, the NACE codes with high DCBA values are also diverse. NACE codes 22, 29, 72, 85, 28 and 70 are common to both segments. Code 45 refers to Wholesale and Retail Trade. Code 74 refers to other Professional, Scientific and Technical activities. Code 30 refers to Manufacturing. The overall trend indicates that while a few industries maintain high connectivity, many others have lower interaction levels within their networks. This distribution may reflect variations in innovation capacity and economic engagement across different divisions.

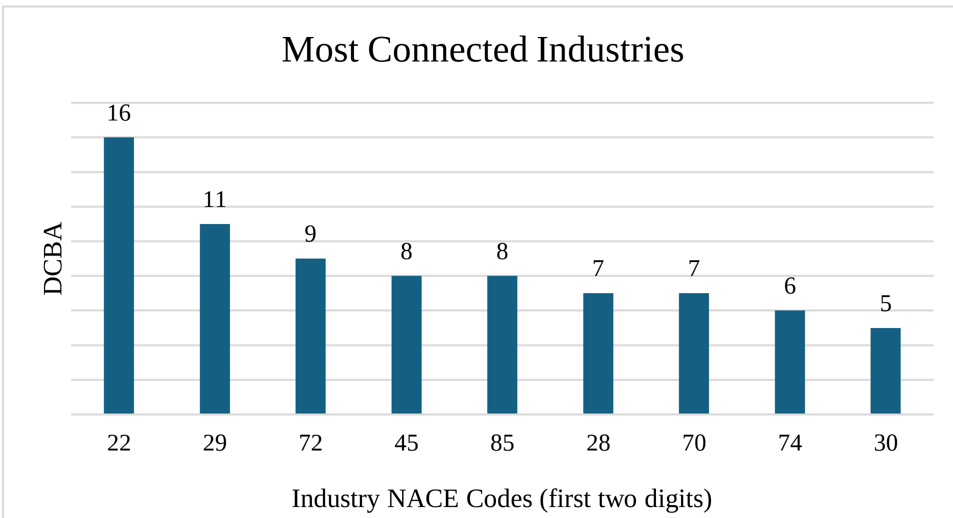


Figure 6.2.2: Most connected industries for Tyres

Chapter 8

Hypotheses Test

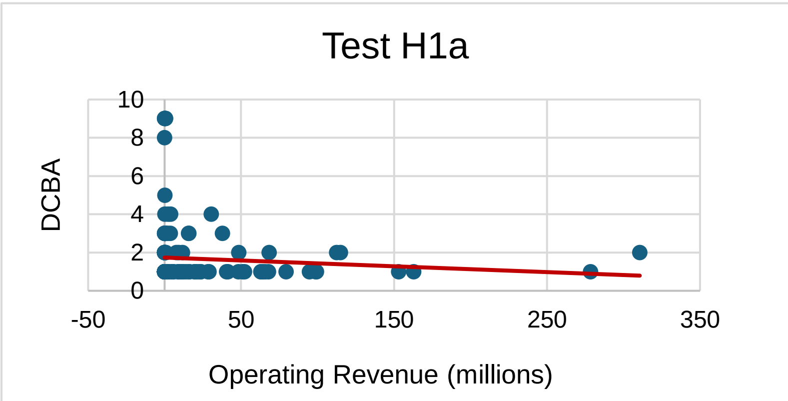
This final chapter tests the hypothesis of linear correlation among the previously analysed variables for the network of the propulsion segment. Using the common significance level of 0.05, the hypothesis test is carried out when the correlation appears significant. The aim is to understand the relationship between the following:

- degree centrality binary absolute and operating revenue
- degree centrality binary absolute and number of employees
- number of patents and operating revenue
- betweenness centrality weighted absolute and operating revenue
- number of patents and employees

Degree centrality binary absolute means that the value is the absolute DC without being normalized or considering the weight of the edge. This method allows for the direct counting of connections of the actors. The null hypothesis, H0, followed by the alternative are given below:

H0: There is no relationship between the variables

H1a: The number of connections an actor has is determined by its operating revenue.

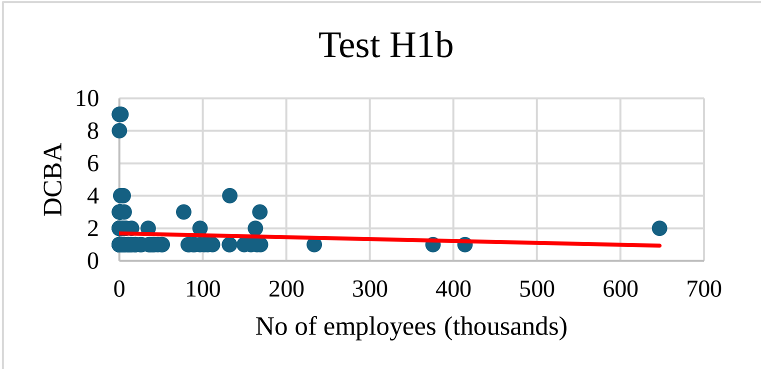


$CORR = -0.0905$

Figure 8.1 Correlation between operating revenue and Degree Centrality Binary Absolute

In *fig 8.1* above, the graph shows that there is a negative linear trend but the low correlation coefficient indicates that no relationship exists between the variables.

H1b: The number of connections an actor has is influenced by its number of employees.

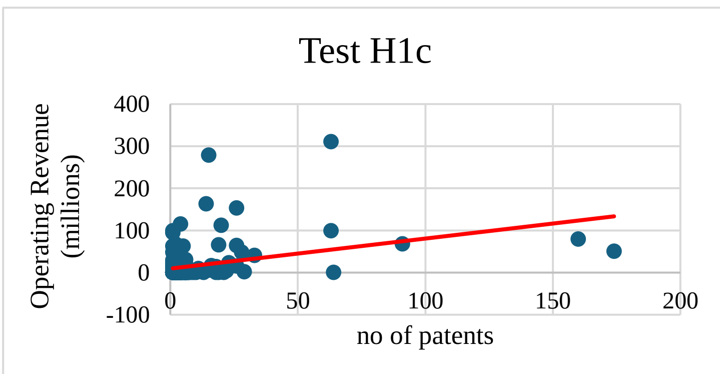


$CORR = -0.0629$

Figure 8.2: Correlation between Number of Employees and Degree Centrality Binary Absolute

Based on the low correlation coefficient we conclude that the connections an actor has is not influenced by its employees.

H1c: The operating revenue generated by an actor is directly related to its number of patents



$CORR = 0.3585$

$P - VALUE = 0.000016$

Figure 8.3: Correlation between Operating Revenue and Number of patents

Unlike the earlier two tests, the correlation coefficient for this test is slightly significant, indicating a positive correlation. Further, the p-value which is less than 0.05 suggests that there is evidence to reject the null hypothesis. This leads to the conclusion that the operating revenue generated by an organisation tends to increase if the number of patents that they produce also increases.

H1d: There is a significant relationship between Betweenness Centrality Weighted Absolute (BCWA) and Operating Revenue

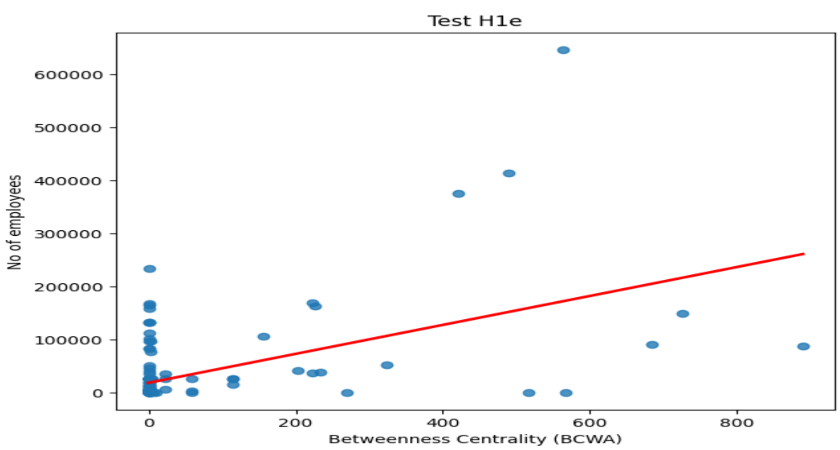
CORR= 0.51

P−VALUE= 0.056989

Figure 8.4: Correlation between BCWA Operating Revenue

The coefficient for BCWA was marginally significant (p ≈ 0.057). While it suggests a positive influence, this result is borderline and requires caution. At a strict 0.05 significance level, we fail to reject the null hypothesis, but with a slightly relaxed threshold, BCWA could be seen as having some impact.

H1e: There is a positive relationship between Betweenness Centrality Weighted Absolute (BCWA) and Number of Employees



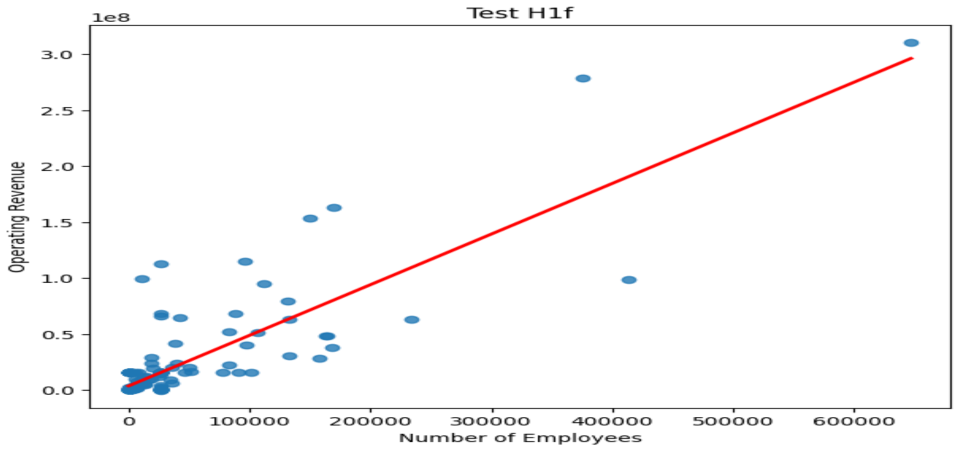
CORR= 0.51

P−VALUE= 0.000

Figure 8.5: Correlation between BCWA and No of employees

Given the p-value < 0.05, we reject the null hypothesis, providing strong evidence that higher BCWA is associated with a larger number of employees. This supports the idea that organisations that are central intermediaries in their network, playing key roles in connecting other entities, tend to be larger in terms of employee count.

H1f: There is a significant relationship between the Number of Employees and Operating Revenue



CORR= 0.83

P−VALUE= < 0.05

Figure 8. 6: Correlation between Operating Revenue and Number of Employees

The Number of employees showed a strong, positive, and statistically significant relationship with Operating Revenue ($p < 0.05$). We reject the null hypothesis, supporting the conclusion that organisations with more employees tend to generate higher revenue.

Conclusion

The analysis of the EU automotive industry's patent networks highlights the significant role of collaboration among organisations across different countries in fostering innovation. The study focused on two key segments: propulsion and tyres. It was found that patent production is typically concentrated among a small number of organisations, which limits the flow of knowledge across the broader network. Although the network demonstrates moderate connectivity, with nodes sharing patents, the overall collaboration remains sparse, leading to fragmented clusters.

In the propulsion segment, the network revealed a relatively low density, with the majority of nodes sharing patents with only a limited number of partners. The centrality measures, particularly Degree and Betweenness Centrality, indicated that only a few organisations play critical roles in the flow of information. These key players, such as Renault and Audi, serve as central nodes that facilitate collaboration, while others remain on the periphery. The small-world analysis for the main component demonstrated that the network exhibit the characteristics of a typical small-world structure, which could promote the efficient exchange of information and innovation.

Similarly, the analysis of the tyre segment highlighted a fragmented network with a few key actors driving collaboration. The clustering coefficient and average path length measures showed that while the network is well-connected in some areas, it remains fragmented in others. Patent collaboration is primarily driven by a small group of organisations, resulting in isolated clusters of innovation. The centrality measures once again indicated that only a few actors hold significant influence within the network, serving as bridges between different parts of the industry.

At the inter-country level, the study found that collaboration between countries is also relatively limited, with most patents being produced by organisations within the same country. Germany, France, and Italy emerged as key players in patent connectivity, with other countries contributing to a lesser extent. The hypothesis testing further supported the conclusion that patent production is correlated with the size of organisations, in terms of operating revenue.

The automotive industry's patent network is characterized by limited collaboration, with a small number of organisations and countries dominating patent production. While there are pockets of high collaboration, the overall network remains fragmented, which may impede the broader exchange of knowledge and innovation. Efforts to increase cross-border collaboration and expand patent partnerships beyond a few key players could help foster more widespread innovation in the industry. The results suggest that future research should explore ways to enhance collaboration and reduce fragmentation within the network to drive further technological advancements in the automotive sector.

Reference List

1. Allianz Research. "Outlook: Automotive Sector." Available at: https://www.allianz-trade.com/en_BE/news/latest-news/outlook-automotive-sector.html.

2. ECFR. "Trust and trade-offs: How to manage Europe's green technology dependence on China." Available at: https://ecfr.eu/publication/trust-and-trade-offs.

3. Antonio, A. "Vehicle propulsion systems: Understanding power transmission in automotive design." Journal of Automotive Engineering, 2023.

4. N. Bromo, F. Husrev & D.Carratelli "Aerospace Industry Network Analysis".

5. Newman, M. (2010). Networks: An Introduction. United Kingdom: OUP Oxford

6. Lucio Biggiero, 'Group Level Analysis', ANDION 2023 LECTURE 3

7. K. Benjamins & T. Correa "ANDION 2023/2024: Exploring the Automotive Industry Through Diverse Perspectives".

8. Lucio Biggiero, 'Lecture 6: Heavy-tail Networks and the Economics of Extremistan', ANDION 2023

Appendix

Python Code for the Merging of Datasets

```
import pandas as pd
import numpy as np

prop_data = pd.read_csv('B60K-propulsion or transmission - orgXorg.csv')

# read the dataset that contains the details of the orgs.
codebook = pd.read_csv('auto_codebook.csv')

# get all the distinct org in the prop_data
codebook = codebook.drop_duplicates(subset=['id'])

# include all the orgs from the propulsion table and the corresponding ones from the codebook.
orgs = prop_data.merge(codebook, how='left', left_on='Source', right_on='id')

# The orgs data can be merged with the economics data on 'BvD ID number'
eco_data = pd.read_csv('economic_data_1.csv')

# include all the orgs from the orgs table and the corresponding ones from the economy table.
autos = orgs.merge(eco_data, how='left', on='BvD ID number')

propulsion = autos[['id', 'Source', 'Target', 'Weight', 'orgName', 'BvD ID number', 'vatNumber','ISO code', 'NACE Rev. 2',
                    'NACE main section', 'Operating rev', 'No of employees']]

propulsion.to_csv('propulsion.csv')
```