MEASURING PERFORMANCE
IN SUPPLY CHAIN NETWORKS

Andreas Seiler

Ph.D. Thesis **2016**

MEASURING PERFORMANCE IN SUPPLY CHAIN NETWORKS

Andreas Seiler

Salford Business School
University of Salford, Salford, UK

Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, JULY 2016

Table of Contents

Table of Contents i
List of Figures iii
List of Tables v
List of Equations viii
Glossary ix
Abstract x
1 Introduction 11
2 Measuring Supply Chain Performance 18
2.1 Supply Chain Development 18
2.1.1 General Business Trends 19
2.1.2 Process Orientation 21
2.1.3 Supply Chain Management 23
2.2 Performance Measurement Development 26
2.2.1 Evolution of Performance Measurement 27
2.2.2 The aim of Overall Organisational Effectiveness 29
2.2.3 Internal and External Benchmarking 32
2.3 Shortcoming of Performance Measurement in a Supply Chain Network 35
2.3.1 Extension of Classical Performance Measurement 36
2.3.2 A Common Performance Measurement System 38
2.3.3 Towards an Advancement in Performance Measurement 40
2.4 Justification of Literature Research Results 41
2.5 Addressing of the Research Gap 42
2.5.1 Method to approach 43
2.5.2 Positioning and Research Themes 46
2.5.3 Impact and Consequences 49
Summary 50
3 Theory 52
3.1 Social Network Analysis 53
3.1.1 Preparatory Information 53
3.1.2 Main Subjects of Social Network Analysis 55
3.1.3 Fundamental Network Issues 56
3.2 The Influence of Context and Relationships 60
3.2.1 Two-Mode Networks 60
3.2.2 Ego-Network Quality 61
3.2.3 Hubs and Authorities 62
3.3 Social Network Analysis in a Supply Chain Context 63
3.3.1 The Network Concept 63
3.3.2 Key Theoretical Perspectives of Network Analysis 64
3.3.3 Role Theory 67
3.3.4 Network Perspective 68
3.4 Linking Social Network Analysis and Performance Measurement 69
Summary 75
4 Methodological Approach 78

4.1 Research Philosophy 78
4.2 Research Methods 80
4.2.1 Scope of the Analysis 80
4.2.2 Explorative Network Analysis 81
4.2.3 Quantitative Business Report Analysis 86
4.2.4 Pilot talks 88
4.3 Sample and Data Access 89
4.3.1 Quick Test 90
4.3.2 The Supply Chain Network 93
4.3.3 Business Reports 94
4.4 Development of New Conceptual Work 95
4.4.1 Design of the Network Creator 95
4.4.2 Data Processing 96
4.4.3 Individual versus Network-based Research 98
4.5 Application of Social Network Analysis 101
4.5.1 Relational Data Linked to Statistics 101
4.5.2 Blockmodelling 104
Summary 107
5 Data Analysis and Results 109
5.1 Initial Overview 110
5.2 Data Collection 112
5.3 Test of the Hypotheses 125
5.3.1 Strength of the Links 126
5.3.2 Centrality of the Nodes 133
5.3.3 Diversity of the Links 141
5.4 Results for Simple Linear Regressions 161
5.5 Verification by Ranking and Prestige 163
5.6 Statistical Performance Measurement Models 168
5.6.1 Revenue per Employee Model 174
5.6.2 Return on Assets Model 175
5.6.3 Operating Profit Model 176
5.7 Results for Multiple Linear Regressions 178
6 Implications 179
6.1 Advancement of Performance Measurement 179
6.2 Blueprint for Network Research 184
7 Conclusions 186
Appendices 188
References 260

List of Figures

Figure 1: Outline of the problem to be addressed ... 11
Figure 2: Outline research methodology ... 14
Figure 3: Timeline of the research process with main tasks up to completion ... 17
Figure 4: Forces and Trends with Impact on the Supply Chain ... 19
Figure 5: Development of Transport and Communication Costs ... 20
Figure 6: Synchronisation of Supply and Demand across the Supply Chain ... 24
Figure 7: Concept of Supply Chain Management Software ... 25
Figure 8: Timeline of Performance Measurement ... 28
Figure 9: Fundamental ©EFQM Concept ... 31
Figure 10: Performance Pyramid ... 32
Figure 11: Extended Timeline for Performance Measurement ... 35
Figure 12: Scale Free Network Perspective ... 44
Figure 13: Percentage Distributions of the Number of Publications by Year ... 46
Figure 14: Exemplary Illustration of a Connected Graph ... 53
Figure 15: Exemplary Illustration of a Path ... 54
Figure 16: Exemplary Illustration of Triadic Closure ... 57
Figure 17: Exemplary Illustration of a Bridge ... 57
Figure 18: Exemplary Illustration of Strong and Weak Ties ... 58
Figure 19: Exemplary Illustration of Proportional Strength ... 58
Figure 20: Exemplary Illustration of Structural Holes ... 59
Figure 21: Concept for Hubs and Authorities Scores ... 63
Figure 22: Summarised Research Approach of the Thesis ... 77
Figure 23: Illustration of the Scope of the Analysis ... 81
Figure 24: Segment of an Exemplary Graph (Sociogram) ... 82
Figure 25: Entity Relationship Model for Data Aggregation ... 96
Figure 26: The Network Creator Application (Cash Flows Tab) ... 97
Figure 27: First Exemplary Ego-network Illustration ... 99
Figure 28: Second Exemplary Ego-network Illustration ... 99
Figure 29: Exemplary Frequency Distribution by Classes of Quality ... 100
Figure 30: Ego-network Illustration of Focal Company 2 ... 116
Figure 31: Ego-network Illustration of Focal Company 8 ... 116
Figure 32: Frequency Distribution by Classes of Expenses Quality ... 118
Figure 33: Frequency Distribution by Classes of Customer Quality ... 119
Figure 34: Directed Graph, $GD(V, A)$, of the Egocentric Network Study ... 121
Figure 35: Distribution of Nodes with each Given Degree (Degree > 1) ... 123
Figure 36: Extracted Subnetwork of $GD(V, A)$ ... 128
Figure 37: Linear Regression RE = f(AS) ... 130
Figure 38: Linear Regression OP = f(AS) ... 130

Figure 39: Box Plot for OP ... 132
Figure 40: Linear Regression OP ex. Outlier = f(AS) ... 133
Figure 41: Linear Regression OP = f(C) ... 137
Figure 42: Linear Regression ROA = f($BP_{\beta = 0.995/\lambda}$) ... 137
Figure 43: Linear Regression OP = f($BP_{\beta = 0.995/\lambda}$) ... 138
Figure 44: Linear Regression OP = f(BC) ... 138
Figure 45: Directed Graph, $GD(V, A)$, of the Egocentric Network Study (Product Types) ... 142
Figure 46: Linear Regression RE = f(HUB) ... 145
Figure 47: Affiliation Matrix of the Industry Network ... 148
Figure 48: Directed Graph $HD(W, B)$ of the Egocentric Network Study ... 150
Figure 49: Subnetwork of the Directed Graph $HD(W, B)$ of the Egocentric Network Study (Industries) ... 155
Figure 50: Linear Regression PFR = f(IND) ... 157
Figure 51: Box Plot for PFR ... 158
Figure 52: Linear Regression PFR ex. Outlier = f(IND) ... 159
Figure 53: Matrix Scatter Plot of All Variables of Interest ... 162
Figure 54: Framework for the Impact of Contemporary Performance Measurement ... 180
Figure 55: Implications for Contemporary Performance Measurement ... 183

List of Tables

Table 1: SCOR® Model Performance Measures 33
Table 2: Metrics in the Supply Chain 39
Table 3: Morphological Analysis for a Network-oriented Approach in Performance Measurement 41
Table 4: Main Themes of Social Network Analysis 55
Table 5: Research Philosophy of the Pragmatist 79
Table 6: Notation for Network Position Properties 83
Table 7: Definition of Network Position Properties 84
Table 8: Illustration of Profit Calculation 87
Table 9: Definition of Financial Performance Measures 88
Table 10: Indicators of the Quick Test 91
Table 11: Quick Test Rating Scale 92
Table 12: Results of the Quick Test of the Convenience Sample 112
Table 13: Overview of the Procurement Side in the Network 114
Table 14: Overview of the Revenue (Sales) Side in the Network 114
Table 15: Percentages of Overall Suppliers and Customers 115
Table 16: Calculation of the Average Number of Partners 117
Table 17: Ego-networks with Suppliers 118
Table 18: Ego-networks with Customers 119
Table 19: All-Degree Frequency Distribution 123
Table 20: Results of the Dependent Variable Performance 125
Table 21: Results of the Aggregated Strength of Focal Companies 129
Table 22: Correlation Results for Hypothesis 1 (AS) 130
Table 23: Test for Significance of Hypothesis 1 (AS) 131
Table 24: Descriptive Statistics (Quantitative Data) for OP 132
Table 25: Additional Correlation Result for Hypothesis 1 (AS) 133
Table 26: Results of the Different Centrality Measures of Focal Companies 135
Table 27: Correlation Results for Hypothesis 2 (C) 136
Table 28: Correlation Results for Hypothesis 2 ($BP_{\beta = 0.995/\lambda}$) 136
Table 29: Correlation Results for Hypothesis 2 (BC) 137
Table 30: Test for Significance of Hypothesis 2 (C) 139
Table 31: Test for Significance of Hypothesis 2 ($BP_{\beta = 0.995/\lambda}$) 139
Table 32: Test for Significance of Hypothesis 2 (BC) 139
Table 33: Summarised Correlation Results for Performance Influenced by BP 140
Table 34: Summarised Significance Results for Performance Influenced by BP 140
Table 35: Results of the Hubs and Authorities of Focal Companies 144
Table 36: Correlation Results for Hypothesis 3 (Hubs) 145
Table 37: Correlation Results for Hypothesis 3 (Authorities) 145

Table 38: Test for Significance of Hypothesis 3 (Hubs) 146
Table 39: Formal Structure of WZ 2008 Code 147
Table 40: Frequency Distribution of Regularly Equivalent Nodes 148
Table 41: Results (nominal) of Industries and Performance of Focal Companies 151
Table 42: Determination of the Frequencies for the Contingency Table 152
Table 43: 2x2 Table for Diversity and Revenue per Employee 152
Table 44: Observed Frequencies for IND’ and RE 152
Table 45: Expected Frequencies for IND’ and RE 152
Table 46: Correlation Results for Hypothesis 3 (IND’) 154
Table 47: Test for Significance of Hypothesis 3 (IND’) 154
Table 48: Overview Number of Participating Industries 156
Table 49: Correlation Results for Hypothesis 3 (IND) 156
Table 50: Test for Significance of Hypothesis 3 (IND) 157
Table 51: Descriptive Statistics (Quantitative Data) for PFR 158
Table 52: Additional Correlation Results for Hypothesis 3 (IND) 158
Table 53: Additional Test for Significance of Hypothesis 3 (IND) 159
Table 54: Additional Test for Significance of Hypothesis 3 (IND) Significance Level = 0.10 159
Table 55: Summarised Test Results by Means of Simple Linear Regression 161
Table 56: Indegree Calculation Based on the Directed Graph $GD(V, A)$ 164
Table 57: Correlation Results for Prestige and Performance Based on $GD(V, A)$ 164
Table 58: Results for Proximity Prestige 167
Table 59: Correlation Results for Proximity Prestige and Performance ($GD(V, A)$) 167
Table 60: Multiple Linear Regression Models (All Dependent Variables) 169
Table 61: Multiple Linear Regression Results Including all Independent Variables 171
Table 62: Significance of the Standardised Regression Coefficients (All Beta Values) 173
Table 63: Multiple Linear Regression Results Including 5 Independent Variables (RE Model) 174
Table 64: Significance of the Standardised Regression Coefficients (5 Beta Values, RE Model) 174
Table 65: Multiple Linear Regression Results Including 4 Independent Variables (RE Model) 174
Table 66: Significance of the Standardised Regression Coefficients (4 Beta Values, RE Model) 174
Table 67: Final Model for the Dependent Variable RE 175
Table 68: Multiple Linear Regression Results Including 3 Independent Variables (ROA Model) 175
Table 69: Significance of the Standardised Regression Coefficients (3 Beta Values, ROA Model) 176

Table 70: Final Model for the Dependent Variable ROA 176
Table 71: Multiple Linear Regression Results Including 3 Independent Variables (OP Model) 177
Table 72: Significance of the Standardised Regression Coefficients (3 Beta Values, OP Model) 177
Table 73: Final Model for the Dependent Variable OP 177
Table 74: Three Most Significant Test Results by Means of Multiple Linear Regression 178

List of Equations

Equation 1: Quality of an Alter as Ego-network Property 61
Equation 2: Calculation of a Hub Score 62
Equation 3: Calculation of an Authority Score 62
Equation 4: Quality of an Alter as Ego-network Property 100
Equation 5: Quality of an Alter as Ego-network Property 117
Equation 6: Exemplary Model Based on Linear Regression 125
Equation 7: t-value for the one-sided t-Test for the correlation coefficient 126
Equation 8: Calculation of the Chi-square Coefficient for 2x2 Scheme 153
Equation 9: Cramers Index 153
Equation 10: Calculation of the Phi-Coefficient 153
Equation 11: Exemplary Holistic Model Based on Multiple Linear Regression 168
Equation 12: Standardisation of the Regression Coefficients 170
Equation 13: Calculation of the F-Value 171
Equation 14: t-value of Standardised Correlation Coefficient 171
Equation 15: Adjusted Coefficient of Determination 175

Glossary

ABS	absolute
AS	aggregated strength
AT	asset turnover
AUTH	authorities
AVG	average
BC	betweenness centrality
BP	Bonacich power
C	degree centrality
CUM	cumulative
CUST	customer
DDR	dynamic debt ratio
DV	dependent variable
EC	eigenvector centrality
EFQM	European Foundation for Quality Management
empl.	employee
ENAPS	European Network for Advanced Performance Studies
FOC	focal company
HUB	hubs
IND	number of complementary industries
IV	independent variable
m.m.u.	millions in monetary units
NACE	nomenclature statistique des activités économiques dans la communauté européenne NACE
OEM	original equipment manufacturer
OP	operating profit
PAT	profit after tax
PBIT	profit before interest and tax
PBT	profit before tax
PFR	profit fixed asset ratio
PM	performance measurement
RE	revenue per employee
ROA	return on assets
SC	supply chain
SCM	supply chain management
SCOR®	Supply Chain Operations Reference
SCS	supply chain system
SNA	social network analysis
SUPPL	supplier
TOPP	not available

Abstract

Today, the formation of increasingly complex supply chain networks sets new demands for performance analysis. Performance analysis needs to look beyond the narrow perspective of the focal firm and measure performance not only from a financial perspective. This thesis illustrates how the network position of a focal company in the supply chain network impacts the economic performance of that company. Thereby the supply chain network is in fact scale-free (has no clear boundaries). Based on different statistical models, it is argued that performance measurement tools should take network positioning into account. As such, a network perspective may complement the internal financial perspective of corporate performance measurement. A convenience sample of small and medium-sized companies in the German plastics processing industry is studied. By using real-time enterprise data of 15 focal companies, their network flows of revenues and expenses are merged to create a supply chain network of 448 companies which is then analysed. Social network analysis provides the necessary quantitative data on characteristics of the focal company's network positioning. By testing corresponding hypotheses, this thesis studies network position characteristics expressing (i) strength of links, (ii) node centrality and (iii) link diversity for their impact on a variety of financial performance measures. The results of applied methods of regression analysis confirm dependencies between characteristics of network positioning and different key financial performance measures. The analysis of different performance measurement models finds that the node centrality measure *Bonacich power* is a major driver of economic performance. *Bonacich power* not only considers the sheer number of business partners, but also whether connected business-partners are themselves well-connected. This way a basis for adapting performance measurement tools which generally lack a network orientation is provided. The application of social network analysis to the supply chain network is an important contribution itself. Based on the findings, reasonable suggestions for the rethinking of business strategy and a holistic performance measurement approach are made. Up-to now, companies often try to consider external effects originating from linear supply chains when analysing performance. However, by integrating gained insight from new conceptual work on supply chain network architecture into performance measurement, this thesis goes one step further. This study concentrates on manufacturing supply chains of one particular industry. A transfer to other (non-) manufacturing supply chains might be valuable.

1 Introduction

This brief overview illustrates the structure of the present study. This study deals with corporate performance measurement in order to make a contribution which adequately reflects recent developments such as supply chain networks. Chapter 1 defines the subject matter and introduces the aim of our[1] study. The main objective is to enhance performance measurement by focussing on the degree to which companies are embedded into their supply chain networks. The awareness to address this topic becomes apparent by looking at Figure 1 which in advance outlines the problem that companies face.

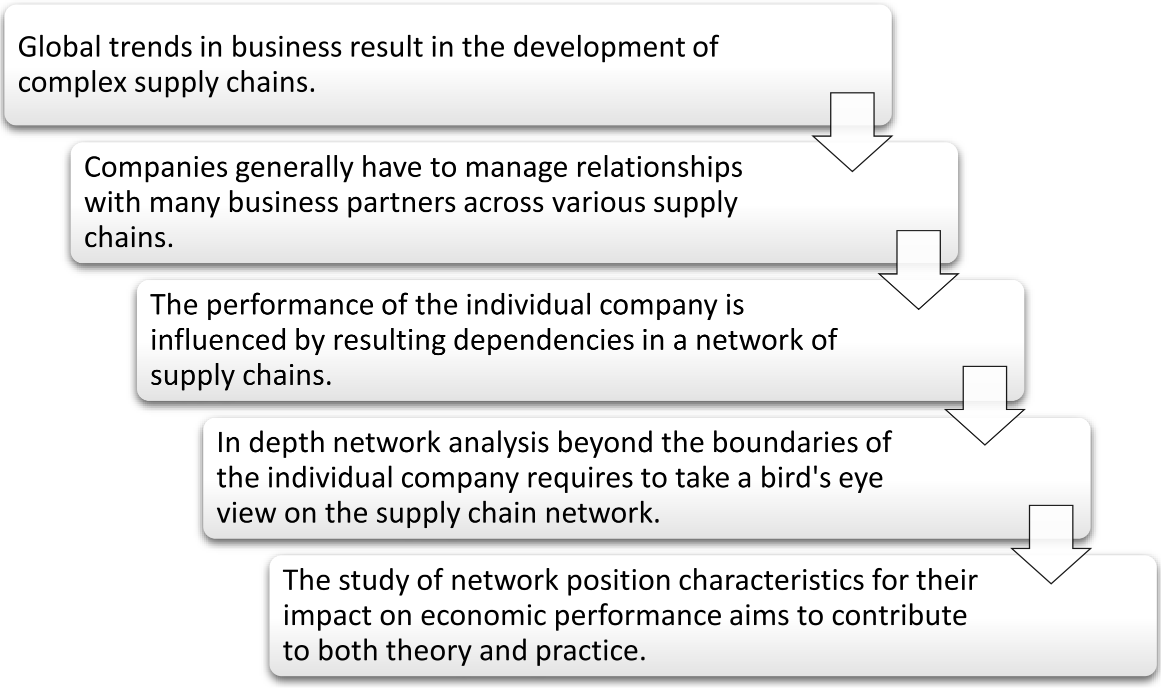


Figure 1: Outline of the problem to be addressed

By definition, performance measurement is the process of identification and quantification of performance measures, also referred to as performance indicators or performance metrics. These performance measures allow to assess the extent to which goals are achieved in terms of quality, time and cost. Indeed, performance measurement is useful in that it can be applied to entire companies, divisions and departments from different perspectives (Gabler Wirtschaftslexikon, 2014). A shorter definition of performance measurement describes it as the process of quantifying the efficiency and effectiveness of action, while a performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action. In

[1] Note: The author's "we" respectively "our" (pluralis modestiae) primarily refers to the researcher and author of the present study. However, in this sense the "we" / "our" also indicates the involvement of the informed reader who to a certain point might follow the author's process of thought.

turn, a performance measurement system can be defined as the set of metrics used to quantify both the efficiency and effectiveness of actions (Neely, Gregory & Platts, 1995, pp. 80–81).

As its name would suggest, embeddedness generally describes the extent to which economic activities find themselves embedded in socio-cultural relation systems or to which extent a company is embedded into its socio-cultural environment (Neumair & Haas, 2014).

It is not necessary to provide a definition for the term company here. While there are various interpretations of what a company is, at this point it is sufficient to say that this study focuses on small and medium-sized companies, manufacturers in the main, and their relations with customers and suppliers. The companies are to be viewed as economic-financial and legal units, for which the economic principle is constitutive.

Given the definition of the main term performance measurement, it is obvious that the methods to measure performance are influenced by the way companies do business and the resulting challenges. In fact, companies are nowadays part of supply chains which stretch across the globe and face a constant demand to bring products to the market both at a faster rate and at lower cost. These changing business conditions have initiated a continuous development in the research field of supply chain management (Gunasekaran, Patel & Tirtiroglu, 2001), (Webster, 2002). These challenges are accompanied by a change from a limited corporate perspective to a more integrative view that goes beyond the boundaries of a single company. Christopher (2011, pp. 23–24) relates the 4 R's (responsiveness, reliability, resilience, relationships) to the challenges companies face. The 4 R's describe influences which companies as part of competitive supply chains need to handle:

- Responsiveness describes the need of just-in-time delivery together with the ability of immediate response to changing customer requirements.
- Reliability of delivery becomes more complicated because of increased pressure resulting from reduced safety stocks.
- Resilience of the supply chain deals with the increasing volatility as a result of unexpected events. There is the attempt to consider possible risks in order to make supply chains less susceptible to shocks.
- Relationships refer to the tendency of customers willing to reduce their supplier base. Strong relationships may prove beneficial but increase dependencies.

Essentially, there are four global trends that influence the development of global supply chains, namely: (i) international trade and capital flows, (ii) the formation of buyer markets, (iii) shortened product life cycles and (iv) a technological change (Arndt, 2006, p. 8), (Webster, 2002, pp. 353–354), (Rolstadas, 1998, p. 989). As a result, the management of these supply chains has become increasingly complex. Therefore, the whole topic of supply chain management supports the administration of complex supply chains together with a framework for cooperation with business partners.

However, to meet the demands of globalisation, business processes need to be monitored and improved continuously. Corporate performance measurement is a key tool of supply chain management. It aims to provide appropriate solutions as basis for any adaptation of business processes. Various methods of performance measurement are suitable to collect relevant information and support managers who are responsible for the adaptation of business processes as alluded to above.

The fact that supply chains blur organisational boundaries must be taken into account, when we want to contribute to performance measurement for the reasons of a new reality in business. In this respect, the outline of our research methodology follows the diagram illustrated by Figure 2. Thereby, the same colours indicate coherence between different steps. For example in terms of the colour blue, the findings of literature review are taken up by the discussion of implications for theory and practice. This shows the logic in order to point out a contribution to knowledge. Another example is the colour red: the posed research question is answered by an in-depth analysis of the results obtained by a preceding quantitative data analysis.

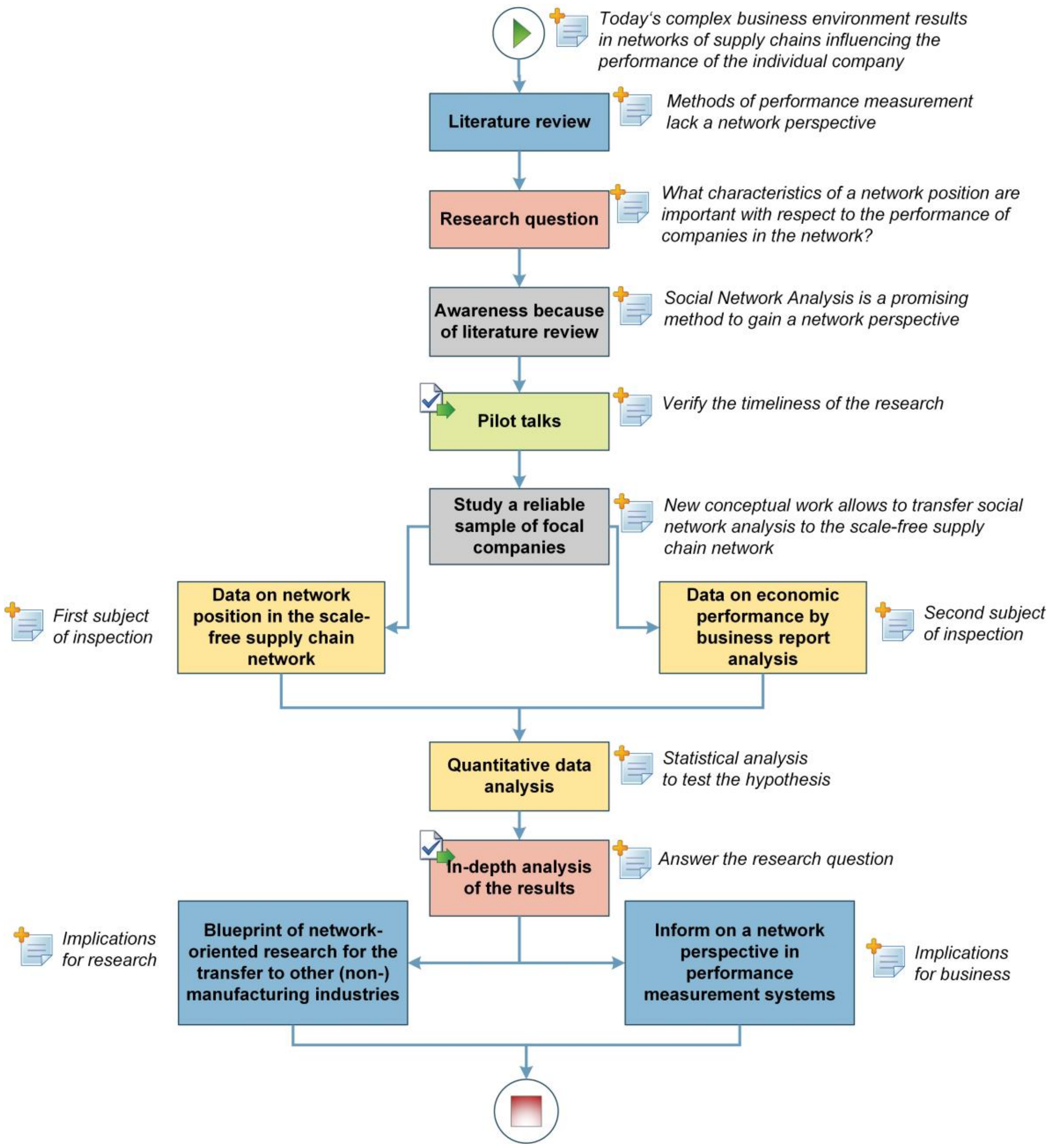


Figure 2: Outline research methodology

Starting with the literature review on performance measurement two major turning points are discussed more fully in Chapter 2. Indeed, it becomes clear that existing tools are not sufficiently developed. After the first turning point, which is the aim to assess overall organisational effectiveness (including relationships of a focal company with its partners), the expansion of supply chain networks (a focal company integrated into a network of many supply chains) marks a second turning point in performance measurement. In order to obtain reliable results for performance measurement, we recognise that it is not enough to consider dyadic relationships between a focal company and its supplier or customer forming a supply chain. In fact, a focal company is embedded in a network of supply chains. Besides internal process effectiveness, the performance of a company also depends on a network with customers and suppliers. As several authors point out, existing measures of performance are inadequate to cover the needs for companies with respect to a network, because these methods lack a supply chain thinking and only encourage local optimisation (Chan & Qi, 2003, p. 209), (MacBryde, Shepherd & Günter, 2006, p. 243), (Gunasekaran et al., 2001, p. 71).

There are collaborative approaches; indeed even the possibility of a common performance measurement system exists. But both concepts are only appropriate for a limited number of partners. By speaking of a change from “monocultural to polycultural performance measurement” (Morgan, 2007, p. 256), Morgan provides an academic argument for this problem of enhanced performance measurement. The academic argument results from a debate addressing the supply chain network development and its analysis. By accomplishing a network perspective for performance measurement, this thesis comprising the development of a network-oriented approach contributes to polycultural performance measurement.

The development of performance measurement methods as presented in Chapter 2 explains the need for a further development of performance measurement. The determination of a lack of measures suitable to evaluate performance across the supply chain network points to the degree of originality of this thesis. Taking existing weaknesses in performance measurement, such as an overly narrow focus on dyadic relationships, as a starting point we reasonably assume that companies might benefit from a broader supply chain network approach. It is expected that companies depend on each other in more than just dyadic terms. Therefore, this study attempts to make a shift from the hierarchical structure of individual supply chains towards a network orientation. New conceptual work making the supply chain network visible helps us to learn from the existing connectedness within a network.

In Chapter 3 we introduce social network analysis, a method of social sciences with its focus on structure, as a solution to identify patterns within the network. Social network analysis not only focusses on the connections among all dyads in a given setting, but also on actors and relationships which are embedded in a larger structure. Thus, this method not only analyses the individual object, but also the object embedded within the network. By transferring social network analysis to the supply chain network, we can develop interdisciplinary research under the assumption that findings regarding the network position of a company influence the performance of that company.

Consequently, the central research question of this thesis asks which characteristics of a network position are important with respect to the performance of companies in the network. Developing three main hypotheses, we expect that several concepts from social network analysis might reveal their potential when transferred to the supply chain network. We formulate specific hypotheses that allow us to test influences on economic performance of a company by measuring key network position variables that express (i) strength of links, (ii) node centrality, and (iii) diversity of links.

By presenting our methodological approach in Chapter 4, we illustrate how the findings of our network analysis are linked to economic performance. We refer to two subjects of inspection, namely the scale-free (no clear boundaries) supply chain network and business reports. Following the definition of our sample of focal companies, we introduce our developed software which processes network flows between companies. In doing so, the focal companies are defined as small and medium-sized manufacturing companies from the German plastics processing industry. The so called plastic converters deliver finished parts or semi-finished parts that are incorporated into final products.

Using our developed software, we create one large network, our first subject of inspection. The network comprises the individual supply chain networks of focal companies. Each of these so called ego-networks consists of a focal company, its suppliers and its customers. We merge the individual supply chain networks, identify common business partners between focal companies and highlight the relationships as connections, illustrating a small section of the scale-free supply chain network. Based on the revenue that underlies each connection, we include the strongest suppliers and customers of each focal company.

In order to determine the performance of focal companies, we introduce wide-ranging financial performance measures. We explain our comprehensive analysis of business reports, the second subject of inspection. Among others, financial performance measures such as operating profit, return on assets and revenue per employee are illustrated.

In Chapter 5 we analyse the scale-free supply chain network and evaluate the business reports. We collect data of network position properties and of financial performance measures of focal companies. By performing a statistical analysis, we test our hypotheses in order to answer the central research question of our thesis. The development of performance measurement models is the starting point for the development of network-oriented performance measurement. Subsequent to the presentation of our results follows a general discussion. In Chapter 6 we discuss the implications of our study for both, theory and practice. To our knowledge, our study is one of the first in the context of supply chain management that integrates gained insight from conceptual work on supply chain network architecture into performance measurement. Concentrating on a typical supply industry, our findings may be of interest for other industries, too. Making recommendations for further research, we think that it would be interesting to see whether our results can be confirmed by transferring our research to other manufacturing supply chains.

In a nutshell, the entire thesis is constructed as follows: Subsequent to the just provided overview of this thesis (Chapter 1), Chapter 2 introduces the research field and describes the problem in more detail. Chapter 3 then explains the theoretical basis of the study and derives a number of hypotheses from this. Chapter 4 describes the methodological approach. We then analyse the gained data and present our results (Chapter 5), while Chapter 6 concludes with a general discussion on implications for both, theory and practice.

The timeline in Figure 3 provides a chronological overview of relevant tasks and milestones in order to write the thesis.

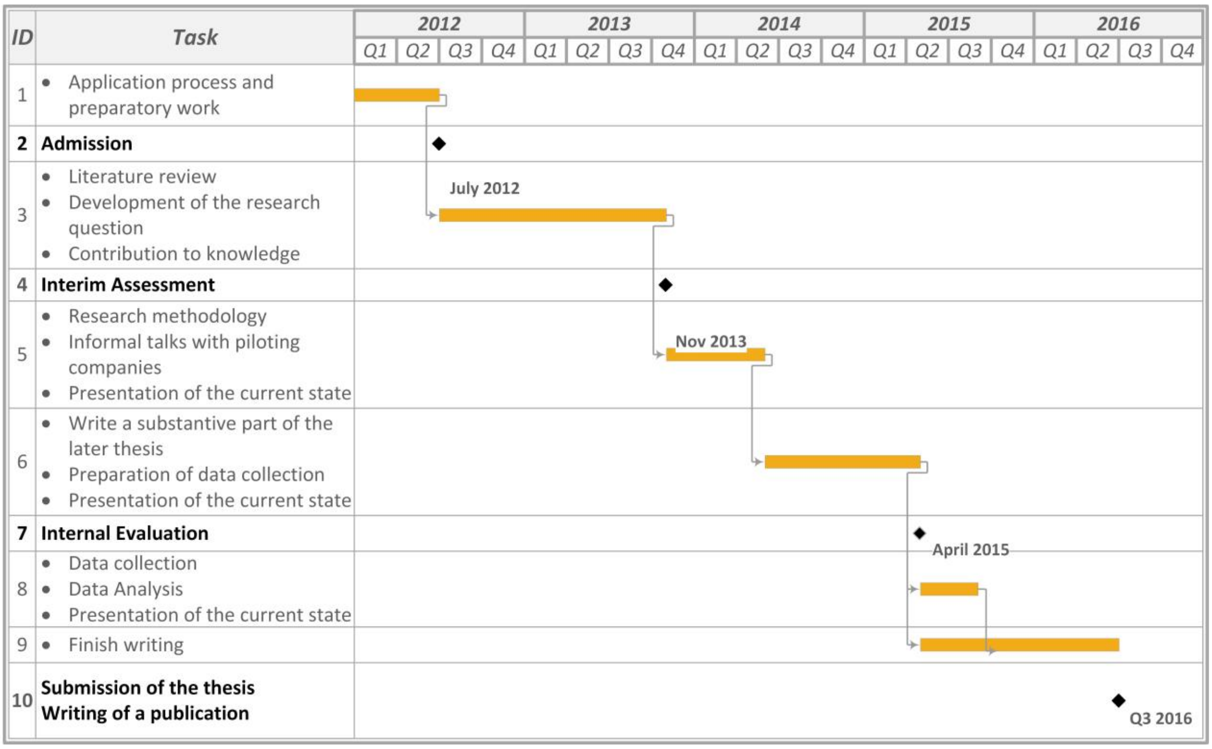


Figure 3: Timeline of the research process with main tasks up to completion

2 Measuring Supply Chain Performance

In order to place this thesis into a wider context, we describe in this chapter the existing business conditions and the development of supply chains. Section 2.1 demonstrates that in recent decades, several global trends have had a particular influence on supply chain development and contributed to the importance of supply chains in general. In order to be able to manage these increasingly complex supply chains, it is vital to use the entire topic of supply chain management to support the administration of the supply chains. Aiming at continuous optimisation of value creation, supply chain management deals with cooperation across the supply chain and goes beyond organisational boundaries. From this perspective it is clear why the topic of supply chain management is closely linked with performance measurement methods. Section 2.2 shows how existing performance measurement methods have evolved in order to meet new demands arising because of today's importance of supply chains. We identify the reasons, why existing performance measurement theory fails in its support of strategy development, decision-making, and performance improvement in this context. Indeed in Section 2.3 it becomes clear that the existing tools are not sufficiently developed to meet the requirements of supply chain networks. In section 2.4 we justify the argumentation of our literature research by means of comprehensive literature synthesis on today's challenges in performance measurement. Finally, the advancement of new techniques as depicted in Section 2.5 explains why performance measurement needs to be adapted to the requirements of supply chain networks.

2.1 Supply Chain Development

Providing a clear definition for the supply chain is difficult, as the following statement underlines:

> “The supply chain is a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer” (Christopher, 1998, p. 15).

The term "network" is of particular importance here because the individual supply chains are in fact linear. Since companies are part of many supply chains, the definition is softened. This problem is described by Tandler (2013) who even speaks of a contradiction between the two terms “supply chain” and “network” (Tandler, 2013, p. 97).

Supply chains are characterised by closely linked customers and suppliers. General business trends such as the internationalisation of the markets, together with the advancement of technology are reasons for continuous change and increased complexity. The resulting dynamics in business relationships have the effect that supply chains need to be redesigned on a regular basis. According to the knowledge of a major global consultancy, Figure 4 summarises the prevailing key forces and trends.

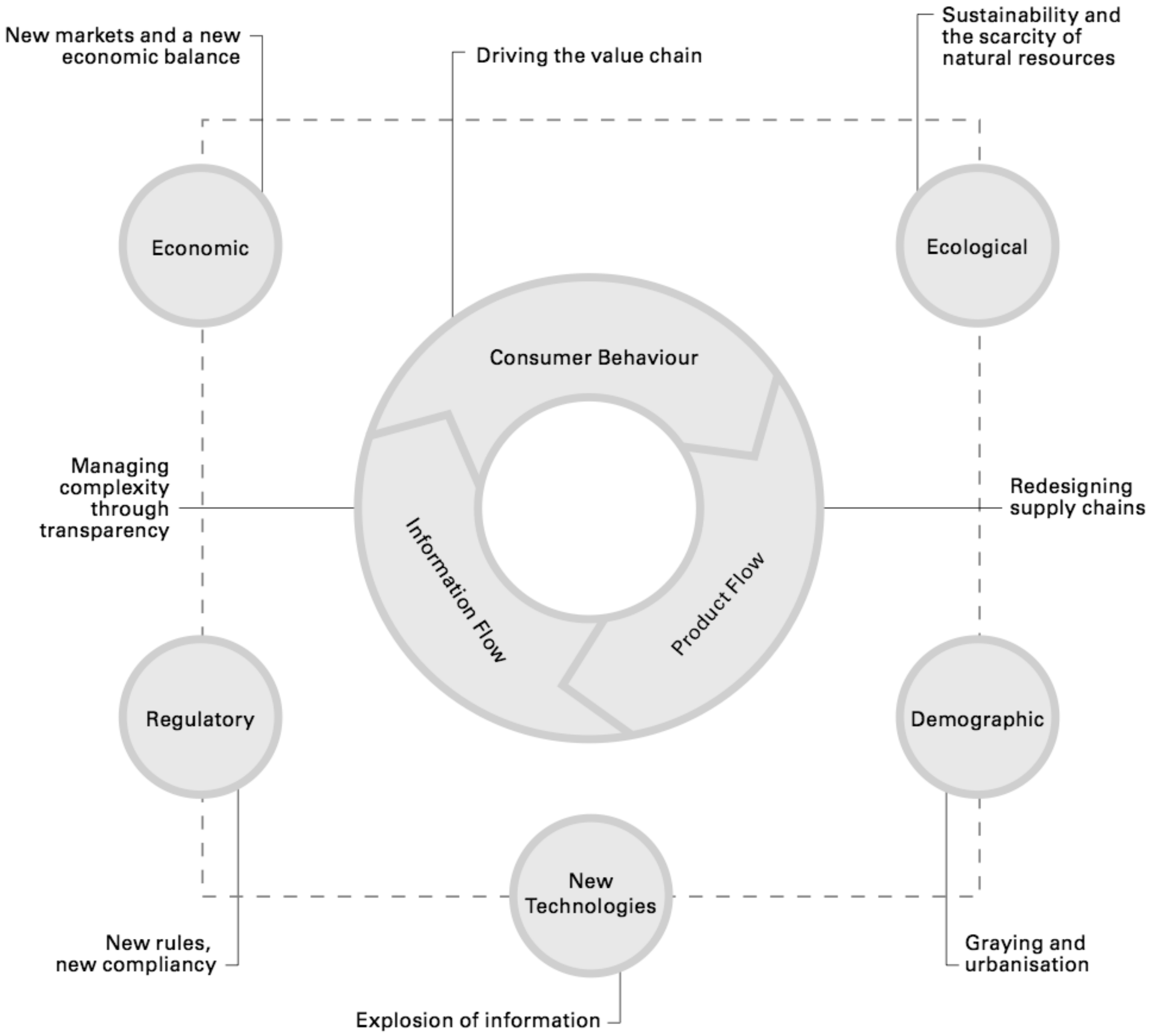


Figure 4: Forces and Trends with Impact on the Supply Chain
(Capgemini, 2008, p. 12)

We assume that the only way to master the increased level of complexity is more transparency across the supply chain. Thus, the individual company might certainly benefit from new network insights as a basis for future strategic decision making.

2.1.1 General Business Trends

The opportunities of globalisation lead to a sharp rise in the complexity of logistics and supply chain management. Together with an international flow of capital and goods, global markets have evolved as a result of market liberalisation and political integration (Arndt, 2006, pp. 8–9), (Koch, 2014, p. 13). Countries have reduced trade barriers to foster the import and export of goods and services. Due to the evolution in transport, technology and information technology, global economic integration has intensified. With the beginning of globalisation, worldwide transport capacity increased, even though ecological trends such as sustainability and the shortage of natural resources have become more influential. A reduction in energy costs with respect to the total distances is accompanied by a higher number of direct connections across the globe. The increasing capacity of aircraft is a further factor in reducing transport times (Koch, 2014, pp. 20–21). These different factors lead to a continuously higher volume of worldwide trade and a steady reduction of transport costs per transport unit. Figure 5 illustrates the development of transport and telecommunication costs since 1930.

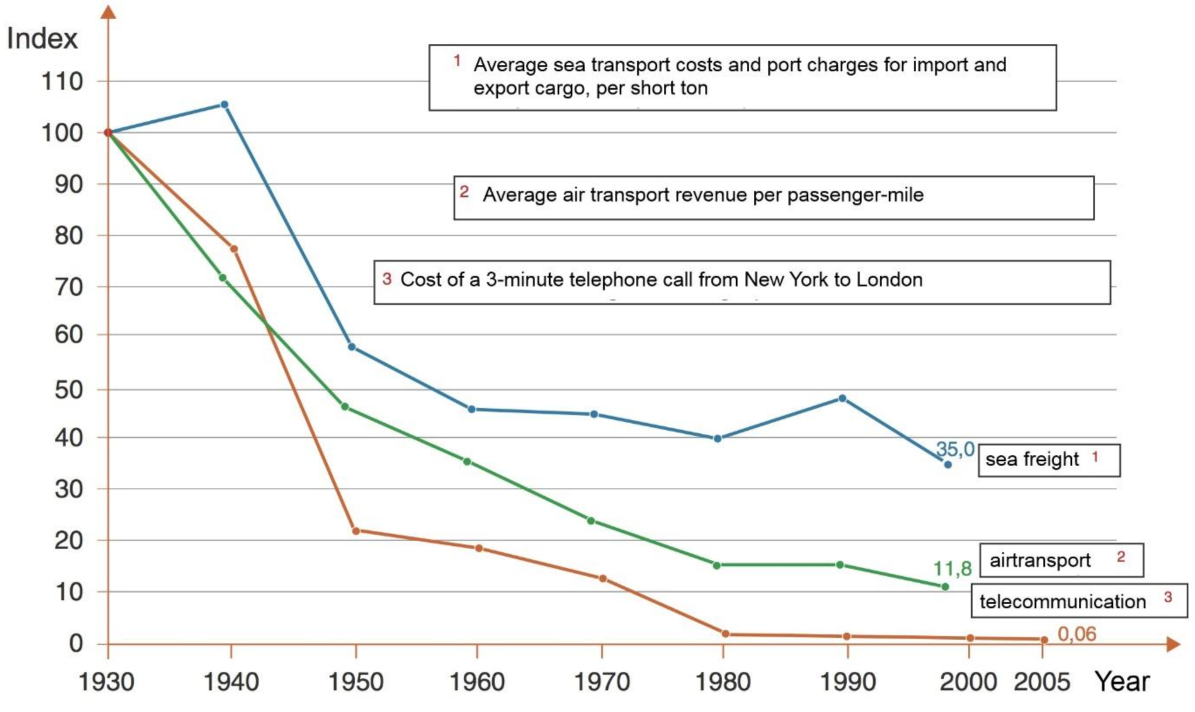


Figure 5: Development of Transport and Communication Costs
(Bundeszentrale für politische Bildung, 2009, p. 1)

Generally conceived, globalisation is a key factor in granting companies access to new markets. As tariffs and investment barriers are reduced, higher sales figures allow companies to take advantage of scale effects (Arndt, 2006, p. 10), (Rolstadas, 1998, pp. 989–990). It is possible to make capital investments directly in other countries, and companies can acquire or develop additional locations abroad. Companies can find the optimal location for a variety of activities. Preliminary products which may also require more labour-intensive operations are performed in low-income countries worldwide. The demanding tasks continue to be carried out in the more expensive industrial countries.

Companies take “make or buy” decisions in order to achieve a higher value creation for their manufacturing processes. More and more manufacturing steps are outsourced, in order to achieve a qualitatively higher, cheaper, faster, more reliable or more flexible result. An on-going concentration process aiming to reduce costs also leads to larger companies (Arndt, 2006, pp. 18–19), (Rolstadas, 1998, pp. 989–990). Through mergers and acquisitions, companies seek to benefit from synergies in terms of reduced costs, expanded markets, improved purchasing conditions and a wider product range. Beside the mentioned benefits of globalisation, the global economy also results in new entrepreneurial challenges like global competition and the coordination of the flow of goods across national borders and continents.

A changing customer-behaviour where “customers increasingly expect suppliers to meet their demand rapidly and accurately” (Webster, 2002, p. 353) is a further factor contributing to the complexity of the business conditions. Many markets have changed from sellers’ markets to customers’ markets over the last few decades (Arndt, 2006, pp. 18–20), (Rolstadas, 1998, pp. 989–990). It is the customer who decides what he wants. There no longer exists a given, pre-established system by which the producer and its suppliers determine what is available to the customer. Given the development of customers’ markets, global competition is reinforced because customers may have a wide range of possible suppliers at hand. Further, worldwide overcapacity such as in the automotive sector together with an easy and worldwide accessibility of information create even more pressure on suppliers. Customers can pit suppliers against each other and thus strengthen their negotiating power (Arndt, 2006, pp. 18–20). This increased competition, new customer requirements and technological progress force a trend towards shorter product life cycles and mass customisation (Arndt, 2006, p. 22), (Lowson, King & Hunter, 1999), (Chan & Qi, 2003, p. 209). The reduction of time-to-market creates additional pressure for product development, production processes and product introduction on the market, because products need to be available as quickly as possible.

The rapid development of information technology helps businesses to cope with the demands placed on them (Arndt, 2006, p. 24). Given a high degree of information exchange across the supply chain, it is possible to improve processes continuously. Technology and the standards of electronic data interchange allow the implementation of complex concepts such as just-in-time and vendor managed inventory.

2.1.2 Process Orientation

In adapting to the new environment of their business, it seems that companies have started to change the way they work. In many cases, the structure within the company is no longer function-oriented, but aligned to key processes (Sihn & Aupperle, 1995). The intention of this process-orientation is to support the interconnection of all processes in order to fulfil the needs of the customers at the best possible level. Unnecessary activities with no additional value to the customer must be eliminated. Process-orientation results in a higher level of transparency because each contribution to fulfil the needs of the customers can be determined. Finally, due to the establishment of an organisation aligned to key processes, companies are able to improve material, information and cash flows by expanding their own narrow corporate perspective to a more integrative one, beyond their own boundaries.

Due to the mentioned general business conditions, purchasing behaviour is difficult to predict. Companies need to be prepared for fluctuations and equally capable of facing them. One major challenge for companies is therefore to achieve the best possible availability of a product. Together with the challenge to handle fluctuations, the described pressure of timely product availability which is a result of volatile purchasing behaviour is passed along the supply chain to suppliers and subcontractors. Nevertheless, customers expect a high reliability of delivery at all levels.

The phenomena of fluctuation is called the bullwhip effect, described by Forrester (1961). Based on the assumption that every single company acts in an isolated way, it is shown that variations in demand become progressively worse by following up each previous step along the supply chain. Since it takes some time to identify changes in demand, delays are the consequence. Further delays are a result of ordering management, as it takes time to transfer order information. Moreover, variation in demand occurs because the individual company does not know the exact reasons for stock changes upwards the supply chain. Therefore, it is important to create safety buffers by increasing stock levels. Indeed, suppliers receiving an adapted order possibly react by increasing safety buffers themselves.

The individual company alone has only limited opportunities to address fluctuations properly: (i) faster handling of orders, (ii) direct order placement by eliminating the distributor level and (iii) modification of the inventory policy (Forrester, 1961, pp. 33–34).

Thus, due to the dependencies between companies Capgemini (2008) identifies true collaboration as one major challenge for the future supply chain. The major global consultancy claims that true collaboration in the supply chain will be imperative for companies. In order to reduce fluctuations, the coming years will see a new era for industry collaboration, which will become an important factor for future success. In many cases, this will force companies to rethink their areas of competitive advantage (Capgemini, 2008, p. 15).

Benefiting from technology, many areas such as the supply industry have implemented guidelines and standards that support just-in-time delivery and regulate the processes along the supply chain. The implementation of standards led to new capabilities in terms of delivery reliability and traceability for supply chain managers. One example are the standards developed by the Association of the German Automotive Industry.

Addressing all the different challenges will require new ways of working, new tool sets and thus new supply chain management capabilities. Supply chain managers should not only look at efficiency, but also understand the potential of innovation and collaboration. If this vision of understanding the potential of innovation and collaboration is to be realised, this will require a change in the mindset on current management capabilities (Capgemini, 2008, p. 15), as will be discussed below.

We can conclude that the described pressure ((i) pressure resulting from reduced safety stocks, (ii) pressure on suppliers, (iii) pressure on product availability) together with a demand for high standards on all levels, make the concept of the supply chain and its management so important. Companies are forced to work together, and close interaction ensures reduced fluctuation across the supply chain (Gunasekaran et al., 2001, p. 71).

2.1.3 Supply Chain Management

Based on all these changing business conditions, the whole topic of supply chain management evolves continuously. Supply chain management needs to contribute to the overall performance of a company.

By definition, supply chain management refers to the design, planning, execution, control and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronising supply with demand and measuring performance globally (Blackstone, 2008, p. 134).

Typically, supply chain management begins with the extraction of raw materials moving through the individual processing stages to the end customer. At the end, the entire process should be optimal in both time and cost. We can state that the main contribution of supply chain management is to help weaken the bullwhip-effect across the supply chain. On the one hand, this includes the use of strategic and tactical design concepts of supply chains, with methods of planning and control on the other. Models can be helpful in monitoring and improving performance of supply chain management activities.

The SCOR® reference model, a strategic concept to standardise different process chains, supports the continuous synchronisation of supply and demand across the supply chain (Supply chain Council, 2010). The participating units are individual companies or different business units. SCOR® is based on the internal chain "source", "make" and "deliver” of each participating unit. All demands and possibilities of covering them are aggregated and matched across the supply chain as illustrated in Figure 6.

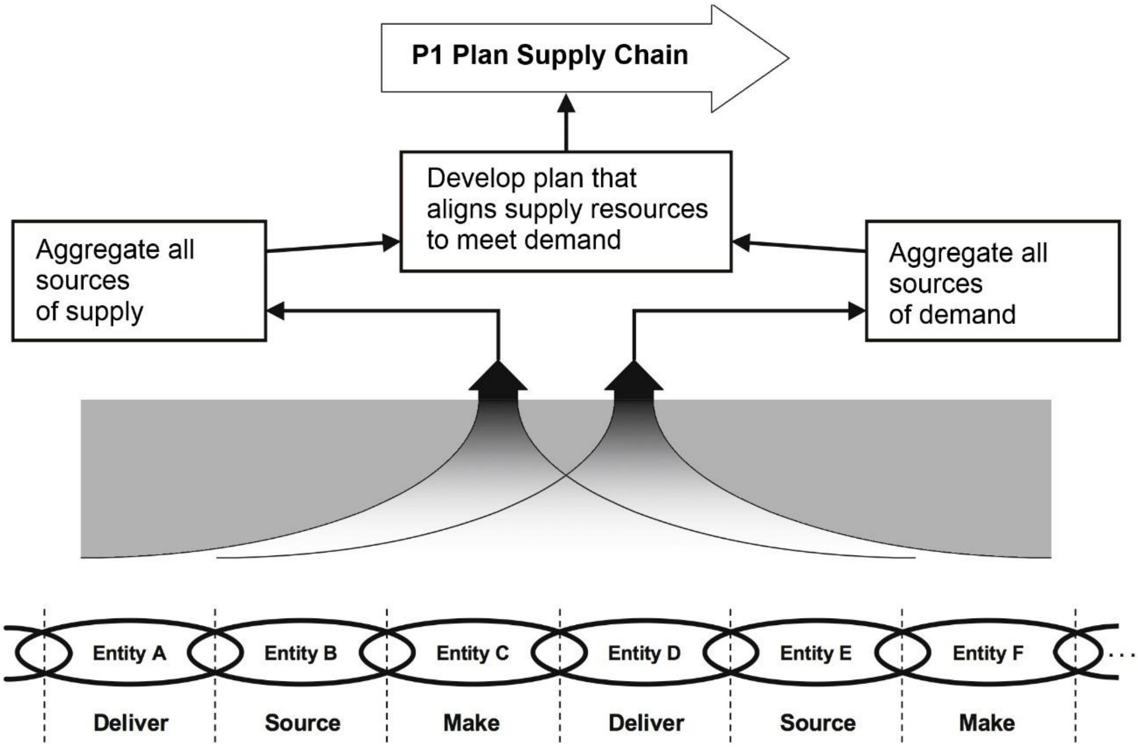


Figure 6: Synchronisation of Supply and Demand across the Supply Chain (Schönsleben, 2011, p. 15)

Assuming that companies decide to cooperate, implementing SCOR® helps to achieve a common process understanding between companies. As the individual objectives of quality, cost, delivery and flexibility are partly contradictory, cooperating companies have to achieve a balance between those objectives. The SCOR® reference model describes each task of the implementation.

Looking at SCOR® in detail, it becomes clear that this model is a very important contribution towards creating successful supply chains and cooperation. Nevertheless, to ensure that standardisation does not lead to stagnation, companies need to find an appropriate strategy between standardisation and customisation (Bolstorff, Poluha & Rosenbaum, 2007, p. 341).

To avoid stagnation is why, from an entrepreneurial perspective, flexibility is very important in addition to costs and delivery reliability. Flexibility results from agile corporate structures, in combination with the fulfilment of information technology requirements, overarchingly supported by supply chain management systems. These are tools that provide companies with the comfort to plan and control value creation beyond the company itself. Such systems are based on company specific Enterprise Resource Planning ERP software. ERP software aims to improve the capacity utilisation in terms of sales and distribution, materials management and production planning. The use of ERP software is inevitable regardless of the company size.

By using supply chain management software, the management of orders and master data still takes place in the local ERP context. Periodically, the supply chain management software receives the data from the local ERP software of each participating company, which is part of a logistics and production chain. The supply chain management software then performs network planning and sends the results back to each of the participating companies. The concept of supply chain management software is illustrated in Figure 7.

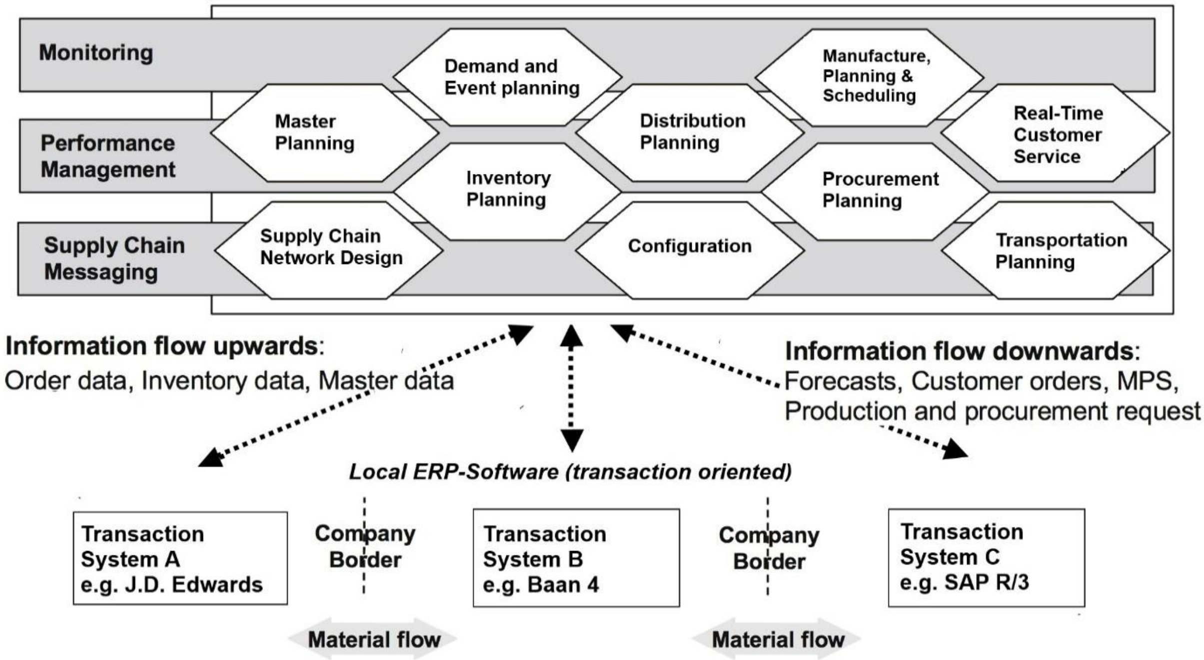


Figure 7: Concept of Supply Chain Management Software
(Schönsleben, 2011, p. 446)

According to Schönsleben (2011, pp. 446–447), the main tasks of the network planning modules are:

- supply chain network design,
- network inventory planning and
- real-time customer service.

The appropriate use of supply chain management software requires trust and reliable relationships among business partners. In his work on supply chain management software, Máximo J. Ortega (2006) investigates whether appropriate software is available for use. Ortega criticises the available supply chain management systems in that they deal with situations only in a reactive manner. Difficulties exist due to dynamic events and even if the advanced planning services run continuously, there is still no possibility of predicting the future. This is also highlighted by Jim Hagemann Snabe, the chief executive officer of the software company SAP (a technology leader in this field). According to Hagemann Snabe, the biggest challenge is to look for patterns and to plan more in the future, rather than simply to report on the past (DW Journal, 2013).

Given that companies recognise the importance of their supply chains, they still face difficulties. Such difficulties are the implementation of supply chain management software and a general change in control. Supply chains lead to a change in control from direct ownership to control based on networking, due to the blurring of boundaries between business partners. The integration of a company across interfaces becomes more important. It is no longer the company itself, but the supply chain together with partners that are considered to be important as a competitive unit. Indeed, the individual company must now see its own position as a contribution to competitiveness of a supply chain. Integration also influences the organisation of a company (Min & Zhou, 2002, p. 231), (Drucker, 1998). Instead of a static organisation, companies need to be flexible and demonstrate their ability to deal with agile and temporal forms of organisation (van Hoek, 1998, pp. 187–188). The question arises to what extent controlling and performance measurement in the corporate context can respond to the developments of integration and temporal organisational forms. Van Hoek (1998) even describes this problem of measuring performance in view of the supply chain context as the question of how to “measure the unmeasurable” (van Hoek, 1998, p. 187).

2.2 Performance Measurement Development

Changing business conditions indicate a trend away from companies as autonomous entities towards companies as part of a wider supply chain. Thus it is reasonable to state: “One of the most significant changes in the paradigm of modern business management is that individual businesses no longer compete as solely autonomous entities, but rather as supply chains” (Lambert, Cooper & Pagh, 1998, p. 1). Garcia Sanz (2007, p. 3) also refers to the supply chain as a competitive unit. Companies have to realise cost savings both for their own business processes, as well as beyond corporate boundaries for the entire value chain (Piontek, 2009, p. 1). Therefore, if a company is to be provided with suitable tools, it is important to assess how performance measurement has evolved. Based on the testimony of non-measurability (van Hoek, 1998), there certainly has been a development. The question is whether the current “state of the art” in performance measurement satisfies the requirements of a supply chain development.

Our literature review includes library-based search, internet search via google (google search, google scholar) and querying major electronic databases[2]. Important keywords are: Supply Chain, Performance Measurement, Performance Management, and Performance Measures. We focus on performance measurement in a manufacturing environment. Further, we also rely on literature review articles. These kind of articles are very important because of the breadth of available literature on performance measurement. In many cases literature review articles add value because they offer a quintessence of relevant articles on a specific subject.

2.2.1 Evolution of Performance Measurement

In 2004, Gomes, Yasin and Lisboa carried out an extensive literature review on the topic of performance measurement and, in accordance with changing business conditions, provided an analysis of relevant articles published between the years 1988 and 2000. The authors cover a total of 388 published articles. About 40 % of the articles published in this period of time (1988 - 2000) are published by 10 different journals. Completed by library based search and relevant conference proceedings, Gomes et al. (2004) suggest several main stages of performance measurement, summarised as (i) performance measurement solely based on cost accounting, (ii) enrichment of the financial perspective by a non-financial perspective, (iii) development of a balanced integrated approach and (iv) the vision of overall organisational effectiveness (Gomes et al., 2004, p. 523):

Until the 1980s, performance measurement was based solely on cost accounting. The retroactive perspective allowed a comparison of the resulting costs to the once budgeted costs.

Due to the formation of systematic larger organisations, it was necessary to add financial data such as return on investment and a general profit orientation to performance measurement.

Starting in the 1980s, together with the beginning of globalisation, performance measurement was enriched with a non-financial perspective in addition to the financial perspective. As companies first used performance measurement only to improve their internal efficiency and to increase capital attraction, the performance measurement enriched with a non-financial perspective enabled them to scrutinise their entire organisation. Claims from Sink and Tuttle (1989) and Harrington (1991) contradict this development of performance measurement by arguing that it is not possible to manage what cannot be measured (Harrington, 1991, p. 43). Nevertheless, in essence we can state that the topic shifted from being a retroactive to a proactive tool.

[2] i.a. Emerald, JSTOR, Sage Journals Online, Science Direct, Wiley, WorldCat

In the 1990s, performance measurement became even more proactive as a result of automated operations and the aim of obtaining suitable results to support an optimised organisational responsiveness. This led to a balanced integrated perspective taking into consideration all the stakeholders of an organisation. After comparing two performance measurement systems in companies, Caplice and Sheffi (1995) concluded that “the nonfinancial measures within their systems were recognized by both systems as being the drivers of future performance” (Caplice & Sheffi, 1995, p. 72). Similarly, Eccles (1991) already described a radical shift from “financial figures as the foundation for performance measurement to treating them as one among a broader set of measures” (Eccles, 1991, p. 131). One major tool in this context is the Balanced Scorecard developed by Kaplan and Norton (1992). Initially based on a financial perspective only, the Balanced Scorecard marked a change in that it integrated several dimensions into performance measurement.

Based on the vision of solutions capable to monitor both, each individual resource as well as the overall organisation, a need for a further adaptation in performance measurement is recognised around the year 2000. In the sense of continuous improvement, such performance measurement solutions would not only assess the effectiveness of each individual resource by using very specific measures, but also of the overall organisation by using very brought measures. To conclude, Figure 8 summarises the timeline of performance measurement.

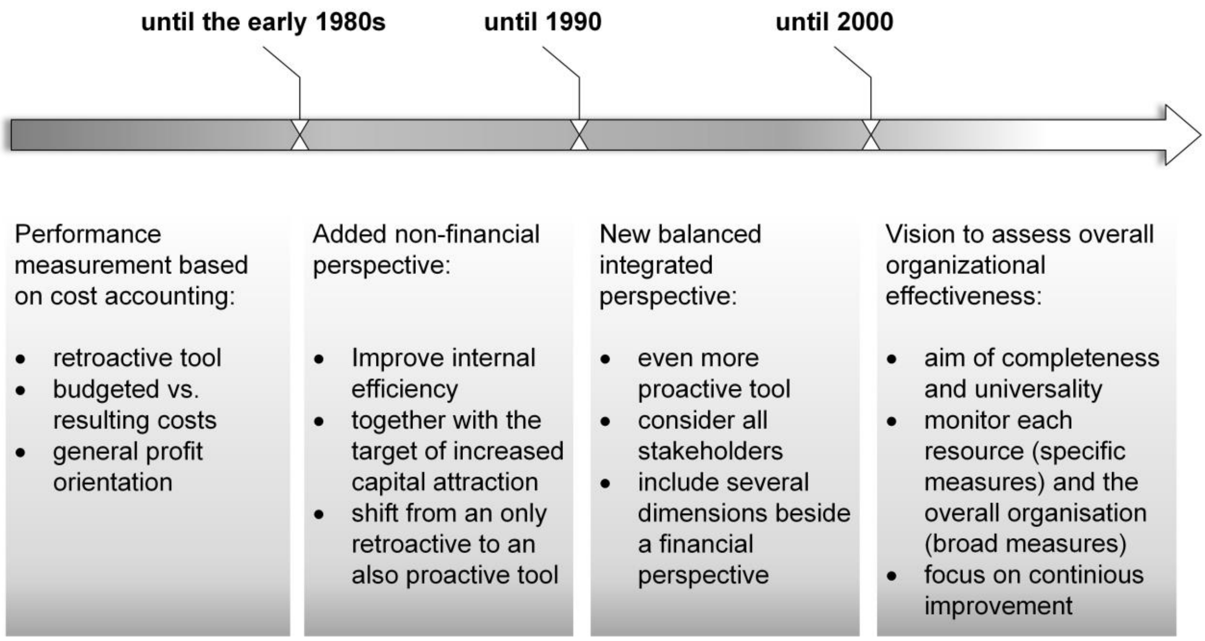


Figure 8: Timeline of Performance Measurement (Gomes et al., 2004, p. 523)

According to Gomes et al. (2004, p. 523), managers seek integrative tools that provide an early warning system, enable them to diagnose the current situation of their company and name appropriate actions that should be undertaken based on the gained knowledge. In the course of this, main characteristics are "inclusiveness, completeness, timeliness, universality, measurability, consistency, integrity and flexibility" (Gomes et al., 2004, p. 523).

The demand for such tools in performance measurement becomes even more evident by looking closer at recent changes in business conditions. Coming from the focal perspective of a single company, the formation of supply chains and dyadic relationships between companies highlight this turning point of a vision of overall organisational effectiveness in performance measurement. For reasons such as to take all relevant performance factors of the environment into account, the increasing integration of relations with customers and suppliers requires an extended performance measurement that goes beyond the company's own corporate boundaries (Lambert et al., 1998), (Chenhall, 2005), (Piontek, 2009).

2.2.2 The aim of Overall Organisational Effectiveness

Having identified the turning point of a vision of overall organisational effectiveness in performance measurement, we evaluate the "state of the art" of performance measurement systems. In this respect, as with Bititci, Carrie and McDevitt (1997), performance measurement systems are at the heart of the performance measurement process within companies. Performance measurement systems are associated with reference models containing standard descriptions of management processes, a framework of relationships among the standard processes and metrics to measure process performance. In terms of the metrics, a wide categorisation is to distinguish between financial and non-financial performance measures (Merchant & Van der Stede, 2007).

In their literature review article, Kurien and Qureshi (2011) analyse existing performance measurement systems (so called frameworks) for their strengths and weaknesses in the light of overall organisational effectiveness. Thereby, the authors' main concern is about overall organisational effectiveness in the sense of supply chain management and measuring performance beyond the individual cooperate boundaries. Specialist books on the subject matter confirm that these models are amongst the most popular performance measurement models and frameworks (Bititci, 2015, pp. 254–262).

The reasons for success or failure of certain models result either from characteristics of the frameworks themselves, or from the use of inappropriate performance measures and design:

- The characteristics that support the success of a framework are "inclusiveness (measurement of all pertinent aspects), universality (comparison under various operating conditions), measurability (data required are measurable), and consistency (measures consistent with organisation goals)" (Beamon, 1999, p. 276).

- According to Kurien and Qureshi (2011, p. 20), appropriate performance measures need to have a clear purpose and need to be easy to use. The metrics should lead to the improvement of performance, rather than just monitoring it. Further, appropriate metrics support the improvement in accordance with the strategic goals of a company. Finally, a clear focus on both, the importance of customers and actions undertaken by competitors, is essential.
- The design of a performance measurement system is based on the challenge to find the right measures, to access the right data, and to obtain broad support across the company by creating a common understanding, which in turn ensures permanent refreshing.

One can distinguish the variety of existing approaches in (i) balanced models, (ii) quality models, (iii) models based on questionnaires, (iv) hierarchical models and (v) support models (Cagnazzo, Taticchi & Brun, 2010, p. 171).

With its financial and non-financial perspectives, the Balanced Scorecard is clearly an example for a balanced model. Aside from the financial perspective, the Balanced Scorecard includes internal business, innovation and customer perspectives. Balanced models usually show indicators of different categories. By considering every category for possible side-effects, companies may avoid a one-sided optimisation.

Quality models pay attention primarily to continuous improvement. One important tool is the model developed by the European Foundation for Quality Management (EFQM, 1999). The aim is to assist companies in creating a business model that links performance results to satisfied people, satisfied customers and a positive impact on society. For this purpose, five enablers (leadership, strategy, employees, partnerships, and processes) and four results (customers, employees, stakeholder, and indicator results) are evaluated against the eight principles illustrated in Figure 9. Starting with the basic activities, to the business processes, to the individual business units, to the business level, the models follows a bottom-up approach.

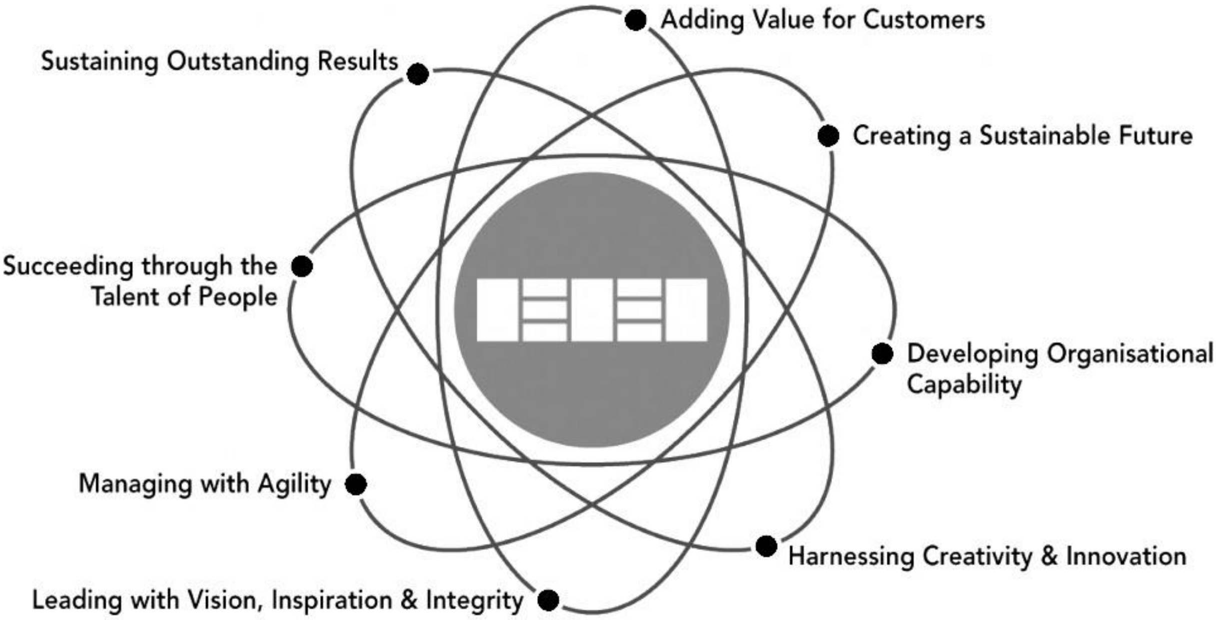


Figure 9: Fundamental ©EFQM Concept (EFQM, 1999)

A useful example of a questionnaire model is TOPP, which was generally developed by studying the manufacturing industry in Norway. This model attempts to measure the performance of a company by using a set of questions. The questionnaire consists of three different parts (general overview, operating of the company, specific areas such as marketing, design, technological planning, etc.). The system measures the performance along three dimensions, namely:

- effectiveness (satisfaction of customer needs),
- efficiency (economic and optimal use of enterprise resources) and
- ability to change (strategic awareness for handling changes).

An independent evaluator rates the answers given on three different levels (top management, middle management and manufacturing level) by qualitative evaluation (current status and status in two years) and their importance (Rolstadas, Andersen, Browne & Devlin, 2004).

Models characterised by a strictly hierarchical structure on different cost or non-cost levels are called hierarchical models. The Performance Pyramid also known as Strategic Measurement and Reporting Technique (SMART) illustrated in Figure 10 is a typical example for a hierarchical model. The main features of the model are structured objectives with associated indicators and measures. This follows in accordance with the balanced involvement of both stakeholder groups: customers and investors. Whilst the left side of the pyramid reflects external effectiveness measures, the right side reflects internal effectiveness.

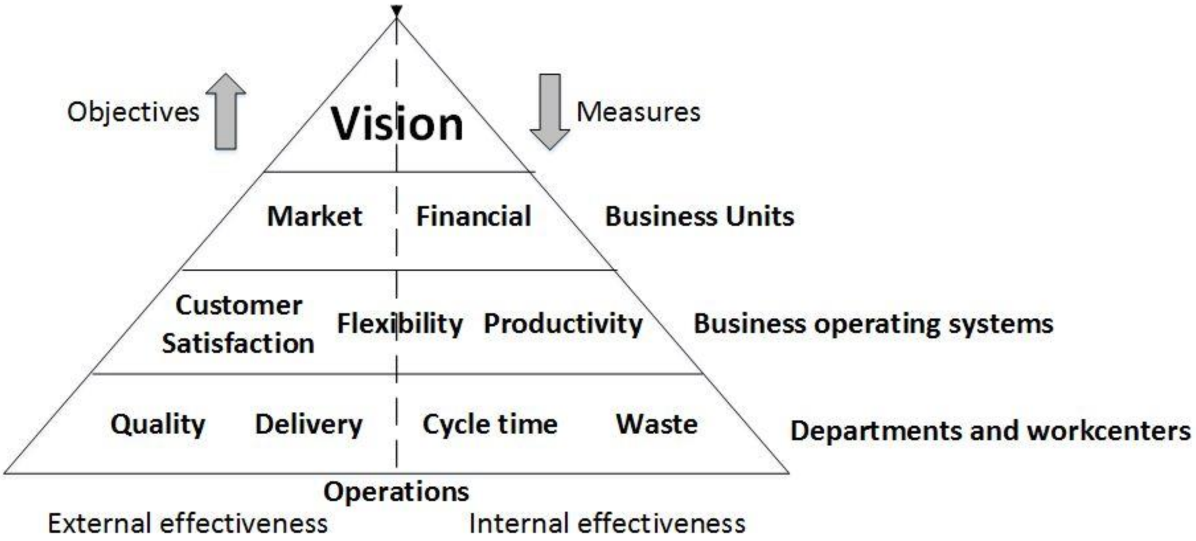


Figure 10: Performance Pyramid (Kippenberger, 1996, p. 10)

Support models do not directly build a performance measurement system but instead support the identification of relevant factors for performance. The Quantitative Model for Performance Measurement Systems by Suwignjo, Bititci and Carrie (2000) is one example in this category. Following Suwignjo et al. (2000, p. 232) the model consists of three steps:

- Firstly, factors affecting performance and the possible relationships among them are identified.
- Secondly, following hierarchical structuring, the effect of the factors on performance is quantified.
- Thirdly, the method from Suwignjo, Bititci and Carrie supports managers by quantifying the level of impact for each factor concerning the overall performance.

The described procedure contributes to improvement activities and, given its analysis of relationships, paves the way to a better understanding of dynamics.

2.2.3 Internal and External Benchmarking

As the broad categorisation for the variety of performance measurement systems shows, there is a trend to consider external influences starting around the year 2000. However, just because external influences (customers, suppliers, employees, society) are taken into account, one cannot conclude that the means for external benchmarking are available at the same time. In fact, as framework for analysing supply chain performance evaluation models by Estampe, Lamouri, Paris and Brahim-Djelloul (2013) points out, most models are only suitable for internal benchmarking.

Thus our analysis of the state of the art also covers recent performance measurement approaches like SCOR® or ENAPS, providing a consistent supply chain orientation. The

SCOR® reference model is one of the most popular approaches to include supply chain partners. SCOR® is one of few models including an internal and external focus.

Aside from the possibility of standardising the supply chain as referred to above, the SCOR® model also includes ways of measuring overall effectiveness. In their review, Huan, Sheoran and Wang (2004) point out that the SCOR® framework has the potential to become industry standard. It is one of the most common frameworks (Huan et al., 2004, p. 28). There are 12 performance measures classified into the categories (i) delivery reliability, (ii) flexibility and responsiveness, (iii) costs and (iv) assets. Table 1 provides an overview and classifies the performance measures.

Table 1: SCOR® Model Performance Measures (Huan et al., 2004, p. 25)

Delivery reliability	Flexibility	Costs	Assets
Delivery performance	Supply chain responsiveness	Total logistics management cost	Cash-to-cash cycle time
Fill rate	Production flexibility	Value-added employee productivity	Inventory days of supply
Order fulfilment lead time		Warranty costs	Asset turns
Perfect order fulfilment			

To explain network dynamics across the supply chain, it is possible to integrate software tools. The previously mentioned supply chain management software aims to support supply chain decision-making and profitability. However, as Huan et al. (2004, p. 26) point out, supply chain management software is criticised as being:

- very expensive,
- hard to implement,
- difficult to use,
- sensitive to compatibility problems.

Compatibility issues between the different companies can only be avoided if all tools, such as for example company-specific ERP solutions, are consequently integrated into SCOR® (Huan et al., 2004, pp. 25–26). From the initial aim to improve supply chain performance, the question arises if, based on the given 12 performance measures, quantifiable measures for supply chain performance can be derived. According to Huan et al. (2004, pp. 26–28), this is possible either by determining absolute priority or by setting the relative importance of different metrics.

The ENAPS process performance model is another model with both an internal and external focus and was developed by the European Network for Advanced Performance Studies (Estampe et al., 2013), (Rolstadas et al., 2004). The ENAPS approach is based on a network of agents in most European countries. The aim of the project is to introduce a solution for advanced business process performance within the process oriented industry (Rolstadas et al., 2004, p. 1). The development of a benchmarking database is essential to ENAPS, the actual benchmarking of companies itself being performed by agents (Rolstadas, 1998, p. 994). The system includes performance indicators on three different levels:

- the enterprise level is very general and suits every manufacturing enterprise.
- the process level emerges out of functions or sub-processes. Exemplary indicators are product development efficiency, outgoing delivery quality and average time to solve complaints.
- the function level is company specific and grouped under the process levels.

The independent network agents measure indicators on the different levels throughout the company including accounts, product development, marketing and sales, planning and production, customer services, purchasing, personnel and others (Rolstadas et al., 2004, p. 18). Then follows the development of quantitative indicators with regard to time, cost, quality, volume, flexibility and environment (Rolstadas et al., 2004, pp. 19–21).

ENAPS consists of the questionnaire-based approach advanced from the TOPP framework described above. The framework is a top down approach used to develop measures and indicators. In case of the same industry and a comparable manufacturing environment, it becomes possible to compare the own company to others. Thus, the underlying assumption of ENAPS is the existence of an optimum that allows comparability within a particular industry. The optimum is given by the company with the most desirable levels of performance. Following this proposal, all similar companies should use the same set of performance measures that focus on the company itself and its position as compared to competitors. However, this approach does not include aspects related to a network orientation or any collaborative elements.

Several other approaches like VICS (2004), Hieber and Schönsleben (2002) or Papakiriakopoulos and Pramatari (2010) build on cooperation across specific supply chains. In this context, each supply chain consists of different companies willing to cooperate. Although strong cooperation helps to improve performance and to reduce the bullwhip effect (fluctuation across the supply chain), the supply chain network itself, being the latest evolution step, remains unconsidered.

Moving beyond the described models, the change from dyadic relationships to the formation of complex supply chain networks raises new issues on performance measurement. Clearly, recognising the importance of dyadic relationships alone is not enough. The expansion of the company's own boundaries towards supply chain integration may only be a first step. Known trends like global sourcing, the internationalisation of distribution and the search for cheap manufacturing labour are factors stimulating the change from dyadic relationships to the design of complex networks (Lambert & Pohlen, 2001). Companies are part of many different supply chains that form a supply chain network. Therefore we point out the transition from a hierarchical structure to a network structure. This means that there seems to be a demand to extend performance measurement in the light of the supply chain network.

2.3 Shortcoming of Performance Measurement in a Supply Chain Network

Next to the emergence of supply chains (the first turning point described in Section 2.2), according to Morgan (2007, p. 255), the second turning point in supply chain performance measurement results from the approximation of supply chains to supply chain networks. Besides the on-going optimisation of value creation together with reduced costs, the removal of trade barriers leads to the creation of large areas of economic cooperation. Due to the development of supply chain networks and the establishment of network cooperation, it is comprehensible why it is important to reflect on being embedded in the supply chain network creating new challenges for performance measurement. This development of extended performance measurement can also be referred to as a shift from "monocultural to polycultural performance measurement" (Morgan, 2007, p. 256). Adding a new stage to the previously presented Figure 8, we expand the timeline of performance measurement as illustrated by Figure 11.

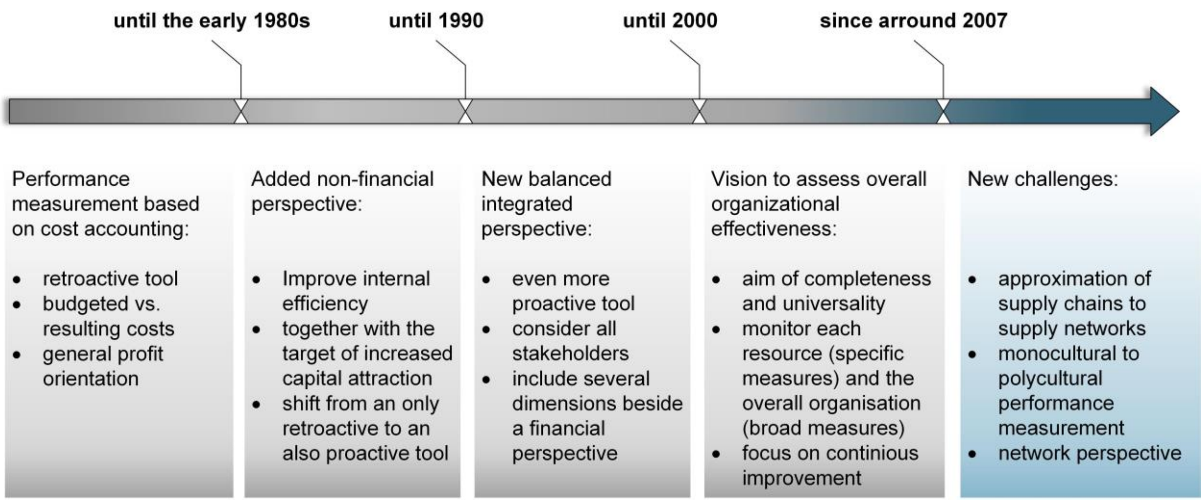


Figure 11: Extended Timeline for Performance Measurement based on (Gomes et al., 2004, p. 523)

The added stage in performance analysis indicates the change from dyadic relationships across a supply chain towards a network perspective. It is no longer sufficient to focus on few companies in the light of dyadic relationships. The thinking of many different relationships which may even influence one another exceeds the methods used to analyse dyadic relationships. In fact, all participating companies are embedded into a network structure. This concept of structural embeddedness was initially introduced by Polanyi (1944). In our present case of supply chains, structural embeddedness is not only a question of supplier management of large OEMs. From the perspective of each individual company, the term embeddedness refers to the dependence on suppliers and customers. Therefore performance is also the result of relationships with suppliers and customers. To summarise, initially planned dyadic relationships between buyer and supplier evolve as both companies become unwittingly part of a common network (Choi & Kim, 2008). Each company is connected to its own extended network of companies. For example, the supplier is connected to sub-suppliers and other customers. Therefore a buying company is connected not only to its supplier, but also indirectly to the sub-suppliers. As all economic processes are part of networks of relations, companies should pay more attention to the analysis of the network.

Recognising the structural embeddedness and the importance of supply chain networks, we have to assess how existing methods for performance measurement can deal with such changes. As pointed out in Section 2.2, performance measurement has become more comprehensive by providing a more holistic view. Nevertheless, financial indicators and internal benchmarking remain basic.

2.3.1 Extension of Classical Performance Measurement

Identifying the need of a supply chain network perspective, one could try to build on classical instruments of performance measurement. Traditionally it is claimed that performance in an organisational context is the result of the interrelationship between effectiveness, efficiency, quality, productivity, quality of work life, innovation and profitability (Sink & Tuttle, 1989). Performance is then determined by the use of the appropriate measures processed in reports. Accounting reports support traditional elements such as forecasting, budgeting, standard costing, overhead absorption and the calculation of return on investment.

A first refinement deals with the concern that the monitoring of developed indicators as part of accounting reports tends to support incorrect decision making for reasons such as (i) inaccurate numbers, (ii) an inability to handle the demands of the process-oriented industry and (iii) outdated reports that lack flexibility (Maskell, 1991, p. 45). Following Maskell (1991, p. 47), focusing only on productivity, profitability and liquidity, is not suitable to cover the needs of performance measurement in a global business environment. Instead, performance measurement needs to support the manufacturing strategy of a company.

This is why a global business environment reinforces the use of non-financial performance measures (Bourne, Mills, Wilcox, Neely & Platts, 2000, p. 756). Factors such as cost reduction, increased margins, return on assets or stock value need to remain important, but should be combined with non-financial factors. Besides, due to worldwide competition, the achievable prices are often market rather than cost-driven. Hence, companies are very different in terms of targeted markets, their management, products and location. Consequently, Maskell (1991, p. 48) promotes the inclusion of quality, reliability, flexibility, innovation, customer satisfaction in performance measurement and encourages further reflection on social issues.

One comprehensive solution building on the traditional instruments of performance measurement is suggested by Neely et al. (1995, p. 81). Their basic idea is to consider the changing business conditions by creating a model that includes several perspectives. In accordance with the adaptation of the Balanced Scorecard, their performance measurement takes place on three different levels, namely (i) the level of individual performance measures, (ii) the level that combines a set of performance measures for the entire performance measurement system and (iii) the level of relationships between the system and the environment of a company.

The first level of individual performance measures specifies the measures to use. On this level, terms like quality, time, cost and flexibility are important. The second level is about different perspectives with equal importance. The Balanced Scorecard is an appropriate tool to bring internal (organisational) and external (market) dimensions together. According to Neely et al. (1995), Lambert and Pohlen (2001), companies tend to ignore external comparisons and non-financial targets. Therefore, the external dimension on the third level is about the inclusion of aspects of the market environment such as customer satisfaction and competition.

Nevertheless we note that the question persists whether a more comprehensive model satisfies the increasing demands of performance measurement for networks, where the individual boundaries of companies are eliminated. A Balanced Scorecard integrating external aspects and performance measures on three different levels still focuses on the individual company in its own right:

- The Balanced Scorecard has no clear competitive view. The question of how a company performs with regard to its competitors cannot be answered.
- Supply chain metrics often just measure internal logistics (Lambert & Pohlen, 2001, p. 2).

- Supply chain management might be misinterpreted as extension of logistics.
- From a supply chain perspective, performance measurement has become very interdisciplinary including strategy, marketing, operational research and logistics.
- Neely et al. (1995) put a clear strategy focus beside a solution for short-term thinking, local optimisation and changing business conditions on the research agenda often missing in Balance Scorecards.
- Several perspectives together, combining too much information, risk to blur what is really important for performance measurement (Papakiriakopoulos & Pramatari, 2010, p. 1299).

2.3.2 A Common Performance Measurement System

Papakiriakopoulos and Pramatari (2010) propose a quite sophisticated idea which is the development of one common performance measurement system. Collaboration across the supply chain clearly has some potential. Nevertheless, the development of a common performance measurement system is not only about the identification of relevant measures and the potential of collaboration. Besides the difficulty to identify appropriate measures in the supply chain context, the sharing of information is a basic requirement. Only by implementing information sharing processes, it is possible to gain advantage from collaboration. Even if collaborating companies maintain information sharing, further difficulties because of technical and managerial issues may arise.

Beamon (1999, p. 280) suggests to add performance measures that focus on strategic aspects such as the measurement of resources, output and flexibility, in order to look beyond measures of logistics.

A list of 26 possible performance measures is presented by Gunasekaran and Kobu (2007, pp. 2832–2833). The share between internal and external measures that focus on the individual company is 50:50. Table 2 illustrates the assignment of performance measures to the dimensions of the Balanced Scorecard. If different companies across the supply chain would agree, the list may serve as basis for the development of a common performance measurement system.

Table 2: Metrics in the Supply Chain (Gunasekaran & Kobu, 2007, p. 2833)

	Financial	Internal Process	Innovation	Customer
Accuracy of scheduling		X		
Bid management cycle time		X		
Capacity utilisation		X	X	
Compliance to regulations		X	X	
Conformance to specifications		X		X
Delivery reliability		X		X
Forecasting accuracy				X
Inventory costs	X	X		
Labor efficiency			X	
Lead time for procurement				X
Lead time manufacturing		X		X
Obsolescence cost	X			X
Overhead cost	X	X		
Perceived quality				X
Perceived value of product				X
Process cycle time		X		
Product development time		X	X	
Product / service variety	X		X	X
Production flexibility		X	X	
Return on investment	X			
Selling price	X			X
Stock out cost	X			X
Supply chain response time		X	X	
Transportation cost	X			
Value added	X			X
Warranty cost	X			X

The collaborative performance measurement system concentrates on the benefits based on external measures. Data quality is essential since different teams of different companies use the same common performance measurement system. A case-study by Simatupang and Sridharan (2002) shows the great potential of common performance measurement. Although the advantages of a common performance measurement are widely recognised, the case-study in Simatupang and Sridharan (2002) can only be a contribution to the alignment of theory and practice. It is essential to share information and to use information technology in the best possible way. This is why one limiting factor of collaborative performance measurement lies in industry-specific conditions. A collaborative performance measurement system has huge potential, but its implementation is only realistic for a limited group. Collaborative performance measurement still has a supply chain focus rather than a real network focus. Both technical barriers, as well as concerns (e.g. lack of trust) in the participating companies themselves limit the application. Assuming that the quality of information is ensured, an increasing number of companies needs to be integrated in a common platform. The technical integration, as well as the requirement of mutual trust are difficult to obtain.

2.3.3 Towards an Advancement in Performance Measurement

Recognising the developments of supply chain networks together with the increasing complexity of business, companies have two alternatives (Morgan, 2007, p. 263): it is either possible to stick to the performance measurement systems that are already in use, or it might be worth looking for new approaches and developing new techniques as a response to new challenges. The first alternative results in a steady adaptation of the known tools in order to face new conditions in business. The second alternative is a chance for companies to gain a leading position because of a knowledge advantage compared to competitors. In order to support the second alternative, this thesis contributes towards a new approach in performance measurement in a supply chain network context. We illustrate the requirements for such a new approach in Table 3. The overview is based on a morphological analysis described by Ritchey (1998). The morphological analysis is a creative technique in the core of which is the so called Zwicky-Box.

We use the Zwicky-Box because it quickly allows to grasp what is needed to close the recognised gap resulting from a missing supply chain network orientation. Based on our literature research, parameters and their different possible occurrences are shown in a matrix. We intuitively fill out the matrix to illustrate what seem to be the most relevant requirements we have to meet (yellow path). To what extent this is finally achieved depends on our results and is part of the implications of this study.

Table 3: Morphological Analysis for a Network-oriented Approach in Performance Measurement

<table>
<tr><th>Parameters</th><th colspan="12">Parameter expressions</th></tr>
<tr><td>Relationships</td><td colspan="6">dyadic</td><td colspan="6">network</td></tr>
<tr><td>Financial data</td><td colspan="4">n/a</td><td colspan="4">exclusively</td><td colspan="4">combined part</td></tr>
<tr><td>Most relevant issues</td><td colspan="2">quality</td><td colspan="2">reliability</td><td colspan="2">flexibility</td><td colspan="2">innovation</td><td colspan="2">customer satisfaction</td><td colspan="2">social issues</td></tr>
<tr><td>Perspective</td><td colspan="6">internal perspective (organisational)</td><td colspan="6">external perspective (market)</td></tr>
<tr><td>Inclusion of the environment</td><td colspan="3">customers</td><td colspan="3">suppliers</td><td colspan="3">competitors</td><td colspan="3">entire network</td></tr>
<tr><td>Levels of measurement</td><td colspan="4">individual (company specific)</td><td colspan="4">several dimensions of equal importance</td><td colspan="4">market conditions (environment)</td></tr>
<tr><td>Interdisciplinary focus (strategy)</td><td colspan="3">strategy</td><td colspan="3">marketing</td><td colspan="3">operational research</td><td colspan="3">logistics</td></tr>
<tr><td>Psychological perspective</td><td colspan="6">short term thinking</td><td colspan="6">long term thinking</td></tr>
<tr><td>Collaborative thinking (share information)</td><td colspan="6">local optimisation</td><td colspan="6">optimisation in the larger context (keep things balanced)</td></tr>
<tr><td>Handling of supply chain measures</td><td colspan="4">n/a</td><td colspan="4">easy to use</td><td colspan="4">complex to use</td></tr>
<tr><td>Process alignment</td><td colspan="4">n/a</td><td colspan="4">encourage process alignment</td><td colspan="4">complex to realize</td></tr>
</table>

2.4 Justification of Literature Research Results

Up to this point, we worked-out the demand to extend performance measurement in the light of the supply chain network. These insights are confirmed if we look at a comprehensive literature synthesis on performance measurement and its future challenges. In their literature review article, Bititci, Garengo, Dörfler and Nudurupati (2012) point out several research gaps in performance measurement and identify which lines of enquiry generally need to be pursued.

In combination to our literature review, this literature review article by Bititci et al. (2012) adds value because the article covers a very broad literature base on the topic of performance measurement. Mapped against a timeline, Bititci et al. (2012) bring literature on performance measurement in line with the literature on global business trends. Such work can only be done by a multidisciplinary team. We can benefit from their results in order to ensure timeliness and completeness of our argument made by literature research.

Following the two mentioned separate literature streams (performance measurement and business trends), Bititci et al. (2012) confirm collaborative organisations in a supply chain context as one main research challenge in the area of performance measurement, The authors recognise that in today’s business environment collaboration beyond the individual organisation is a given. Thus, further research in the context of supply chains and performance measurement is still needed, because "most of the research presented is either theoretical in nature or based on simple supply-chain case studies" (Bititci et al., 2012, p. 313).

As we pointed out in Section 2.2.2, although aiming for overall organisational effectiveness, Bititci et al. (2012) validate our argument by stating that existing performance measurement systems focus on "a single organisation and rely on defined business structures and processes" (Bititci et al., 2012, p. 314). To conclude, at this point, the authors also affirm our findings of a further intensification of this challenge in performance measurement (Section 2.2.3), because in fact collaboration is not only about few business partners; rather it is about being involved in complex networks of companies. Even if there might exist different ideas of how to cope with inter-organisational performance measurement (Section 2.3.1, Section 2.3.2), these ideas remain limited to case studies in individual companies. Thus, it is reasonable to assume that with respect to collaborative organisations in a supply chain context "Today's frameworks and models for performance measurement may not be able to deal with this level of complexity and dynamism" (Bititci et al., 2012, p. 314).

2.5 Addressing of the Research Gap

The requirements for a new approach in performance measurement arise from the weaknesses of the existing approaches that we analysed. Our findings are consistent with the main reasons for failure of supply chain performance measurement. Kurien and Qureshi (2011), as well as Morgan (2007) point out the following reasons: (i) a lack of network focus, (ii) an inability to make supply chains visible, (iii) a missing coordination of marketing and supply chain activities and (iv) managers who are not concerned about the linking of performance measurement and strategic rethinking.

As suggested by Allee (2000), Bovet and Martha (2000), companies need appropriate models together with supply chain metrics, if they want to take the transformation of a linear value chain into a complex network of large-scale activities between companies into account. According to Lambert and Pohlen (2001, p. 5), relevant issues for supply chain metrics for performance measurement in an industrial context are:

- the lack of suitable measures to capture performance across the supply chain,
- the need to go beyond internal metrics and take a supply chain perspective,
- the difficulty to recognise the relationship between corporate and supply chain performance,
- the general complexity of supply chain management,
- the necessity to broaden the line of sight within the supply chain,

- the need to differentiate the supply chain to obtain competitive advantage and
- the encouragement of cooperative behaviour across corporate functions and across the supply chain.

2.5.1 Method to approach

One possible reason for the problems summarised by Lambert and Pohlen (2001, p. 5) could be the fact that a too narrow focus lies on dyadic relationships. As justified by Section 2.4 and in line with our argument (Section 2.2, Section 2.3), there is a need for further research into performance measurement beyond dyadic relationships (Nudurupati, Bititci, Kumar & Chan, 2011), (Bititci et al., 2012) (Melnyk, Bititci, Platts, Tobias & Andersen, 2014). A broader supply chain network perspective or strategy is missing.

It is conceivable that companies may not be able to make the supply chain network visible, either because of a lack of technical knowledge or because of missing available information. Further, it is also possible that companies just do not recognise the importance of holistic performance measurement together with strategy adjustment of their own company (Morgan, 2007, p. 263).

Considering that “practitioners are currently struggling to manage in volatile environments” (Melnyk et al., 2014, p. 183), our approach is to draw relevant lessons for performance measurement by analysing the network what involves the development of a new methodological approach by transferring social network analysis to the business context. The opportunity to quantify network position as one major subject of social network analysis justifies the application of this method. Besides, as a method originating from social sciences, social network analysis is a promising approach to overcome the gap between local optimisation and structural complexities in a network (Basole, Rouse, McGinnis, Bodner & Kessler, 2011).

Commonly, social network analysis focuses on structures such as human groups, markets, world organisation or society in general. In our present context of companies doing business with each other, we interpret the supply chain network as a network of ties. This network is complex and has properties which are not obvious at first hand. The degree of distribution of the connections between the nodes is neither regular nor entirely coincidental. The assumption of a scale-free network (no clear boundaries) is based on a distribution of links per node that follows a power law. Information flows bi-directionally between companies. The broader network perspective is illustrated in Figure 12.

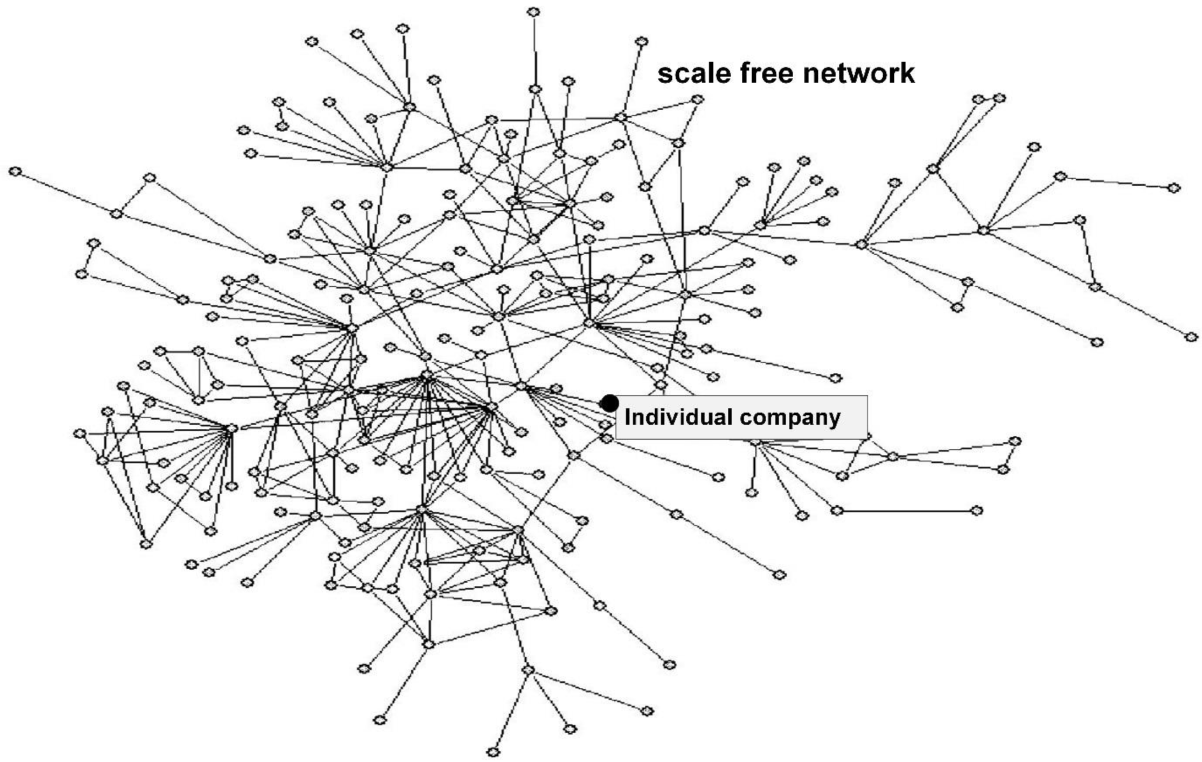


Figure 12: Scale Free Network Perspective (Wuchty, 2001, p. 1698)

Recognising the existence of a network structure, one possible approach to gain in-depth knowledge for the network design/structure could be behavioural research, either by mass surveys or case studies as means of primary data collection. We suppose that both alternatives have their limitations:

- Surveys require a sufficient amount of feedback. Since it takes time to fill out a questionnaire, people might become reluctant if there are too many requests.
- Case studies are a very interesting alternative. Nevertheless it is difficult to generalise the gained results, because of the limited quantity of feedback.

By contrast, our approach, practiced in this thesis, is the application of social network analysis. Such analysis focuses on the relationships/connections among actors or groups. Transferred to the supply chain network, social network analysis is the descriptive and statistical method to illustrate how the nodes are positioned, connected and embedded within the supply chain network (Bellamy & Basole, 2013, p. 239). Besides, social network analysis allows relationships among actors to be mapped to a graph. The ties between different actors are combined and a network becomes visible. The main goal is the detection of structural patterns such as centrality or cohesion. Social network analysis does not concentrate on an object that is independent of other objects. Instead:

- Social network analysis takes the individual object as an embedded part of a larger structure.
- Potentially, new findings based on the study of the interrelationships would not be accessible without social network analysis.
- The method assumes that hidden, informal knowledge exists within the structure.

The transfer of social network analysis to a business context is either possible within the single organisation or between different organisations. We focus on the second option.

Social network analysis makes different kinds of flows within the network visible and analyses the overall structure. The overall structure may consist of a set of activities, workers, technological and physical infrastructures and policies together with the procurement of raw materials, the conversion to finished and unfinished goods and logistics (Hassan, Mohsen M. D., 2006).

To date, social network analysis has been used in different ways to reveal findings from supply chain networks. Due to the fact, Bellamy and Basole (2013) are the first to provide an "organizing framework to facilitate an understanding of the plethora of supply chain management issues examined using network analysis" (Bellamy & Basole, 2013, p. 236), we refer to Bellamy and Basole's extensive analysis of publications concentrating on network analysis in the supply chain context. Their review underlines the relevance and increasing interest in this field of research.

According to Bellamy and Basole (2013, pp. 236–237), 126 relevant articles were published between 1995 and 2011. The first article on the level of a network of independent companies (interorganisational) or a network of business units of one lager company (intrafirm) was published in 1995. Out of all 126 articles, only 19 were published between 1995 and 2003. Over 50 % of all articles were published between 2008 and 2011. Figure 13 illustrates the increasing interest in network analysis in the supply chain context.

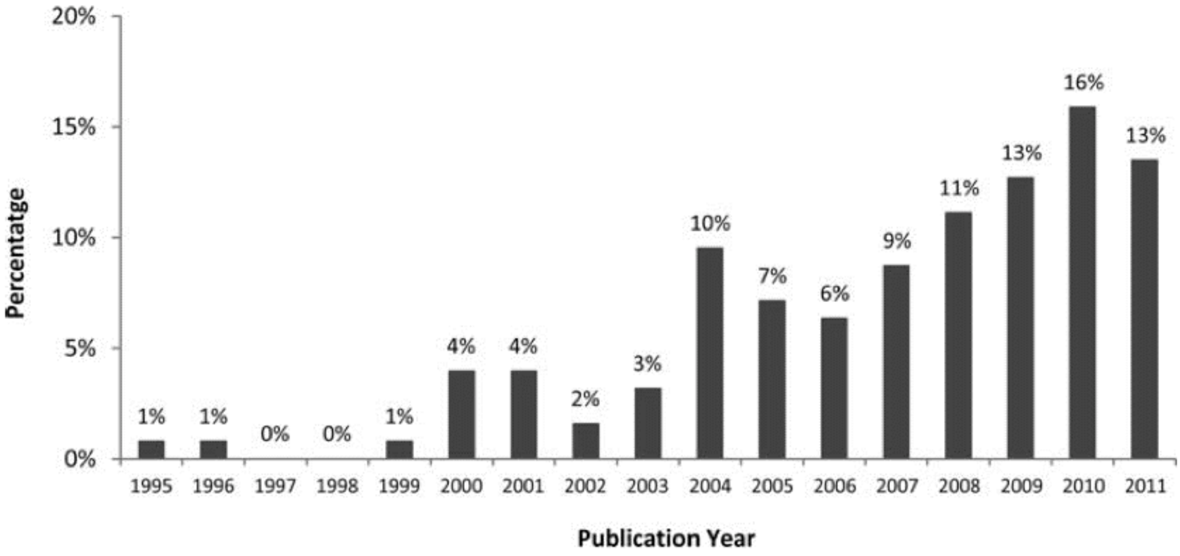


Figure 13: Percentage Distributions of the Number of Publications by Year (Bellamy & Basole, 2013, p. 237)

Bellamy and Basole (2013, p. 236) write that one surge in scholarly debate focuses on studies modelling a supply chain system as a complex network of interactions between system entities. The first paper that recognises the network of supply chains as a complex adaptive system is provided by Choi, Dooley and Rungtusanatham (2001).

The application of network analysis in order to engineer a system is practiced in very few cases. According to Bellamy and Basole (2013, p. 236), the main focus is set on product development. No paper deals with network analysis for the purpose of creating and analysing a network of supply chains. Bellamy and Basole (2013) point out a window of opportunity "to review and illustrate the value in adopting the network lens to better understand, design, and manage supply chains as complex engineered systems" (Bellamy & Basole, 2013, p. 236). This research gap is taken up by our thesis. Thus, the following section provides further insights on the relevant themes of social network analysis and what this means for our primary data collection.

2.5.2 Positioning and Research Themes

Bellamy and Basole (2013) provide a systematic review of available literature together with the organisation of their findings in an integrative framework. The suggestions of Bellamy and Basole for future research in the field of network analysis in the supply chain context are particularly helpful for our research. Bellamy and Basole (2013, p. 237) identify three main research themes:

- Network structure is about structural properties of networks of supply chains.

- Network dynamics concentrates on the formation, change and evolution of networks of supply chains together with possible effects for the robustness, responsiveness and resilience of those networks.
- Network strategy deals with strategies of companies used to improve performance of supply chain networks. The underlying intent, the level of scope (dyadic, triadic, network) and the nature of governance are distinguished.

It becomes clear that the main part of the studies is assigned to network structure and network strategy (Bellamy & Basole, 2013, p. 237). To contribute to performance measurement by the use of social network analysis, the present thesis spans between network structure and network strategy by, on the one hand, systematically formulating and building a supply chain network, and on the other hand, using the results of network analysis as evidence to improve managerial practice.

Maier (2006) provides a definition for network structure or architecture: “Architecture is the fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution” (Maier, 2006, p. 147). We model the supply chain network as a complex network. Nodes within the supply chain network (suppliers, manufacturers, customers) represent the components. This is only possible because of new conceptual work. In order to derive a network structure, networkdata needs to be collected either in a direct or in an indirect way. As with Wasserman and Faust (1994), there are measures referring to nodes as well as to the entire network.

Social network analysis has shown its potential for the analysis of structural and relational properties in many disciplines. According to Carter, Ellram and Tate (2007, p. 140), the transfer of social network analysis often focuses on strategic alliances. That means, one uses the aspects covered by social network analysis to examine interrelationships between organisations together with suppliers, interlocking directorates or horizontal alliances. But beyond this focus on interrelationships, as Bellamy and Basole (2013) state, “Surprisingly, there is comparatively little work that uses social network analysis in supply chain management” (Bellamy & Basole, 2013, p. 239). At this point, where “lacks a study integrating the insight gained from conceptual, empirical, and modelling/simulation work on SCS (note: supply chain system) architecture” (Bellamy & Basole, 2013, p. 239), this thesis contributes to the knowledge of performance measurement in the light of supply chain networks.

The use of social network analysis in an organisational context addresses structural properties on three different levels, namely: (i) node level properties, (ii) network-level properties and (iii) link-level properties (Borgatti & Li, 2009), (Ahuja, Soda & Zaheer, 2012).

- With respect to node level properties, node centrality is particularly important. There are several variants of node centrality measures. Following Kim, Choi, Yan and Dooley (2011), centrality may refer to prominence in the supply chain network. Higher centrality results in more power and control compared to peripheral companies. Besides node centrality, we use several node level properties such as the aggregated strength, determined by the proportional strength of links.
- At the network level, density (the actual existing ties compared to the maximum possible ties in the network) or network centralisation may be important. Further one distinguishes between different network topologies. If as in our case, the topology of the supply chain network is scale-free, it contains hubs and its degree distributions is heavy tailed following a power law. According to Strogatz (2001), this results in a number of entities with the most power and control in the system.
- The link level is about connections between system components (nodes). Links express buyer-supplier relationships, flows of product types, cash flows and information exchange. The type of flow, multiplexity (multiple links between nodes) and the strength of the individual link are typical properties on the link level. We calculate proportional strength as a result of cash flows between common business partners. Only a few publications like Oke and Idiagbon-Oke (2010) attempt to integrate tie strength into their models.

An appropriate example of the application of social network analysis regarding network structure is provided by Carter et al. (2007). Carter et al. (2007) examine performance differences of automotive companies as a result of the extent to which an automotive company together with its suppliers makes asset-specific investments. There are indicators that the level of asset-specific investments (site, physical, and human asset-specific investment) influences performance positively. A tightly-integrated network performs better than a less specialised and loosely-coupled production network. Carter et al. (2007) measure performance based on quality, new model cycle time, inventory holding costs and profitability. Based on the findings of individual networks (ego-networks of the automotive companies), it is conceivable to draw conclusions in a wider context. For example it seems to be evident that stronger links prove to be advantageous with respect to performance.

In addition to the focus on network structure, this thesis deals with questions of network strategy. Network strategy refers to the planning and execution of strategies of companies as a result of the evolution of the supply chain network. Network strategy starts with the described shift in focus from the individual company to a more interorganisational level. Collaboration on the dyadic level is recognised by Pathak, Day, Nair, Sawaya and Kristal (2007) and Beamon (1998). The authors pay increasing attention to the development from the dyadic relationship to the total supply chain network. Following Chen, Paulraj and Lado (2004, p. 519), our further research adopts network strategy, because dyadic, buyer-supplier relationships are embedded in larger supply chain networks. This holistic view becomes even more important if companies are part of global, large-scale supply chain networks. Buhman, Kekre and Singhal (2005) reaffirm our point of view in stating that the review of a representative sample of publications shows that "interdisciplinary research has offered insights into a wide range of issues faced by organizations and that interdisciplinary research remains a fertile area of research with almost unlimited potential" (Buhman et al., 2005, p. 508). Buhman et al. (2005) add that operations management research "shall embrace the concept of networked organization and establish the necessary multi-disciplinary global teams to create the new science of networked enterprises" (Buhman et al., 2005, p. 508). By performing a case study, Wareham, Mathiassen, Rai, Straub and Klein (2005) also recognise these insights. Their case study shows the potential to go beyond the dyadic relationships, but only for one company (ego-network) with direct partners.

2.5.3 Impact and Consequences

Following the previous findings, we are convinced that a company's performance is influenced by its network position. The reasons for this include advantages in network positioning, a more valuable network or certain links that provide support and higher performance. Not every network configuration is helpful in the same way. A large network might be less helpful than a structural advantageous position within a smaller, well-informed network. For example an actor, who is in the position to connect or disconnect others, has advantages in terms of control and information. Diversity of the relationships may also be relevant for the performance of a company. So it is obviously worth asking whether we can identify relevant characteristics within a supply chain network influencing performance. There ought to be a link between the network position in the supply chain network and the performance of a company. Further, it might be possible to recognise advantageous positions where participation affects performance.

As we reviewed, based on several applications of social network analysis, there is an opportunity to transfer social network analysis to the supply chain network. In the light of a network perspective, the aim is to contribute to performance measurement and identify structural aspects of network positioning that influence performance. Choi et al. (2001) also underline the potential for network analysis in supply chain management: they argue that companies who are able to understand the network will outperform other companies.

Thus, our aim is to change the focus of supply chain management from the individual company, respectively a single company and its dyadic relationships, to a network of companies. A broader level of scope considers dyadic relationships between different companies together with the structure of the supply chain network. At this network level we want to contribute to the evaluation of how network positioning affects the individual company and its performance.

Summary

We described changes in business conditions that lead to an organisational structure aligned to key processes. Companies set up their processes to deliver the best possible benefit to the customer. In order to ensure the best possible customer service, companies need to expand their own narrow perspective to a more integrative and process-oriented view that also includes their business partners. The integration of business partners and the process-oriented perspective lead to the necessity of managing globally expanding supply chains. Developments such as just-in-time, a lean production strategy and reduced production depth have intensified the dependencies across the whole supply chain. The main features associated with this change are a high level of automation, the total quality management approach, the just-in-sequence production and a very strong focus on processes. All these changes in business together with worldwide supply chains inevitably lead to fluctuations across the supply chain (bullwhip effect).

Supply chain management tries to support these activities and provides a framework for the synchronisation of supply and demand. However, supply chain management always requires the will to cooperate and exchange information. Individual supply chain projects are created on a common standard and agreed between the participants. The presented SCOR® model helps cooperating companies achieve a common understanding. The use of information technology may help companies to increase their flexibility. Supply chain management software is one way to plan and control value creation beyond the own company.

For companies, the development of supply chains goes hand in hand with a change in ownership. It is inevitable that companies shift their focus from a view that is primarily based on direct ownership towards ownership based on networking. The change of ownership towards networking influences controlling and performance measurement in a corporate context. The presentation of different types of performance measurement models provides a general overview about the development in performance measurement. All models try to avoid optimisation of individual parts to the expense of the whole company. As it is not sufficient to view the company in an isolated way but as part of the supply chain, the review of different performance measurement models towards supply chain orientation is a resulting requirement.

All these models are suitable means for performance analysis, but they cover neither the further development, nor the needs of network embedded companies. In fact, companies are part of supply chain networks rather than part of a limited number of more or less stable supply chains. An optimal solution for performance measurement should recognise the importance of financial data, but include non-financial indicators supporting the development of supply chain networks. The case study of one common performance measurement system shows the huge potential of collaboration. However, the development of a common system including business partners remains very difficult. A common performance measurement system is a matter of trust, because information needs to be shared. Besides, technological and managerial problems originating from different IT systems, media breaks or cultural differences between the companies cannot be avoided.

We aim to make the supply chain network visible in order to inform on a network perspective in performance measurement. We present a first step towards network orientation, assuming that performance is also a result of the company's network position. If social network analysis makes the network visible and allows the analysis of the structure, it should be an appropriate method to gain information about relational data. The search for patterns and information within the structure is a major aspect of our study. Several findings are mentioned, where social network analysis deals with matters of supply chains. One generally expects that companies which are in a position to understand the network have the opportunity to surpass other companies. Adequate performance measurement is a valuable tool to gain such understanding. Given a network understanding, it is possible to go beyond the boundaries of the own company and create network strategies affecting the own performance. For good reasons, it seems as if in many cases network position is more important than individual characteristics.

Given its holistic focus on patterns of connectedness and the opportunity to make the network visible, we promote the transfer of social network analysis on supply chain networks and the business context of a globalised economy. In the following chapters, we explain our approach.

3 Theory

To contribute to performance measurement in an industrial context, this study applies social network analysis to the supply chain network. Social network analysis allows both, to take a network perspective and to discover patterns based on connectedness. The network is defined as a set of nodes (actors, vertices) and ties (links, edges, connections, relationships). Two nodes which are connected by a link are called pair (dyad). In a global manufacturing context, there are networks consisting of material suppliers, manufacturing companies, customers and the relationships among them. A graph represents the network with its nodes as points and links as lines. Given the network structure, some nodes are almost certainly more central because they are involved in many network paths, while others are more peripheral and barely involved. The connectedness of the network structure not only covers the question “who is connected to whom?” but also behavioural aspects such as actions of the actors within the network.

Due to our research in a business environment, companies (actors) have strong incentives to improve their outcomes. Therefore, companies do not simply accept that their success depends on others, they rather plan their own actions, strengthen certain relationships and try to bargain or even play different actors against each other. Given such behavioural aspects, our analysis of a network model also needs to take strategic behaviour and strategic reasoning into account. Actions within a network are cause-and-effect relationships, which is why the concept of social network analysis presented in Section 3.1 also looks for popularity in the network. We examine why some actors seem more prominent than others. The assumption is that there are small advantages based on interconnectedness that make some actors more successful than others. As our thesis is an approach to get closer to this issue, Section 3.2 looks at the influence of the context and relationships. Given these details, we investigate the state of the art of social network analysis in the light of the supply chains in Section 3.3. In order to understand a highly interlinked network, the research of networks borrows from different scientific disciplines. In the case of supply chain networks, there exist various concepts. Thus, we introduce major concepts of graph theory and strategic interactions.

The study of a larger segment of the supply chain network aims to show details that are relevant in the big picture and not only for the single company. Our studied segment might be a proxy for the data of an indeed scale-free network without clear boundaries (no start and no end). Given this target, we develop hypotheses in order to answer our introduced research question by linking social network analysis and performance measurement in Section 3.4. We will summarise the later planned illustration of a supply chain network in the form of a collaboration graph. The graph shows which company works with whom. There are focal companies (manufacturing companies), their customers and their suppliers. We study the relationships among companies under several aspects like strength and total quantity. Our predominant way to do this is evaluating the relationships for procurement on the supplier side, and revenues (sales) on the customer side.

3.1 Social Network Analysis

3.1.1 Preparatory Information

The study of patterns of connectedness using social network analysis is based on a graph. Basically, a graph is a mathematical model representing a network structure. The nodes in this network make choices and influence link creation. As illustrated by Figure 14, the graph is connected if every node can reach every other node using a path (Wasserman & Faust, 1994, p. 109).

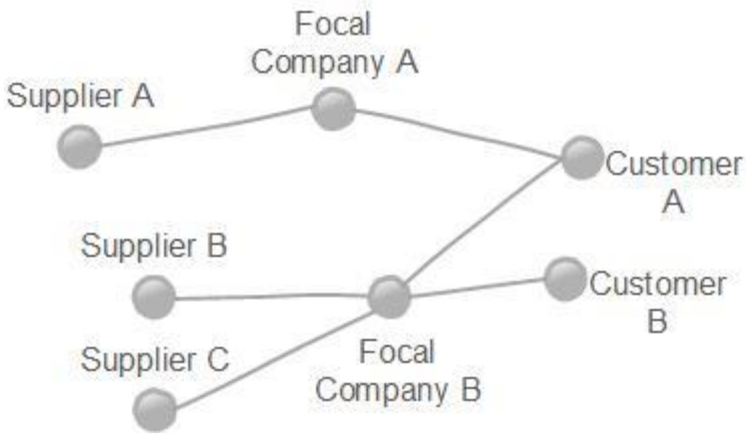


Figure 14: Exemplary Illustration of a Connected Graph

Since supply chain networks arise because of network flows, the resulting network will be connected. However, in order to analyse a network, one needs boundaries. The network is either broken up into different groups of nodes (components), or it is analysed based on a giant component. In the present case of the supply chain network which consists of several industry-specific focal companies, their suppliers and customers, the result is a giant component. Given just one common node between two focal companies, each focal company is indirectly connected to many other companies that are unknown at first sight.

In our thesis, depending on the network type, nodes represent companies or entire industries. The ties symbolise network flows or just the existence of a link to a certain industry. The link between two nodes is also described as a path. A path means that nodes illustrated by a graph are sequentially linked by edges or ties. Each pair of nodes is linked without interruption. A path is defined by Wasserman and Faust (1994) as “a walk in which all nodes and lines are distinct” (Wasserman & Faust, 1994, p. 107). In the context of a supply chain network, the individual supply chain consisting of material supplier, manufacturing company and customer is called a path (Figure 15).

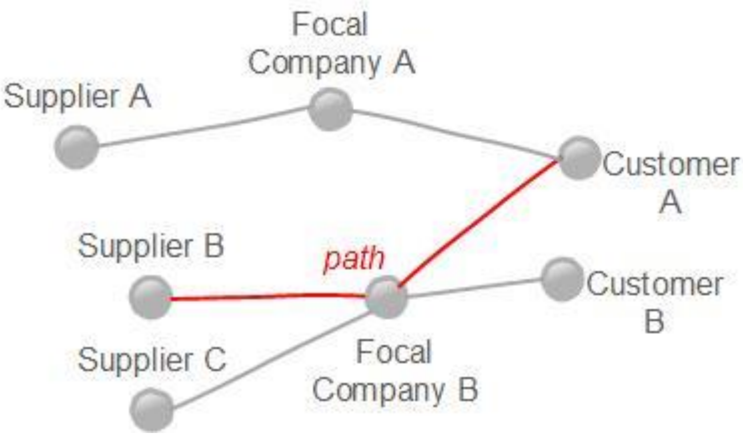


Figure 15: Exemplary Illustration of a Path

Beside the information as to whether two nodes are connected, path distance (path length) is often of interest. The number of edges from one node to the other equals the path distance (Wasserman & Faust, 1994, p. 107). Path distance is the basis to investigate whether two nodes are closely linked or far apart. Path distance is always the shortest path that information can take from one actor to another.

To analyse a network in more detail, it might be necessary to partition a graph. There are different approaches to do so:

- Using divisive methods, it is possible to remove links between different tightly connected groups of nodes. As a result, the network falls into pieces.
- In contrast to the divisive methods, agglomerative methods do not concentrate on the relationships between the regions, but rather on the closely linked regions themselves. One tries to find nodes that likely belong together and then start to merge the group via a bottom-up approach.

Traditionally social network analysis is applied to look for patterns of ties within households, friendship or communication networks (Wallman, 1984). In their analysis of online social network data, Ungar, Craven, Gunopulos and Eliassi-Rad (2006) look for singletons, isolated communities and a giant component. Based on a large amount of data, Ungar et al. (2006) capture the structure, and develop a model for network growth. Other applications of social network analysis refer to diffusion patterns such as the spreading of innovation based on Rogers (1983).

The growing interest for social network analysis in an organisational context includes the study of interlocking directorates and the network effects on the individual company (Scott, 1986), (Pettigrew, 1992). The centralisation of power, but also the opportunity to cooperate become apparent if a director of one company is also part of the board of directors of another company.

Choi et al. (2001) provide one of the first studies that applies social network analysis on the supply chain. The authors understand the supply chain network as a complex adaptive system, where supply chain managers are supported in their task to balance between "how much to control and how much to let emerge" (Choi et al., 2001, p. 351). By introducing social network analysis, Carter et al. (2007) also recognise the method's potential for logistics and supply chain management. As social network analysis allows to describe and analyse interrelationships of units or nodes within a network, the method is applicable "to study both organizational and interorganizational phenomena" (Carter et al., 2007, p. 139).

3.1.2 Main Subjects of Social Network Analysis

The integrated framework of Bellamy and Basole (2013) helps us to provide an overview of the three main subjects of social network analysis illustrated by Table 4. The three main subjects are (i) system architecture (structure), (ii) system behaviour (dynamics) and (iii) system strategy. As we intend to find characteristics from network analysis influencing performance, we describe in more detail the two relevant subjects (system architecture and system strategy) in relation to this thesis.

Table 4: Main Themes of Social Network Analysis
(Bellamy & Basole, 2013, p. 239)

System Architecture	System Behaviour	System Strategy
Node-Level Properties	Stimuli	Scope
Network-Level Properties	Phenomenon	Intent
Link-Level Properties	Sustainability	Governance

System architecture includes all imaginable properties either on the node-level, the network-level or the link-level:

- Centrality is one basic property on the node-level. There exist different measures of centrality all covering different aspects. Beside centrality, the clustering coefficient is another node-level property. The clustering coefficient equals the proportion of direct links with a path distance of one and the nodes that are themselves connected to each other. Embeddedness combines centrality and clustering. Following Choi and Kim (2008) we refer to the term "embeddedness" as the evaluation of nodes based on their network position together with the relationships between them.

- Density is one example on the level of network properties. Density is the proportion of existing links in the network compared to the maximum number of possible links. Network centralisation shows whether some nodes in the network are more centrally connected than others. Further, overall clustering is an indicator for network modularity. It is obvious that in a network with low clustering, power is centralised because only few nodes are well connected. The different network topologies which are (i) random, (ii) small-world and (iii) scale-free networks describe the overall structure of the network on the level of network properties.
- The main properties on the link level are the type of links (flow type), multiple ties and tie strength. In the case of the supply chain network, flow type refers to cash flows and product flows. Multiple ties (multiplexity) may occur if a supplier is also a customer. We refer to tie strength as the monetary value of the relationship (goods, materials are exchanged either on the sales or on the procurement side).

System strategy as the second relevant subject of this thesis is about the design and execution of a plan of action:

- The scope either refers to the individual node or the entire network. The individual node and its dyadic relationships are defined as ego-centred (Wasserman & Faust, 1994, p. 53). One generally expects that a more holistic understanding is possible by focussing on the entire network. The broader level includes dyadic relationships as well as the complex structure.
- System strategy mainly distinguishes the resource-based view and social capital. A resource-based view concerns the management of resources within the network. Social capital refers to shared goals or values within the system.
- Governance or control is about strategies to coordinate or cooperate within the network.

3.1.3 Fundamental Network Issues

Finally, we describe some fundamental network issues in order to understand effects in the local setting, with reference to the whole context. The consideration of the triadic closure invented by Simmel and Wolff (1950) is one basic issue. At first sight, the illustration of a network is a static structure. In fact, in the case of a supply chain network, this is just a snapshot. The network evolves if new connections are built or removed. Thereby, the triad is defined as a subset of three nodes and possible ties among them (Wasserman & Faust, 1994, p. 19).

Triadic closure describes an additional connection between two nodes that are not directly connected initially. For example in the supply chain network, an additional connection between a material supplier and a customer of a focal company may arise, beside the existing dyadic connections (supplier connected to focal company and focal company connected to customer). The dotted line in Figure 16 illustrates the closing effect creating a triangle. The transfer of triadic closure to the supply chain network is relevant under the impression of bargaining positions and network strategies. The triangle is a possibility to surpass a company or to increase pressure on it. So in contrast to friendship networks, where a certain interest exists to connect friends with each other, in the supply chain network companies try to minimise triadic closure.

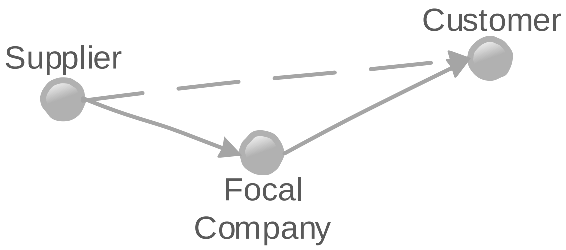


Figure 16: Exemplary Illustration of Triadic Closure

Bridges and cutpoints are two other basic issues of interest. If a link between two nodes can be removed and the removal results in the formation of separate components, the link is called a bridge (Wasserman & Faust, 1994, pp. 114–115). Bridges are rare but the principle is important because they connect specific nodes to other worlds. If we analyse the supply chain network for strategies of diversification, this principle of connections to different worlds is important. For example if the only link to a certain market is removed, the focal company loses access to the whole industry. The dotted line in Figure 17 illustrates this principle. However, this is not completely correct, because one of the direct partners himself can again have a link in this particular market. In this case one speaks of local bridges, because the removal just leads to a greater path distance, but not to inaccessibility. Cutpoints are analogous to bridges, but refer to the node level only. According to Wasserman and Faust (1994, pp. 112–113) a node is a cutpoint if the number of components increases after deleting this specific node.

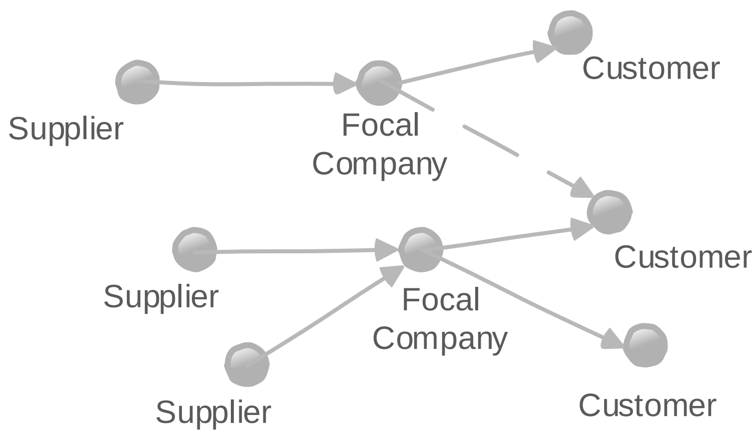


Figure 17: Exemplary Illustration of a Bridge

Another basic issue of social network analysis with possible relevance to our study is the question of tie strength illustrated in Figure 18. Stronger links are generally closer and used more often. As ties may represent various kinds of relationships, the definition of tie strength depends on the given network. The initial work on strong and weak ties is provided by Granovetter (1973). Coming from a friends network, the distinction between strong and weak implies that it is more likely that an additional link from node B to node C is formed if node A has strong links to both nodes B and C (Easley & Kleinberg, 2010, p. 49). Weak ties are difficult to recognise because of triadic closure.

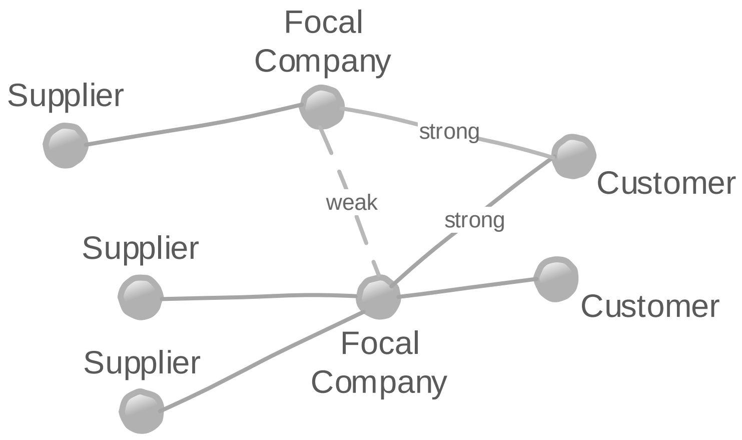


Figure 18: Exemplary Illustration of Strong and Weak Ties

Transferred to the supply chain network, the cash flow (either procurement or sales) characterises each relationship. So we state that tie strength varies because the cash flows exchanged by different focal companies with a mutually shared business partner vary from focal company to focal company. Due to relationships to these mutually shared business partners (customers or suppliers), it is possible to aggregate the different financial cash flows between different focal companies and each of their mutually shared business partner.

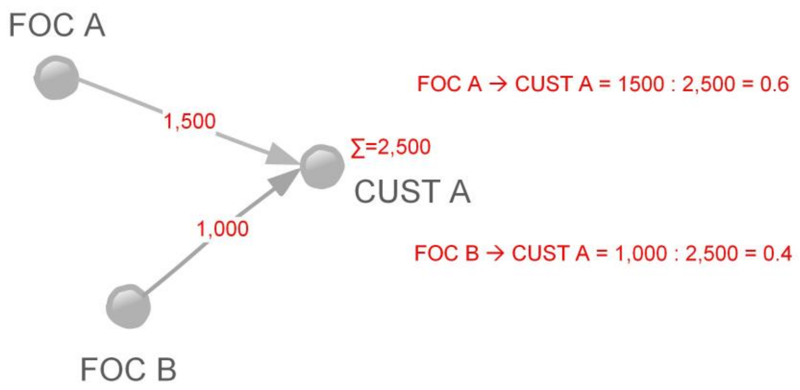


Figure 19: Exemplary Illustration of Proportional Strength

As illustrated in Figure 19, proportional strength equals the share the focal company holds of the aggregated sum. The calculation of aggregated strength ultimately expresses the strength of the links. To summarise the fundamental concept of proportional strength requires that the network is reviewed for overlapping neighbourhoods which refer to the calculation of tie strength.

Besides the evaluation of ties that link certain groups, it is worth looking at the roles played by specific nodes within the network. The position of a node influences its importance. Some actors are situated between multiple groups, while others are in the centre of one homogenous group.

On the subject of links, embeddedness is the number of common neighbours shared by two endpoints and equals the numerator of neighbourhood overlap calculation. Embeddedness is zero if a link is a local bridge. In case of an embedded link between two nodes, the nodes have mutual partners (Easley & Kleinberg, 2010, p. 59).

Another concept in social network analysis is the one of structural holes described by Burt (1992). A structural hole may exist if a node is at the interface of different parts within the network. If, without this particular node, the different parts are not connected, there is a structural hole. As one particular node is in an advantageous position because the node has the opportunity to exploit the structural hole by bargaining or holding back information, actors generally attempt to reduce structural holes. Figure 20 illustrates the basic idea. One way to reduce structural holes is the mentioned concept of triadic closure. The creation of a link connecting previously unconnected nodes may form a triad which also changes the network structure. Having in mind that the network structure is just a static snapshot, the given structure can change and structural holes may disappear. Thus, a changing structure can suddenly turn a previously advantageous position caused by a structural hole, into a weaker one.

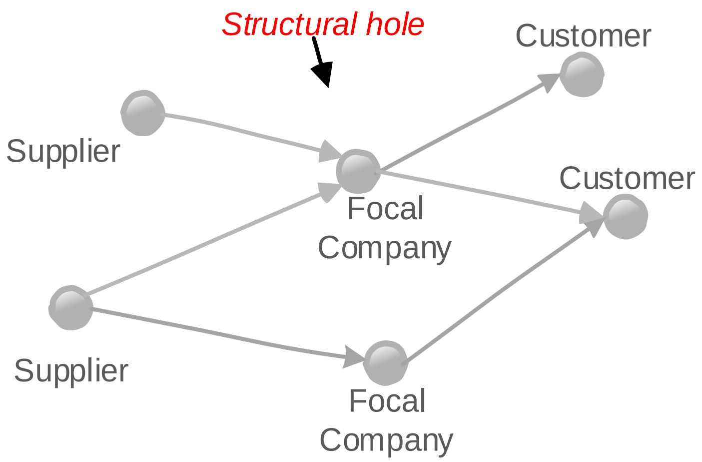


Figure 20: Exemplary Illustration of Structural Holes

Whether a marginal position together with the opportunity to benefit from structural holes or general embeddedness is more beneficial, depends on the given situation. At this point we can only state that further research that focusses on a particular case is necessary. As our thesis takes a bird's eye view on the supply chain network, we achieve a trade-off between embeddedness and structural holes.

3.2 The Influence of Context and Relationships

Up to this point, we have treated similarities and behaviour of nodes as a given aspect, outside the network. But it is also possible to include contexts into a network together with the original nodes.

3.2.1 Two-Mode Networks

The inclusion of similarities and behaviour offers the opportunity of a broader insight into the network. One can integrate context and relationship in a common network by the use of a two-mode network.

In general, social network analysis distinguishes between one-mode (unipartite) and two-mode (bipartite) graphs:

- The one-mode network consists of one set of elements and the relationships between these elements. The supply chain network with companies and the relationships between the companies is one example.
- By using a two-mode or affiliation network it is possible to integrate context and relationships into one common network. The bipartite graph represents a mathematical model that consists of connections between two different sets of elements. One common example for a two-mode network is one which consists of people and organisations. Connections indicate membership (affiliation) between the two different sets of nodes.

In consequence, affiliation networks represent participating nodes in a set of foci. A bipartite graph allows the nodes to be divided into two sets. Every edge connects a node of one set to a node in the other set. The distinction is helpful where there are two different categories of nodes. The bipartite graph provides a basis for understanding how the nodes of one category are associated with the nodes of the other category, as all edges go between the two different sets. The distinction described is an appropriate way for understanding participation in structural activities. One well-known example of an affiliation network is the previously mentioned study of interlocking directorates. By performing an in-depth analysis, Mizruchi (1996) reviews the study how executives of companies are connected to supervisory boards.

All social networks, one-mode as well as two-mode networks, develop or change over time. Yet both types also differ with respect to link formation:

- In case of a one-mode network, change is characterised by the creation or destruction of links between nodes. This is different for two-mode networks.
- Change in the two-mode network is not about link creation from one node to another, but link creation or destruction to a focus. For example by referring to the study of interlocking directorates, two executives of companies are connected because both participate in the same board. In case one director withdraws from the board, the indirect connection between both executives is lost.

In our case of the analysis of the supply chain network, we look at both kind of ties. The first kind of ties concerns professional collaboration between companies as business partners in the one-mode supply chain network. The second kind of ties may represent connections to certain foci such as producing and selling on a target market. Companies participate in certain industries and are therefore dependent on their general prevailing conditions.

3.2.2 Ego-Network Quality

One alternative allowing to look at the relational context of companies is the analysis of the so called ego-network quality of each focal company. The ego-perspective proposed by Borgatti and Li (2009) means that one analyses the direct relationships (incoming and outgoing links) of a company. From an intuitive understanding, the ego-network approach matches the supply chain network of one focal company. This approach is not holistic, but it allows the comparison of different ego-networks. From an ego-network perspective, it is apparent that not all relationships to suppliers and customers are equal. Some trading partners are more stable, provide a more stable flow of materials or are financially stronger. One assumes that the quality of a focal company depends significantly on its partners. As pointed out by Borgatti and Li (2009) the quality of alters, nodes a focal company (ego) is connected to, results from calculating an ego-network property x. The quality q of an ego's network then results from the sum of x weighted by an attribute a for each adjacent node j. The choice of the attribute may vary and depends on the individual case (Borgatti & Li, 2009, p. 8). Borgatti and Li (2009) suggest the following equation:

$$q_i = \sum_j x_{ji} \cdot a_j$$

Equation 1: Quality of an Alter as Ego-network Property
(Borgatti & Li, 2009, p. 8)

We apply this approach as an interim step towards defining our network-oriented approach. Doing so, the quality q of a focal company i results from the sum of its relationships, measured by the cash flow of each relationship x_{ji} multiplied by an attribute a. The attribute a equals a factor such as the proportion of the number of partners of a focal company divided by the average number of partners across all focal companies. By dividing the quality q by the total number of connected alters, we calculate the average quality score of the relationships. The average quality score is the basis to compare different ego-networks of focal companies. In order to compare focal companies for their ego-network quality, variance and standard deviation can also be of interest.

3.2.3 Hubs and Authorities

Going back to Equation 1, it is conceivable to set the attribute a in two other different ways. The attribute a may either represent the number of focal companies to which a supplier of a focal company delivers, or it may represent the number of focal companies from which a customer of a focal company is buying. The two relevant equations adapted from Borgatti and Li (2009, p. 9) are illustrated by Equation 2 and Equation 3. The scaling value suggested by Borgatti and Li (2009, p. 9) is left out, because we do not expect to have information from the suppliers and customers. The quality is determined based only on the data of the focal companies.

$$u_i = \sum_j x_{ji} \cdot v_j$$

Equation 2: Calculation of a Hub Score (Borgatti & Li, 2009, p. 9)

$$v_j = \sum_i x_{ji} \cdot u_i$$

Equation 3: Calculation of an Authority Score (Borgatti & Li, 2009, p. 9)

A focal company gets a high score u_i for delivering to customers which have many focal companies as suppliers (hubs). Further, a focal company gets a high score v_j for being supplied by suppliers which have many focal companies as customers (authorities). Taking the perspective of focal companies, we define hubs as pointers to popular companies and authorities as the receipt of pointers from popular companies. Borgatti and Li (2009, p. 10) distinguish four kinds of companies in their hubs and authorities concept as illustrated by Figure 21. Very agile companies are hubs as well as authorities. Agile companies act in very competitive markets. Companies that are hubs but not authorities are sales-oriented and face strong competition. The third type of companies are authorities but not hubs. These are procurement-oriented with simple sales environments. The fourth type of company, neither hubs nor authorities, is in a very comfortable position but risks stagnation.

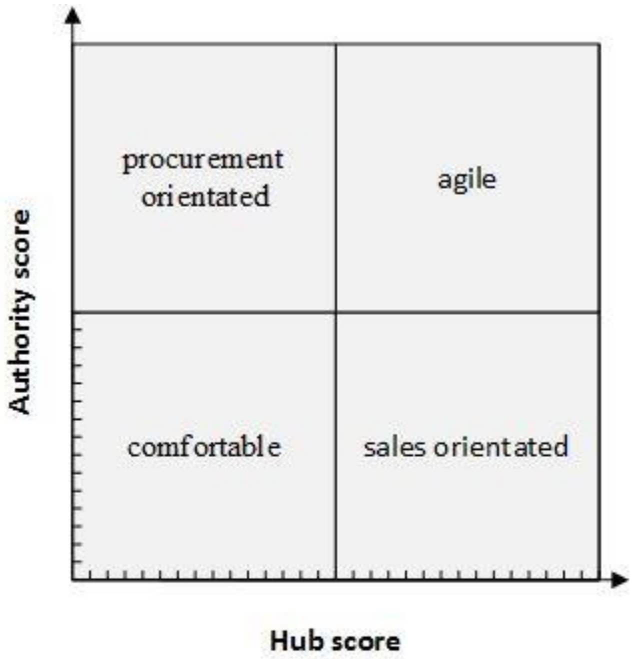


Figure 21: Concept for Hubs and Authorities Scores (Borgatti & Li, 2009, p. 10)

3.3 Social Network Analysis in a Supply Chain Context

In their work on social network analysis in a supply chain context, Borgatti and Li (2009) provide supply chain research with an initial overview for the potential application of social network analysis. Borgatti and Li (2009) claim that the interpretation of success in business has changed. Success is not only the result of the application of certain processes, but it also has a relational component. The inclusion of the environment and the ability for adaptation become important. As Borgatti and Li (2009, p. 2) state, the supply chain network has always been there, but the realisation for a need to go beyond an analysis of dyadic relationships is still recent. Borgatti and Li (2009, p. 2) therefore support the development of network concepts in the supply chain context that benefit from aspects of social network analysis.

3.3.1 The Network Concept

In general the ties between companies can be of many types. The different types are similarities, social relations, interactions and flows. The ties are either discrete or continuous. In the context of the supply chain network with companies as our subject of inspection, we set the general focus on the sale of products or materials. Therefore the focussed economic relations between companies abstracted as product or cash flows are a result of similarities, social relations, interactions and other flows. It is conceivable that different kinds of ties exist simultaneously. Their illustration in one or several graphs for each type is possible. We aggregate the different types of ties in three seperate graphs and analyse the relationships for the totality of the existing ties as product or cash flows within the network. We distinguish actors and dyads within the supply chain network for their unit of data:

- Actors have attributes suitable to identify each actor.
- Dyads have attributes that describe the pair of actors.

The main concept for social network analysis is the dyad. Other theories like the principal agent theory also focus on dyadic relationships. The outstanding reason why we consider the application of social network analysis to be promising is its link to a network instead of a focus on independent dyads. Using social network analysis we are able to study the relationships among all actors.

Nevertheless, despite its potential, Bellamy and Basole (2013) state that "surprisingly, there is comparatively little work that uses social network analysis in supply chain management" (Bellamy & Basole, 2013, p. 239):

- Up to this point, network studies in a supply chain context are in fact based on sections from the supply chain network. Kim et al. (2011) compare different supply chain networks of focal companies (ego-networks) for structural characteristics. With respect to the identification of correlations, it is conceivable that one reviews such sections, which means that data of the whole network is not required (Borgatti & Li, 2009, p. 4). The ego-network approach suits to deal with the difficulty that quantitative data for an entire supply chain network, or at least a part of it, is complex and difficult to collect.
- Other studies that analyse real networks are based on qualitative methods in order to derive theoretical and practical knowledge. Jarillo and Stevenson (1991, p. 64) studied companies that have become successful because they turned competitors into allies. The focus is set on cooperation instead of competition. Harland, Lamming, Zheng and Johnsen (2001) investigated different types of supply chain networks in order to manage network creation and operations.

Based on the idea to compare different supply chain networks of focal companies (Kim et al., 2011), such studies cause the question as to whether we can not only link network position to performance at the node level, but also study one single scale-free supply chain network comprising possibly overlapping local supply chain networks.

3.3.2 Key Theoretical Perspectives of Network Analysis

Both, the flow mechanism as well as the bonding mechanism are key theoretical perspectives of network analysis.

- The flow mechanism is the fact that actors within the network influence each other. According to this theoretical perspective, information is transferred when two nodes begin to interact. A few concepts that contribute to the understanding of this perspective are: (i) degree centrality, (ii) betweenness, (iii) closeness, (iv) eigenvector or Bonacich power and (v) structural holes as a source to exclusive network flows.
- The bonding mechanism is based on the assumption that specific ties between actors lead to a unified structure of otherwise autonomous nodes. Main concepts on this perspective are: (i) the strength of ties, (ii) structural holes as a source of power, (iii) embeddedness and (iv) the adaptation mechanism.

As with the flow mechanism, actors receive information through ties. Several concepts of centrality help to understand this mechanism using different properties on network positioning.

If information flows through ties, more ties mean more information. The appropriate measure for quantification is degree centrality. Degree centrality might have an impact on performance, if one assumes that information influences to a certain extent performance. If few actors in the network have many ties, it is easy to identify the actors holding the majority of the information in the network. Naturally, it might be strategically useful to establish a connection to such an actor. However it is also conceivable that not all links have the same relevance.

If the path distance between two nodes is relevant for information flow, nodes lying at a shorter distance to most nodes should benefit. Path distance is the sum of links from one actor to another. Betweenness centrality as another network position property identifies nodes that are either in a position to control information flows or simply act as bottlenecks for the transfer of information. Indeed, social resource theory says that all kinds of resources may flow through social ties. Therefore, following Lin (2001), a focal company with a strong network, providing valuable resources, will likely perform better (Lin, 2001, p. 66).

Closeness centrality is another indicator to measure the importance of a node in the context of the supply chain network. Closeness centrality expresses the sum of distances from or to a node to reach all other nodes in a network. In a supply chain network links are firstly directed from focal companies to suppliers and from customers to focal companies. A directed link expresses the flow of materials and products and shows who orders from whom. Therefore closeness centrality might be problematic to rely on, because some nodes cannot be reached. By discarding the unreachable links, it is preferred to define a so-called “in-closeness”, as the average distance of links from all other nodes to a focal company. Longer chains probably show a higher risk of disruption. Given the difficulty of realising a complete network, this concept is rather theoretical.

In contrast to closeness centrality, the eigenvector centrality allows a direct transfer to the supply chain network. As by Bonacich (1972), one assumes that a node which itself is connected to well-connected nodes, is more central than a node which has the same number of nodes but less connected ones. We suppose that a focal company that supplies a customer with many links is more central than a company with less important players in the network: the products offered by a company with less connected nodes will probably not affect the same number of companies in the overall supply chain network.

Finally, it can be of interest if the alters of a focal company are connected between each other. Where there are existing links, taking the perspective of the focal company, a connection to an unconnected node might be beneficial because this ensures new, exclusive information. According to the previously described concept of structural holes, it is more efficient to obtain a network with many structural holes (Burt, 1992). These structural holes provide more exclusive information, which leads to better performance.

Beside the above described flow mechanism, the bonding mechanism as the second key theoretical perspective in network analysis helps to recognise that a unified structure emerges because of specific ties between actors.

One implication for the theory of bonding is the assumption that the stronger the ties, the stronger the bonding to a unified structure. On the one hand, this offers the potential of prospering together. On the other hand, in the case of a strong, unified structure the risk of a common fate is amplified. The coherence of closely related companies may even be transferred onto direct competitors (Ford Motor Company, 2008, p. 5).

Further structural holes, already mentioned with respect to information benefits, provide autonomy and power benefits. In the case of negotiating, the initial situation of an actor is improved when there are several alternatives without mutual connections between these alternatives.

In terms of network governance, ties between companies also serve as a matter of control. Less embedded companies are capable of greater deviance. In terms of negotiation situations in connected networks, information flows frequently depend on mediating nodes. This observation differs from the first obvious point of view where, according to degree centrality, the most central node has the greatest power. The intermediary nodes can control the flow of information and also prevent it. Since intermediary nodes are not excludable, without giving up connections, the nodes in between have a strong bargaining power.

Another phenomenon of network bonding is the transfer of attributes from one actor to another. The transfer occurs simply because of an existing link between them. Podolny (2001, pp. 34–35) describes the transmission of attributes as the phenomenon of making inferences about the quality of an actor because of an actor's market relations. The adaptation mechanism further describes influence from the environment. Adaptation means that actors acclimate to their environment. The underlying assumption is that similar environments lead to similar adaptations. In our context, this shows that structurally equivalent companies (same kind of ties to the same type of others) develop in the same way.

From a conceptual point of view, using social network analysis in the supply chain network allows to conclude that the analysis is not only about relationships of supply. Of course, the main important relationships are the ties that express the cash flows and the product flows (conversion of raw materials to products). Yet beyond this, ties may originate from similarities, social relations, interactions and other flows. By studying the resulting cash flows and product flows, we approximate these different reasons of tie formation.

3.3.3 Role Theory

Beside the two previously described key-theoretical perspectives, role theory performs network analysis for the structural composition of groups. To do so, nodes are grouped into classes which can be assigned to roles. One example is to assign focal companies to a specific industrial role. Such role may expresses the industries a focal company is active in.

Prior to assigning these roles, it is fundamental to identify regions or coherent areas in the network. These are referred to as cohesive subgroups. The emergence of these cohesive subgroups can be made into a wide variety of theory. For instance, density as the number of ties for a set of nodes is one concept which influences cohesion. There exist different algorithms to look for subgroups like business groups and interrelated companies.

In reference to companies in an economy and cooperative ties as the basis for the network, the analysis for equivalence is another very interesting concept to identify subgroups. As by Lorrain and White (1971) two nodes are said to be structurally equivalent if they are connected in the same way. This means that both nodes have the same incoming as well as outgoing ties from the same partners. In our case of supply chains, companies sharing the same customers and suppliers face the same requirements as a result of their similar environments. It is assumed that structurally equivalent companies develop the same processes on a functional level and therefore perform in the same way. Of course, it is conceivable that companies compare themselves to each other, which is why they take part in mutual benchmarking with respect to innovation and competitive steps in order to gain market share. The ENAPS approach, described in Section 2.2.3, is based on a similar assumption, even though it does not come from the perspective of network analysis.

Regular equivalence is a generalisation of structural equivalence. In other words, instead of the same structures with respect to the environment, one assumes that nodes are regularly equivalent if they are connected to nodes that are equivalent but not the same. For example, two customers do not share any manufacturer, but the manufacturing companies are regularly equivalent and may share structurally equivalent suppliers.

Both concepts, structural and regular equivalence, allow the creation of a reduced model of the network. Such blockmodels consist of nodes and ties, representing the equivalent classes and perhaps existing ties from the original network. Blockmodels allow data reduction and a faster understanding of correlations.

3.3.4 Network Perspective

After describing some potentials which stem from the application of social network analysis to the focal company, we want to consider the entire network. Although the supply chain network is in fact scale-free, some properties such as network density may be of interest for the chosen segment. Network density results from the number of existing ties divided by the maximum number of possible ties.

A very general property is the network type. In contrast to unipartite (one-mode) networks, bipartite (two-mode) networks consist of two types of nodes. In our thesis we consider three different types of networks:

- The different ego-networks (focal company with its partners) are unipartite networks, because all actors are companies.
- For the same reason, the second network which is a section of the scale-free supply chain network is also a unipartite network. This network is merged from different ego-networks of focal companies and includes the business partners of all focal companies in one single network study.
- As third network, we create a two-mode or bipartite network in which all focal companies and their target markets are brought together to be analysed.

Following Markovsky, Willer and Patton (1988) one can also analyse the unipartite network for benefits and exclusion, by looking for bargaining positions and the development of isolated ties. The network perspective in this thesis concentrates on a system of companies (focal companies, suppliers and customers) which are the actors in the supply chain network. We want to go beyond dyadic relationships or different, individual ego-networks. We expect that the creation of a more holistic architecture of the supply chain network, which integrates the results from our new conceptual, empirical, and modelling work will deliver new insights and will contribute to performance measurement. In order to identify possible correlations, we use quantitative methods.

For the purpose of data collection and to illustrate the network, social network analysis generally relies on surveys. The nodes or actors within the network are companies with supplier or customer relationships. Consequently, the focus of such a survey is to ask a focal company for its suppliers and customers. The next step involves verifying the links and asking other companies for their customers and suppliers, in some kind of snowballing system. Yet creating the necessary confidence and trust to collect the required data is difficult. In case of resistance or refusal, another approach might be aggregation. Lin and Dumin (1986, p. 371) suggest asking for categories instead of specific actors. In the context of companies, categorisation is also conceivable, for example by asking for supplier and customer categories and not for specific names. Nevertheless, the collection of data remains difficult because surveys are time-consuming and participants need to be convinced.

In contrast to such surveys, as part of our thesis, we develop a new method to collect and process quantitative data of the participating focal companies. We describe the developed software in more detail as part of our methodological approach in Section 4.4. In using quantitative methods, we obtain objective results that do not depend on possible prejudices and subjective perceptions of the researcher or the respondents. We expect that this way, one can better explain such complex phenomena as a network. On the basis of the collected data and the investigation of our research question, we develop a mathematically comprehensible model for performance measurement in the context of the supply chain network in Section 5.4.

3.4 Linking Social Network Analysis and Performance Measurement

According to Borgatti and Li (2009, pp. 6–7), virtually every kind of social network analysis attempts to answer one of two types of research questions: either about homogeneity (sameness) or performance (difference). Homogeneity asks why some actors have similar characteristics whereas the performance question investigates why some actors perform better than others. The first question is oriented towards certain characteristics of a node (value-neutral), while the performance question deals more with outcomes (value-oriented).

As we want to contribute to performance measurement from a network perspective, we assume a link between the network position of a company in the supply chain network and its economic performance. Given this link, we have to look at the network position of companies and the structure of networks in which companies operate. This goes hand in hand with the examination of how companies develop partnerships which allow them to prosper. The aim is to develop network-based performance models suitable for target setting and monitoring company performance. In sum, our overall research question is:

- What characteristics of a network position are important with respect to the performance of companies in the network?

To find answers, we apply the theory of social network analysis. As per Borgatti and Lopez-Kidwell (2011, p. 40), studying network theory is either about the theory of tie formation or the theory of advantages of social capital. The term “theory of tie formation” implies that network properties are considered to be dependent variables, which means independent previous variables result in a certain network structure. This theory contrasts with the theory of social capital, where the network construct is the independent variable, and theory considers the consequences of network phenomena. As we link properties of network positioning to outcomes, our study concentrates on the second case, meaning consequences or benefits because of a distinct position. Bellamy and Basole (2013) reaffirm our position as they write “the social capital perspective considers the shared goals, values, and experiences among the respective firms within a supply chain system, incorporating interfirm cooperation and the influence of network resources on firm capabilities into their strategy” (Bellamy & Basole, 2013, p. 243).

However, network theory is not just about the knowledge that a variable in the network leads to a certain result. We apply network theories to identify underlying mechanisms or principles they propose. These mechanisms are combined in order to generate new theory.

Given the aim to contribute to new theory, we develop hypotheses to show a link between characteristics of network positioning and economic performance. There are several documented examples, where position is fundamental in structural theory. Snyder and Kick (1979) address world-system or dependency theories of economic growth among different nations. In this respect, Snyder and Kick investigated the theoretically specified network position (core, semiperiphery or periphery) and the dyadic relationships among the nations. Building on this, Burt (1987) applied different network models to study social contagion in the diffusion of technological innovation. As basic evidence, Burt analysed the diffusion of medical innovation among physicians. The question is whether innovation is spread because of cohesion (conversation in subgroups) or structural equality (equal structural position). Friedkin (1984) also deals with structural cohesion and structural equivalence.

Cook et al. (1983) described a theoretical analysis for structural determinants of power in exchange networks and applied two theoretical traditions. The first relates to node centrality within the graph, while the second focuses on power dependence principles. In contrast to power dependence concepts, the measures of centrality are available in the literature and find easy application. Power dependence concepts are suitable for generating hypotheses about power distributions. These concepts may provide an even superior solution compared to node centrality. Markovsky et al. (1988) also deal with the problem to locate power positions in the network. Markovsky et al. (1988) provide a theory that is both consistent with previous research and generalised to conditions that are not considered by other formulations. Further, Erickson (1988) describes an illustration of position in the network related to similarity. Burt (1978) also studied the previously mentioned economic success related to interorganisational networks.

As illustrated, there are many concepts where scholars argue that network position leads to some kind of benefit. With respect to the supply chain network, our analysis aims to show added value for network design and profit structure of focal companies. The analysis goes hand in hand with the development of a strategic tool for managing sustainable supply chains. Subordinate facets are therefore the identification of aspects supporting strategic planning and the opportunities of information transfer across the network. If applied as a strategic tool, the transfer of performance measurement into business planning can be tested for success. Any adaptation of business strategy should be done in light of the future development of a specific company, based on network orientation.

To achieve added value and to provide a strategic tool, relationships between companies can best be measured by cash flows or product flows between companies. Both types of flows allow to give each individual relationship a specific value. The cash flows indicate procurement costs (in case of supplier relationships) or sales revenues (in case of customer relationships). The product flows represent the number of different product types bought from suppliers and delivered to customers, as raw materials are converted to products. The hypotheses of our study consequently result from social network theory and the analysis of network data in general.

- Hypothesis 1: The stronger the connections of a company in the network are, the better the performance of that company:

As with the bonding mechanism, a strong relationship with partners across the network is expressed by trust and has advantages in terms of information sharing, sharing of investments and fast, constructive feedback. Links of various strength characterise the position of a company within the network. Strength in the supply chain network results from the share of cash flows (proportional strength). Where this is confirmed, a possible recommendation might be to focus on the improvement of certain relations in the network. But a too narrow focus encompasses the business strategy problem of interdependency. The problem of interdependency is based on the assumption which stems from the network analysis. This states that closely linked companies tend either to prosper or go down together. It is part of our analysis to show if network theory provides a concept that suits better for further optimisation.

- Hypothesis 2: The more central the role of a company in the network is, the better the performance of that company:

Initially originating from the flow-mechanism, centrality is reflected in the quantity of links to different partners. A central position in the network ought to strengthen the negotiating position with partners. As with Bonacich (1987) centrality does not necessarily equal more power which is why a central role needs to be recognised as a leadership position (Bonacich, 1987, p. 1170). Cook, Emerson, Gillmore and Yamagishi (1983) also deal with point centrality compared to principles of power dependence. In this regard we agree with Cook et al. (1983), stating that point centrality cannot be generalised, meaning that it is also important to think about node centrality as a result of power dependence.

Given the remarks of Bonacich (1987) and Cook et al. (1983), we have to measure centrality using several different measures. A central company might either have several ways (network paths) to achieve its goals or it cannot be excluded from information flows which is why we adapt the centrality measures from network exchange theory. Although a central position appears ideal, there is of course the strategic problem of focusing on one particular market. This market can vary greatly because of exogenous influences and business conditions that may suddenly change; therefore a too narrow view presents a risk.

- Hypothesis 3: The more diverse the individual links of a company are, the better the performance of that company:

A position in the network which is characterised by several strong, diverse links ought to reduce dependency as several network paths are available to increase economic success. Applying the concept of hubs and authorities we study link diversity on the procurement as well as on the sales side of focal companies. Further, based on structural isomorphism (Borgatti & Everett, 1992, p. 10), we must identify different characteristics that shape diversity of a company’s network position. By considering aspects from network role theory, we create and assign classes of focal companies to roles. By examining a network, nodes may be structurally similar to each other. The different nodes within the network are reduced to classes that share certain characteristic relations with each other.

A so-called blockmodel represents a reduced model of the network. The different classes play different structural roles and have different social environments, which is why the nodes occupying a certain position face different consequences as a result of the said position. Within the boundaries of statistical variation, the different classes show the same results when it comes to experimental investigation (Borgatti & Everett, 1992). As suggested by Klibi, Martel and Guitouni (2009), through links to various markets, the vulnerability to fluctuations in demand ought to be reduced and exogenous influences may have less drastic consequences (Klibi et al., 2009, p. 19). In our case, given that companies have links to different markets, an inevitable product variety results from different prevailing market conditions and customers. We assume that a company which is able to satisfy the different needs should perform better. Finally, by increasing their innovation capacity and by establishing links to different markets, companies should reduce the problem of uncertainty. From a business strategy standpoint, we think that diverse clusters can be more important than centrality, since exogenous influences may have a strong, unpredictable negative impact from which companies which score high on centrality are less shielded.

In conclusion, there are three characteritcs of network connectedness to be tested: strength of links, node centrality and link diversity. In order to deal with network theories, our analysis is created on the network flow model, described by Borgatti and Lopez-Kidwell (2011, pp. 43–44). The network flow model is about "true" flows, which essentially remain the same from start to end. It is stated that theorising based on the network flow model is deconstructed in three layers:

- The deep layer defines the rules of a theoretical framework in which we work. Following Borgatti and Lopez-Kidwell (2011), this layer is described as "the platform for theorizing" (Borgatti & Lopez-Kidwell, 2011, p. 43). As a simple model, this layer describes the function of the network through which a resource flows from node to node along paths.
- The middle layer consists of a theorem derived from the rules of the theoretical framework (deep layer). Compared to the deep layer, the middle layer is more about reasoning with clusteredness and closure, affecting the network flows. One can prove or disprove this kind of theorem, as the elements are drawn from the underlying network. In a closed world with known rules, the theory at this level is about constructs defined on the underlying model which includes centrality, betweenness and other concepts.
- The surface layer connects the variables associated with a special empirical setting and adds variables to the basic theory. The variables on this layer result from our empirical context.

The three layers create a theory of which different theorems present different views. Our aim is to show how different theorems from the same set of rules work and how they create different but compatible theories. It is important that all these theorems serve as a basis for the conceptual design of properties such as centrality. We finally have to relate the properties to statistical probabilities. Borgatti and Lopez-Kidwell (2011, p. 44) state that the properties are only elements of methodology having a connection to theory. In fact, these are derivations of a model, in the context of a theoretical process. Transferred to the theoretical context of our thesis, it means for the hypotheses:

- H1: Transitivity is a theorem derived from the underlying flow model. It might be useful to create a new theory on the surface layer, which is important for later optimisation or performance improvement.
- H2: The theorem centrality is based on the number of links a node receives. A higher number of links on the underlying flow level results in a higher centrality (Freeman, Roeder & Mulholland, 1979). On the surface level, one interprets centrality as an indicator for a higher exposure within the network. In the case of useful links, this should lead to better outcomes (performance).
- H2: As with Freeman (1977) it may also be of interest if nodes are in a position to control the flows.
- H2 and H3: The theorem regarding the quality of the nodes that are connected to a certain node was developed by Bonacich (1972). With respect to the examined node, the connectivity of its connected nodes becomes important. Following Lin (1982), the theorem about social resource theory goes in the same direction. The connected nodes of an ego are rated for their power, wealth, expertise etc.

In general, theories based on the network flow model distinguish between an underlying infrastructure that enables or constrains network flow and the traffic of what flows through the network. Borgatti and Lopez-Kidwell (2011, pp. 44–45) go one step further and describe four categories of dyadic phenomena, namely: (i) similarities, (ii) social relations, (iii) interactions and (iv) flows. With respect to our thesis, all categories are important. The flow category is about resources or information, flowing from one node to another. This category matters in nearly every network theory.

Finally, as with Borgatti and Lopez-Kidwell (2011), we want to clarify several analytical observations. At first, much of the argumentation of the flow model exists because it is difficult to measure flows directly. It is the theory that links the observable network of social relations to the latent flows. Further, the flow model also depends on the relative permanence of ties.

Therefore, research for advantageous network position of nodes based on interactions or flows also needs to consider that relations may change at any time. Power use can lead to a modification within a network of events. Nevertheless, we focus on the analysis of network positions because of relational states, instead of a network of events.

This thesis includes aspects of network flows, as well as aspects of network exchange theory. Consequently we note that the distinction between the network flow model and network exchange theory is rather a sort of guidance. Both types, ties as pipes (network flows) and ties as bonds (network exchange theory), form the theoretical basis of this thesis.

Summary

Companies create products and services through complex supply chains. The existing business conditions require a continuous adaptation of the supply chains. In fact, the supply chain perspective evolves towards a network of supply chains. The aim of supply chain management is to create and manage supply chains as efficiently as possible in order to maximise customer satisfaction. We transfer social network analysis as a technique to identify patterns of connectedness based on a graph (sociogram) representing a section of the scale-free supply chain network. As with Basole et al. (2011), the use of social network analysis is a promising approach to capture structural and behavioral aspects within the network.

Traditionally, social network analysis was used to analyse friendship, communication networks or contagion processes. However, one can determine an increasing interest in the organisational context. Given its holistic approach and the focus on all the relationships instead of just dyadic ones, Bellamy and Basole (2013) write that "there is growing recognition by the supply chain community of the significant benefits a network analytic lens can provide to understand, design, and manage supply chain systems" (Bellamy & Basole, 2013, p. 235). Further, the authors identify a window of opportunity “to review and illustrate the value in adopting the network lens to better understand, design, and manage supply chains as complex engineered systems” (Bellamy & Basole, 2013, p. 236).

Our method to model the supply chain network uses the concept of a giant component. Many individual supply chains consisting of supplier, focal company and customer are part of this giant component illustrating a part of the *de facto* scale-free supply chain network. We refer to the individual supply chain within the supply chain network as path. A path adds information of connectedness from supplier to focal company to customer and vice versa.

For a thematic classification in the large field of social network analysis, this thesis incorporates both system architecture and system strategy. Analysis of properties on the node-level, the network-level and the link-level are put together with strategy where the scope is on the entire network.

The relationships between companies are approximated to the cash flows and product flows between companies. However, beside the analysis on the one-mode level (relationships between companies), we have to include context and relationships in the analysis. A two-mode network consists of two sets of elements and the relationships among them. Depending on the network, we distinguish two kinds of ties:

- In the first case of the supply chain network, the ties are initially about professional collaboration between companies in the one-mode supply chain network.
- The second kind of ties in the two-mode network may represent connections to certain foci such as producing and selling on a target market. Companies participate on certain industries and are therefore dependent on their general prevailing conditions.

In a first step, we present the ego-network approach as a method to compare different ego-networks (focal company together with business partners) and to assess the quality of the individual supply chain network. This involves a discussion of different concepts regarding strength of links, diversity (hubs and authorities) and centrality. At this point we want to go one step further. The ego-network approach is an interim-step towards defining our network-oriented approach which is presented in further detail in the following chapter. In the following, this thesis brings social network analysis and a section of the scale-free supply chain network together.

Borgatti and Li (2009) provide supply chain research with an initial overview for the potential application of social network analysis. We follow Borgatti and Li (2009) who write that “the network paradigm provides a common language that many different fields can use to conceptualize interactions among actors, and many of the concepts of network analysis, such as centrality or equivalence, are highly portable across fields” (Borgatti & Li, 2009, p. 15). We are sure that social network analysis has great potential and can be related to a performance question. As we have pointed out, up to this point studies have either compared individual supply chain networks (ego-networks) or were based on qualitative methods.

In order to contribute to performance measurement based on a supply chain network perspective, our thesis aims to be more holistic than the standard analysis of dyadic connections of company-specific supply chain networks (ego-networks). Based on a “bird’s eye” view on the scale-free supply chain network, we identify network position properties in the light of a performance question. The research question of our thesis is therefore:

- What characteristics of a network position are important with respect to the performance of companies in the network?

The question results in three main hypotheses. The verification of these hypotheses requires an analysis of network position properties to determine strength of the links, node centrality and link diversity. We use social network analysis so that quantitative methods are applicable to inform on a network perspective in a performance measurement tool. We illustrate our approach in Figure 22 below:

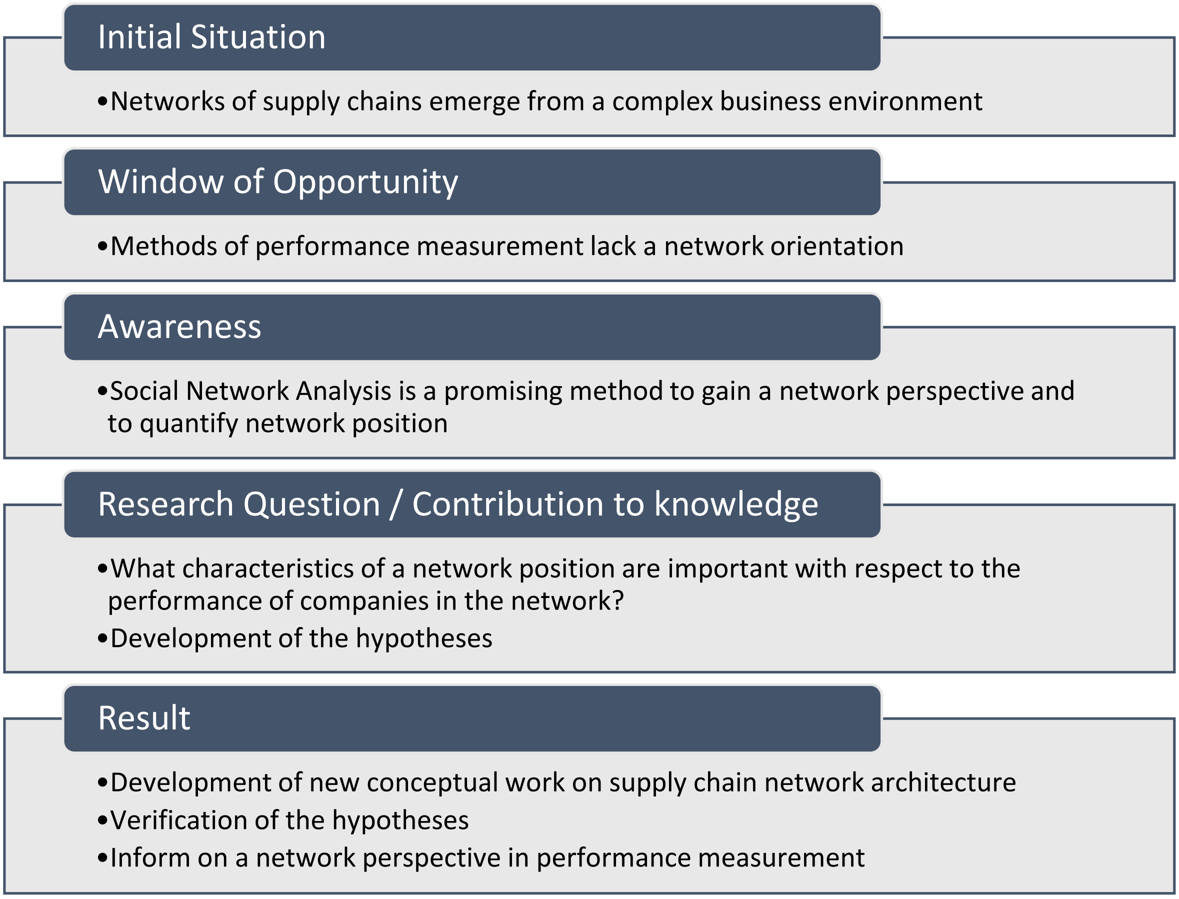


Figure 22: Summarised Research Approach of the Thesis

4 Methodological Approach

As the previous chapter illustrated, we aim to analyse a section of the scale-free supply chain network using network and graph theories transferred from social network analysis. We assume that characteristics of the network position of a company within the supply chain network influence the performance of the individual company. The verification of this assumption is only possible because of our new conceptual work which visualises a section of the scale-free supply chain network.

Testing the hypotheses requires the development of a cross-sectional analysis where we obtain quantitative data by means of deductive, as well as explorative methods. Following the description of our research philosophy in Section 4.1 (ontological and epistemological position for this research), Section 4.2 introduces an explorative approach of social network analysis. We use this approach to collect quantitative information on network position properties within a created supply chain network. This is followed by the description of our quantitative analysis of business reports of companies to determine financial performance measures that express performance. We set the focus on financial performance measures that express economic performance in terms of liquidity, stability and profitability. Prior to the planned procedure, the implementation of several informal pilot talks with experts aims to provide a first feedback from practice.

We present a solution that allows us to create a supply chain network based on quantitative network data. After specifying our sample in Section 4.2.4, the development of an appropriate software tool in Section 4.4 puts us into a position to study a network that is based on collected real-time data.

Finally, by means of our methodological approach, the development of a mathematically comprehensible model for performance measurement in the context of the supply chain network becomes possible.

4.1 Research Philosophy

As previously stated, we want to study the link between characteristics of the network position of a company within the supply chain network and the performance of this individual company, In this context, it is obvious that the quality of expected results is influenced by the system of beliefs of the author. We have to be clear about our chosen philosophical standpoint, because this lays down how research objects are seen (ontology) and what kind of data is collected (epistemology). Further the role of values and ethics (axiology) in the research process should be defined. Basically this is about either being a positivist (applying scientific quantitative methods) or an interpretivist (applying humanistic qualitative methods).

We aim for objectivism which is why one would be inclined to recognise the philosophical standpoint of a positivist. Following Saunders, Lewis and Thornhill (2015, p. 129), we see our research objects (companies) as real objects, expecting one true reality (universalism).

In terms of epistemology, data collection is about measurable facts and numbers because of observable phenomena. Further, being detached from our research objects we treat them neutral and value-free. The suitable methods are quantitative and highly structured.

However, we recognise the positivist in management research as a natural scientist (Saunders et al., 2015, p. 135). As we are convinced that reality is complex (ontological position), the classification positivist versus interpretivist might therefore be too strict in terms of our study. Table 5 shows, the philosophy of a pragmatist which is more about the management researcher as a problem solver or outcome seeker.

Table 5: Research Philosophy of the Pragmatist
(Saunders et al., 2015, p. 137)

Ontology	Epistemology	Axiology	Typical methods
processes, experiences, practices are flexible	**data collection supports problem solving and informs future practice**	**research is initiated by the researcher's doubts and beliefs**	a range of methods (could be anything) is available to fit the research problem
reality is complex in a way that reality is the practical consequence of ideas	search for practical meaning of knowledge in specific contexts	researcher reflexive	main emphasis on practical solutions and outcomes
	theories that enable successful action		
	focus on problems, practices and relevance		

Trying to expand existing knowledge on performance measurement, the research philosophy of the pragmatist describes our identity in a best possible way. In the light of informing future practice, we collect data in order to contribute to problem solving (epistemological position). Thereby, initiated by doubts and beliefs, we aim to be reflexive.

Regarding the chosen methods, the pragmatist may theoretically consider every possible method. Therefore, after assigning methods in the context of our usage, we specify the methods in more detail (Section 4.2.2, Section 4.2.3). As stated in Table 5, the main emphasis is on practical solutions and outcomes.

4.2 Research Methods

4.2.1 Scope of the Analysis

The hypotheses-testing of this thesis is based on a cross-sectional methodology that comprises five steps: (i) processing of ego-network data, (ii) network creation, (iii) evaluation of business reports and the supply chain network, (iv) statistical analysis, and (v) interpretation of this analysis in such a way that motivates the enrichment of performance measurement metrics.

The approximation of a supply chain network involves the processing of quantitative real-time data of focal companies to capture network position properties. We then analyse business reports for financial measures of performance.

- In a first step, we ask focal companies (manufacturing companies in the plastic processing industry) for network flows with their suppliers and their customers querying their enterprise databases. Our developed software tool "Network Creator" is able to approximate these quantitative network flows (cash flows and product flows collected from databases) to relationships between companies. As real-time data is processed, the relationships are either the result of procurement with suppliers or of sales with customers. The aggregation of the network flows is ensured by our developed software which uses the query language SQL to create sums per customer or supplier of one fiscal year. The first option of the software is the creation of individual ego-networks of focal companies. Each ego-network illustrates the individual supply chain network of one specific focal company.
- As all focal companies are part of the same industry, every ego-network is part of the scale-free supply chain network. In a second step, we are therefore able to merge the ego-networks of all focal companies. By the use of our own software-tool, the data is processed which allows for the creation of a larger section of the scale-free supply chain network. The software then generates a graphical representation of the network (sociogram), which we analyse using the explorative approach of social network analysis.
- In a third step, we collect network position properties (explorative) which form the first fragments of our analysis. The network position properties are the independent variables IV of the analysis. The second fragment of the analysis is data regarding the economic performance of each focal company. We obtain this data by quantitative analysis of business reports. We use typical financial performance measures. The outcomes are the dependent variables DV.

- In a fourth step, we put the financial measures for performance collected by quantitative methods together with the network position properties (explorative network data). The result is the set S which comprises all DVs and IVs. Using standard methods of statistics, it is possible to perform the test our hypotheses. All information is metric, therefore the linear regression which explains a DV by an IV is a main part in order to test the hypotheses and look for statistical associations.
- The final step is the development of appropriate statistical models that contributes to performance measurement in the light of the supply chain network. Multiple linear regression allows for the development of models that depend on several network position properties (IVs).

In consequence, the main subjects of analysis are the supply chain network (sociogram) on the one side, and the business reports of focal companies on the other side. Recalling the outline of our research design (Figure 2 in Chapter 1), Figure 23 illustrates the scope of the analysis in order to find evidence of our hypotheses (colours match the task in the research design).

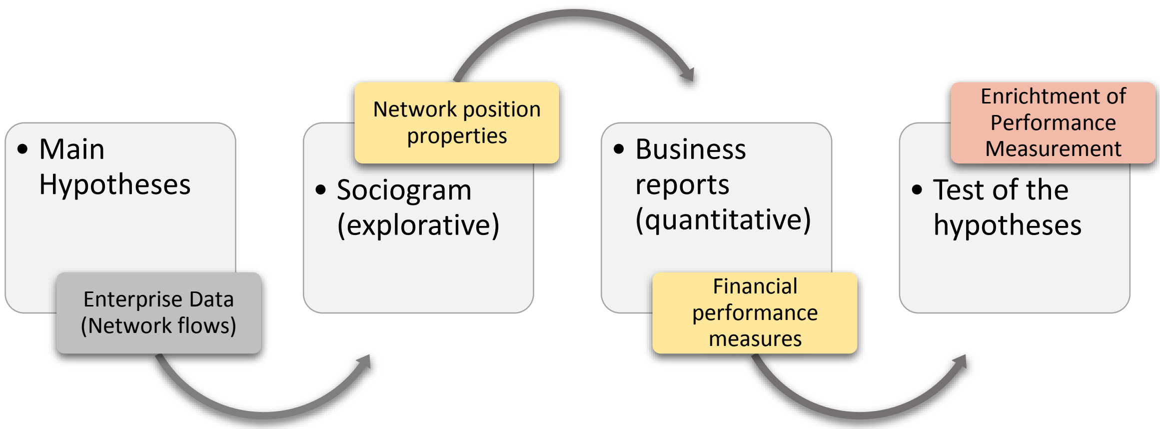


Figure 23: Illustration of the Scope of the Analysis

4.2.2 Explorative Network Analysis

The graphical representation of a group structure visualising the network is called a sociogram. In order to provide more details, Figure 24 shows an exemplary illustration.

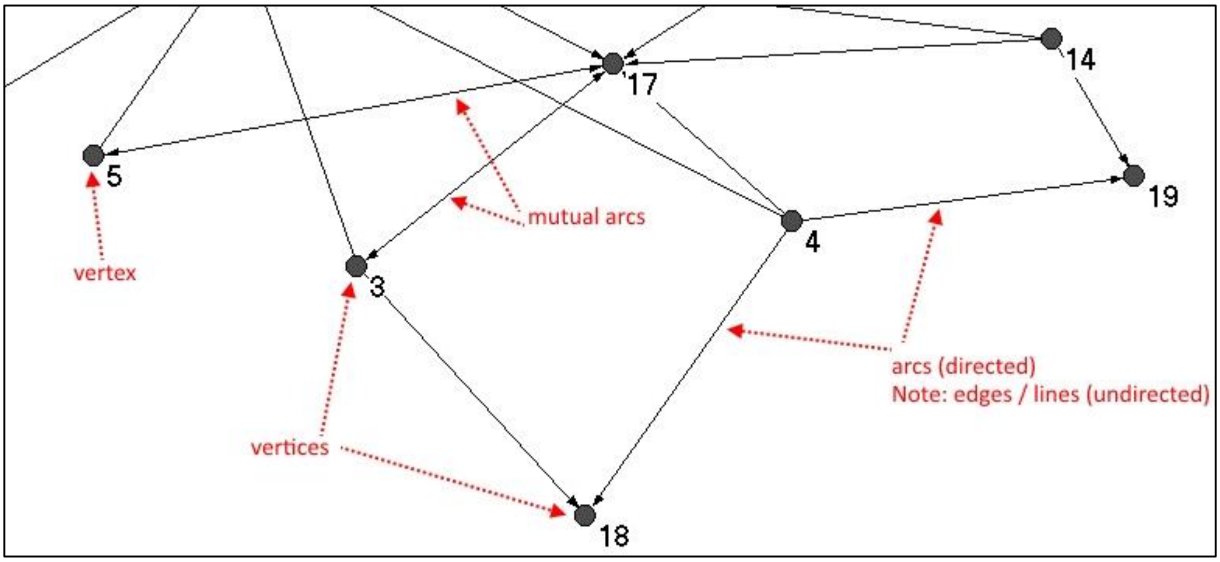


Figure 24: Segment of an Exemplary Graph (Sociogram)

We create the sociogram by using data from manufacturing companies in the plastic processing industry. The manufacturing companies generally convert raw materials into products. Consequently, the sociogram consists of suppliers, focal companies (manufacturing companies) and their customers. Each company in the sociogram is represented by a circle. For the sake of clarity, each company can be identified by a name, written next to the circle. Arcs (arrows) from one cycle to another represent network flows (cash flows and product flows). Network flows are the result of trade between two companies. In sum, the sociogram shows the structure and the ties within our social network.

We analyse the sociogram using methods of social network analysis which generally look for patterns of connectedness. The main goal of the explorative procedure is to detect and interpret such patterns by means of network position properties. The notation in Table 6 defines the entities we use in the definitions of our network position properties (Table 7). Table 7 provides a short description for each property of network positioning. We go more into detail when analysing our data.

Table 6: Notation for Network Position Properties

$G_{\mathrm{D}}(V, A)$	The directed graph that is the set V of nodes (companies) and the set A of arcs (cash flows). The companies are the focal companies, their suppliers, and their customers.
v	$v = \|V\|$, the number of nodes in $G_{\mathrm{D}}(V, A)$ (the number of companies in the network).
u	The number of focal companies, $u < v$.
w	The number of industries in which the focal companies trade.
x_{ij}	Defined on $G_{\mathrm{D}}(V, A)$, $x_{ij} \geq 0$ for all *i* and *j* is the weight of the arc from node *i* to node *j* (monetary value of the procurement by company *i* from company *j*). In terms of the supply chain network we study, this is the cash flow from a company to its supplier to pay for materials or the cash flow from a customer to a company to pay for manufactured product. Note: in the network we consider a company may act as both a customer and a supplier.
X	The $v \times v$ matrix (x_{ij}) of cash flows, called the *cash flow matrix.*
$G_{\mathrm{U}}(V, E)$	The undirected graph that is the set V of nodes (companies) and the set E of edges (links).
y_{ij}	Defined on $G_{\mathrm{U}}(V, E)$, for all *i* and *j*, $y_{ij} = 1$ if company *i* trades with company *j* and $y_{ij} = 0$ otherwise; y_{ij} indicates the presence or absence of an edge (link) in $G_{\mathrm{U}}(V, E)$.
Y	The symmetric $v \times v$ matrix (y_{ij}), called the *adjacency matrix.*
$H_{\mathrm{D}}(W, B)$	The directed graph that is the set W of nodes (the *u* focal companies and *w* industries in which they operate) and the set B of arcs (from a focal company to an industry if the focal company operates in that industry). This network simplifies the network $G_{\mathrm{D}}(V, A)$ by aggregating, into industries, the trade between focal companies and their suppliers and customers.
r_{ij}	Defined on $H_{\mathrm{D}}(W, B)$, $r_{ij} = 1$ if company *i* operates in industry *j*, $r_{ij} = 0$ otherwise.
R	The $u \times w$ matrix (r_{ij}), called the *affiliation matrix*.
p_{ij}	Defined on $G_{\mathrm{D}}(V, A)$, p_{ij} is the number of different types of product procured by company *i* from company *j* in V. The product types procured by *i* from *j* each have a corresponding cash flow that sum to x_{ij}.
P	The $v \times v$ matrix (p_{ij}), called the *product-mix matrix*
g_{ij}	Defined on $G_{\mathrm{D}}(V, A)$, g_{ij} is the number of arcs in the shortest path from node *i* to node *j*
G	The $v \times v$ matrix (g_{ij}), called the *geodesic distance matrix.*
h_{ijk}	Defined on $G_{\mathrm{D}}(V, A)$, the shortest path from node *i* to node *k* that passes through node *j*.

Table 7: Definition of Network Position Properties

Strength		
Aggregated strength, AS	$AS_i = \sum_j \frac{x_{ij}}{\sum_k x_{kj}} + \sum_j \frac{x_{ji}}{\sum_k x_{jk}}$	The aggregated share of cash flows from and to company *i*.
Centrality		
Degree centrality, C	$C_i = \sum_j y_{ij}$	Total number of companies with links to company *i*.
Betweenness centrality, BC	$BC_j = \sum_{i<k} h_{ijk}/g_{ik}$	How often company *j* lies on the shortest path between any two other companies (Borgatti, Everett & Johnson, 2013, p.174).
Eigenvector centrality, EC	The *eigenvector centrality* vector, $\boldsymbol{e}$, is the solution of the set of linear equations $\mathbf{Y}\boldsymbol{e} = \lambda\boldsymbol{e}$ for which λ, a scalar, is maximum. This λ, λ_{max}, is the largest eigenvalue of $\mathbf{Y}$. The *i*th component e_i of $\boldsymbol{e}$ is the eigenvector centrality of node *i*.	A centrality measure in which connections (links) to well-connected nodes score more highly, in relative terms, than connections to less well-connected nodes.
Bonacich power, BP	$BP_i(\beta) = \sum_j(\alpha - \beta C_j)y_{ij}$	A more general measure of centrality than C and EC. Implementing β, BP allows the regulation between the total number of links and connections to well-connected nodes. BP is discussed more fully when it is applied.
Diversity		
Hubs, HUB	$HUB_i = \sum_j \frac{p_{ij}}{\sum_k p_{kj}}$	Similar to aggregated strength, but this is not the value of product (cash flow) but the proportion of product types sold that is aggregated, and the more diverse the product types a company provides upstream in the supply chain, the higher its HUB score
Authorities, AUTH	$AUTH_i = \sum_j \frac{p_{ji}}{\sum_k p_{jk}}$	Essentially the complement of HUB, so that the more product types a company procures from the downstream supply chain, the higher its AUTH score.
Industries, IND	$IND_i = \sum_j r_{ij}$	The number of different industries to which company *i* is connected.

By transferring social network analysis to the supply chain network, the focus is generally set on a holistic view. Nevertheless, it would not be realistic trying to collect data that covers the entire world, meaning the setting of boundaries is essential. In this study, we focus on small and medium-sized companies, working in a particular industry (plastic processing). This industry is characterised by a high degree of maturity which is why all focal companies face similar business conditions. We explain the refining criteria in the subsequent chapter. This is very important, because the specification of network boundaries has a strong influence on the network structure. We deal with a sample created by using the technique of convenience sampling (Saunders et al., 2015, p. 304).

Following Nooy, Mrvar and Batagelj (2011), the explorative approach of social network analysis consists of the four steps (i) network definition, (ii) network manipulation, (iii) determination of structural features and (iv) visual inspection (Nooy et al., 2011, p. 6).

- In the first step, concepts of graph theory help to provide the network definition. As a branch of mathematics, graph theory makes the structure of a network available. As Nooy et al. (2011) state, a graph is defined as "a set of vertices and a set of lines between pairs of vertices" (Nooy et al., 2011, p. 7). As previously illustrated, a vertex is the smallest unit in the network (Figure 24). The lines between two vertices can either be directed (arcs) or undirected (edges). In the case of a directed graph, arcs point from sender to receiver. In general, multiplexity (multiple lines) between two vertices is allowed. However, in our case of the supply chain network, network flows between two companies are aggregated to only one line. A graph combined with additional information on vertices and lines between those vertices formulates a network definition. With respect to our analysis, the supply chain network is represented by a simple directed graph $G_{\mathrm{D}}(V, A)$, which contains no multiple arcs. The creation of ready-to-use network files requires new conceptual work. We create network files for the cash flow matrix **X**, the affiliation matrix **R** and the product mix matrix **P**. Additional information such as vertex labels and line values are obligatory for our analysis.
- The second step of the explorative approach refers to network manipulation. Social network analysis is not limited to a certain size. All the same, it may be useful to reduce a network to inspect the meaningful subset of nodes. An adequate size of a network is easier to deal with. The determination of the adequate size depends on the specific case and is part of our data analysis. The network can be depicted what facilitates visual inspection. In general, the best way of network manipulation is to create a new network based on the initial network. For example, one use of network manipulation technique

regarding the supply chain network is the reduction of multiple lines. Multiple lines between two vertices may occur if a company (supplier) supplies different materials to a focal company. Given that it is necessary to know the total number of product types supplied, network manipulation allows to reduce the multiple lines to one single line and to sum the different line values representing the total number of product types.

- The inspection for structural features is the third part of the explorative approach. Inspections may target the calculation of properties for either the entire network, a group of vertices (subnetwork) or several single vertices. While in the case of all vertices in the network or in the case of a group of vertices, the calculation of a node property provides a list of numbers, the calculation of a network property results in one single number. The calculation of properties for a group of vertices is stored in data objects called partitions or vectors. Table 7 defines the network position properties of this thesis.
- In the fourth step, a proper network visualisation might support pattern recognition, to demonstrate concepts and evidence. As by Nooy et al. (2011), visualisation also supports an intuitive understanding of network concepts (Nooy et al., 2011, p. 17). To avoid misinterpretation, visualisation should be performed using automatic procedures. By minimising the variations in line length, automatic procedures create an optimal layout. Using Pajek[3] as tool for network analysis, several commands are available. The "Kamada-Kawai" command is best suited for small, connected networks (Kamada & Kawai, 1989). Networks over approximately 1000 vertices are more rapidly optimised by the use of the "Fruchterman-Reingold" command (Fruchterman, Thomas M. J. & Reingold, 1991).

In general, one improves the actual network analysis by using special software for social network analysis. Well-known programs are Pajek, UCINET or Gephi. In our thesis, we perform social network analysis by using Pajek and UCINET.

4.2.3 Quantitative Business Report Analysis

Beside the network (sociogram), business reports form the second subject of our analysis. Given the aim to study the dependence of companies' performance from characteristics of their network position in the supply chain network, we need appropriate financial performance measures of each focal company. The analysis of the key figures thereby requires a holistic perspective. This means that it is not sufficient to stick to just one indicator. Each company is different and follows an individual strategy. Indeed, companies not only differ in their target

[3] http://pajek.imfm.si/doku.php

markets, but also as to their general business objectives and overall strategic direction. Therefore, a comparison on the basis of only one financial performance measure would be insufficient. In order to evaluate companies comprehensively, the financial performance measures need to cover their liquidity, stability and profitability (Deyhle, 2008). Further, it is important that the figures build on the same rules of accounting. In this respect, Table 8 illustrates the profit calculation we apply. This is of particular importance, because profit in different forms is the basis to calculate financial performance measures.

Table 8: Illustration of Profit Calculation

	Profit after taxes PAT
	+ tax expenses
	- tax income
=	**Profit before taxes PBT**
	+ interest expenses
	- interest income
=	**Profit before interest, taxes PBIT**
	+ depreciation of fixed assets
	- Additions to fixed assets
=	**Profit before interest, taxes, depreciation and amortisation OP**

In our study, we calculate and apply the financial performance measures according to the definitions in Table 9.

Table 9: Definition of Financial Performance Measures

Operating profit, OP	$OP = profit\ after\ tax + tax + interest + depreciation$	OP is the difference between revenue (sales) and expenditure (costs). This absolute measure indicates profitability and liquidity. OP is a well-known measure for internal controlling and financial communication.
Revenue per employee, RE	$RE = \frac{revenue}{number\ of\ empl.}$	Looking at the ratio between revenue (sales) and a company's number of employees, RE indicates profitability. To compare companies within the same industry, this financial performance measure is more independent of the size of a company.
Return on assets, ROA	$ROA = \frac{profit\ before\ tax}{total\ assets}$	ROA is another indicator of profitability. This measure expresses how profitably the assets of a company are used to generate income. The figure is very revealing as it is indicative for a careful use of company capital.
Asset turnover, AT	$AT = \frac{revenue}{total\ assets}$	AT indicates the efficiency with which a company is able to deploy its assets in order to create revenue from sales, without considering any costs.
Dynamic debt ratio, DDR	$DDR = \frac{debt}{cash\ flow}$	As a measure of financial risk, DDR indicates liquidity. DDR expresses the time in years it would take a company to pay off its debts. The shorter the time period, the better the company's ability to carry its debt, and the lower the financial risk for investors.
Profit fixed asset ratio, PFR	$PFR = \frac{profit\ before\ interest, tax}{fixed\ assets}$	PFR as the ratio of profit and fixed assets measures how successfully a company can use its fixed assets in generating earnings.

4.2.4 Pilot talks

With respect to our research, the implementation of qualitative pilot talks only serves to check the cross-sectional methodology. This includes presenting the methods to obtain quantitative data as presented in Section 4.2.2 and Section 4.2.3, in order to avoid possible mistakes. We aim to benefit from suggestions made by practical experts.

This qualitative aspect is to be considered independent from our later quantitative analysis. The piloting companies are not part of our statistical analysis in order to answer our research question. Thus, the statements of the piloting companies only indirectly influence our research by strengthening our methodology before the research is actually carried out.

Further, presenting the methodological approach including our new conceptual work we aim to get feedback on the timeliness of our study. The open discussions makes it possible for us to strengthen the understanding on our (the researcher's) side.

As Section 4.4 illustrates, we develop a new method to make the supply chain network visible. Using real-time network data enables us to perform an in-depth analysis of the scale-free supply chain network. However, this also limits the sample size. Therefore, we also want to receive feedback about the quality / relevance of the expected results.

4.3 Sample and Data Access

In order to apply social network analysis and to show its potential for the supply chain network, we make use of a convenience sample of businesses, labelled *the focal companies*, operating in the German plastics processing industry. There is no scheme behind this sampling, but it is not completely random either (Saunders et al., 2015, p. 304). To perform an analysis on the given level of detail using a large random sample is hardly feasible. Financial resources and limited reputation set limits. However, we are not dealing with a niche:

- In Europe there are some 54,000 plastics companies, 95 % of them are small and medium-sized companies in the plastics processing industry (Plastics Europe, 2011, p. 28).
- Following the economic crisis in 2008, the plastics processing industry of 27 European countries (EU-27) increased its business by 9 % to 203 billion EUR in 2010 (Plastics Europe, 2011, p. 5). The upward trend continued to 212 billion EUR in 2013 (Plastics Europe, 2015, p. 7).
- The plastics processing industry provides work for approximately 1.27 million Europeans and many more given its close connections with other industries (Plastics Europe, 2015, p. 7).
- In a long-term perspective, the industry has grown by approximately 5 % per year over the last 20 years (Plastics Europe, 2011, p. 5).

Plastic processing is a typical supply industry, which is why we can expect to gain important insights using our methodology on our data.

To our knowledge, we are the first to perform a quantitative network analysis on company performance to this level of detail. Therefore, not only our findings, but also the use of our methodology may be of interest to study other industries, too.

The fulfillment of the following criteria ensures that our sample of focal companies is clearly defined:

- Our analysis is based on data of typical, plastic processing companies which are all small and medium sized companies in Germany.
- All companies have globally stretched supply chains.
- All companies are manufacturing companies (material converters) and produce for different industries such as the automotive sector.
- To a certain extent, the companies are comparable as they face similar industry-specific, legal and economic conditions in Germany and the European Union.
- We perform the analysis in detectable confidence limits. For this reason, all focal companies are economically stable, which reflects the current status of the economy. This means that none of the focal companies is on the edge of insolvency.

4.3.1 Quick Test

We apply the quick test by Kralicek (2009) to ensure that the sample is reliable and within detectable confidence limits. The quick test is generally used as an early warning system for insolvency or as a general business valuation tool. The test generates a rating based on only four figures and classifies each company. The four quick test figures are (i) the equity ratio, (ii) the debt repayment period, (iii) the return on assets and (iv) the cash flow performance rate. According to Kralicek (2009, p. 54), the four indicators are not considered to be susceptible to interference. Here, one takes every effort to use all the available information of the balance sheet, together with the profit and loss account, in order to capture as much data as possible using just four indicators. Therefore the information covers the areas of financing, liquidity, profitability and expenditure.

The indicators (i) equity ratio and (ii) debt repayment period show whether a company has too much debt. The gained information is based either on total assets (absolute) or cash flow (relative). The indicator (iii) return on assets is chosen as it disregards leverage. The indicator (iv) cash flow performance rate measures earning power while overlooking depreciation. These disregards are positive in order to reduce the influences because of any financial arrangements. Table 10 provides an overview of the quick test.

Table 10: Indicators of the Quick Test (Kralicek, 2009, p. 53)

Area	**Indicator**	**Formula**	**Statement**
Financing	Equity ratio (%)	$\frac{Equity}{Total\ assets}\ x\ 100$	Financial strength
Liquidity	Debt repayment period (years)	$\frac{Debt - Cash\ position}{Cash\ flow}$	Debt
Assessment of financial stability			
Profitability	Return on assets (%)	$\frac{Profit\ before\ tax}{Total\ assets}\ x\ 100$	Return
Expenditure structure	Cash flow performance (%)	$\frac{Cash\ flow}{Operating\ capacity}\ x\ 100$	Financial capacity
Assessment of earning power			

As by Kralicek (2009) we use a reverse grading scale in order to receive an accurate valuation. The quick test is based on a five-part grading scale which allows each indicator to be rated from 1 to 5. A rating of 1 is considered to be very good, whereas a rating of 5 means danger of insolvency. The arithmetic mean of the four individual scores provides the overall score. In addition, following Kralicek (2009) we calculate the arithmetic mean of financial stability and earning power separately. Given a separate calculation of financial stability and earning power, it is easier to detect possible problems because it can be stated whether the problems are related to earnings or financing. This also means that companies can perform countermeasures more specifically. Table 11 shows the rating scale used by the quick test.

Table 11: Quick Test Rating Scale (Kralicek, 2009, p. 54)

Indicator	very good (1)	good (2)	mean (3)	bad (4)	Danger of insolvency (5)
Equity	> 30 %	> 20 %	> 10 %	< 10 %	negative
Debt repayment period	< 3 years	< 5 years	< 12 years	< 30 years	> 30 years
Intermediate result of financial stability: arithmetic mean based on the grades of equity ratio and debt repayment period					
Return on assets	> 15 %	> 12 %	> 8 %	< 8 %	negative
Cash flow performance	> 10 %	> 8 %	> 5 %	< 5 %	negative
Intermediate result of earning power: arithmetic mean based on the grades of return on assets and expenditure structure					
Overall rating: arithmetic mean of all four indicators					

The balance sheet provides information on equity, total assets, cash position and debts which are obligatory numbers for the application of the quick test. Further, we derive operating capacity, interest on debts, profit before tax and cash-flow from the profit and loss account. The results are interoperated in the following way:

- According to Kralicek (2009, p. 61), the equity ratio should be at least 20 %. This ratio is important as it influences the number of years during which a decline in sales can be absorbed.
- In terms of liquidity, the debt repayment period is a particularly informative figure which states how many years the company would be able to pay its debt on its own. So, one can see to what degree the company is dependent on its lenders.
- Return on assets reflects the efficiency with which a company uses the total capital invested in the company, regardless of its financing. The higher the percentage, the better.
- The cash flow performance indicates what percentage of the overall performance of a company is available for financing.

In sum, the quick test is a good instrument for business valuation. It includes all relevant areas based on the balance sheet and the profit and loss account of a company. The result is an approximate but comprehensive assessment that provides ordinal data. The main reasons for the application of the quick test or similar tools are the buying and selling of businesses, investments or the check of creditworthiness.

Applied to our study, the quick test helps us to make sure that the sample of focal companies is reliable. We want to ensure that our sample shows no signs of a one-sided distribution with respect to economic performance.

4.3.2 The Supply Chain Network

Based on our sample of focal companies, analysed by the quick test, this thesis examines if there is a link between financial performance measures and network position properties. We are convinced that this link can be analysed best by approximating a supply chain network from network flows between focal companies, using reported ego-networks and available, comparable performance data. Thus, our first subject of inspection is the supply chain network. Even if our sample is not completely random, it is, as previously pointed out, in detectable confidence limits. Due to the difficulty of data collection, the only way one could carry out a comparable analysis with completely random data is the use of qualitative data collection. However, the qualitative approach is problematic in several respects:

- To analyse relationships, it is necessary to have reliable data, which becomes more difficult if the feedback rate is low.
- In the case of the supply chain network, only the chief executives, the upper management or supply chain experts in participating companies are able to answer relevant questions. This target group probably has insufficient time to answer a comprehensive questionnaire. Given this lack of time, one cannot be sure who answers the questions at the end, so that it is difficult to rely on the results.
- In addition, our study requires some explanation. To act as an unknown with respect to the participants makes it difficult to convince people to spend their time on the questionnaire and weigh their answers.

Consequently, our study is called an egocentric network study based on a quantitative approach. A convenience sample of focal companies reports their ego-network querying enterprise databases. Including the network flows, each company-specific ego-network consists of a focal company and a number of important alters (suppliers and customers). According to the Pareto rule (80 / 20 principle) described by Koch (1999), in our analysis we concentrate on 80 % of the procurement, as well as on 80 % of the revenues (sales) of each focal company. A cut-off sample referring to Stier (1999, p. 120) is used to ensure that the sales and procurement data are sufficiently reliable.

In descending order, we include as many customers and suppliers as are responsible for at least 80 % of sales and 80 % of procurement of each focal company.

Our own method then allows us to merge the individual ego-networks within one single network study.

To conclude, this comprises two steps:

- In a first step, we have an independent sample of observations.
- In a second step, the observations are put together by new conceptual work. The network structure is derived from ego-network sampling.

The creation of network structure based on ego-network sampling allows us to analyse several hundred supply chains as part of this study. Recognising the idea of comparing ego-networks separately (Section 3.3.1), the aim is to find network evidence in a larger context and to go beyond the analysis of separate ego-networks.

Compared to ego-network sampling, the ultimate alternative would be to carry out a network study on a larger scale across several levels. Such a study would include the connected nodes (alters) of the supplying companies, the alters of the alters and so on. As mentioned previously, the scale-free supply chain network has no clear boundaries. Therefore, such snowball sampling is too extensive and fails because starting from the focal companies, one would have to convince the suppliers, the sub-suppliers of the suppliers, the customers, the customers of the customers and so on. Such an extensive study cannot be carried out in the framework of this thesis because of certain limitations such as financing, time and a lack of reputation.

4.3.3 Business Reports

Aside from the supply chain network, we have to take a closer look at the focal companies and the data collected from their balance sheets and databases of digital business information. Business data make up the second subject of our inspection. We focus on Bisnode[4], Dafne[5] and the business register of the German Federal Gazette[6]:

- Bisnode is one of the major European providers for digital business information. The main focus of Bisnode is to provide business-to-business information, which includes comprehensive data on more than 5.1 million German and 97 million European companies (Bisnode Deutschland GmbH, 2015).

[4] https://www.bisnode.com/Group/
[5] https://dafneneo.bvdep.com
[6] https://www.unternehmensregister.de/

- Dafne offers current as well as historical financial information on 800,000 German and Austrian companies. Depending on the legal form, both separate financial statements as well as consolidated financial statements are available. The basis is the information and the rating of Creditreform, a credit reporting and collection service. In the field of business information, Creditreform provides information with regard to creditworthiness, financial structure and the environment of corporate customers.
- In addition, the business register powered by the German Federal Gazette allows us to have a central access to information about companies.

While the aim of the state-owned business register is to provide legally essential information to the public, Bisnode and Dafne are commercial companies. Although the three sources of data provide us with much relevant information, the published information on each company may differ. This is because not every company meets the rules on publishing balance information. Consequently, we have to collect all available information and prepare an overview on data that is mostly available for all companies. This ensures that we can draw conclusions based on comparable information.

4.4 Development of New Conceptual Work

Part of this thesis devotes itself to the development of a software tool called “Network Creator”. This application is capable to read and merge supply chain data of our sample of focal companies. The reading of data includes cash flows and product flows from relationships of focal companies with customers (sales) and with suppliers (procurement). We merge and link the data to show the network flows within the network. The “Network Creator” software creates the network file which we analyse. The network file contains a section of the scale-free supply chain network merged on the basis of different ego-networks. This file is the starting point for the explorative analysis using social network analysis.

4.4.1 Design of the Network Creator

Our developed software tool “Network Creator” is coded using the object-oriented programming language Microsoft C#. In the Appendix A1 we provide a class diagram which is a graphical representation of the program structure and its source code.

We merge the quantitative network flows by using a database that is designed according to Figure 25. The table “Company” contains the focal companies (manufacturing companies). Each focal company is identified by a unique identifier and linked to data within three tables that store many datasets of customers or suppliers. The link is also called a 1:n relationship which means that one focal company is assigned to a great many of revenue (sales), procurement and industry datasets. We have to process the data of customers and suppliers in order to fit the given structure.

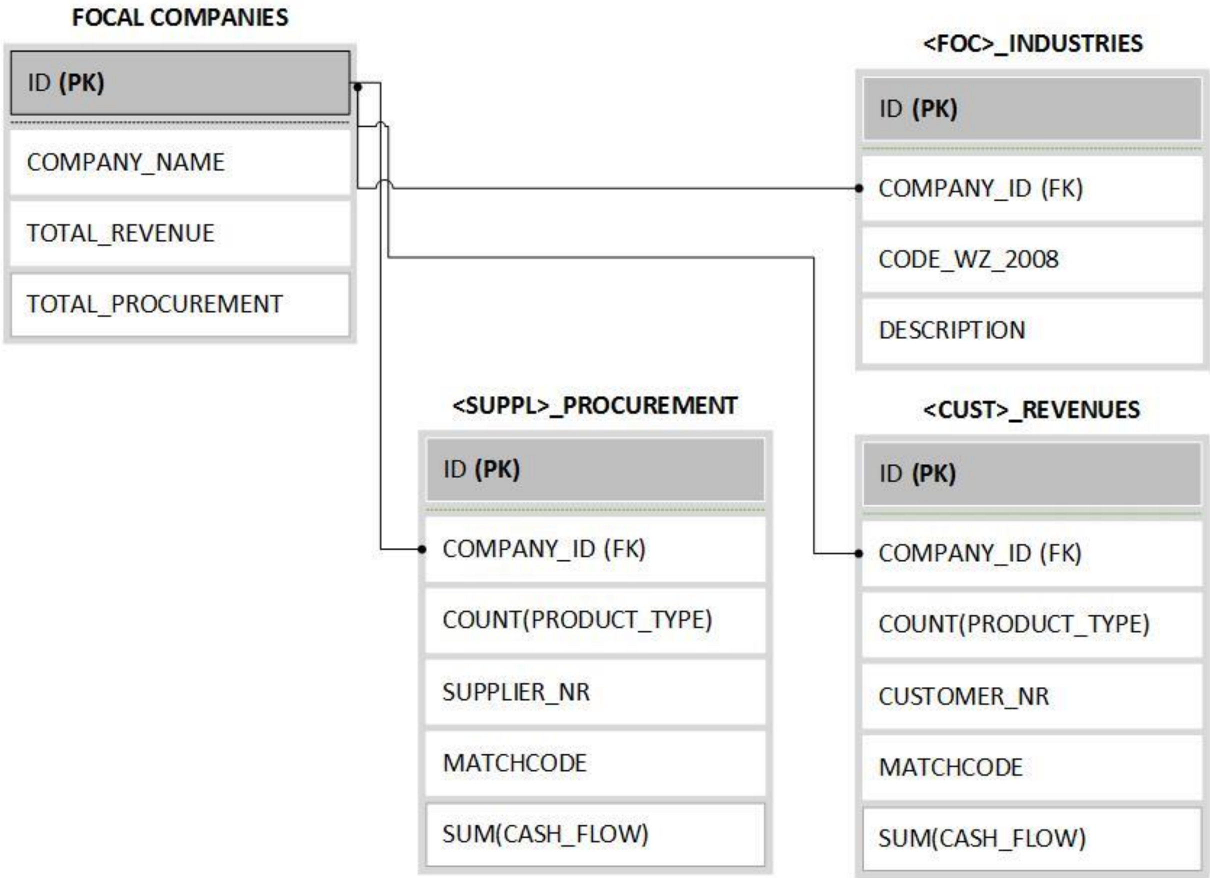


Figure 25: Entity Relationship Model for Data Aggregation

Originating from procurement data, as well as revenue data (sales), we include the customers and suppliers of each focal company. When processing the collected data, we have to verify each dataset for proper naming. Otherwise the network generation would not be able to identify common nodes between different focal companies. For example, a common customer named VW AG must be written the same in all datasets of focal companies (VW AG instead of VOLKSWAGEN or VOLKSWAGEN AG).

Besides, in order to make sure, that the network has an adequate size, the sample may have a limiting criteria. Thereby it is important to keep in mind that the network still needs to contain the main partners of each company and no important information is lost.

4.4.2 Data Processing

We have to be aware of ethical issues and treat the given data confidentially. Robins (2015, p. 154) describes this task as the duty of care which means data collection must not lead to any distress or discomfort for the participants. Starting with an ego-network design of each focal company, the customers and suppliers of these companies do not know each other. The focal companies are independent of each other. Each focal company has alters that are included in the study based on our created database. The different network flows describe the links between the focal companies and their alters. In general, there is no need to know the identity of the alters. As researchers, we only need to be able to distinguish between the alters in each ego-network. Further, there is also no need to identify each focal company as a participant. However, we want to go beyond ego-network sampling and derive a larger network structure. This means that merging the different ego-networks is crucial.

In order to allow for the creation of a network structure, while avoiding any discomfort for the participants, the developed software called “Network Creator” ensures that the data is de-identified. Figure 26 shows the graphical user-interface. There are three main options (tabs) for network generation.

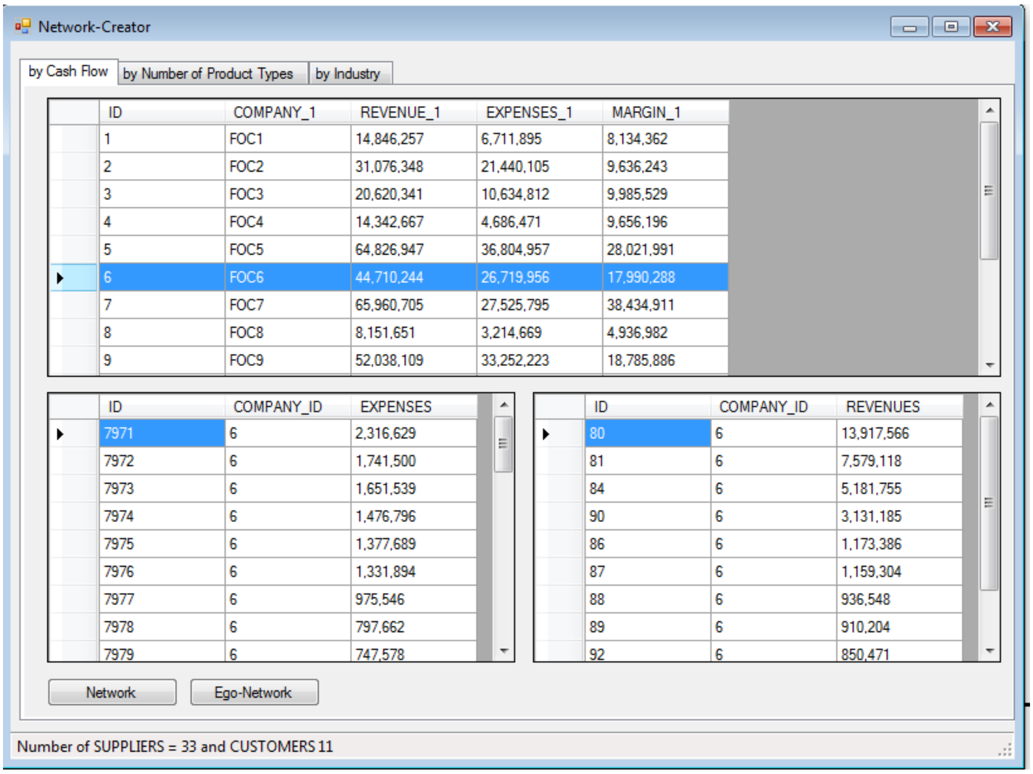


Figure 26: The Network Creator Application (Cash Flows Tab)

Apart from the opportunity to create individual ego-networks, our tool allows to derive the network structure from ego-network sampling. While processing, the data is de-identified. We therefore do not have to provide clear names, which is an advantage compared to qualitative sampling based on interviews which would require a name generator at the very least. The cash flows are also de-identified, we therefore process data without the naming of a specific currency. Instead of EUR or GBP we use an arbitrary monetary unit. In addition, although the network flows do not represent the most current data, they reflect nevertheless a typical economic year (2012) without general recession. In sum, we guarantee the required anonymity by adhering to the following points:

- Names and cash flows are encoded.
- Data originates from a representative economic year, but is not the most recent data.
- It is not possible to decode network flows or participants.
- The "Network Creator" tool ensures that data is encoded without losing any correlation.

The implemented algorithm to merge the different ego-networks executes several technical steps, namely (i) creation of temporary datasets, (ii) data storage, (iii) data encoding, (iv) network-file creation:

- First, the software creates temporary datasets (memory tables).
- In a second step, these datasets store the links between focal companies and their customers and suppliers. Using a query language called LINQ we make sure that the datasets do not contain duplicate entries for customers or suppliers. In case a customer or supplier already exists, the software only adds a new entry for a relationship between the focal company and this existing entry (customer or supplier).
- In a third step, we encode the given data. The use of the temporary datasets allows to encode the data and to recognise mutually shared business partners (e.g. VW AG) at the same time.
- In a final step, the data is written in a network-file.

We are aware that a customer of one focal company might be a supplier of another focal company. This is why the direction of the arcs gets important. The node classification (customer or supplier) is thus less relevant for the transfer of the concept of social network analysis than to consider the direction of the arcs.

4.4.3 Individual versus Network-based Research

The particular advantage of this network-based approach becomes apparent when we compare network-based research to an individually-based research. After the data collection, it is possible to start with an individually-based research design, focusing on individual, independent outcomes for each focal company (ego). As described, this approach is suggested by Borgatti and Li (2009) and applied by Kim et al. (2011).

In the context of business relationships and economic potentials, an individual research design looks at different companies and their key figures. All the companies in the sample have different ego-networks and perform differently. Figure 27 below shows one possible ego-network. Here we have a focal company in the centre and the previously identified important suppliers and customers surrounding it. The direction of the arcs (sending or receiving) illustrates the cash flow. The size of the vertices is adjusted to indicate the share of the cash flows. The suppliers are colored in red, the focal companies in yellow and the customers in green.

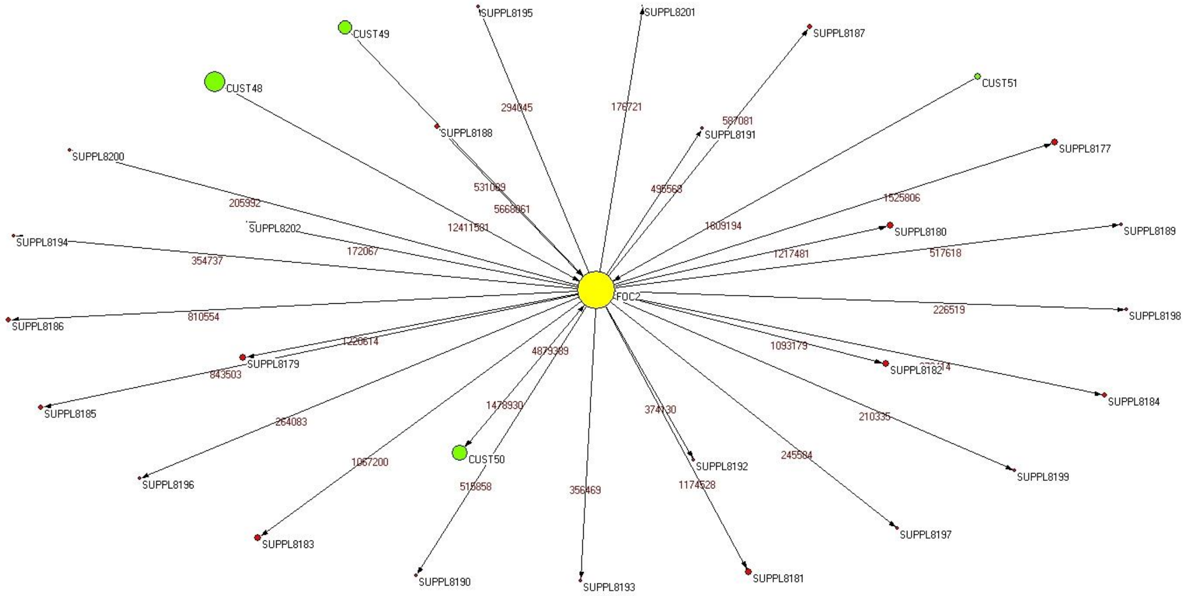


Figure 27: First Exemplary Ego-network Illustration

The ego-network of another company might look totally different. Figure 28 shows a network with only one main customer and few strong suppliers.

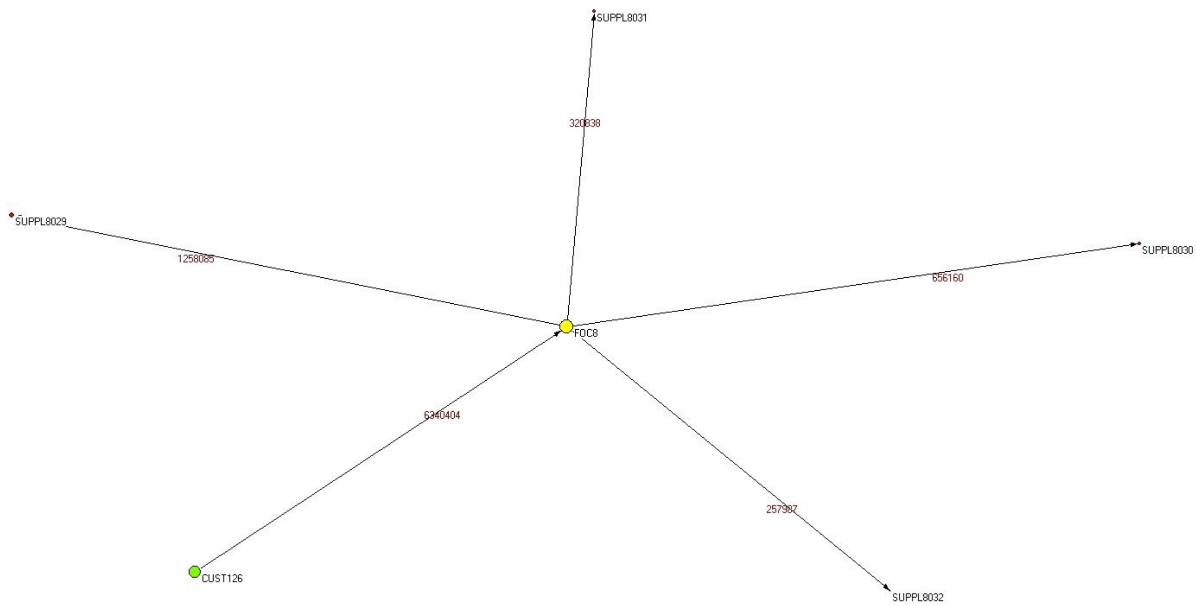


Figure 28: Second Exemplary Ego-network Illustration

One may use statistics in order to compare and assess the quality of the different ego-networks. According to the previously (Section 3.2.2) mentioned ego-network property for the quality of alters (connected nodes) of a focal company (ego), different attributes influence quality. For example on the customer side as well as on the supplier side, companies have an average cash flow to their strong partners. We can multiply the average cash flow with a diversification attribute which equals the proportion of the number of partners divided by the average number across all ego-networks of focal companies. The idea is to have an attribute that expresses whether a focal company has few or many strong partners. Thus, using the already mentioned Equation 4, the quality of an ego is influenced by its indegree (receiving arcs) on the customer side, and the outdegree (sending arcs) on the supplier side.

$$q_i = \sum_j x_{ji} \cdot a_j$$

Equation 4: Quality of an Alter as Ego-network Property
(Borgatti & Li, 2009, p. 8)

The quality q of an ego results from the sum of its relationships, measured by the cash flow x_{ji} respectively x_{ij} of each relationship and multiplied with the described diversification coefficient a. The calculation of the ego-network quality, divided by the total number of alters, finally expresses the average quality value q of each alter the focal company i is connected with. Variance and standard deviation may also be of interest.

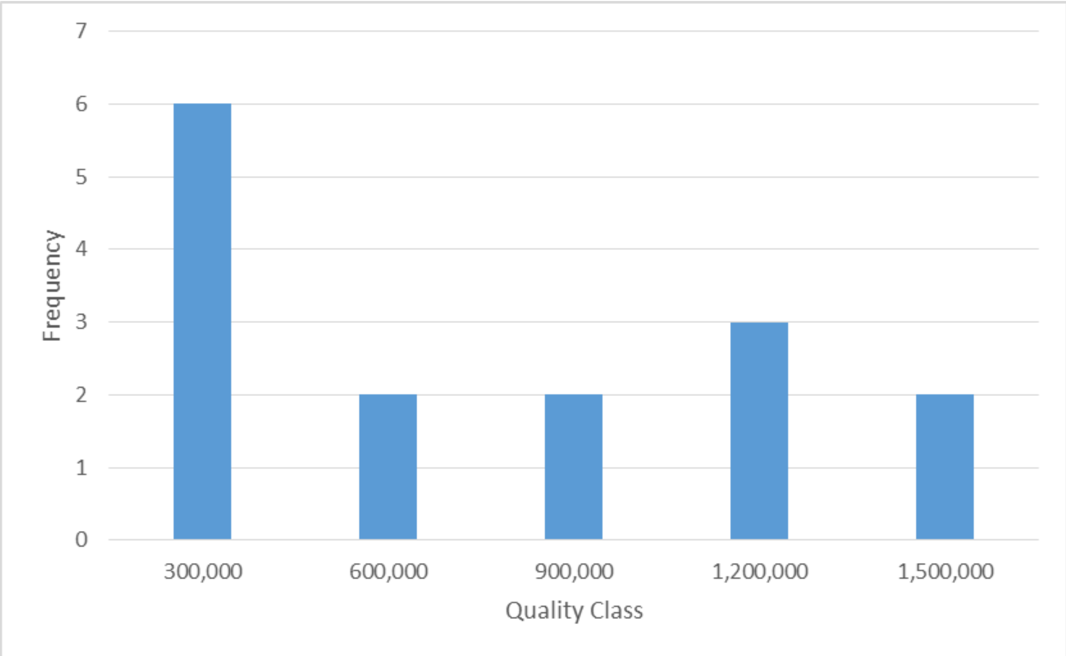


Figure 29: Exemplary Frequency Distribution by Classes of Quality

A frequency distribution such as illustrated by Figure 29 distinguishes different classes of quality. The exemplary illustration shows 15 focal companies categorised according to their quality. The analysis of financial performance measures on each focal company creates comparability. By the use of statistics, it is possible to verify whether focal companies in higher classes perform better.

In contrast to this presented individually-based analysis, we developed a network-based research design. Performing an egocentric network study which is merged from different ego-networks, we apply social network analysis to study a section of the scale-free supply chain network. As we suppose that the observations are not independent from one another, we want to take interference into account. This approach follows Robins (2015) who points out that "networks are based on connectivity, not atomization. Networks are structured and patterned, not summed and averaged" (Robins, 2015, p. 12). Our network based approach attempts to contribute to the balance between the individual and the system by conducting an egocentric network study. Using the algorithm mentioned above in 4.4.2, we merge the ego-networks of different focal companies so that overlapping connections between focal companies become apparent. This allows for a "bird's eye" view of part of the scale-free supply chain network. This approach is more holistic than the standard analysis of dyadic relationships of company-specific ego- networks.

4.5 Application of Social Network Analysis

The explorative approach of social network analysis requires measurable and coded relationships. Given that both vertices and arcs have attributes that are part of our study, values need to be stored. Values stored in partitions or vectors allow us to combine relational data (network position properties) with non-relational data such as economic performance (financial performance measures).

In case of partitions, as well as in case of vectors, we distinguish between properties on network positioning and node properties. One attribute on network positioning is node centrality, whilst the aggregated revenue for a common business partner between focal companies is a node property.

Finally, the focus of the explorative approach shifts from structural concepts to blockmodels. While concepts like centrality are the result of patterns of ties, a blockmodel deals with the roles and associated patterns of ties in the network at large. As with Nooy et al. (2011), blockmodelling is a flexible method for the analysis of social networks. By the use of a single technique, one can detect different kinds of structures.

4.5.1 Relational Data Linked to Statistics

Using attributes we can study subsections of the network. The social network analysis software Pajek uses partitions for classification or clustering of the network. Beside vertices and arcs, partitions are yet another data object in network files. Within a partition, each vertex (node) is assigned to exactly one class. As with Nooy et al. (2011), a partition of a network is defined as "a classification or clustering of the vertices in the network such that each vertex is assigned to exactly one class or cluster" (Nooy et al., 2011, p. 36). Partitions store discrete information of vertices. The term discrete means that there is a limited number of classes and that each class may contain several nodes. The different classes are assigned to integers.

Thus, by using classifications stored in partitions, one can extract exclusive subsets or parts of the network. For example, in the present case of the supply chain network, nodes are assigned to their number of connected business partners (degree centrality). Following Nooy et al. (2011) we distinguish three different ways of network reduction in which different extraction and shrinking processes are combined:

- The local view expresses a subset of the original network. This is the easiest method of network reduction. A group of vertices and the ties among them are extracted.
- The global view is based on the reduction of different classes. This process is called shrinking. One creates a new vertex that stands for each class. In contrast to the local view, the global view refers to a perspective that zooms out. It is not the individual vertex that is important, but rather the relationships between classes representing groups of vertices.
- The third way of reduction is the contextual view. Using a contextual view one can focus on the vertices of one particular group, which are connected by aggregated ties to new vertices representing each other class. This means that all classes are shrunk except one. The vertices of that one class remain existent, while the other vertices are replaced by one new node/vertex as a representative of their class.

Further, attributes allow us to interpret the network structure. By considering relations as channels that transport cash and product types between organisations, we investigate how these values and information flow. As with the previously mentioned flow mechanism (Section 3.3.2), we distinguish several concepts of centrality. Basic concepts such as (i) degree centrality, (ii) betweenness centrality and (iii) eigenvector centrality all cover different aspects. In all cases, a central or strategic position is the result of the system of channels. As network structure enables information exchange to take place, a central position leads to additional pressure together with an opportunity for power and profit.

For our analysis, differences in centrality scores should provide interesting remarks that allow us to draw conclusions from them. We expect to find out whether it is only important to be central or if a company also benefits from a position across many paths or if the centrality of the business partners is also key to performance.

To summarise, centrality is either about accessibility or importance (source of power). It is part of our analysis to go more into detail. With respect to the individual node, centrality might promise advantages because of the position. We apply a variety of measures, because it is not always the sheer number of links, but the diversity or quality of the connected nodes that counts.

Beside vertices, arcs and partitions, vectors are another important data object for network analysis. As mentioned above, partitions store discrete information of vertices and allow clustering or the interpretation of the network structure. In contrast to partitions, vectors are the best way to store continuous information. A continuous property stored in a vector takes not only integers but also decimal values. For example, in case of the supply chain network, we create a vector to aggregate cash flows because of revenue (sales) or procurement of different focal companies. If two focal companies (manufacturing companies) have a common customer or supplier, we aggregate the different cash flows to this customer or supplier. We store this information in a vector which allows us to review relationships for the matter of proportional strength. A vector is not intended to group vertices into classes, which means it is by never the right way to reduce a network. In fact, the previously mentioned opportunities of extraction or shrinking are reserved to partitions. The probability that two companies show exactly the same cash flow characterising their relationships tends towards zero which is why we do not use partitions here. Further, the result of any kind of calculation is often a decimal value and as already mentioned, only vectors can store continuous information.

Of course, a frequency table with boundaries for classification is not only of interest for partitions, but also for vectors. Using a frequency table one can create an overview of the distribution of stored values and have a basis for statistics. Values stored in a vector are continuous which is why each value probably occurs once. By setting boundaries the creation of a frequency distribution is also possible for vectors. In addition, statistical information such as average and standard deviation may be relevant.

To conclude, it becomes clear that partitions and vectors have different applications. Partitions help us to create subsets or store discrete information such as degree centrality. Vectors are best suited as a basis for calculation.

The graphical output of a stored attribute is either possible by printing the value next to the vertex, or by adapting their size relatively within the sociogram. Both help to recognise possible findings in the sociogram even faster.

Attributes such as different centrality measures, aggregated cash flows of vertices are part of our later statistical analysis. Statistics offer many possibilities to describe attributes and investigate possible associations between attributes. However it is not possible to use relational data directly. Where it is possible to express network position properties of vertices as attributes or properties of actors, such information is included in a statistical analysis. Thus, partitions and vectors which store such network position properties form the bridge between social network analysis and statistics.

4.5.2 Blockmodelling

Based on the previously described necessity to identify classes of nodes (Section 3.3.3), blockmodelling is our preferred method to do so.

Blockmodelling is based on structural concepts such as structural or regular equivalence. Vertices grouped into clusters and the relationships between the clusters are of interest. Thus, blockmodelling is about network analysis at large. As with Nooy et al. (2011), this stands in contrast to structural concepts like centrality, where the network position of each individual vertex is computed. Blockmodelling uses matrices for the computation and visualisation of the results. As Nooy et al. (2011) point out, akin to the two different network types (one-mode or two-mode), there are also two types of matrices (Nooy et al., 2011, p. 301):

- Within an adjacency matrix, each vertex is represented by a row and a column. In general the row entry is the sender, and the column entry the receiver. In the case of an undirected network, all choices are responded because of reciprocal relationships between sender and receiver. The illustration of an adjacency matrix is a square, for the reason that every vertex in a row is also represented by a column. This stands in contrast to the affiliation matrix.
- The affiliation matrix is also a rectangle but not necessarily a square. According to the two-mode network, there are two different sets of elements. The rows represent one set and the columns the other. The number of elements within the two sets may differ.

For the purpose of illustration, one uses black (filled) and white (unfilled) cells in the matrix. The filled cells represent existing ties.

At first sight, when looking at a matrix, there may be no scheme whether cells are filled or not. This is because the rows and columns representing existent or absent ties are randomly placed. The reordering of the vertices (permutation) may result in a much more regular pattern without changing the network structure. Following Nooy et al. (2011), the number of the vertices in the rows and columns as well as any reordering lead to a different matrix that represents the same network structure (Nooy et al., 2011, pp. 302–303). Thus, the permutation process simply helps to detect what already exists but what is hidden at first sight. As a key element of blockmodelling, permutation helps us to recognise whether actors with similar patterns of ties exist, and if so, whether these patterns are associated with a specific role. As by Nooy et al. (2011), social network analysis declares that based on particular patterns of ties it is possible to build equivalence classes or to find equivalent positions (Nooy et al., 2011, p. 306).

The previously mentioned structural and regular equivalence are two major types of equivalence. Nooy et al. (2011) give the following definition: “Two vertices are structural equivalent if they have identical ties with themselves, each other, and all other vertices” (Nooy et al., 2011, p. 307). Thus, structural equivalence means that two vertices are associated with each other and form a subgroup. Both vertices within this subgroup occupy identical relationships to vertices outside their own subgroup. Further, if one vertex creates a new relationship to another vertex outside the subgroup, the structural equivalent vertex is also automatically linked to the vertex outside the subgroup.

Transferred to the matrix perspective, the structural equivalence between two vertices only refers to their profile of rows respectively columns in the matrix. This means that two vertices are still structurally equivalent, even if two of their connected vertices have different connections by themselves.

Regular equivalence as another type of equivalence is less strict. In case of regular equivalence, it is only important that the compared vertices are connected to vertices in the same class. In order to identify vertices within the same class as regularly equivalent, it is important that these vertices are connected to vertices of the same class, but the connection to just one vertex is sufficient as a condition for regular equivalence. It is not important to be connected to all the vertices. If we transfer this condition to the blockmodel, the blocks do not have to be complete (Nooy et al., 2011, p. 322).

The graphical representation of a matrix may show lines that demarcate classes of vertices. These lines are used to divide the matrices into blocks. Consequently, the matrix can be simplified. Each class in the matrix is reduced to one single entry in a new matrix. Structural equivalence only allows complete or empty blocks. Regular equivalence allows regular blocks as well. A regular block consists of at least one arc in each row and one arc in each column. The simplified matrix is called an “image matrix”. The image matrix is the last step towards defining a blockmodel which, as per Nooy “assigns the vertices of a network to classes, and it specifies the permitted types of relation within and between classes" (Nooy et al., 2011, p. 316). Consequently, a blockmodel requires a partition and an image matrix:

- The partition assigns vertices to classes and it divides the matrix into blocks.
- The image matrix identifies the types of relations within and between the classes, as it defines the kind of blocks that are allowed and where they occur.

In sum, the blockmodel describes the overall structure of the network and it states the position of each vertex within this structure.

When performing social network analysis, it is unlikely to know the basic blockmodel which consists of the partition of vertices and the image matrix. Instead, it is common to start with a network and to look for the blockmodel that captures its structure. We therefore perform the process of blockmodelling in three steps:

- First, we specify the number of potential classes.
- The second step relates to defining the blocks and their location in the image matrix.
- The final step involves the partitioning of vertices into the specified number of classes. As with Nooy et al. (2011), we perform this step according to the specifications defined by the model (Nooy et al., 2011, p. 317).

By completing the three steps, the blockmodel is comprehensive. The first two steps define the image matrix. We fix the number of classes, as well as the type of relations (blocks). The information as to which vertices are part of a particular class is the result of step three.

It is obvious that at least some knowledge with regard to the network and an appropriate number of classes is obligatory. If each block of the matrix is checked for the right type according to the image matrix, one compares an ideal image matrix with the real matrix. The image matrix sets the constraint and the third step of blockmodelling includes the finding of the partition that fits best. Using a recursively called algorithm, Pajek as software for social network analysis supports us finding the appropriate partition with the lowest error score. Given the random movement of vertices, this approach of optimisation cannot guarantee that one always gets the best solution. However, it is very likely that constant improvement finally results in the best possible solution. Further it is important to keep in mind that another number of classes or permitted types of blocks may lead to a better fitting blockmodel. That is why as with Nooy et al. (2011) it is best to test slightly different blockmodels with a varying number of classes or other constraints to the same data (Nooy et al., 2011, p. 318).

When looking for a blockmodel that fits a particular network, the main focus is on the detection of a particular structure. The possibly existing equivalent classes may be used later as variables for statistical analysis. In this context, we have to consider that there will always be a best fitting blockmodel. We must therefore align with Nooy et al. (2011) who state that “we will always find a best fitting blockmodel, even on a random network that is not supposed to contain a regular pattern. Therefore, we should restrict ourselves to blockmodels that are supported by theory or previous results” (Nooy et al., 2011, p. 324).

In general, one therefore starts with an idea concerning the number and types of blocks. In addition, it is helpful to test the result. One opportunity for verification involves linking the result of equivalent classes to data like actor attributes.

Transferred to the supply chain context, structural equivalence is clearly too strict. If two vertices were structurally equivalent, one company could just replace the other, because they would be identical. In terms of our analysis, blockmodelling contributes to analyse companies with regard to their industry specific connections. Based on an affiliation matrix in which we assign companies to the industries they work for, we create a blockmodel based on regular equivalence.

Summary

Our cross-sectional research design involves explorative, as well as quantitative analysis. We collect quantitative data on two subjects of analysis, namely the supply chain network and business reports. Network position properties are part of the data collection of the created supply chain network of companies. The data of financial performance measures are the result of a quantitative analysis of business reports.

Combining both, the network position properties as well as the financial performance measures, we deal with metric data. For the reason of metric data, linear regression is our preferred approach to test our hypotheses in the way of a network position property influencing performance. Consequently, the network position properties are the independent variables IVs of our later analysis. The financial measures of performance are the dependent variables DVs.

In order to obtain reliable results, the given sample of focal companies must be within a certain specification framework. The sample therefore consists of typical German plastics processing companies, which are all globally active. As already defined, these focal companies are manufacturers for their customers. The companies deliver finished or semi-finished parts that are incorporated into final products. That is to say, to a certain extent, the companies are comparable. The application of a quick-test ensures that a general broad spectrum is covered and no company is on the verge of insolvency.

We create the network file for our analysis using the software-tool which we programmed for this purpose. We explain why this adds to a new methodological approach by comparing the ego-network approach to our egocentric study on a supply chain network. Instead of comparing different individual supply chain networks (focal company with its business partners) for their quality, our egocentric network study aims to allow a view on a section of the scale-free supply chain network. We can only take this view because of the new conceptual work.

We analyse the supply chain network by means of the explorative approach of social network analysis. The main focus in this context is the supply chain network. Companies and the relationships among them form a one-mode network. Using partitions, there exist different methods to reduce a network. The local view, the global view and the contextual view help us to analyse the network in an explorative way. The calculation of properties of network positioning such as proportional strength and different concepts of centrality add value to our following analysis.

As the final part of the methodology, blockmodelling contributes by taking a view at large. By means of blockmodelling, it is possible to look for structural or regular equivalent classes. This can contribute to the later analysis in terms of the diversity question. While structural equivalence is too strict, the use of regular equivalence might add value to our analysis.

5 Data Analysis and Results

In Section 5.1, we first summarise the results of three independent pilot interviews prior to our data collection. The pilot interviews with chief executives of typical manufacturing companies confirmed the timeliness of our network-oriented research for performance measurement.

In Section 5.2 we analyse our convenience sample of focal companies. The results of the quick test confirm that our sample shows no signs of a one-sided distribution with respect to economic performance. Subsequently, we explain our way to collect indirect networkdata. Using a cut-off sampling we make sure that the network we create has an adequate size. We explain more in detail the difference between the well-known idea of ego-network quality and our network-oriented approach. Using our software-tool “Network Creator”, we create the section of the scale-free supply chain network which we study. Data of network position properties of focal companies is associated with financial performance measures from business reports. The aggregated results of the business report analysis are presented.

In Section 5.3, we perform the detailed test of our three main hypotheses to answer our research question. The major part of our results is based on linear regression. We study the statistical association between two observed features by means of correlation. Linear regression adds an equation with which we can calculate the dependent financial performance measure on the basis of the independent variable of network positioning.

Following the presentation of the summarised results (Section 5.4), we verify whether any observed influence of network position properties on financial performance measures can be confirmed by measures for ranking and prestige (Section 5.5). As illustrated, structural prestige because of ranking and prestige does not necessarily mean social prestige. Yet, if we acknowledge that, economic performance (measured by financial performance measures) leads to social prestige, we can indirectly establish a link between structural prestige and social prestige. The confirmation of structural prestige influencing social prestige strengthens our results.

In Section 5.6 we finally develop performance measurement models by means of multiple linear regression in Section. Using multiple linear regression, we study the combined effect of several variables (network position properties) on each financial performance measure of the results that were found to be the most significant of our hypotheses testing. Using a backward elimination process it is possible to identify the influencing network position properties. The presented results (Section 5.7), form the basis to inform on a new network perspective in performance measurement in the subsequent Chapter 6.

5.1 Initial Overview

To put things together, we go briefly through the guide for network design suggested by Robins (2015, p. 59).

- What are the outcomes of interest? How are these outcomes measured or observed?
  Our outcome of interest is the exploration of a link between the different network positions of companies in the supply chain network and their financial performance. To achieve this, we investigate the three derived hypotheses. We assume that economic performance depends on the independent variables specifying (i) strength of links, (ii) node centrality, and (iii) link diversity. The outcomes are primarily related to the individual level of each actor.
- Who are the actors?
  The actors of this study are focal companies (manufacturing companies in the German plastics processing industry), their customers and their suppliers. Using the definitions in 4.2.2, we set the main focus on a unipartite (one-mode) network design ($G_{\mathrm{D}}(V, A)$). When looking for diversity, a bipartite graph (two-mode) containing the focal companies and their industries is added ($H_{\mathrm{D}}(W, B)$).
- Is there an obvious network boundary?
  We consider the egocentric network study as a kind of a network sampling. Boundaries for the analysis are given by the limited number of participants (focal companies) and their business partners. Nevertheless, one has to keep in mind that the underlying supply chain network is scale-free and has no obvious boundaries.
- What are the important relational ties?
  Relationships between companies, as well as relationships to complementary industries are the important ties. The ties either represent network flows (cash flows and product flows) between companies or affiliation to different complementary industries. Consequently, negative ties do not exist in our study.
- Is time important?
  This study of the network position with respect to the economic performance of companies is no longitudinal study. In any case, carrying out future research based on this work might explore the development of the network over time. Where data access and financial limitations do not present a problem, a review for a 3 to 5 year period would add value. This is also part of our later discussion and might be an application of this work.

- Are there other exogenous factors that might be relevant? What is the scale of the research context?
  There are no other relevant exogenous factors. Our study explores a convenience sample of focal companies. If additional resources are available, our developed approach is also applicable on a larger scale. In theory, the methods to analyse our research question are also tractable for very large data. The transfer to a larger population or a review in other industrial sectors might be an additional application of our results.

Prior to data collection, we interviewed three companies as piloting companies. The piloting companies are not part of our study. All three interviewees were chief executives. In one case, we carried out a comprehensive meeting in which the supply chain manager of the company was present too. Aside from a general explanation of our network-oriented research, the main part of the discussion involved the following three points:

- Are your strategic decisions influenced by the transition from individual supply chains to a supply chain network in which your company operates?
- Are you concerned whether it is possible to improve your own position in the supply chain network?
- Do you think about performance measurement with respect to the supply chain network?

In all three cases, the interviewees confirmed the timeliness of our supply chain network approach, considering their own network position. One company confirmed that they were in a good position to play suppliers off each other in order to reduce prices. However, strategic decisions are often based on a gut feeling. In all three cases, companies use performance measurement solely with an internal focus, although they recognise the limitations and problems of these measurements with respect to the supply chain network. Because these companies consider the supply chain network to be non-transparent, they just “muddle through”.

Finally, thanks to the comprehensive explanations given, all interviewees understood the presented methodological approach of our study well. With respect to data collection, they encouraged us to collect quantitative data. In accordance with our previously mentioned concerns such as the potential poor quality of given responses, the interviewees encouraged us to rely on our methodology although this sets limits to the sample size. Instead of hoping for some pseudo generalisation because of accessing an industrial association, we were told to expect more in-depth network knowledge by convenience sampling.

5.2 Data Collection

As mentioned, our analysis is based on convenience sampling. To study the impact of characteristics of network positioning on financial performance, the following analysis is based on a network with $u = 15$ focal companies and their customers and suppliers, $v = 448$ companies (nodes) in all. In the statistical analysis, we focus on the results of the focal companies. Acknowledging the previously described duty of care (encoding of companies and relationships), we found a sample size of 15 focal companies accessible. Section 4.2.4 explains why we consider our sample reliable.

Table 12 below shows the result of the quick test which underlines the reliability of our sample. The quick test confirms that there is no one-sided distribution. The sample includes reviews on companies ranked from very good, good, mean to bad. No company seems to be on the edge of insolvency. We provide the complete quick test of each company in the Appendix A2. The performance of a company is one part in any business valuation like the quick test. Nevertheless, there are other important factors that affect the final score such as financial stability, for example. The few missing values result from incomplete information of business reports analysis. Inaccessibility or imperfect fulfilment of accounting policies are possible reasons.

Table 12: Results of the Quick Test of the Convenience Sample

	Financial stability (year 1)	**Earning power (year 1)**	**Financial stability (year 2)**	**Earning power (year 2)**	**Avg. Ø**
FOC1	3	4.5	3	4.5	3.75
FOC2	3	3.5	3	3.5	3.25
FOC3	1	1	1.5	2.5	1.5
FOC4	1	1	1	1	1
FOC5	1.5	2	1	1	1.375
FOC6	2.5	4	2	3	2.875
FOC7	2	2.5	3.5	4	3
FOC8	-	-	-	-	
FOC9	-	-	-	-	
FOC10	1	1	1	1	1
FOC11	3.5	4	3.5	4	3.75
FOC12	3	3	3	3	3
FOC13	1	2	1	2.5	1.625
FOC14	-	-	-	-	
FOC15	1	3	1	3.5	2.125

In general, data collection using social network analysis focuses on structure of choice within a group. We collect data by looking for favourites with respect to a certain activity like for example being in a central position. Different techniques like questionnaires or interviews are one possible way for data collection. Other studies in our field of supply chain research, such as done by Harland et al. (2001), are based on this method of qualitative data collection.

One important novelty of our thesis is the transfer of findings of sociometrists to the supply chain network which is created from a sample of quantitative real-time data (Section 4.3.2). Thus, in carrying out our quantitative network analysis, we collect networkdata in an indirect way.

As with Nooy et al. (2011), the quality of indirect networkdata is better than the quality of direct data (e.g. collected through surveys). The authors hold that responded data “rely on the often inaccurate recollections of respondents” (Nooy et al., 2011, p. 26).

The values of network flows originating from revenues (sales) or procurement are one major characteristic of relations in the supply chain network. We add characteristics of vertices to the analysis. One simple characteristic in the supply chain network is the type of each company. Companies are either suppliers, focal companies (manufacturing companies) or customers.

Due to the necessity of clarity mentioned above, we concentrate on the top suppliers and customers of each focal company using a cut-off-sampling. Given the need to detect an adequate size, we sort the suppliers and customers of each focal company in descending order either based on their share of revenues (sales) or based on their share of procurement. Then we calculate the 80 % limit of revenue (sales) and procurement for each focal company. The network study involves as many suppliers and customers as are responsible for 80 % of the revenues and procurement of each focal company. This reduction ensures that each focal company is represented by the same proportion of its customer and supplier base in the final network $G_{\mathrm{D}}(V, A)$.

By showing the company specific procurement limit, Table 13 illustrates how many top suppliers are involved in order to get close to the 80 % limit.

Table 13: Overview of the Procurement Side in the Network

Company	80 % Limit	Involved TOP suppliers
FOC1	5,369,516	25
FOC2	16,895,739	26
FOC3	8,507,849	12
FOC4	3,749,177	7
FOC5[7]	21,426,463	62
FOC6	21,375,965	33
FOC7	22,020,636	25
FOC8	2,571,735	4
FOC9	26,601,778	27
FOC10	11,392,082	16
FOC11	4,771,906	16
FOC12	14,461,748	7
FOC13[7]	26,565,968	13
FOC14	2,036,342	15
FOC15	5,002,563	10

In a similar way compared to the procurement side, Table 14 shows the 80 % limit of revenues (sales) originating from a number of involved top customers.

Table 14: Overview of the Revenue (Sales) Side in the Network

Company	80 % Limit	Involved TOP Customers
FOC1	11,877,006	16
FOC2	24,861,078	4
FOC3	16,496,273	5
FOC4	11,474,134	9
FOC5[8]	50,000,259	10
FOC6	35,768,195	11
FOC7	52,768,564	16
FOC8	6,521,321	1
FOC9	41,630,487	10
FOC10[8]	33,486,902	62
FOC11[8]	7,643,216	4
FOC12	24,259,803	7
FOC13	52,031,219	46
FOC14	4,789,456	16
FOC15	13,897,052	10

In order to make the network easier to handle, Section 4.3.2 justifies why we decided to limit the analysis to 80 % of the revenues and procurement of each focal company. The fact that the proportion of customers (respectively suppliers) responsible for 80 % of revenues (procurement) is relatively small compared to the entire customer (supplier) base confirms us.

[7] Internal procurement with subsidiary excluded
[8] Internal revenue with subsidiary excluded

The sample of our 15 focal companies shows that the main part (80 %) of procurement costs is spent on a relatively small proportion ranging from 2.8 % up to 18.75 % of all the suppliers. Thus in terms of procurement, companies clearly focus on their strong connections. As Table 15 illustrates, we can recognise the same for the revenue side. Companies make 80 % of their revenues (sales) with 1.79 % up to 21.68 % of all their customers. However, this says nothing about the success of this business strategy. A correlation coefficient of -0.0012 indicates that there is no dependency between the major part (80 %) of the generated revenue and the company-specific share of customers responsible for it. We see this lack of correlation as positive for our sample of focal companies and our general approach of network thinking.

Table 15: Percentages of Overall Suppliers and Customers

Company	**Suppliers (Procurement)**			**Customers (Revenue)**		
	TOP	**Total**	**%**	**TOP**	**Total**	**%**
FOC1	25	203	12.32	16	129	12.40
FOC2	26	272	9.56	4	46	8.70
FOC3	12	163	7.36	5	55	9.09
FOC4	7	110	6.36	9	130	6.92
FOC5	62	800	7.75	10	128	7.81
FOC6	33	422	7.82	11	156	7.05
FOC7	25	190	13.16	16	121	13.22
FOC8	4	41	9.76	1	56	1.79
FOC9	27	539	5.01	10	111	9.01
FOC10	16	417	3.84	62	286	21.68
FOC11	16	163	9.82	4	44	9.09
FOC12	7	235	2.98	7	54	12.96
FOC13	13	465	2.80	46	1048	4.39
FOC14	15	80	18.75	16	118	13.56
FOC15	10	69	14.49	10	71	14.08

Following the data collection, we proceed with an individual, ego-based research design, focusing on independent outcomes of ego-network quality for each focal company, such as explained in Section 4.4.3. Although we have already described the individual research approach briefly, we explain its application here more in detail. This is important in order to illustrate to what extent our network-oriented approach is innovative. The individual research design looks at different companies and their cash flows. All the focal companies in our sample have different ego-networks and perform differently. Figure 30 to 31 illustrate two different ego-networks. Bidirectional arcs indicate that a business partner is supplier and customer at the same time. As already mentioned, in case the node type is important for the purpose of our analysis, we use an incoming or outgoing links for classification in order to ensure a clear identification. We provide the complete sample of 15 ego-networks in the Appendix A3.

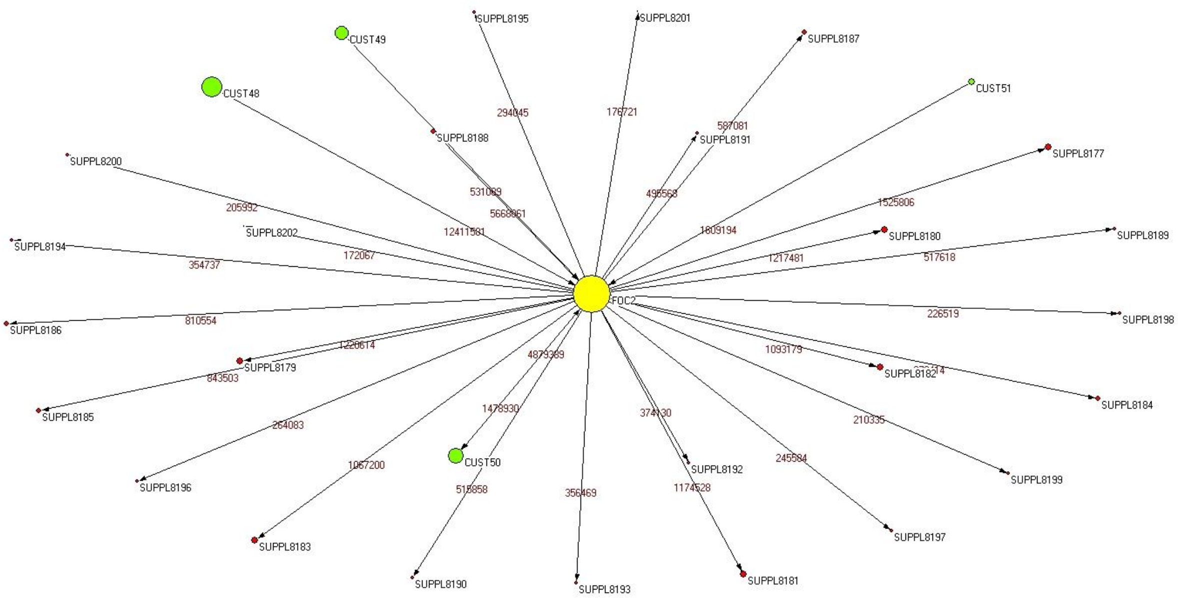


Figure 30: Ego-network Illustration of Focal Company 2

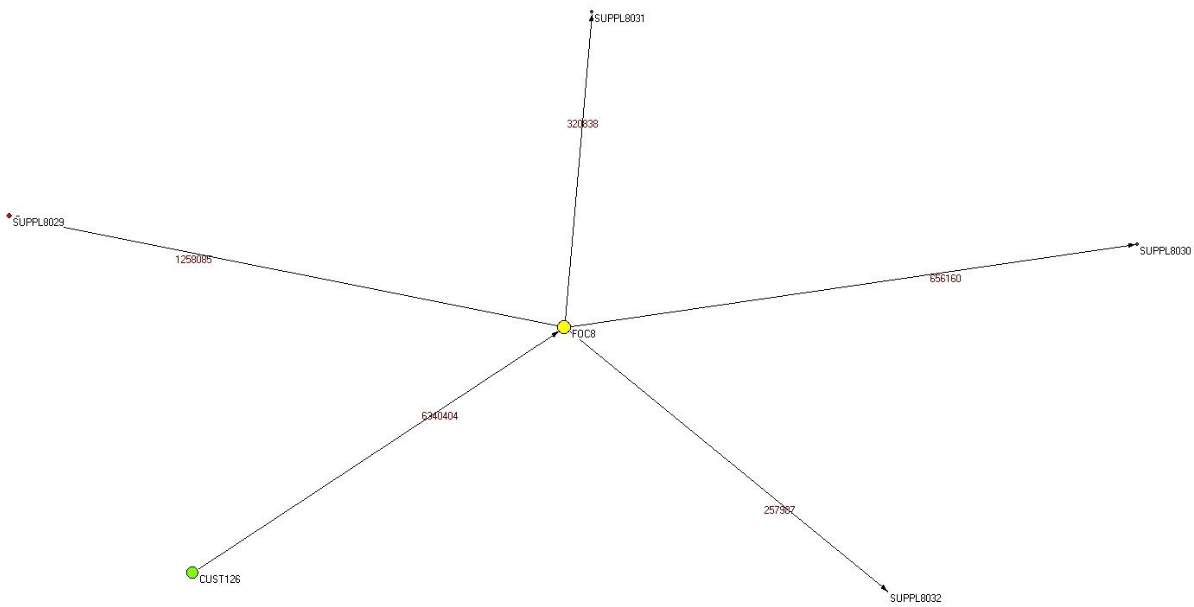


Figure 31: Ego-network Illustration of Focal Company 8

We use descriptive statistics to compare the quality of the different ego-networks. According to the ego-network property described in Section 3.2.2 which is proposed by Borgatti and Li (2009) in order to assess the quality of alters of an ego, different attributes influence quality. For example on the customer side, companies have on average 15 strong partners. On the supplier side, we determine an average of 19 partners. We define a diversification attribute which equals the proportion of number of partners and the average number illustrated by Table 16. Our basic idea is to have an attribute that expresses whether a focal company has few or many strong partners.

Table 16: Calculation of the Average Number of Partners

	Suppliers	Customers
Sum of top partners	298	227
Number of Focal Companies (Egos)	15	15
Average number of partners	19	15

Thus, using Equation 5, the quality of a focal company (ego) is influenced by its indegree on the customer side, and the outdegree on the supplier side because of the attribute *a*.

$$q_i = \sum_j x_{ji} \cdot a_j$$

Equation 5: Quality of an Alter as Ego-network Property
(Borgatti & Li, 2009, p. 8)

The calculated quality of an ego is the result of the sum of its relationships, measured by the cash flow x_{ij} respectively x_{ji} of each relationship and multiplied with the diversification coefficient. The calculation of the ego-network quality divided by the total number of alters, gives the average quality value of each alter. Variance and standard deviation can also be of interest.

Table 17 shows the calculation for the quality of supplier relationships. As measure of location, we calculate a median of 598,505 for the quality of relevant alters (suppliers). The average of all values equals 670,857 and the standard deviation is 452,892. Figure 32 illustrates different classes of ego-network quality and shows the frequency distribution of focal companies.

Table 17: Ego-networks with Suppliers

	Procurement $\sum x$	**Suppliers** n	**Coefficient** a	**Quality** q **(EgoNet)** $\sum x \cdot a$	**Quality (node)** q / n
FOC1	5,315,354	25	$25/19 = 1.316$	6,993,886.84	279,755
FOC2	16,838,108	26	$26/19 = 1.368$	23,041,620.94	886,216
FOC3	8,470,505	12	$12/19 = 0.632$	5,349,792.63	445,816
FOC4	3,672,271	8	$8/19 = 0.421$	1,546,219.37	193,277
FOC5	21,365,633	62	$62/19 = 3.263$	69,719,434.00	1,124,507
FOC6	21,333,024	33	$33/19 = 1.737$	37,052,094.32	1,122,791
FOC7	21,892,583	25	$25/19 = 1.316$	28,806,030.26	1,152,241
FOC8	2,493,070	4	$4/19 = 0.211$	524,856.84	131,214
FOC9	26,570,546	27	$27/19 = 1.421$	37,758,144.32	1,398,450
FOC10	11,371,598	16	$16/19 = 0.842$	9,576,082.42	598,505
FOC11	4,754,826	16	$16/19 = 0.842$	4,004,064.14	250,254
FOC12	14,440,422	7	$7/19 = 0.368$	5,320,155.62	760,022
FOC13	25,654,228	14	$14/19 = 0.737$	18,903,115.72	1,350,223
FOC14	2,034,065	15	$15/19 = 0.789$	1,605,840.48	107,056
FOC15	4,988,038	10	$10/19 = 0.526$	2,625,283.27	262,528

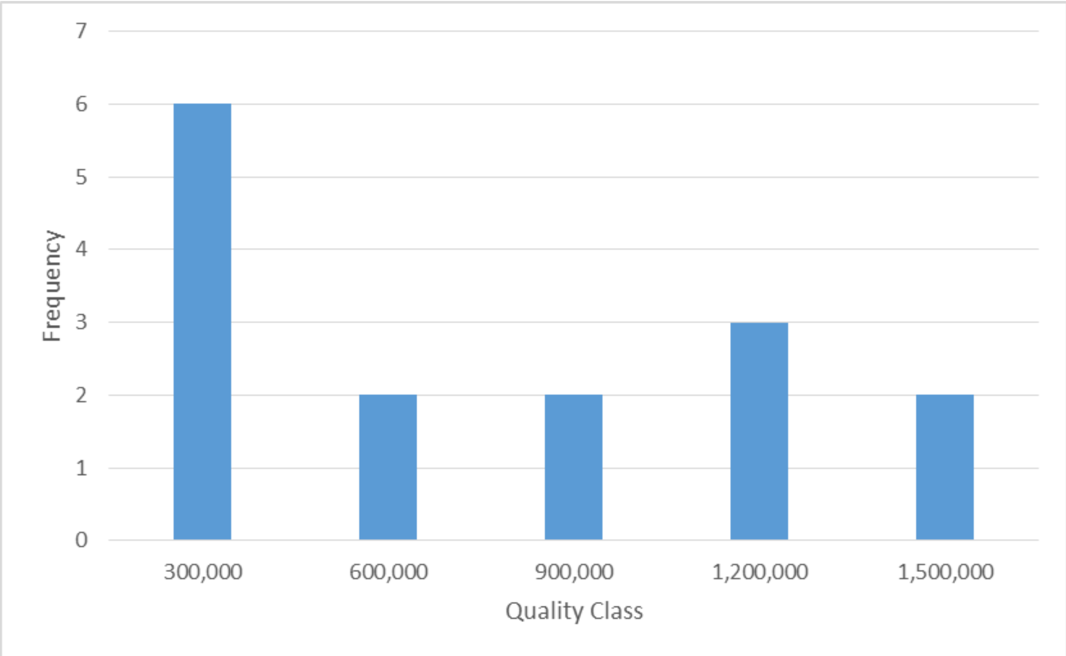


Figure 32: Frequency Distribution by Classes of Expenses Quality

In the same way, Table 18 shows the quality calculation of customer relationships. In terms of customers, the median is 1,558,719. The average of all values is 1,711,840 and we measure a standard deviation of 1,123,488. The frequency distribution of focal companies illustrated by Figure 33 distinguishes different classes of quality.

Table 18: Ego-networks with Customers

	Revenues $\sum x$	**Customers** n	**Coefficient** a	**Quality** q **(EgoNet)** $\sum x \cdot a$	**Quality (node)** q/n
FOC1	11,757,362	22	$22/15 = 1.467$	17,244,131.36	783,824
FOC2	24,568,225	4	$4/15 = 0.267$	6,551,526.74	1,637,882
FOC3	15,582,984	5	$5/15 = 0.333$	5,194,327.92	1,038,866
FOC4	11,387,591	12	$12/15 = 0.800$	9,110,072.87	759,173
FOC5	49,992,887	11	$11/15 = 0.733$	36,661,450.40	3,332,859
FOC6	35,659,217	25	$25/15 = 1.667$	59,432,027.93	2,377,281
FOC7	52,499,257	21	$21/15 = 1.400$	73,498,959.73	3,499,950
FOC8	6,340,404	6	$6/15 = 0.400$	2,536,161.72	422,694
FOC9	43,131,485	12	$12/15 = 0.800$	34,505,188.03	2,875,432
FOC10	33,361,455	67	$67/15 = 4.467$	149,014,497.70	2,224,097
FOC11	7,323,539	6	$6/15 = 0.400$	2,929,415.45	488,236
FOC12	23,380,787	7	$7/15 = 0.467$	10,911,034.12	1,558,719
FOC13	51,845,592	48	$48/15 = 3.200$	165,905,895.41	3,456,373
FOC14	4,757,067	17	$17/15 = 1.133$	5,391,343.15	317,138
FOC15	13,576,102	11	$11/15 = 0.733$	9,955,808.27	905,073

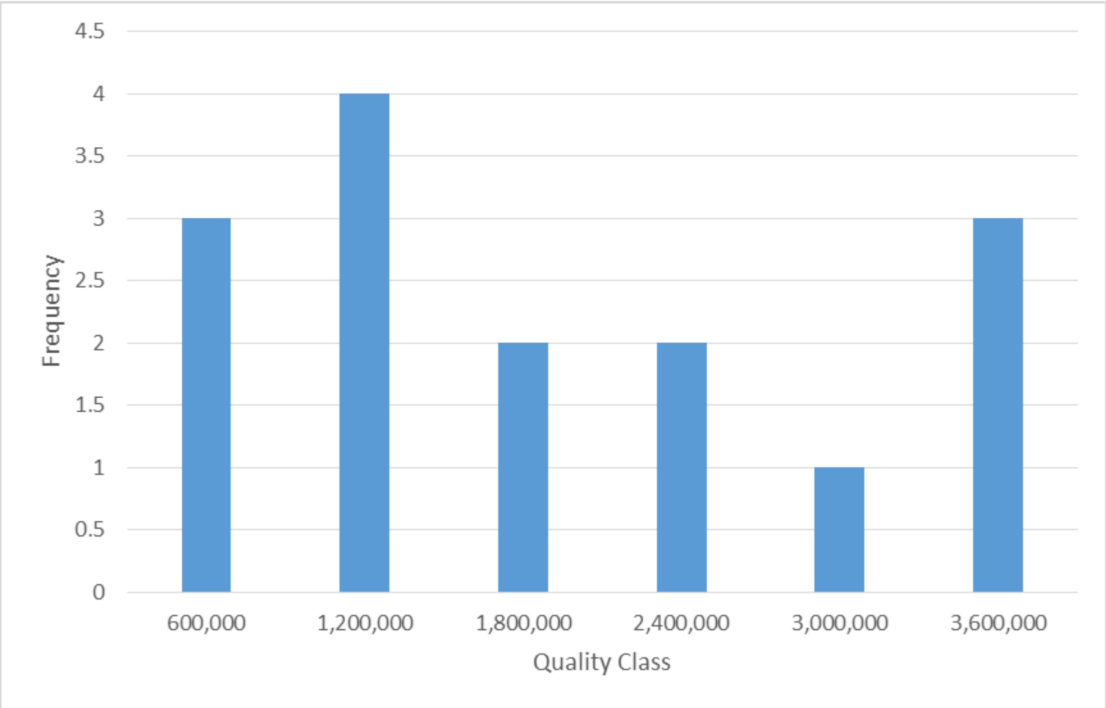


Figure 33: Frequency Distribution by Classes of Customer Quality

The focal companies FOC5, FOC7, FOC9 and FOC13 all have strong relationships of high quality. Given the now obvious question whether these kinds of relationship promise success, the financial analysis of business reports for each company would allow to find answers.

However, at this point we take a different, more holistic approach compared to the just applied ego-network approach. Focusing on a network-based approach, we transfer network and graph theories from social network analysis to analyse a section of the scale-free supply chain network. We suppose that the observations of different focal companies are not independent from one another. On the contrary, if mean values are to be calculated we have to take interference into account. Robins (2015) underlines this point by holding that “networks are based on connectivity, not atomization. Networks are structured and patterned, not summed and averaged” (Robins, 2015, p. 12). Our network based approach tries to contribute on the balance between the individual (focal company) and the system (network). Figure 34 provides an overview of our egocentric network study. The network file is created by our programmed “Network Creator” software (Section 4.4). The software is used for the following main features:

- Processing enterprise, real-time data by the use of a database.
- Merging relationships between different focal companies and their business partners.
- Identifying overlapping connections among different focal companies.
- Encoding names and network flows, to ensure that ethical requirements are fulfilled.
- Creating ready-to-use network files for the purpose of our analysis.

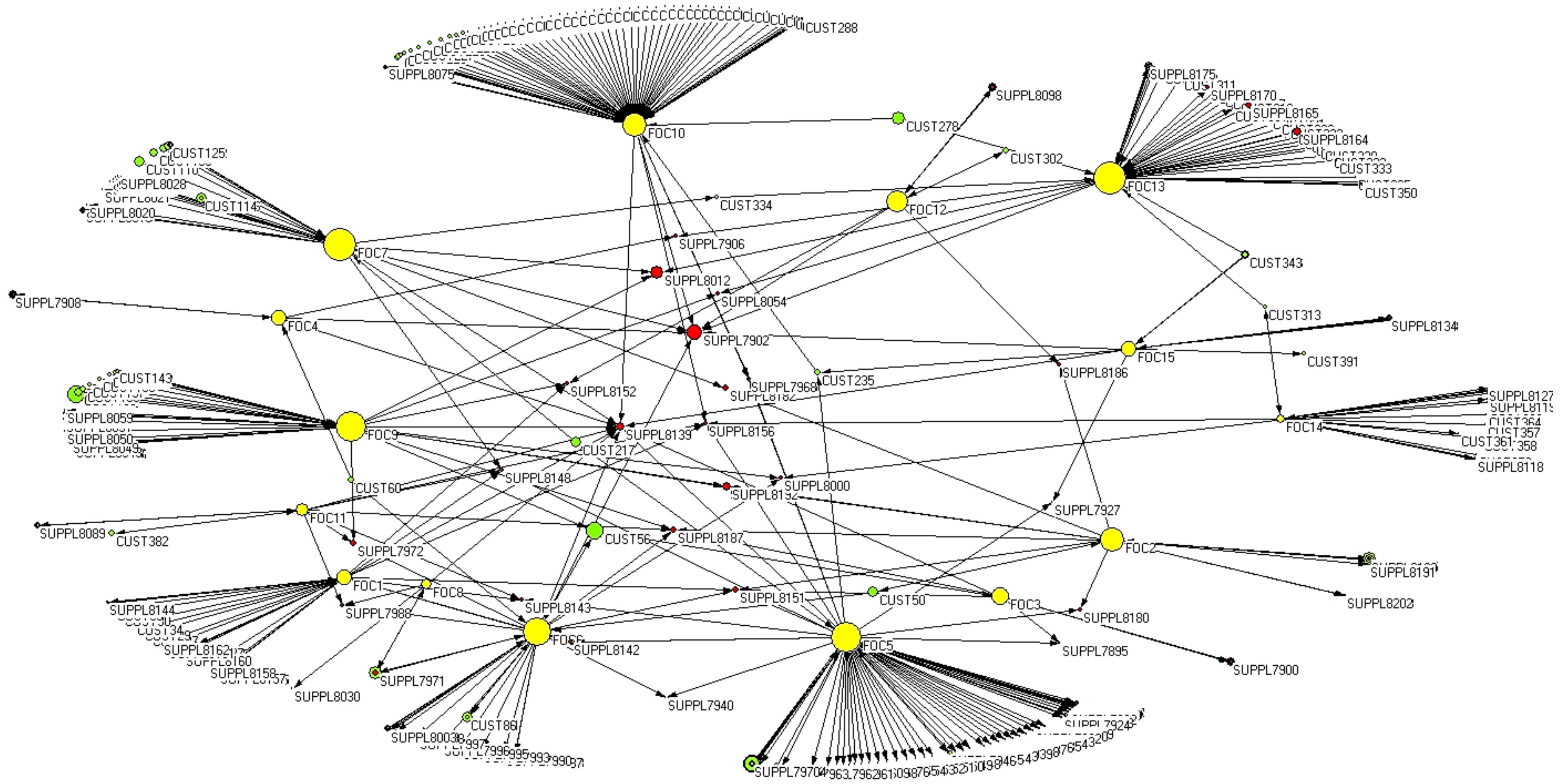


Figure 34: Directed Graph, $G_D(V, A)$, of the Egocentric Network Study with $v = 448$ companies of which $u = 15$ are focal companies (coded yellow). Suppliers are coded red, and customers coded green. Where companies are both suppliers and customers the designation of supplier or customer is determined by the direction of the arc representing the cash flow. The size of the node is proportional to the total cash flow, $\Sigma_j x_{ij}$, to the company j at that node. The arrows indicate the direction of cash flow. A double ended arrow indicates cash flow in both directions, and hence two arcs, one in each direction.

The pairs of actors (dyads) together with the ties between those actors, are a main focus of our analysis. Instead of concentrating only on a binary network (present or absent ties), this analysis also considers that ties are weighted. Thus, as previously described for the individual-based approach, ties of different strength exist and can be made visible through the “Network creator”.

Taking a closer look at the section of the scale-free supply chain network, density and the average degree per node are two general properties on the network level:

- Density as the most basic network property expresses the proportion of ties that are present compared to the total number of possible ties within the network. Our network created from ego-network sampling has a density of 0.00262 under the condition that self-ties (connections with one-self, also known as loops) are permitted.
- Further, the average degree (number of direct links) per node is 2.3437.

As both figures of density and average degree per node are rather informative, the degree distribution goes more into detail. The all-degree distribution shows which nodes are very prominent, because of the highest number of arcs sent and received. As Table 19 shows, the degree ranges from 1 up to 78. The # sign indicates that several nodes are in the appropriate class. Given that focal companies may have connections to a node which acts at the same time as customer and supplier, arcs pointing from and to one business partner may exist at this point of our analysis.

Table 19: All-Degree Frequency Distribution

Degree	Number of vertices	Percentage	Example
78	1	0.2232	FOC10
72	1	0.2232	FOC5
59	1	0.2232	FOC13
44	1	0.2232	FOC6
41	2	0.4464	#FOC1
37	1	0.2232	FOC9
31	1	0.2232	FOC14
30	1	0.2232	FOC2
20	2	0.4464	#FOC11
17	1	0.2232	FOC3
16	1	0.2232	FOC4
14	1	0.2232	FOC12
11	1	0.2232	SUPPL8139
7	1	0.2232	SUPPL7902
5	5	1.1161	#FOC8
4	1	0.2232	SUPPL8148
3	11	2.4554	#CUST50
2	35	7.8125	#CUST26
1	380	84.8214	#CUST27

Figure 35 shows a histogram of the degree distribution. For the sake of clarity, the class with a degree of only 1 is not included, because nodes in this class are only connected to one focal company.

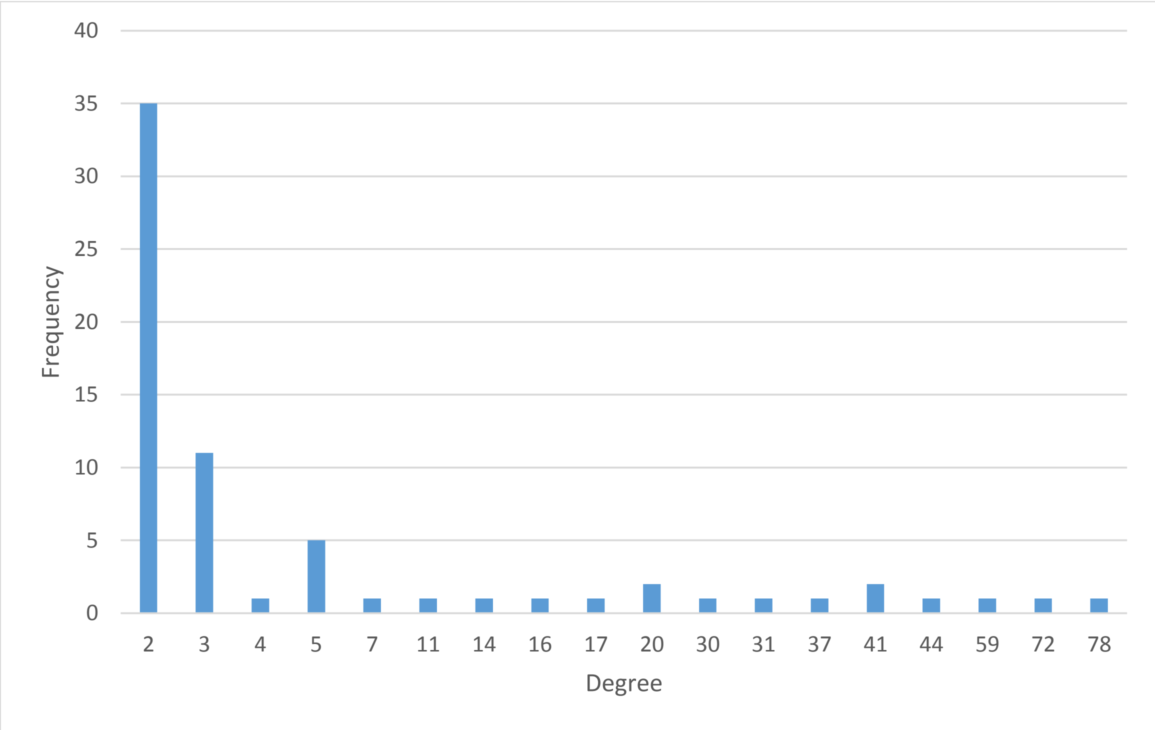


Figure 35: Distribution of Nodes with each Given Degree (Degree > 1)

Due to the fact that this study is an egocentric network study which illustrates a section of the scale-free supply chain network, it is no surprise that the number of vertices with a degree of only 1 is relatively high. The expected presence of patterns may reflect underlying structural processes within the network. In some cases of our analysis we have to concentrate on a degree of more than 1 in order to identify these patterns. Vertices with a degree of only 1 are then excluded using a local view (see Section 4.5.1), a way of network reduction described more in detail in Section 4.5.1. For example in case of proportional strength (see Section 4.2.2.), the presence of a pattern goes hand in hand with network connectivity. Given that paths between vertices enable them to be reachable, in terms of network connectivity a maximal subgraph with paths between all nodes is required.

Centrality as a node level attribute reflects importance to the structure (network). Given that different measures of centrality all cover different aspects, we apply several measures of centrality. Following the definitions in Section 4.2.2, this process is based on the undirected network $G_{\mathrm{U}}(V, E)$, a simplification of $G_D(V, A)$. Instead of arcs, edges indicate relationships between nodes. Due to the underlying theoretical concept of reciprocity, we do not distinguish in- and out-degree. Relationships between the different companies tend to be reciprocal as goods are exchanged for money. As the most common measure, degree centrality is relevant here, because it is directly linked to the degree distribution shown previously. As with Robins (2015), degree centrality reflects the degree of a node within the network and therefore concentrates on the activity of a node, rather than on possible effects on the connectivity (Robins, 2015, p. 26).

Vertices within the supply chain network hold a variety of different network positions. As described, we assume that actors in the same position face similar circumstances because of that position. As structural equivalence as a result of identical relationships is not very likely, we try to generalise structural equivalence to regular equivalence. The concept of regular equivalence can come into play if we review focal companies for their links to complementary industries using the affiliation network $H_{\mathrm{D}}(W, B)$ defined in Section 4.2.2.

Aside from network creation, the second subject of interest concerns the results based on the quantitative analysis of balance sheets and databases for digital business information. Table 20 shows our aggregated results of the dependent financial performance measures according to Section 4.2.3. The detailed calculation of each focal company can be found in Appendix A4.

Table 20: Results of the Dependent Variable Performance

	RE (m.u.)	ROA	AT	OP (m.u.)	DDR	PFR
FOC1	141,072	-3.45	2.43	530.698	9.96	-3.42
FOC2	139,204	4.63	1.89	2,482.658	6.66	11.77
FOC3	192,076	20.21	3.05	1,801.428	2.29	90.24
FOC4	198,975	31.97	2.19	2,328.492	0.46	1,115.03
FOC5	163,937	7.69	1.34	9,515.121	3.65	18.53
FOC6	189,582	3.66	2.51	1,196.354	14.75	21.80
FOC7	155,372	6.57	2.05	5,669.225	5.62	19.03
FOC8	160,544					
FOC9	151,600					
FOC10	196,656	44.55	1.97	14,866.154	0.45	91.72
FOC11	161,075	-0.43	2.70	346.226	12.27	11.10
FOC12	142,125	-4.68	0.77	3,401.898	6.90	-4.04
FOC13	244,912	10.60	1.99	7,466.250	2.01	28.39
FOC14	142,246		2.51			
FOC15	171,872	6.26	1.52	1,610.081	1.08	19.69

5.3 Test of the Hypotheses

For the most part, we test our three main hypotheses by means of linear regression. The statistical linear relationship between two observed features is expressed by the correlation coefficient r. A value of 1 expresses a completely positive linear relationship, a value of -1 a completely negative linear relationship. An approximate classification is to interpret the absolute coefficients in the following way:

- values lower than 0.05 signify no correlation,
- values between 0.05 and 0.25 mean a weak correlation,
- coefficients between 0.25 and 0.60 are an indicator for moderate correlation,
- and values from 0.60 to 1.00 are interpreted as a strong correlation.

Regression analysis adds an equation similar to Equation 6 with which we can calculate a value on the basis of the other. Thereby, Y is the dependent financial performance measure, X is the independent variable (network position property), and b_0 and b_1 are the regression parameters.

$$Y = b_0 + b_1 X$$

Equation 6: Exemplary Model Based on Linear Regression

The coefficient of determination R^2 expresses the proportion of variation in the dependent variable, which is explained by the linear regression. In this case the value of R^2 is the square of the value of the correlation coefficient r. The value of R^2 lies between 0 (no linear relationship) and 1 (perfect linear relationship).

To test the significance of our results, we generally apply a t-test. We formulate a hypothesis H0. At first one assumes that the hypothesis H0 is correct and no statistically significant correlation exists. To be able to reject the hypothesis H0, the calculated t-value must exceed the critical t-value (t-theoretic). In this case, one can confirm the alternative hypothesis H1. Equation 7 provides the formula for the t-value of the one-sided t-test. The critical t-value (t-theoretic) is the left-quantiles of the t-distribution (degree of freedom = n - 1, significance level $\alpha = 5\ \%$).

$$t = \frac{r \cdot \sqrt{n-2}}{\sqrt{1-r^2}}$$

Equation 7: t-value for the one-sided t-Test for the correlation coefficient (Cohen, 2003, p. 49)

Other statistical measures we use in the context of hypotheses testing are the calculation of the Chi-Square and the Phi-Coefficient. Their use is explained more in detail on the particular case.

5.3.1 Strength of the Links

We express the strength of links by the cash flows between the companies. Each focal company within the supply chain network obtains relationships of different strength to its suppliers and customers. We now discuss the first hypothesis in order to prove that there is a correlation between the network position and the performance of a company in the network. To recapitulate, Hypothesis 1 states that the stronger the links of a company in the network are, the better the performance of that company.

Initially, Figure 34 provides a general overview of the graph $G_D(V, A)$ for the evaluation. We show different focal companies, surrounded by a number ($v - u = 433$) of their partner companies.

To draw a conclusion with regard to the influence of the strength of the links on the economic performance, one would be inclined to aggregate the sales and to investigate the relationships. However, this approach means nothing more than the question of whether companies with higher revenues are more successful. At this point having the opportunity to calculate proportional strength, the application of social network analysis again shows its potential.

The creation of an all-degree partition allows for a reduction of the network. As proportional strength can only be calculated for overlapping connections, network reduction according to the following steps is necessary:

- In a first step, we convert the network and turn arcs (directed links) into edges (undirected links). The cash flows are bidirectional, because goods are exchanged for money. Multiple lines may exist if a partner company is both a supplier and a customer at the same time. In case of any existing multiple lines, we aggregate the cash flows.

- In a second step, we create the all-degree partition. Cluster 1 of this partition contains all nodes having a degree (number of direct links) of only one.
- In a third step, we eliminate the nodes of cluster 1, as it is not possible to calculate proportional strength for them. Thus, we extract a subnetwork which equals the previously described maximal connected subgraph. It is now possible to assess the proportional strength of these relationships depicted in this subnetwork.

Our procedure results in a graph with nodes (customers and suppliers) that are shared among at least two focal companies. All focal companies are still part of the network. This means that every focal company has at least one partner that is shared with another focal company. Figure 36 shows the reduced network (subnetwork) with common suppliers and common customers between the different focal companies.

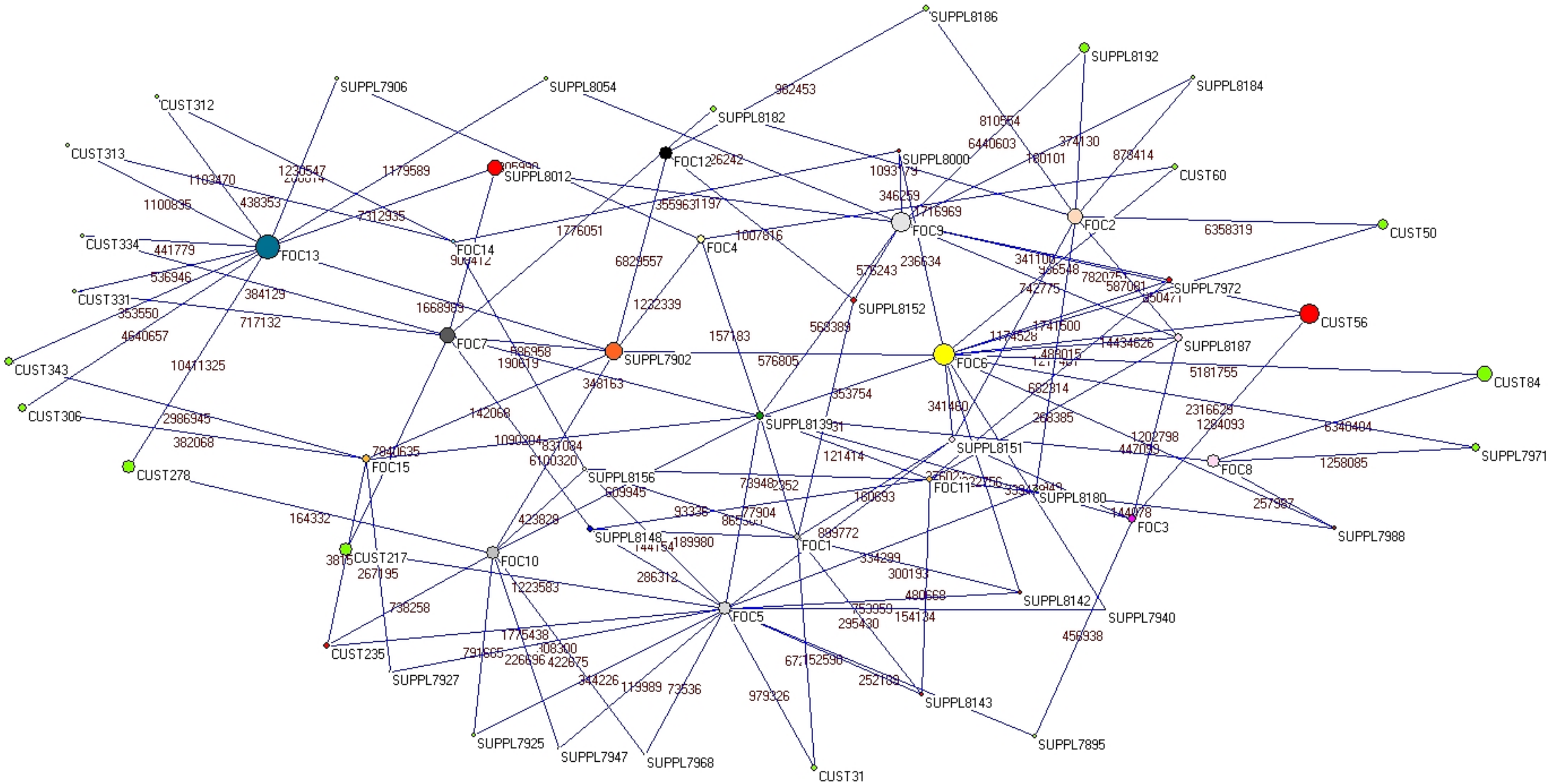


Figure 36: Extracted Subnetwork of $G_D(V, A)$ with all focal companies and their mutually shared business partners

Using the created subnetwork, we can now sum cash flows of different focal companies to their common suppliers or customers. Based on the corresponding proportions of cash flows, we calculate aggregated strength AS (see Table 7 in 4.2.2). We show the detailed calculation for the strength of all links based on proportional strength in the Appendix A5.

In summary, Table 21 shows the aggregated strength of links for each focal company.

Table 21: Results of the Aggregated Strength of Focal Companies

Company	**Strength of links**	**Number of links**
FOC1	1.4081	8
FOC2	3.9926	8
FOC3	1.1947	5
FOC4	0.9485	4
FOC5	5.0957	16
FOC6	4.8878	14
FOC7	3.3544	8
FOC8	1.2680	4
FOC9	3.1511	10
FOC10	3.4048	8
FOC11	1.1663	7
FOC12	1.5385	3
FOC13	6.7891	11
FOC14	1.0652	4
FOC15	1.7352	6

Both the individual performance metrics in Table 20 (Section 5.2), as well as the strength of the links in Table 21 are metric values. Consequently, we carry out the measurement of the statistical association by performing a correlation calculation. Table 22 shows the calculated results for each DV, dependent on aggregated strength (IV). In the case of our analysis, two results stand out:

- The correlation coefficient of AS and RE is 0.47.
- Further, the correlation coefficient of AS and OP is 0.5.

Table 22: Correlation Results for Hypothesis 1 (AS)

Aggregated strength AS	R^2	r	t	n	t theoretic
RE	0.22	0.47	**1.92**	15	-1.76
ROA	0.00	-0.01	0.03	12	-1.80
AT	0.05	-0.23	0.78	13	-1.78
OP	0.25	0.50	**1.83**	12	-1.80
DDR	0.00	0.00	0.01	12	-1.80
PFR	0.11	-0.33	1.10	12	-1.80

Figure 37 and Figure 38 illustrate the linear regression of the two strongest correlations. We present the other linear regressions in the Appendix A6.

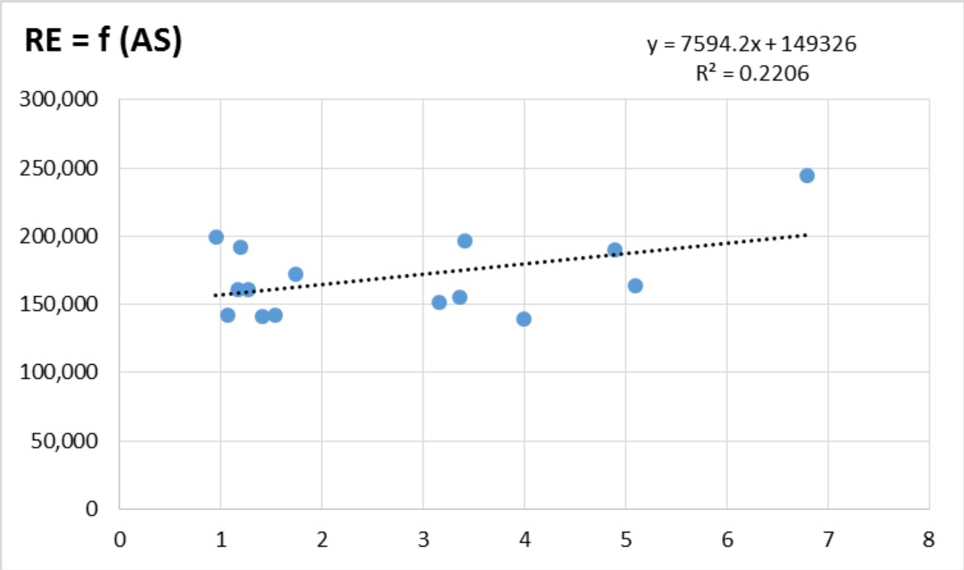


Figure 37: Linear Regression RE = f(AS)

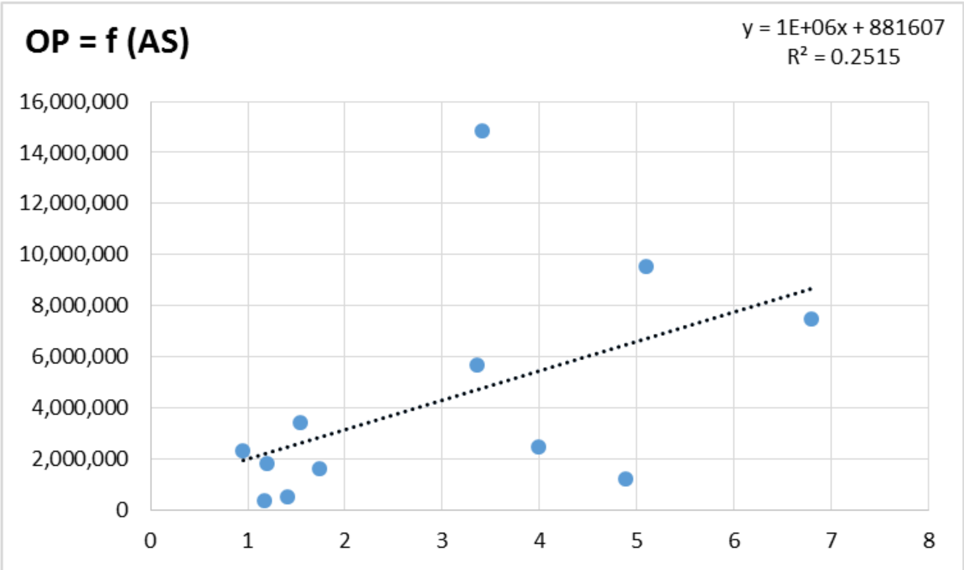


Figure 38: Linear Regression OP = f(AS)

We use the previously described one-sided t-test illustrated by Equation 7 to verify the significance of our gained results. The hypothesis H0 is rejected in favour of the alternative H1, if the calculated t-value exceeds the critical t-value (t-theoretic).

Table 23: Test for Significance of Hypothesis 1 (AS)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
AS	RE	-1.76	$H0: t < \| 1.76\|$	**1.92**	**H1**
AS	ROA	-1.80	$H0: t < \| 1.80\|$	0.03	H0
AS	AT	-1.78	$H0: t < \| 1.78\|$	0.78	H0
AS	OP	-1.80	$H0: t < \| 1.80\|$	**1.83**	**H1**
AS	DDR	-1.80	$H0: t < \| 1.80\|$	0.28	H0
AS	PFR	-1.80	$H0: t < \| 1.80\|$	1.10	H0

Based on the results illustrated in Table 23, we can justify a statistical association between the strength of links in the supply chain network and two important financial performance measures (RE and OP). The illustration of the distribution with the regression line in Figure 38 shows one point at (3.4/14,866,154) that could be an outlier. Consequently, we apply an additional box test, in order to verify whether one can reasonably assume an outlier in the statistics. For the present case of the regression analysis of OP = f(AS) we can confirm the outlier. The box plot in Figure 39 summarises important measures for scattering and robust measures of location (i.e. arithmetic mean, 1st quartile, median, 3rd quartile) in one presentation. Table 24 shows the descriptive statistics for the box plot.

Table 24: Descriptive Statistics (Quantitative Data) for OP

Number of observations	15
Missing values	3
Sum of weights	12
Minimum	346,226
Maximum	14,866,154
Amplitude	14,519,929
1st quartile	1,506,649
Median	2,405,575
3rd quartile	6,118,482
Sum	51,214,585
Mean	4,267,882
Variance (n-1)	19,243,266,396,065
Standard deviation (n)	4,199,960
Standard deviation (n-1)	4,386,715
Standard error of the mean	1,266,335
Lower limit of the mean (95 %)	1,480,696
Upper limit of the mean (95 %)	7,055,068
Geometric mean	2,548,533
Harmonic mean	1,429,665
Interquartile range	4,611,833
upper limit outliers	10,730,314

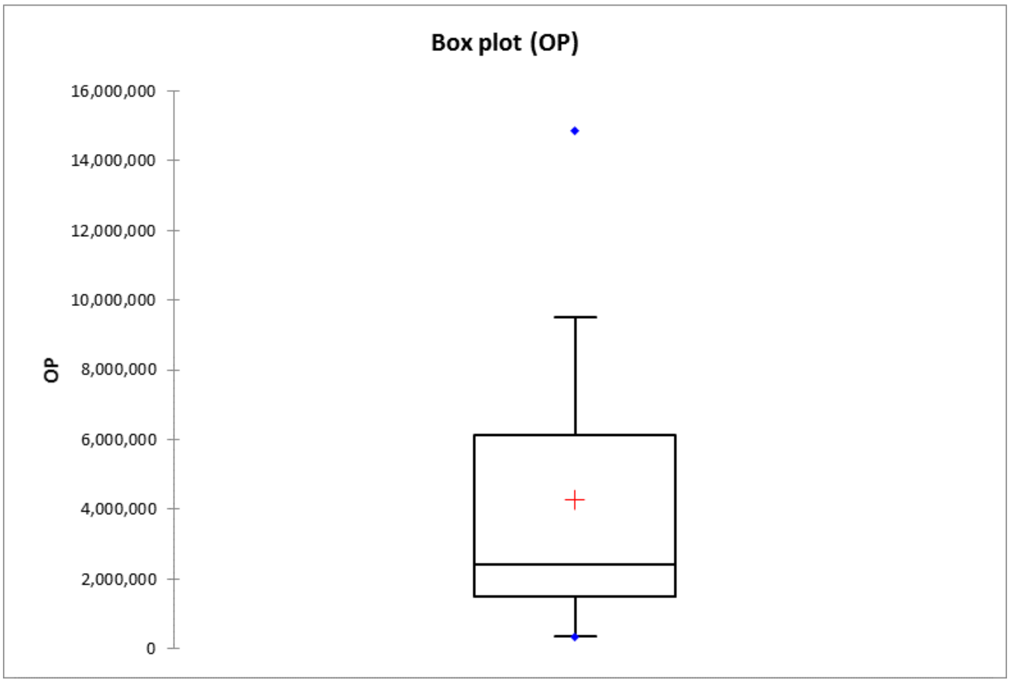


Figure 39: Box Plot for OP

We therefore continue the statistical analysis for OP = f(AS). In fact, we perform an additional regression analysis excluding the identified outlier. The results are shown in Table 25. The coefficient of determination R^2 rises to 0.47 from 0.25. Based on a significance level of 0.05 the significance of the result increases. The distribution of the linear regression analysis is shown in Figure 40.

Table 25: Additional Correlation Result for Hypothesis 1 (AS)

Aggregated strength AS	R^2	r	t	n	t theoretic
OP (ex. outlier)	0.47	0.69	**2.85**	11	-1.81

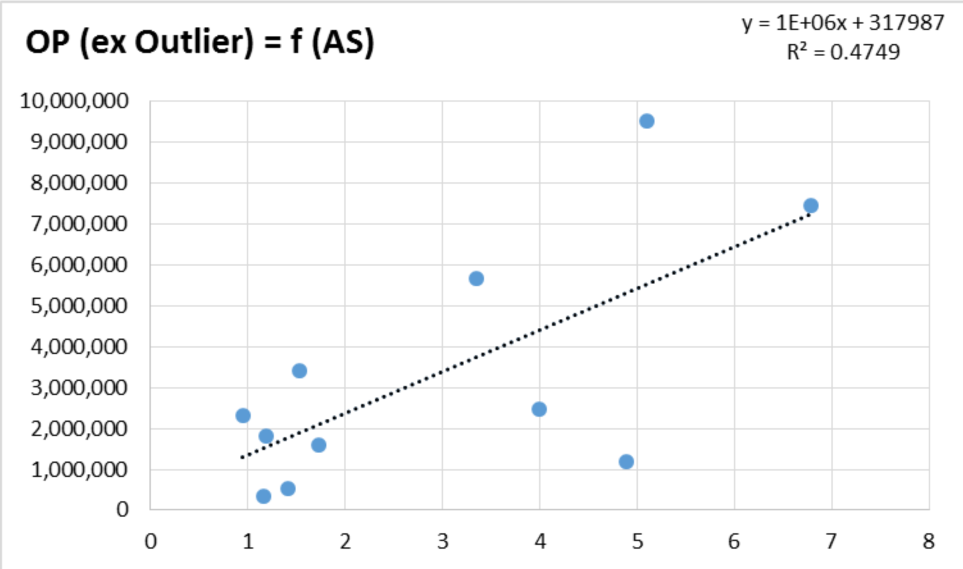


Figure 40: Linear Regression OP ex. Outlier = f(AS)

5.3.2 Centrality of the Nodes

Based on Hypothesis 1, one might think that larger companies also have stronger links because they generate more cash flows. The question of centrality arises. Hypothesis 2 therefore states: the more central the role of a company in the network is, the better the performance of that company.

The analysis of the degree distribution, as previously presented in Table 19, is a first step in our analysis of centrality. Nevertheless, the degree distribution provides more an overview about the network as a whole. As already stated, there are different measures of centrality that all cover different aspects. Consequently, it is not sufficient to draw conclusions on just one measure identifying the most central node because of the highest degree. Following Robins (2015, p. 182) it is best to take at least degree centrality and betweenness centrality into account. We also analyse Bonacich power in more detail, because our network analysis indicates effects of the immediate environment of focal companies. In view of the flexibility of Bonacich power, we can omit to analyse eigenvector centrality separately (see Table 7 in 4.2.2).

As we will calculate centrality scores and use results in terms of a regression analysis, it is important to consider the following advice given by Robins (2015): "researchers should realize that the regression assumes nodes are independent of each other once centralities are taken into account - in other words, that the network is entirely decomposable into a set of nodal centralities. This is quite a dubious assumption and ignores, for instance, closure effects in human social networks" (Robins, 2015, p. 182). Due to the fact that our egocentric network study results from real-time network flows between companies, possible closure effects should not be a problem, although caution would be advised. Given that our network is in fact scale-free, we can only draw conclusions on the focal companies.

Looking at $G_D(V, A)$ illustrated by Figure 34, bidirectional arcs exist if a focal company maintains a relationship to a company which is supplier and customer at the same time. In terms of Hypotheses 1, we therefore consider incoming as well as outgoing cash flows. For Hypothesis 2 this is different. A company which acts as supplier and customer at the same time should only add one existing link to the calculation of node centrality. The reason is that it is less important whether an arc between a focal company and a connected business partner points "from" or "to" or "in both directions". For the analysis it is rather central that the two companies do business with each other. The undirected graph $G_{\mathrm{U}}(V, E)$ simplifies $G_D(V, A)$. We calculate different centrality scores as defined in 4.2.2 (Table 7).

- We interpret degree centrality C as the popularity of a node which equals the degree of a node. In fact, this is the number of business partners (direct links) a focal company maintains. We expect that actors with more connections benefit from various possibilities to fulfil their needs. Further, more connections are also the reason why one assumes that well-connected nodes are less dependent and have better access to resources in general. A resulting brokerage role might add value.
- Eigenvector centrality EC of a given node considers how central the network partners of this node are. A higher EC results from connections to well-connected nodes. In contrast to C, EC is not only about the number of connected nodes but also about the centrality of these network partners. The eigenvector centrality of each vertex is the result of the centrality of the vertices it is connected to.
- A generalisation to C and EC is Bonacich power BP. Bonacich (1987) modified the basic idea that nodes with a higher degree centrality benefit from their opportunity to affect more actors. For example, having the same degree centrality does not necessarily mean that two actors are equally important. Again, to follow Bonacich (1987), BP is a function of how many connections a specific node has, but also how many connections its connected actors have (and how far away they are). Thus, nodes with a higher degree centrality are not necessarily more powerful. Clearly being more central permits access

to a lot of other actors, but if these other actors are themselves well-connected they will not be particularly dependent on this specific node. The connections to well-connected actors make a node more central, but not more powerful. The other way round, being connected to nodes with few connections makes an individual node more powerful with respect to these connections. By implementing the parameter β, BP considers whether being connected to well-connected nodes brings positive ($\beta > 0$) or negative ($\beta < 0$) benefits. Setting β is a matter of the researcher. Before analysing the impact of modifying β in a second step, we first rely on the automatic algorithm of the social network analysis software UCINET[9]. To calculate BP, UCINET automatically sets β to 0.995/λ = 0.10796.

- Betweenness centrality BC points toward the importance of a node because of a network through short paths. BC captures how often a node is in position on geodesics between all other pairs of nodes.

The social network analysis software UCINET offers a "Centrality - Multiple measures" command. The software calculates the values for the different described centrality measures, presented in Table 26. All values are normalised automatically by UNICET. Note the testing of our hypotheses is invariant to these scaling factors because the multiplication of an IV by a constant does not change the "p-value" of the significance test in the regression.

Table 26: Results of the Different Centrality Measures of Focal Companies

Company	C	$BP_{\beta=0.995/\lambda}$	$BP_{\beta=-0.995/\lambda}$	$BP_{\beta=0.5/\lambda}$	$BP_{\beta=-0.5/\lambda}$	EC	BC
FOC1	0.085	49.183	-49.465	92.794	-100.394	0.151	0.142
FOC2	0.065	14.149	-14.477	65.016	-72.102	0.041	0.099
FOC3	0.038	19.808	-19.876	41.942	-43.31	0.061	0.057
FOC4	0.036	16.724	-16.826	38.719	-40.422	0.051	0.061
FOC5	0.161	185.045	-185.443	187.747	-207.972	0.581	0.271
FOC6	0.092	46.436	-46.734	101.93	-107.935	0.141	0.165
FOC7	0.087	36.021	-36.498	93.517	-102.178	0.108	0.168
FOC8	0.011	10.522	-10.493	14.72	-13.495	0.033	0.007
FOC9	0.081	24.716	-25.111	85.57	-92.385	0.072	0.148
FOC10	0.174	236.811	-237.153	202.248	-228.024	0.754	0.314
FOC11	0.043	28.666	-28.708	48.841	-49.708	0.088	0.062
FOC12	0.029	7.040	-7.159	28.878	-31.391	0.021	0.049
FOC13	0.130	35.036	-36.417	137.957	-156.268	0.099	0.219
FOC14	0.063	12.066	-12.447	61.214	-69.385	0.035	0.112
FOC15	0.043	26.204	-26.322	47.185	-49.458	0.081	0.075

[9] https://sites.google.com/site/ucinetsoftware/home

In terms of Hypothesis 2, the type of results is similar to the type of results of Hypothesis 1: both the financial performance measures in Table 20 (Section 5.2), as well as the centrality results in Table 26 are metric values. Consequently, we also measure the statistical association by performing a correlation calculation. Tables 27 to 29 show our calculated results for performance, dependent on the different kinds of centrality of the focal companies. As our network paths are not very long, $BP_{\beta=0.995/\lambda}$ makes EC obsolete. In a first step, we concentrate on C, $BP_{\beta=0.995/\lambda}$ and BC. In terms of our analysis, two important points emerge:

- For all measures of centrality, the correlation coefficient between the specific centrality measure and ROA indicates a moderate association. The correlation coefficient ranges from 0.36 to 0.53.
- Further, the correlation coefficient between the specific centrality measure and OP indicates a strong association. The correlation coefficient is between 0.85 and 0.86.

Table 27: Correlation Results for Hypothesis 2 (C)

Degree centrality C	**R^2**	**r**	**t**	**n**	**t theoretic**
RE	0.12	0.34	1.32	15	-1.76
ROA	0.13	0.36	1.20	12	-1.80
AT	0.02	-0.15	-0.51	13	-1.78
OP	0.72	0.85	**5.05**	12	-1.80
DDR	0.03	-0.18	-0.59	12	-1.80
PFR	0.07	-0.26	-0.85	12	-1.80

Table 28: Correlation Results for Hypothesis 2 ($BP_{\beta = 0.995/\lambda}$)

Bonacich power $BP_{\beta = 0.995/\lambda}$	**R^2**	**r**	**t**	**n**	**t theoretic**
RE	0.05	0.21	0.79	15	-1.76
ROA	0.28	0.53	**1.96**	12	-1.80
AT	0.04	-0.20	-0.69	13	-1.78
OP	0.73	0.86	**5.24**	12	-1.80
DDR	0.08	-0.27	-0.90	12	-1.80
PFR	0.02	-0.13	-0.43	12	-1.80

Table 29: Correlation Results for Hypothesis 2 (BC)

Betweenness centrality BC	R^2	r	t	n	t theoretic
RE	0.11	0.33	1.28	15	-1.76
ROA	0.14	0.38	1.30	12	-1.80
AT	0.02	-0.16	-0.52	13	-1.78
OP	0.74	0.86	5.36	12	-1.80
DDR	0.04	-0.19	-0.62	12	-1.80
PFR	0.06	-0.25	-0.80	12	-1.80

In the following, we set the focus on the strongest correlations of these three measures of centrality. In the Appendix A7, we present the other linear regressions for C, $BP_{\beta=0.995/\lambda}$ and BC.

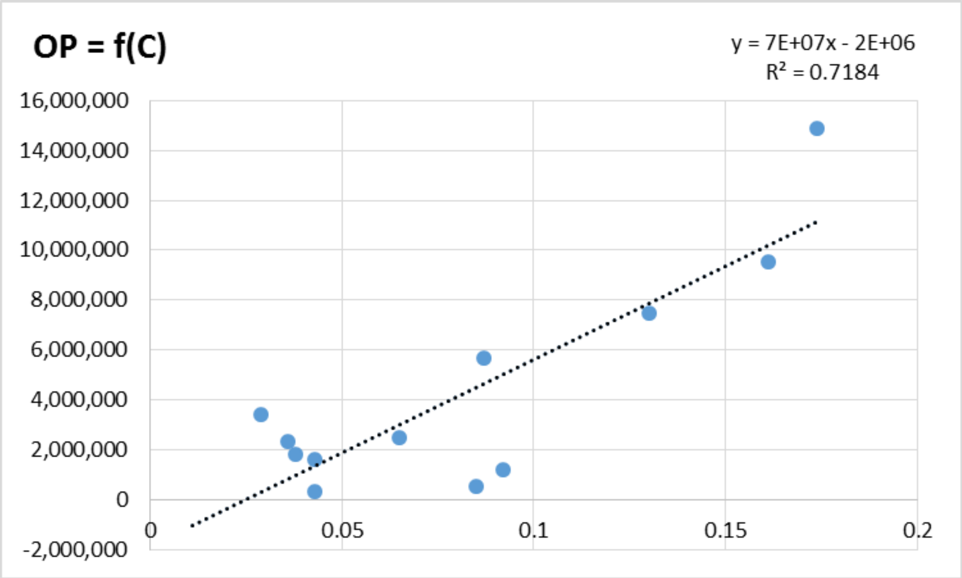


Figure 41: Linear Regression OP = f(C)

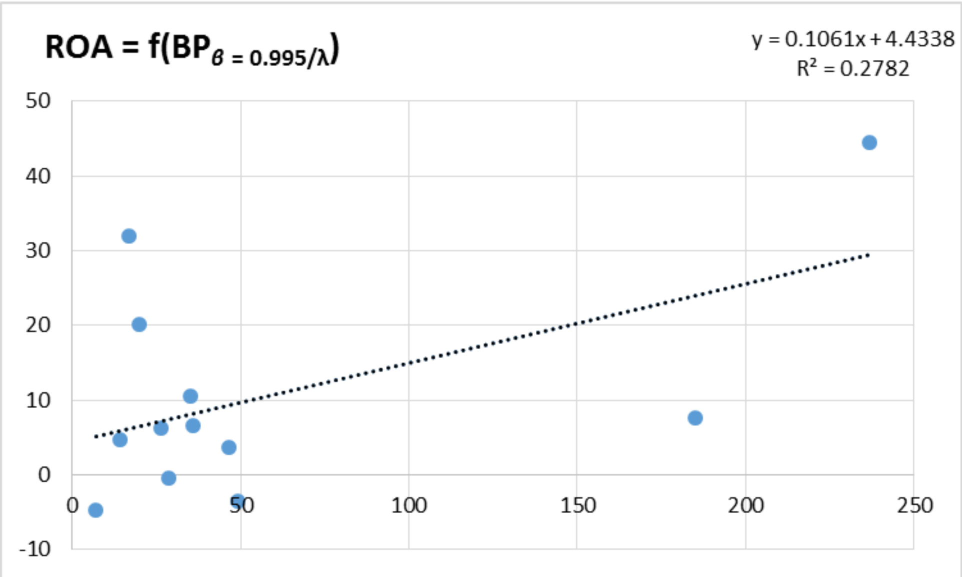


Figure 42: Linear Regression ROA = $f(BP_{\beta = 0.995/\lambda})$

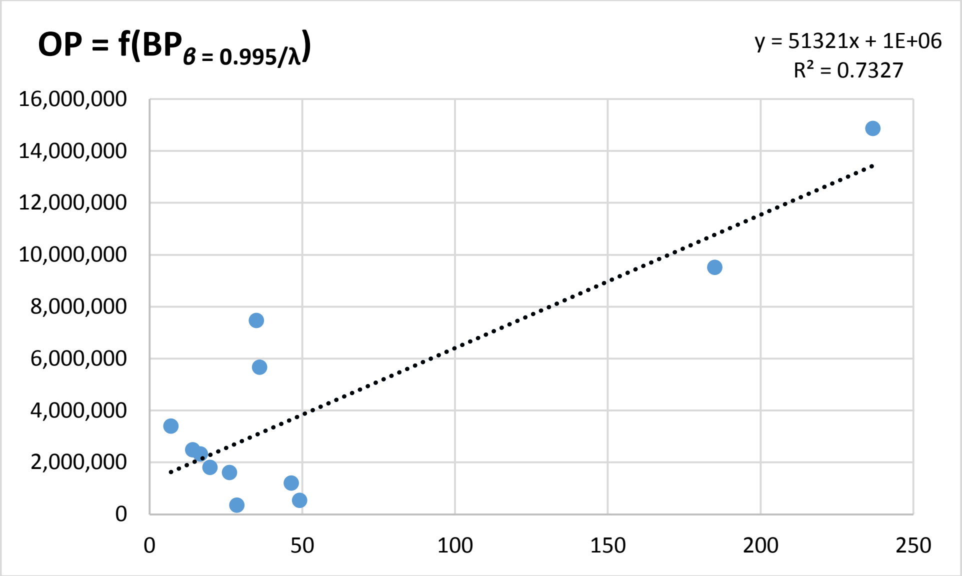


Figure 43: Linear Regression OP = f($BP_{\beta = 0.995/\lambda}$)

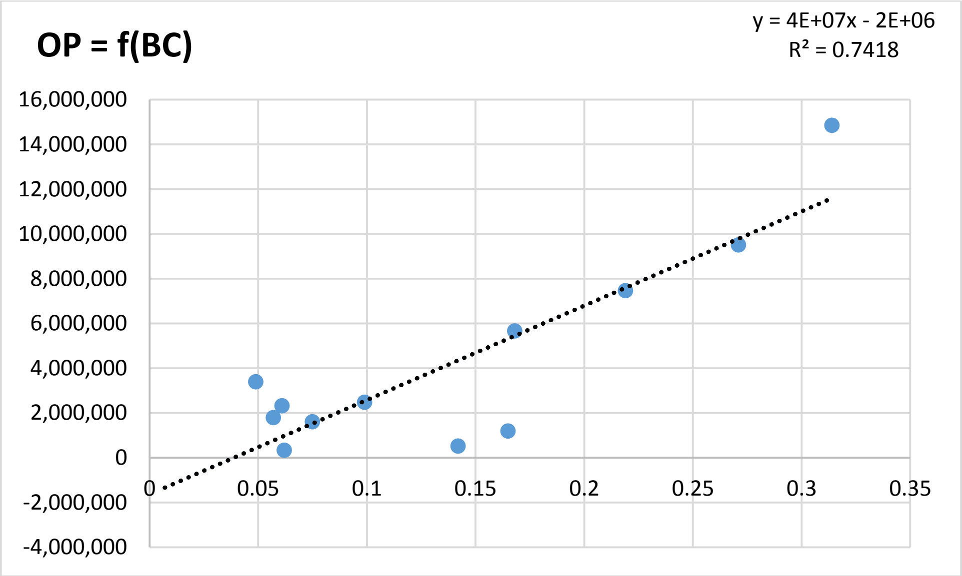


Figure 44: Linear Regression OP = f(BC)

To verify the significance of our gained results, we also apply the previously described one-sided t-test illustrated by Equation 7. The hypothesis H0 is rejected in favour of the alternative H1, if the calculated t-value exceeds the critical t-value (t-theoretic).

Table 30: Test for Significance of Hypothesis 2 (C)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
C	RE	-1.76	$H0: t < \| 1.76\|$	1.32	H0
C	ROA	-1.80	$H0: t < \| 1.80\|$	1.20	H0
C	AT	-1.78	$H0: t < \| 1.78\|$	-0.51	H0
C	OP	-1.80	$H0: t < \| 1.80\|$	**5.05**	**H1**
C	DDR	-1.80	$H0: t < \| 1.80\|$	-0.59	H0
C	PFR	-1.80	$H0: t < \| 1.80\|$	-0.85	H0

Table 31: Test for Significance of Hypothesis 2 ($BP_{\beta = 0.995/\lambda}$)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
$BP_{\beta = 0.995/\lambda}$	RE	-1.76	$H0: t < \| 1.76\|$	0.79	H0
$BP_{\beta = 0.995/\lambda}$	ROA	-1.80	$H0: t < \| 1.80\|$	**1.96**	**H1**
$BP_{\beta = 0.995/\lambda}$	AT	-1.78	$H0: t < \| 1.78\|$	-0.69	H0
$BP_{\beta = 0.995/\lambda}$	OP	-1.80	$H0: t < \| 1.80\|$	**5.24**	**H1**
$BP_{\beta = 0.995/\lambda}$	DDR	-1.80	$H0: t < \| 1.80\|$	-0.90	H0
$BP_{\beta = 0.995/\lambda}$	PFR	-1.80	$H0: t < \| 1.80\|$	-0.43	H0

Table 32: Test for Significance of Hypothesis 2 (BC)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
BC	RE	-1.76	$H0: t < \| 1.76\|$	1.28	H0
BC	ROA	-1.80	$H0: t < \| 1.80\|$	1.30	H0
BC	AT	-1.78	$H0: t < \| 1.78\|$	-0.52	H0
BC	OP	-1.80	$H0: t < \| 1.80\|$	**5.36**	**H1**
BC	DDR	-1.80	$H0: t < \| 1.80\|$	-0.62	H0
BC	PFR	-1.80	$H0: t < \| 1.80\|$	-0.80	H0

Based on our results presented in Tables 30 to 32, we can justify a statistical association between different measures of centrality in the supply chain network and two important financial performance measures (OP and ROA). In particular, the statistical association between different centrality measures and OP stand out. In order to achieve a higher OP, we can say that it is beneficial for a focal company to obtain a network position that is characterised by:

- a higher number of directly linked customers and suppliers (C),
- a higher betweenness, resulting from a network position on geodesics between as many pairs of nodes as possible (BC),
- many relationships to partners that are themselves well-connected (BP).

In addition, $BP_{\beta = 0.995/\lambda}$ appears to influence ROA. Beside OP, the ROA of a focal company is higher, if the network position of that company is characterised by many relationships to nodes that are themselves well-connected.

If we now focus on BP as the IV with the most significant influence, we have to discuss the parameter β more fully. In a second step, following Bonacich (1987, p. 1171), we analyse BP from the viewpoint of bargaining situations ($\beta < 0$). In these kind of situations, it is not about benefiting from connections to well-connected nodes, but the risk of being played out by nodes having several alternatives at hand. As previously presented in Table 26, we do this by setting $\beta = -0.995/\lambda$. In addition it might add value to look at the results for $\beta = 0.5/\lambda$ respectively $\beta = -0.5/\lambda$.

Table 33 provides an overview of the calculated correlations. In Table 34, we show the results of the corresponding significance test.

Table 33: Summarised Correlation Results for Performance Influenced by BP

	RE	ROA	AT	OP	DDR	PFR
C	0.34	0.36	-0.15	0.85	-0.18	-0.26
BP$_{\beta=0.995/\lambda}$	0.21	0.53	-0.20	0.86	-0.27	-0.13
BP$_{\beta=-0.995/\lambda}$	-0.22	-0.53	0.20	-0.86	0.28	0.13
BP$_{\beta=0.5/\lambda}$	0.35	0.38	-0.16	0.85	-0.19	-0.25
BP$_{\beta=-0.5/\lambda}$	-0.35	-0.38	0.17	-0.87	0.21	0.24
EC	0.21	0.53	-0.20	0.85	-0.28	-0.13

Table 34: Summarised Significance Results for Performance Influenced by BP

	RE	ROA	AT	OP	DDR	PFR
C	1.32	1.20	-0.51	5.05	-0.59	-0.85
BP$_{\beta=0.995/\lambda}$	0.79	1.96	-0.69	5.24	-0.90	-0.43
BP$_{\beta=-0.995/\lambda}$	-0.80	-1.96	0.69	-5.27	0.91	0.43
BP$_{\beta=0.5/\lambda}$	1.33	1.29	-0.52	5.19	-0.61	-0.80
BP$_{\beta=-0.5/\lambda}$	-1.34	-1.32	0.56	-5.47	0.68	0.80
EC	0.77	1.99	-0.68	5.19	-0.91	-0.41

The different DVs combined with the different key points on the scale of possible occurrences for $\beta > 0$ (C, $\beta = 0.5/\lambda$, $\beta = 0.995/\lambda$, EC) indicate that the results for $\beta < 0$ are nearly the opposite of the positive results. The given results confirm that the relationship of BP to the DVs depends on the value of β. The positive influence on several DVs for BP ($\beta > 0$) ranges between the results of C and BP$_{\beta = 0.995/\lambda}$. However, from the viewpoint of bargaining situations the risk of being played out is present. Centrality scores for BP ($\beta < 0$) that are the opposite of BP ($\beta > 0$) indicate that the positive effect on performance by means of connections to well-connected nodes may turn into a negative one, in case business partners manage to exploit bargaining situations.

Both, the analysis of strength of the links (Hypothesis 1) as well as the analysis of node centrality (Hypothesis 2), confirm our assumption of a link between the structural position of a company and its individual performance. However we have to note that this relates to performance mainly in the sense of profitability. While for the strength of the links the cash flows within the network are important, measures of centrality are simply based on a the existence or absence of links. A higher degree centrality results from more relationships to suppliers or customers and serves as an indicator for importance or prominence within the network. To a certain extent, one can also interpret degree centrality as an indicator for the diversity of a company. Indeed, we can reasonable state that a company with a higher degree centrality is less dependent on its partners and obtains several alternatives to achieve its goals. That is to say that although the partner companies are all very similar in the long run, it is better to have more than few of them.

5.3.3 Diversity of the Links

As a result, the question arises whether we can make a more detailed statement about the diversity of the links. Hypothesis 3 therefore states that the more diverse the individual links of a company are, the better the performance of that company. Instead of studying $G_{\mathrm{D}}(V, A)$ for cash flows, we focus in a first step on flows of product types. In a second step, our analysis of an affiliation network looks at the diversity of branches of industries with which a company operates. $H_{\mathrm{D}}(W, B)$ simplifies $G_{\mathrm{D}}(V, A)$ by aggregating into industries, the trade between focal companies and their suppliers and customers.

Our developed software "Network Creator" allows us to create both network files for analysis. Based on the collected data, we study the product-mix matrix $\mathbf{P}$ as well as the affiliation matrix $\mathbf{R}$.

Figure 45 illustrates the created network with flows of product types. In contrast to the analysis of node centrality, we require a clear distinction between incoming and outgoing links in order to identify hubs (popular customers) and authorities (popular suppliers) to study flows of product types. Thereby:

- arcs pointing from suppliers to focal companies indicate the delivery of different product types (materials),
- arcs pointing from a focal company to a customer indicate selling of different products types (finished or semi-finished goods), after the material was converted.

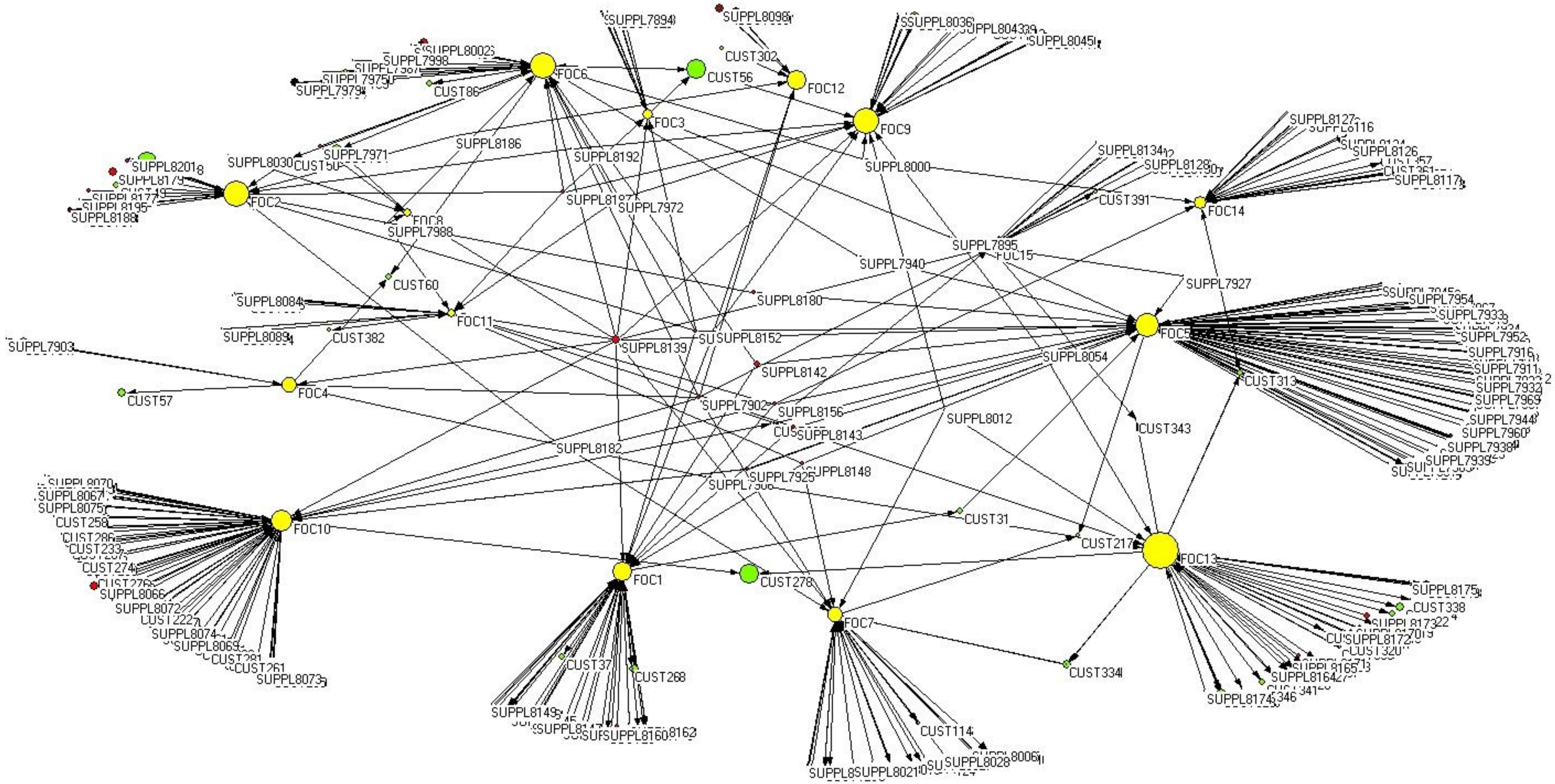


Figure 45: Directed Graph, $G_D(V, A)$, of the Egocentric Network Study (Product Types) with $v = 448$ companies of which $u = 15$ are focal companies (coded yellow). Suppliers are coded red, and customers coded green. Where companies are both suppliers and customers the designation of supplier or customer is determined by the direction of the arc representing the flow of product types. The size of the node is proportional to the total flow of product types, $\Sigma_j p_{ij}$, to the company j at that node. The arrows indicate the direction of the product flow. A double ended arrow indicates product flow in both directions, and hence two arcs, one in each direction.

Looking at diversity because of product types, we identify suppliers with a higher out-degree as authorities. These companies combine a higher share of different materials supplied to different focal companies. On the other side, we identify customers buying products from several focal companies as hubs. Hubs combine a higher share of different products bought from different focal companies. Based on the definitions in Table 7 (Section 4.2.2), the concept of hubs and authorities allows us to calculate a proportion of the diversity both on the procurement side (AUTH), as well as on the sales side (HUB) of every focal company.

We use Pajek to analyse the directed network of product flows depicted by Figure 45. The identification of hubs is based on the following procedure:

- In the first step we calculate the all-degree partition. This partition stores the degree of every vertex in the network. There is no distinction between indegree and outdegree.
- In the next step we create a subnetwork using the all-degree partition. A subnetwork that is based on a degree higher than 1 results in a new network. This network contains only vertices with a degree (input or output) higher than 1. Mutual relationships between companies, for example arcs between focal company and supplier pointing in both directions, remain existent.
- Consequently, in the third step we calculate the indegree partition. Due to the fact that the network is directed, only customers and focal companies have an indegree.
- We then use the indegree partition to create the network of hubs and focal companies. Hubs are companies supplied by more than one focal company. The focal companies are also part of the network because initially these nodes were connected to suppliers and thus have an indegree.
- Based on the created network we can finally calculate the total share on the most diversified hubs. In the Appendix A8 we show the detailed calculation.

Compared to our analysis of hubs, we perform the identification of authorities in a similar way:

- The analysis of authorities also starts with the directed network of product flows and uses the previously created all-degree partition:
- Based on the all-degree partition, we create a subnetwork that contains only vertices with a degree higher than 1. As previously mentioned, the mutual choices remain existent in this step.

- In contrast to the analysis of hubs, in the next step we create an output degree partition. Due to the fact that the network is directed, only suppliers and focal companies have an outdegree.
- The next step is the creation of a new network based on the outdegree partition. The reduced network ought to contain the authorities with an outdegree higher than 1 together with the focal companies of the egocentric network analysis. It is important to check the focal companies for their outdegree. A possible adjustment might be necessary in order to avoid that focal companies are left out because of an outdegree which is too low.
- Based on the created network, we finally calculate the total share of the most diversified authorities. In the Appendix A9 we show the detailed calculation.

We calculate for each focal company the aggregated shares of the hubs and authorities within the network. The calculation of each share is based on proportional strength. As a result, the aggregated shares presented in Table 35 provide a first overview of the diversification of the companies within the supply chain network, either on the procurement or on the sales side.

Table 35: Results of the Hubs and Authorities of Focal Companies

Company	HUB	AUTH
FOC1	0.0000	1.2883
FOC2	0.7857	2.7862
FOC3	0.0582	0.6501
FOC4	0.4747	0.9179
FOC5	0.2000	7.2243
FOC6	1.5469	4.4875
FOC7	0.8000	1.1734
FOC8	0.6616	0.6360
FOC9	0.4728	3.6037
FOC10	0.0018	1.2738
FOC11	0.0000	1.4406
FOC12	0.0000	1.0262
FOC13	3.1886	1.6080
FOC14	0.8351	0.5026
FOC15	0.9745	0.3815

In order to measure the statistical association for Hypothesis 3, we chose the same procedure as for the previous hypotheses. Both the individual financial performance measures in Table 20 (Section 5.2) as well as HUB and AUTH values in Table 35 are metric. Therefore, we measure again the statistical association by performing a correlation calculation. Tables 36 and 37 show the calculated results for performance, dependent on either HUB or the AUTH of the focal companies. In the case of our analysis, two points clearly stand out:

- On the customer side, the correlation coefficient between HUB and RE indicates a strong association. The correlation coefficient is 0.61. The other results signify no correlation.
- On the supplier side, all calculated results between AUTH and the dependent performance value indicate no or only weak correlations.

Table 36: Correlation Results for Hypothesis 3 (Hubs)

Hubs HUB	**R^2**	**r**	**t**	**n**	**t theoretic**
RE	0.37	0.61	2.79	15	-1.76
ROA	0.01	-0.09	-0.27	12	-1.80
AT	0.00	0.01	0.03	13	-1.78
OP	0.00	0.06	0.18	12	-1.80
DDR	0.00	-0.06	-0.20	12	-1.80
PFR	0.01	-0.07	-0.24	12	-1.80

Table 37: Correlation Results for Hypothesis 3 (Authorities)

Authorities AUTH	**R^2**	**r**	**t**	**n**	**t theoretic**
RE	0.00	-0.04	-0.14	15	-1.76
ROA	0.03	-0.18	-0.57	12	-1.80
AT	0.05	-0.23	-0.79	13	-1.78
OP	0.06	0.25	0.81	12	-1.80
DDR	0.07	0.27	0.88	12	-1.80
PFR	0.04	-0.19	-0.62	12	-1.80

Figure 46 illustrates the linear regression of the strongest correlation on the sales side. In the Appendix A10 we present the other linear regressions.

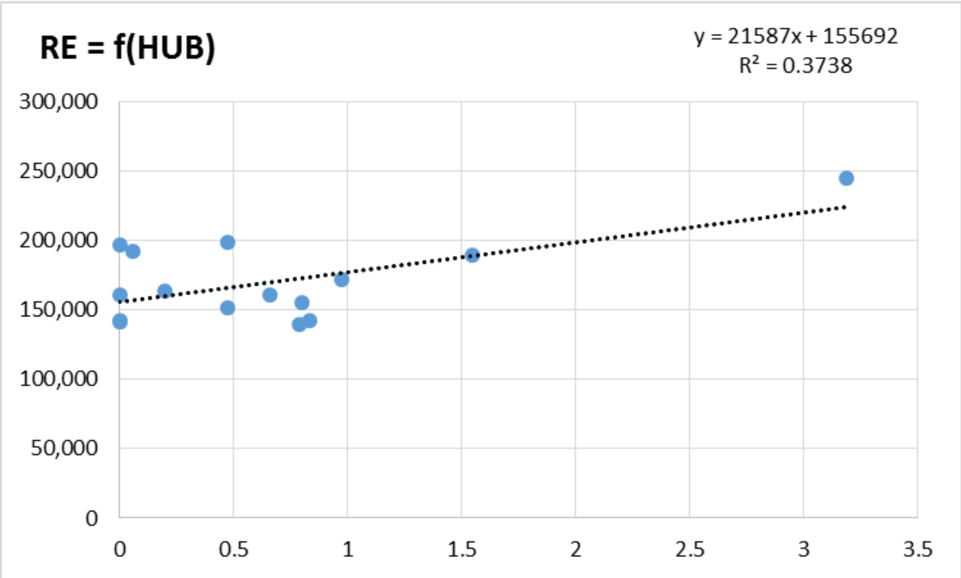


Figure 46: Linear Regression RE = f(HUB)

To verify the significance of our gained results, we also use the previously described one-sided t-test illustrated by Equation 7. The hypothesis H0 is rejected in favour of the alternative H1, if the calculated t-value exceeds the critical t-value (t-theoretic).

Table 38: Test for Significance of Hypothesis 3 (Hubs)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
HUB	RE	-1.76	$H0: t < \| 1.76\|$	**2.79**	**H1**
HUB	ROA	-1.80	$H0: t < \| 1.80\|$	-0.27	H0
HUB	AT	-1.78	$H0: t < \| 1.78\|$	0.03	H0
HUB	OP	-1.80	$H0: t < \| 1.80\|$	0.18	H0
HUB	DDR	-1.80	$H0: t < \| 1.80\|$	-0.20	H0
HUB	PFR	-1.80	$H0: t < \| 1.80\|$	-0.24	H0

The results illustrated in Table 38 confirm the statistical association between the relative share of the hubs (HUB) within the supply chain network and one important performance indicator (RE). Concerning the relative share of the authorities AUTH, we cannot confirm a correlation with respect to the performance of the individual company. Consequently, we can omit a test of significance. We can only reasonably assume that companies benefit from the diversity of their relationships on the sales side. The diversity of relationships to hubs, nodes buying a wide range of products, are more important than the diversity of relationships to authorities, nodes selling a wide range of materials. One possible reason for this might be the industry-specific focus. In the manufacturing sector, particularly in the plastic processing industry, there is a transparent procurement market for granulates, colours and other source materials. It is obviously more important to be innovative and to provide the market with a variety of product types currently in demand.

Following the first results of Hypothesis 3, we ask whether in addition to the diversity on the product level, we can make a statement regarding the diversity of branches of industry. Although all focal companies of our egocentric network study are plastic processing companies, these companies might produce for various industrial sectors. For purposes of classification, we use WZ 2008. WZ 2008 classifies the economic activities in the European economic area.

According to Statistisches Bundesamt (2008), the structure of the Classification of Economic Activities 2008 edition, called WZ 2008, benefits from extensive involvement of data users and data producers in management, business, research and society. WZ 2008 takes into account the requirements of the statistical classification of economic activities in the European Community, also known as *"Nomenclature statistique des activités économiques dans la Communauté européenne"* NACE Revision 2. NACE is established by Regulation (European Community) No 1893/2006 of the European Parliament and of the Council published on 20 December 2006

(Official Journal of the European Community list number 393 p. 1). The approval of the European Commission under Article 4, paragraph 3, of the above mentioned regulation is available.

The use of the Classification of Economic Activities 2008 (edition WZ 2008) for statistical purposes, results from Article 8 of the regulation mentioned above.

- The article describes that from the 1st of January 2008, statistics that relate to economic activities need to be based on NACE Revision 2.
- In Germany, the article is the basis of the Classification of Economic Activities WZ 2008. An international explanation is also available.[10]

In consequence, the WZ 2008 classification suits us to look at diversity in terms of industrial sectors. We query the previously mentioned Bisnode[11] database to collect the data of the WZ 2008 codes. The formal structure illustrated by Table 39 classifies WZ 2008.

Table 39: Formal Structure of WZ 2008 Code

Level of classification	Description	Count	Code
1	Section	21	A-U
2	Division	88	01-99
3	Groups	272	01.1-99.0
4	Classes	615	01.11-99.00
5	Sub-Classes	839	01.11.0-99.00.0

As previously mentioned, our developed software “Network Creator” allows us to analyse the affiliation matrix **R** of which $H_{\mathrm{D}}(W, B)$ is the corresponding graph. This graph shows the focal companies and the number of industries IND they do business with. In general, we make the classification of different industries on level 2 (the division level) according to WZ 2008. This avoids an overly-detailed classification on the level of groups or classes. For example, the general production of plastic parts (WZ 22290) and the production of plastic packaging (WZ 22220) are subsumed under the plastics industry. In the Appendix A11 we provide the exact grouping. In contrast to the previous networks, this two-mode network results in a bi-partite graph. We have no connections between companies, and no connections between the different industries. Relationships only exist between the two types of nodes (focal companies and their industries).

[10] https://www.destatis.de/DE/Methoden/Klassifikationen/GueterWirtschaftklassifikationen/klassifikationWZ08englisch.xls
[11] https://www.bisnode.com/Group/

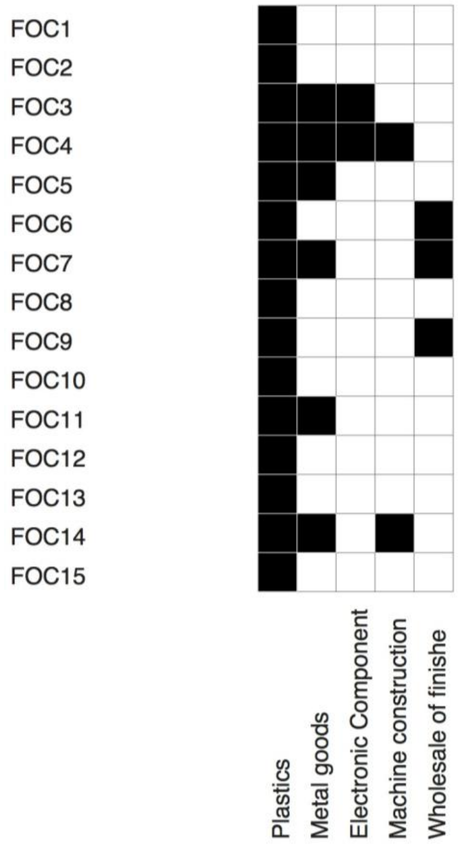


Figure 47: Affiliation Matrix of the Industry Network

Using blockmodelling (Section 4.5.2), we can not only distinguish between companies that are diversified across different sectors, but also group companies that are regularly equivalent. Based on the affiliation matrix **R** (Figure 47), we can identify 7 different classes of regularly equivalent nodes. Table 40 shows the different classes and their frequencies. Besides class 1, only class 4 and class 5 comprise several regularly equivalent nodes.

Table 40: Frequency Distribution of Regularly Equivalent Nodes

Class	**Frequency**	**Representatives**
1	7	FOC1, FOC2, FOC8, FOC10, FOC12, FOC13, FOC15
2	1	FOC3
3	1	FOC4
4	2	FOC5, FOC11
5	2	FOC6, FOC9
6	1	FOC7
7	1	FOC14

Due to the fact, that class 4 and class 5 contain only two focal companies, it is not promising to study a statistical association on this level of regular equivalence. Based on our findings, we are therefore looking for regular equivalence because of cluster of two rows and two columns. Figure 48 shows the generated graph for **R'**. The vertices are described by a partition as a result of blockmodelling. We assign focal companies to class 1 which are more diversified, and those to class 2 which are only connected to the plastics industry. This way, we look at diversity from a binary (is diversified across industries) perspective.

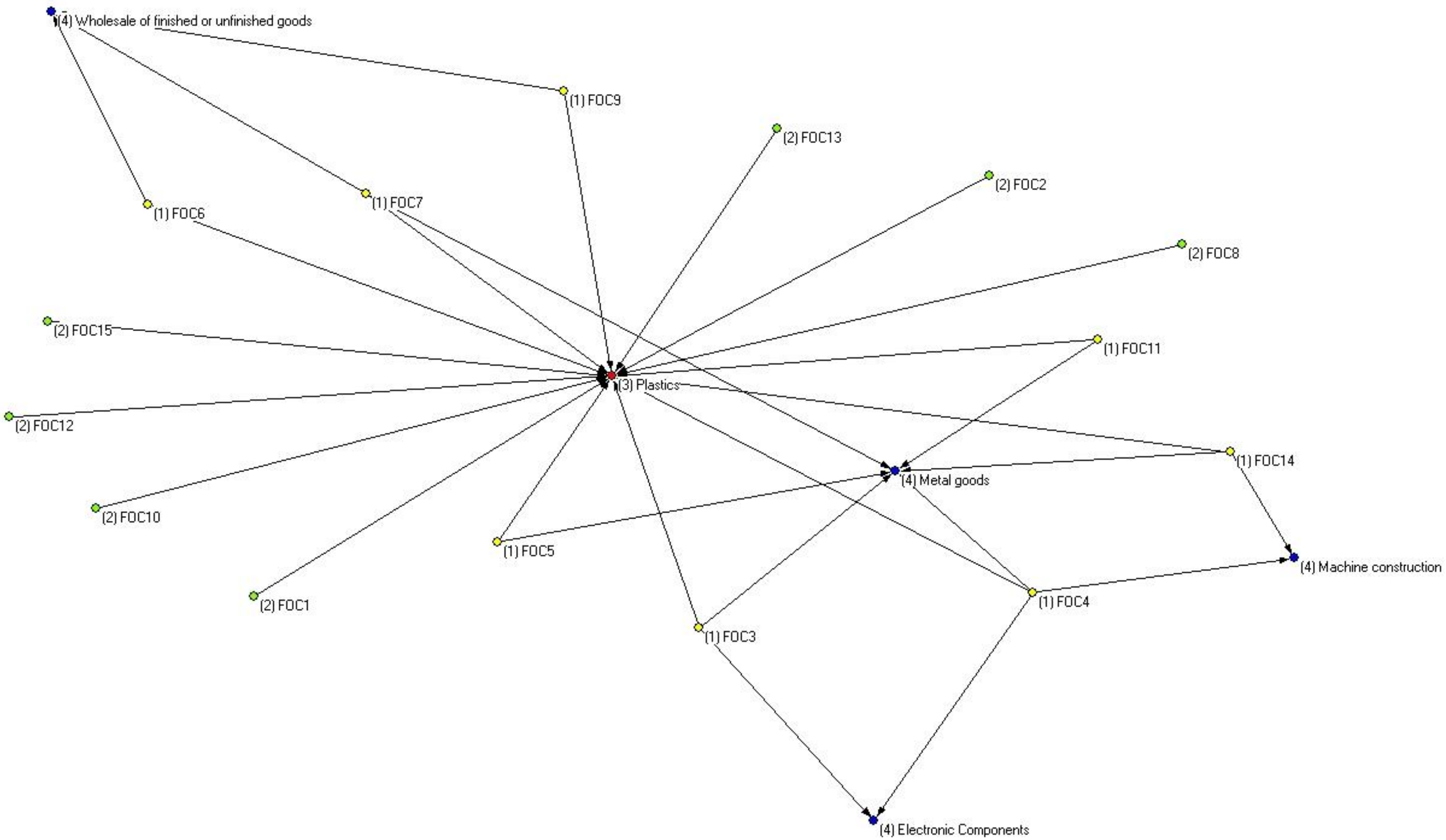


Figure 48: Directed Graph $H_D(W, B)$ of the Egocentric Network Study with w = 5 industries (coded blue) and u = 15 focal companies (coded in green or coded in yellow, in case of at least one connection besides plastics). The arrows pointing from focal company to industry indicate the affiliation of a focal company in a specific branch of industry. Arcs only exist between the two different types of nodes.

Beside the plastics industry, the focal companies are involved in the following industries:

- Production of metal goods
- Production of electronic components
- Manufacturing of machines
- Wholesaling of finished or unfinished goods

We omit connections that are not the main business lines. As we cannot weight the individual industries, unnecessary connections would distort the statistics.

In Table 41, we show the aggregated results of diversity and the different financial performance measures based on our results of Table 20 (Section 5.2). We require nominal data, because the scale level of a variable to express diversity (whether a focal company is diversified across industries), implies this. The values IND' illustrate whether a focal company is diversified (1 = complementary industries besides plastics because IND > 1) or not (2 = no complementary industries, IND = 1). We evaluate each financial performance measure by the median of the collected data. We use the median in order to reduce the influence of possible outliers. Where the financial performance measure of a specific company is higher than the calculated median, we select the nominal class 1 for this company. Otherwise, where the value is below the median, we select the nominal class 2.

Table 41: Results (nominal) of Industries and Performance of Focal Companies

	IND'	RE	ROA	AT	OP	DDR	PFR
Median		161,075	6.4159	2.0525	2,405,575	4.635	19.3595
FOC1	2	2	2	1	2	1	2
FOC2	2	2	2	2	1	1	2
FOC3	1	1	1	1	2	2	1
FOC4	1	1	1	1	2	2	1
FOC5	1	1	1	2	1	2	2
FOC6	1	1	2	1	2	1	1
FOC7	1	2	1	2	1	1	2
FOC8	2	2					
FOC9	1	2					
FOC10	2	1	1	2	1	2	1
FOC11	1	2	2	1	2	1	2
FOC12	2	2	2	2	1	1	2
FOC13	2	1	1	2	1	2	1
FOC14	1	2		1			
FOC15	2	1	2	2	2	2	1

Due to the nominal data, our first approach to measure the statistical correlation between diversity across different industries and economic performance uses the contingency coefficient. We determine the statistical association by comparing the actual frequencies $f_{b(j,i)}$ of two variables, IND' and each particular financial performance measure, with the expected frequencies $f_{e(i,j)}$ in case of independence.

Table 43 shows an exemplary 2x2 table for IND' and RE. We create the 2x2 table based on the determined frequencies illustrated by Table 42. These frequencies result from the nominal data for IND’ and RE in Table 41. The different colours help to categorise the results. For purposes of clarity, we add the sums at the margins.

Table 42: Determination of the Frequencies for the Contingency Table

IND'	2	2	1	1	1	1	1	2	1	2	1	2	2	1	2
RE	2	2	1	1	1	1	2	2	2	1	2	2	1	2	1

Table 43: 2x2 Table for Diversity and Revenue per Employee

		RE		
		1	**2**	
IND'	**1**	A = 4	B = 4	**8**
	2	C = 3	D= 4	**7**
		7	**8**	**N=15**

We give an exemplary illustration for the comparison in Tables 44 and 45. These highlight the actual observed relative frequencies and the expected frequencies in the case of independence. We calculate the expected values using the sums at the margins of the contingency table.

Table 44: Observed Frequencies for IND’ and RE

		RE		
		1	**2**	
IND'	**1**	$\frac{4}{15}$	$\frac{4}{15}$	
	2	$\frac{3}{15}$	$\frac{4}{15}$	

Table 45: Expected Frequencies for IND’ and RE

		RE		
		1	**2**	
IND'	**1**	$\frac{8}{15} \cdot \frac{7}{15}$	$\frac{8}{15} \cdot \frac{8}{15}$	
	2	$\frac{7}{15} \cdot \frac{7}{15}$	$\frac{7}{15} \cdot \frac{8}{15}$	

$$\chi^2 = \sum_{i=1}^{2}\sum_{j=1}^{2}\frac{(f_{b(i,j)} - f_{e(i,j)})}{f_{e(i,j)}}$$

Equation 8: Calculation of the Chi-square Coefficient for 2x2 Scheme

The chi-square coefficient or square contingency calculated by Equation 8 now serves as measure of correlation. The hypothesis H0 formulates that there is no appreciable difference between the observed and expected frequencies. As a first alternative to estimate the significance of the result, one could use a table of the distribution function of the χ^2 distribution. Bortz (1999, pp. 773–774) provides the appropriate table. In case of a 2x2 table the number of degree of freedom is always 1.

Nevertheless, the informative value concerning the significance across different samples is low. This lack of informative value is because the upper limit of the chi-square coefficient depends on the number of occurrences of the variables and the size of the given sample. Consequently, one can use Cramers V as a symmetric measure for the strength of the relationship between two or more nominally scaled variables. Cramers V or Cramers Index expresses the degree of dependence of two nominally scaled features. Equation 9 illustrates the calculation of the index.

$$CI = \sqrt{\frac{\chi^2}{N \cdot (\min(i,j) - 1)}}$$

Equation 9: Cramers Index (Bortz, 1999, p. 225)

Regardless of the number of rows and columns, we can use Cramers V for any cross-table. In our present analysis of the hypothesis that diversity across different industries influences performance, we have a 2x2 contingency table. A 2x2 table means that Cramers V in fact equals the absolute amount of the phi-coefficient calculated according to Equation 10.

$$r_{\ddot{0}} = \frac{BC - AD}{\sqrt{(A + B) \cdot (C + D) \cdot (A + C) \cdot (B + D)}}$$

Equation 10: Calculation of the Phi-Coefficient (Cohen, 2003, p. 31)

The value of Cramers V respectively the Phi-coefficient is always between 0 and 1. As the value is always positive, we cannot make any statement about the direction of the correlation results shown in Table 46.

Table 46: Correlation Results for Hypothesis 3 (IND')

	RE	ROA	AT	OP	DDR	PFR
Chi Square	0.0765	1.3333	3.8985	1.3333	0.0000	0.0000
Cramers V	0.0714	0.3333	0.5476	0.3333	0.0000	0.0000
Phi Coefficient	0.0714	0.3333	0.5476	0.3333	0.0000	0.0000

According to Quatember (2011, p. 65), values from 0 to 0.2 express a weak statistical association. Further, the values from 0.2 up to 0.6 are to be interpreted as a moderate association. Finally, values above 0.6 indicate a strong statistical association. Table 47 shows our results based on a significance level of 0.95.

Table 47: Test for Significance of Hypothesis 3 (IND')

Variable	Variable	X^2 theoretic	Formulation of the hypothesis H0	$X^2_{(1;95\,\%)}$	Cramers V	rΦ	Test decision
RE	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	0.0765	0.0714	0.0714	H0
ROA	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	1.3333	0.3333	0.3333	H0
AT	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	3.8985	0.5476	0.5476	H0
OP	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	1.3333	0.3333	0.3333	H0
DDR	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	0.0000	0.0000	0.0000	H0
PFR	IND'	3.841	$H0{:}\ \chi^2 < \lvert 3.841 \rvert$	0.0000	0.0000	0.0000	H0

Thus, our analysis of the nominal data points to at least one moderate statistical association between one performance indicator (AT) and the diversification across more than just one industry (IND'). As with Quatember (2011, p. 65), due to the moderate statistical association of 0.5476, we do not consider the result as sufficiently significant to justify the rejection of H0 in favour of H1.

Moreover, beside the above analysis of a statistical correlation using the chi-coefficient for nominal data, we can collect metric data. Therefore our analysis for diversity across different industries comprises a second part. We expect additional information for two reasons:

- Firstly, metric data is of higher quality than nominal data.
- Secondly, an additional statement concerning the significance can be made.

The most important industry is obviously the plastics industry. This is no surprise because all focal companies are plastic processing companies. In order to look at diversity on an industrial level, we therefore omit the plastics industry. Based on a reduced subnetwork illustrated by Figure 49, we calculate IND which is defined as the number of complementary industries of the focal companies (Table 7 in Section 4.2.2).

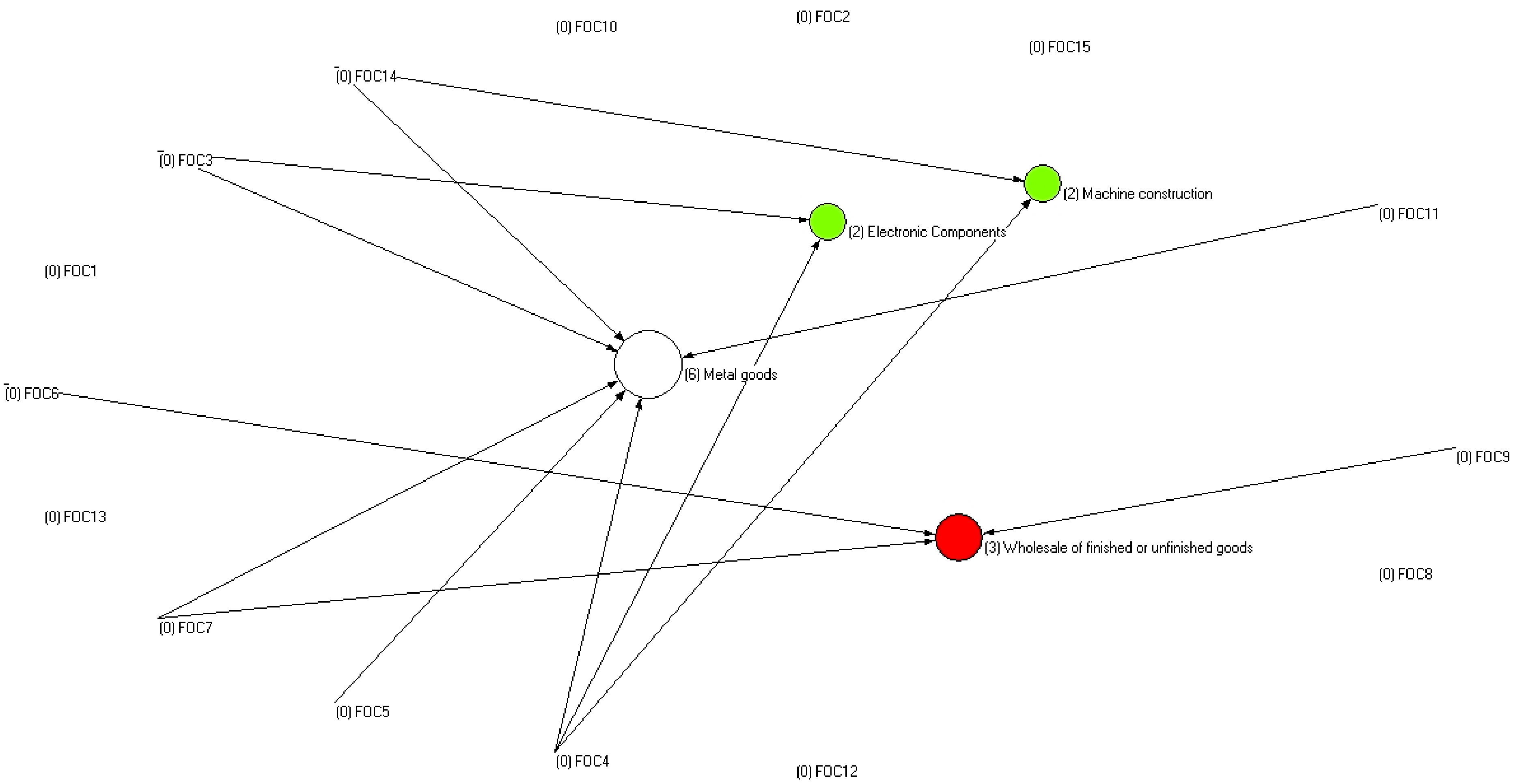


Figure 49: Subnetwork of the Directed Graph $H_D(W, B)$ of the Egocentric Network Study (Industries) with w = 4 industries and u = 15 focal companies. The arrows pointing from focal company to industry indicate the affiliation of a focal company in a specific branch of industry. Arcs only exist between the two different types of nodes.

The output-degree in Table 48 equals the total number of participating industries IND.

Table 48: Overview Number of Participating Industries

Company	IND
FOC1	0
FOC2	0
FOC3	2
FOC4	3
FOC5	1
FOC6	1
FOC7	2
FOC8	0
FOC9	1
FOC10	0
FOC11	1
FOC12	0
FOC13	0
FOC14	2
FOC15	0

Both the individual performance metrics in Table 20 (Section 5.2) as well as the calculated number of industries IND in Table 48 are now metric values. We can therefore measure the statistical association by a correlation calculation.

Table 49 shows our results calculated for each financial performance measure, dependent on the number of industries. In this case, we have only one strong result for a statistical association between PFR and IND.

Table 49: Correlation Results for Hypothesis 3 (IND)

Industries IND	R^2	r	t	n	t theoretic
RE	0.01	0.08	0.28	15	-1.76
ROA	0.11	0.32	1.08	12	-1.80
AT	0.21	0.46	1.72	13	-1.78
OP	0.04	-0.20	-0.63	12	-1.80
DDR	0.02	-0.13	-0.43	12	-1.80
PFR	0.46	0.68	**2.94**	12	-1.80

Figure 50 illustrates the linear regression of the strongest correlation. In the Appendix A12 we present the other linear regressions.

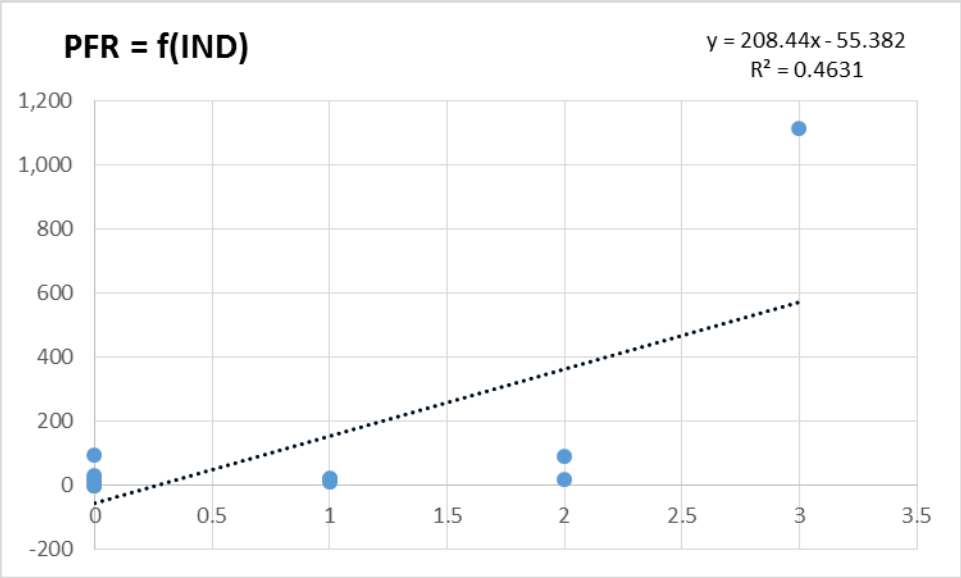


Figure 50: Linear Regression PFR = f(IND)

To verify the significance of our gained results, we also use the previously described one-sided t-test illustrated by Equation 7. The hypothesis H0 is rejected in favour of the alternative H1, if the calculated t-value exceeds the critical t-value (t-theoretic).

Table 50: Test for Significance of Hypothesis 3 (IND)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
IND	RE	-1.76	$H0: t < \mid 1.76\mid$	0.28	H0
IND	ROA	-1.80	$H0: t < \mid 1.80\mid$	1.08	H0
IND	AT	-1.78	$H0: t < \mid 1.78\mid$	1.72	H0
IND	OP	-1.80	$H0: t < \mid 1.80\mid$	-0.63	H0
IND	DDR	-1.80	$H0: t < \mid 1.80\mid$	-0.43	H0
IND	PFR	-1.80	$H0: t < \mid 1.80\mid$	**2.94**	**H1**

Our results illustrated in Table 50 confirm the statistical association between the number of different industries IND beyond the plastics industry and one important performance indicator, namely PFR. Our previously described moderate correlation between IND' and AT illustrated by Table 47 again does not seem to hold enough significance (t-value = 1.72). However, the presented results of the linear regression in Figure 50 give the impression that the significance of PFR may be backed by one single outlier at (3/1,115). The implementation of a box plot test confirms this. The box plot in Figure 51 summarises various measures for scattering and robust measures of location in one presentation. Table 51 shows the descriptive statistics for the box plot.

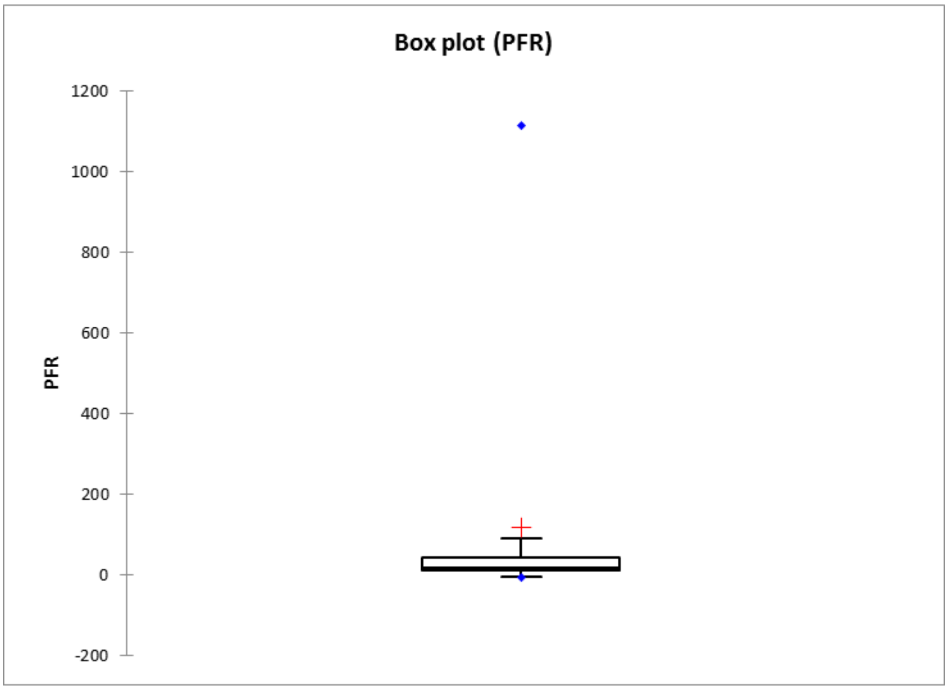


Figure 51: Box Plot for PFR

Table 51: Descriptive Statistics (Quantitative Data) for PFR

Number of observations	15
Minimum	-4,038
Maximum	1115,025
1st quartile	11,606
Median	19,359
3rd quartile	43,855
Mean	118,321
Variance (n-1)	99500,309
Standard deviation (n-1)	315,437

We therefore continue our statistical analysis for PFR = f(IND). We show the results of an additional regression analysis excluding the identified outlier in Table 52. The correlation coefficient *r* is now only 0.29 compared to 0.68 including the outlier. The distribution of the linear regression analysis is shown in Figure 52.

Table 52: Additional Correlation Results for Hypothesis 3 (IND)

Industries IND	**R^2**	**r**	**t**	**n**	**t theoretic**
PFR ex. Outlier	0.08	0.29	0.90	11	-1.81

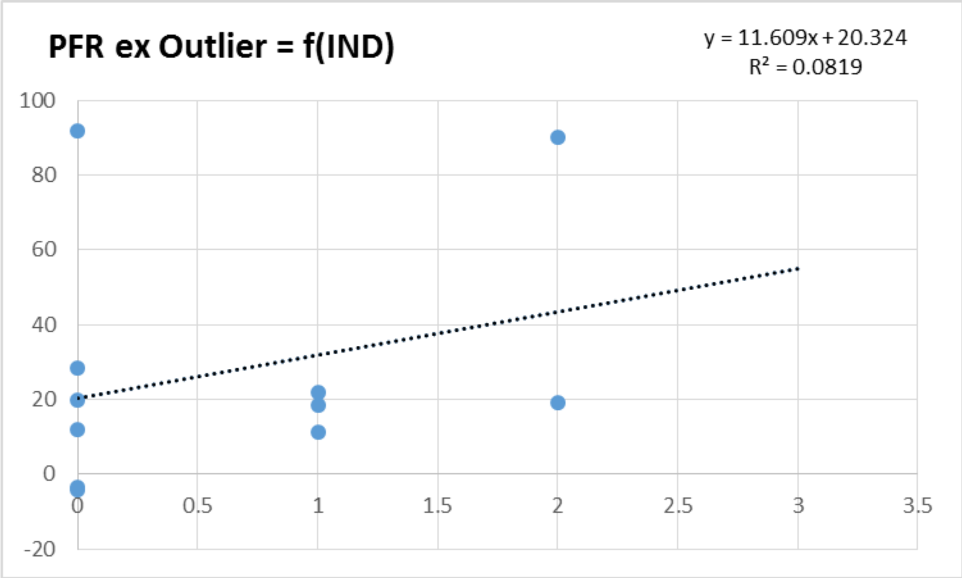


Figure 52: Linear Regression PFR ex. Outlier = f(IND)

In conclusion, it would be wrong if we rejected H0 as shown in Table 50. Table 53 illustrates the corrected result.

Table 53: Additional Test for Significance of Hypothesis 3 (IND)

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
IND	PFR ex. Outlier	-1.81	$H0: t < \|1.81\|$	0.9	H0

We cannot draw clear conclusions from a correlation between the number of industries a company is involved in and the performance of a company. The only result that we can determine is a moderate correlation between IND' and AT. As shown in Table 50, the correlation of the independent variable IND influencing the dependent variable AT is at the limit of being a significant result. If we were to accept a significance level of 0.10 instead of 0.05, the result would look as presented in Table 54.

Table 54: Additional Test for Significance of Hypothesis 3 (IND)
Significance Level = 0.10

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
IND	AT	-1.36	$H0: t < \|1.36\|$	**1.72**	**H1**

Nevertheless, we cannot consider this result as being sufficiently significant. The reason why the analysis for the number of industries shows only a weak or moderate statistical association can have many facets:

- While data for the economic performance of the focal companies is very detailed, the total number of industries is only a rough measure.

- By giving each industrial sector the same weight, business conditions and the level of innovation of each industrial sector play no role.
- Even if the industries were weighted, we could not clearly allocate revenue to a particular industry.
- Further, a focal company can be very successful, working in a niche of just one industrial sector.

Nevertheless, our analysis for the industries offers at least one additional relevant information. All focal companies are allocated to the manufacturing of general plastic products WZ 22290 or the manufacturing of plastic materials for packaging WZ 22220. If we look at the other industries they are involved in, we can conclude that plastic processing companies clearly tend to complement their portfolio by processing metal, acting as wholesalers of finished or unfinished goods, electrical engineering and the construction of machinery and tools.

Up to this point of our data analysis, all three hypotheses (strength of links, node centrality and diversity) have been investigated for their impact on performance. As a means of in depth analysis, we used simple linear regression in the main. The simple linear regression is the appropriate tool for analysing the correlation of two metric characteristics. The following section summarises the results.

5.4 Results for Simple Linear Regressions

The present study contributes to performance measurement by examining the link between network position of companies in the supply chain network and their economic performance. After the identification of some key network position characteristics, we investigated the question to what extent the economic performance of a company is influenced by network position properties. Thereby, the economic performance is determined by various financial performance measures.

We answered our research question (posed in Section 3.4) by showing that AS, different measures of node centrality (C, BC, $BP_{\beta=0.995/\lambda}$) and one measure of link diversity (HUB) show significant results when studied for their influence on different financial performance measures (RE, OP and ROA). As the summarised results of the simple linear regression in Table 55 indicate, the influence of $BP_{\beta=0.995/\lambda}$ stands out.

Table 55: Summarised Test Results by Means of Simple Linear Regression

IV	DV	t-theoretic	Formulation of Hypothesis H0	t-value	Test decision
AS	RE	-1.76	$H0: t < \|1.76\|$	**1.92**	**H1**
AS	OP	-1.80	$H0: t < \|1.80\|$	**1.83**	**H1**
AS	OP (ex. outlier)	-1.81	$H0: t < \|1.81\|$	**2.85**	**H1**
C	OP	-1.80	$H0: t < \|1.80\|$	**5.05**	**H1**
BC	OP	-1.80	$H0: t < \|1.80\|$	**5.36**	**H1**
$BP_{\beta=0.995/\lambda}$	ROA	-1.80	$H0: t < \|1.80\|$	**1.96**	**H1**
$BP_{\beta=0.995/\lambda}$	OP	-1.80	$H0: t < \|1.80\|$	**5.24**	**H1**
HUB	RE	-1.76	$H0: t < \|1.76\|$	**2.79**	**H1**

Our implications for the measurement of BP confirm that the results for BP depend on the parameter β. As illustrated in Section 5.3.2, centrality scores for BP ($\beta < 0$) that are the opposite of BP ($\beta > 0$) indicate that the positive effect on performance by means of connections to well-connected nodes may turn into a negative one, in case business partners manage to exploit bargaining situations. However, in conclusion we stick to our results for BP setting $\beta > 0$. Following Borgatti et al. (2013, p. 172), the negative centrality scores for BP ($\beta < 0$) would imply that it is best to have no connections at all. In our case of the scale-free supply chain network, this is not realistic. The fact that companies need to link, is in the nature of things. Yet, our results reveal the importance of a network perspective, in order to improve performance.

Figure 53 provides a simplified matrix scatter plot of all our variables (IV and DV). The significant results are marked in green.

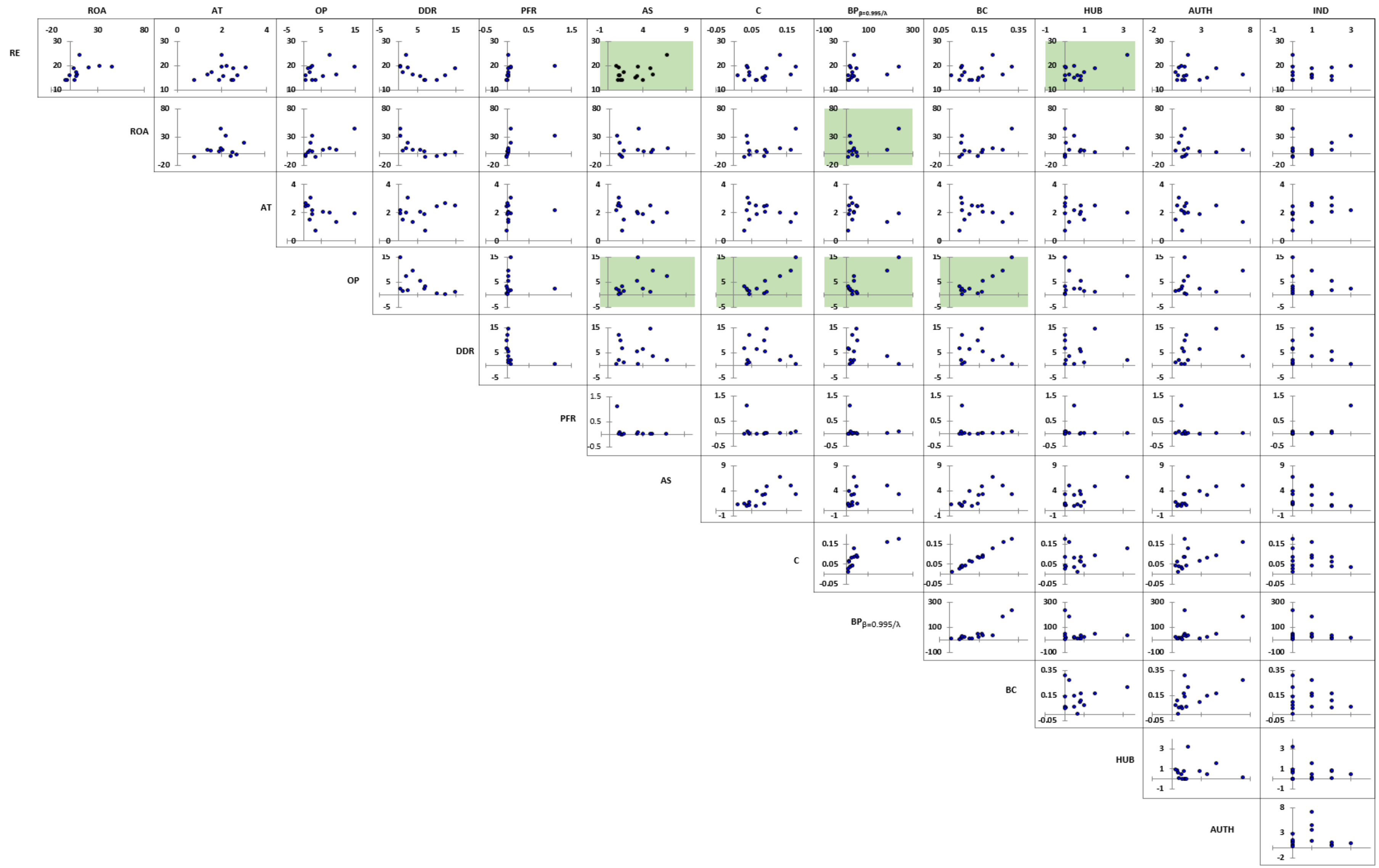


Figure 53: Matrix Scatter Plot of All Variables of Interest with Significant Associations between IV and DV coded green

5.5 Verification by Ranking and Prestige

Subsequent to the presentation of our results, we verify whether the observed influence of network position properties on financial performance measures is also confirmed by measures for ranking and prestige.

Up to now, we assumed relations, characterised by cash flows or product flows between companies in the supply chain network, to be balanced. We built on the fact that goods are delivered in return for an equivalent monetary value. This is different for the concepts prestige and ranking which imply an asymmetry in the relations.

In our case of a manufacturing industry which supplies finished or semi-finished goods, the customer is clearly in a position to exercise some power. The customer is the one who initiates a tie by ordering goods. Therefore, nodes (focal companies) that maintain many incoming links from customers are structurally more prestigious. Thus, in social network analysis, structural prestige is the result of a specific pattern of ties.

In contrast to structural prestige, social prestige originating from social sciences is about the reputation of entities or persons among social ties. The question, whether structural prestige goes along with social prestige is to be examined. Assuming that economic performance results in social prestige, we can analyse whether social prestige correlates with structural prestige. In case of a positive confirmation, focal companies may exercise power with respect to their suppliers and their customers. Further, prestigious companies may have a stronger position compared to competitors.

A first insight to approach structural prestige is popularity or indegree on a vertex. Indegree equals the number of incoming ties in a directed network. When adapting this concept to the supply chain network, we build on orders as choices. In general, more customers indicate a higher structural prestige. It is obvious that indegree is only applicable in directed networks.

The calculation of indegree resembles the previous known calculation of degree, which was also part of our Hypothesis 2. The only difference is that indegree cares about the direction. Using Pajek, we store the indegree in a partition data object. Table 56 shows our results for the calculated indegree of the focal companies in $G_D(V,A)$ illustrated by Figure 34.

Table 56: Indegree Calculation Based on the Directed Graph $G_D(V, A)$

Company	Indegree
FOC1	16
FOC2	4
FOC3	5
FOC4	9
FOC5	10
FOC6	11
FOC7	16
FOC8	1
FOC9	10
FOC10	62
FOC11	4
FOC12	7
FOC13	46
FOC14	16
FOC15	10

To explain social prestige as a result of structural prestige, we can conceive that a higher indegree centrality goes hand in hand with better performance, expected to increase social prestige. At this point, we again link social network analysis and statistics. Given that both structural prestige as well as performance results are metric, we calculate the correlation coefficient to assess statistical association. A positive correlation coefficient would indicate that a structural prestigious company performs better. In contrast, a negative correlation coefficient is an indicator that the two features repel each other.

Table 57 shows that structural prestige influences several important performance measures. RE, ROA and OP all show either moderate or strong associations. Again, we apply the one-sided t-test according to Equation 7. We can confirm the three results to be significant.

Table 57: Correlation Results for Prestige and Performance Based on $G_D(V, A)$

Indegree	R^2	r	t	n	t theoretic
RE	0.33	0.57	**2.52**	15	-1.76
ROA	0.34	0.59	**2.28**	12	-1.80
AT	0.00	-0.05	-0.18	13	-1.78
OP	0.64	0.80	**4.17**	12	-1.80
DDR	0.16	-0.40	-1.38	12	-1.80
PFR	0.01	-0.08	-0.26	12	-1.80

As only direct (one-step) choices from customers are taken into account, the measurement of popularity built on indegree centrality is only a limited indicator to conclude social prestige as a result of structural prestige.

In the following, we assume that it might be relevant to consider whether choices come from vertices that are themselves popular or not. Structural prestige calculated only on the direct incoming choices disregards the overall structure. A possible solution to this problem would be to extend prestige to indirect (several steps) choices which we call an input domain. As with Nooy et al. (2011), the input domain of a vertex in a directed network is defined as “the number or percentage of all other vertices that are connected by a path to this vertex” (Nooy et al., 2011, p. 222). Thus, to determine such input domain means to count all vertices that choose a specific vertex either by direct or indirect choice. The input domain is also denoted as influence domain, because vertices that have a big input domain are thought to influence others. Following Nooy et al. (2011), we assume that the larger the input domain is, the higher the structural prestige (Nooy et al., 2011, pp. 221–222).

We can easily adapt the concept of the input domain to the output domain: it depends only on the perspective. We achieve this change in perspective by transposing the network which means the direction of the arcs is inverted (a sender becomes the receiver and vice versa). Whether the analysis focuses on an output domain or an input domain depends on the studied structure. The so-called overall domain forms the union of input and output domain. As we focus on focal companies, we rely on the input domain because we want to consider customer choices.

The result of any domain analysis is influenced by the connectedness of the entire network. It is not surprising, that based on a well-connected network it is easy for most vertices to reach the other vertices. Consequently, in case of a well-connected network, the size of the different input domains varies little. As shown by Nooy et al. (2011), the restriction on one step (direct choices) or two steps (direct and indirect choices) instead of the entire domain is a solution to this problem of little variation (Nooy et al., 2011, pp. 222–223).

At first sight, the input domain of one specific vertex equals the result of the command “k-neighbours” in Pajek when no limitation to distance is entered for the variable *k*. However beside the “k-neighbours” command for only one specific vertex, we can also compute the input domain of all vertices in just one step. Using the command “proximity prestige” in Pajek, we store the input domain of all vertices in a partition. However, the “proximity prestige” command creates three data objects:

- A partition stores the total number of vertices within the input domain of each vertex.
- The first of two vectors stores the normalised size of each input domain. The normalised size results from the number of vertices within one domain divided by the total number of vertices without the one vertex for which the size is computed.

- The second vector stores the average distance of paths in the input domain for each individual vertex.

Thus, the information we gain from this calculation is not only the basis for the input domain of all vertices, but also leads to the proximity prestige concept. Following Nooy et al. (2011) proximity prestige of a vertex is defined as “the proportion of all vertices (except itself) in its input domain divided by the mean distance from all vertices in its input domain” (Nooy et al., 2011, p. 226).

As we already noted, it is not useful to build on the entire input domain as an indicator for structural prestige. In the case of a well-connected network, there is little variation in the size of the different input domains. The described restriction on connections of $k = 1$ or $k = 2$ steps can only be a random choice in order to limit the input domain. This suggests that proximity prestige is a solution for the initial problem of little variation. By calculating proximity prestige we take the entire input domain into account, but the distance becomes a factor as well. The distinction if choices come from vertices nearby or from vertices more distant, influences the proximity prestige of the vertex in focus. Proximity prestige weights relationships for their distance which is the opportunity to include path distance. This way, a higher distance contributes less than a small distance, but every vertex contributes to the result of the proximity prestige.

We calculate the proximity prestige of a vertex by the proportion of the input domain of a vertex divided by the average distance from all vertices in the input domain. In the case of a larger input domain (numerator) we get a higher proximity prestige, because more vertices have direct or indirect links to the specific vertex. As with Nooy et al. (2011), the other way around, a smaller average distance also results in a higher proximity prestige, because the specific vertex is nominated by more vertices nearby (Nooy et al., 2011, p. 226).

In Pajek it is quite simple to calculate the proximity prestige. Using the “Proximity Prestige” command creates two vectors. To calculate proximity prestige we just divide the vector of input domain size by the vector of average distance. The result is the proximity prestige which we store in a vector data object, containing values between 0 and 1. Table 58 shows the proximity prestige of the focal companies.

Table 58: Results for Proximity Prestige

Company	Proximity Prestige
FOC1	0.0191
FOC2	0.0089
FOC3	0.0084
FOC4	0.0201
FOC5	0.0224
FOC6	0.0134
FOC7	0.0358
FOC8	0.0022
FOC9	0.0094
FOC10	0.0835
FOC11	0.0089
FOC12	0.0157
FOC13	0.0542
FOC14	0.0358
FOC15	0.0224

We now calculate the correlation coefficient in order to verify the statistical association between proximity prestige and economic performance. We also calculate the input domain based on $G_D(V, A)$ (see Figure 34). Our previous results of prestige based on indegree illustrated in Table 57 are also confirmed by proximity prestige illustrated in Table 59. RE, ROA and OP show either moderate or strong association. The one-sided t-test confirms the three significant results.

Table 59: Correlation Results for Proximity Prestige and Performance ($G_D(V, A)$)

Proximity prestige	R^2	r	t	n	t theoretic
RE	0.22	0.47	**1.93**	15	-1.76
ROA	0.40	0.63	**2.57**	12	-1.80
AT	0.02	-0.12	-0.41	13	-1.78
OP	0.75	0.86	**5.44**	12	-1.80
DDR	0.24	-0.49	-1.78	12	-1.80
PFR	0.00	-0.03	-0.11	12	-1.80

In sum, we can consider indegree and proximity prestige as the two main concepts to deal with structural prestige. As already mentioned, structural prestige does not necessarily go along with social prestige. At first, structural prestige is only a pattern of ties. By correlation analysis, we examined a specific association between structural prestige and dependent variables (financial performance measures) for social prestige.

The fact that we identify strong correlations for the same financial performance measures as already noted in Section 5.5, underlines the results of our hypotheses testing.

5.6 Statistical Performance Measurement Models

The final step of our analysis is to check how the results evolve, if we review several independent variables at once for their influence on each financial performance measure. By means of multiple linear regression, we develop a holistic model, in which we test all the influencing factors accurately. The independent variables result from:

- Hypothesis 1: AS
- Hypothesis 2: C, $BP_{\beta=0.995/\lambda}$, BC
- Hypothesis 3: HUB, AUTH, IND

We perform the multiple linear regression by using the statistic software XLSTAT[12]. XLSTAT is an efficient statistical and multivariate data analysis package. The program uses Microsoft Excel as an interface. Similar to the simple linear regression, the software identifies the regression parameters on the criterion of least squares. Backhaus (2011, p. 69) describes this process more in detail. Performing a multiple linear regression is only possible with considerable computational effort. Therefore the use of statistical software is essential.

We can describe a holistic model which includes all the independent variables similarly to Equation 11.

$$Y = b_0 + b_1 \cdot AS + b_2 \cdot C + \cdots + b_7 \cdot IND$$

Equation 11: Exemplary Holistic Model Based on Multiple Linear Regression

Y is the financial performance measure described as dependent variable (regressand/response). AS, C, etc. are the network position properties x_i described as independent variables (regressors/predictors) and b_0 up to b_7 are the regression parameters.

Table 60 summarises all models of our multiple linear regression including all the independent variables IV.

[12] http://www.xlstat.com/

Table 60: Multiple Linear Regression Models (All Dependent Variables)

	Regression parameters							
Y	$\mathbf{b_0}$	$\mathbf{b_{AS}}$	$\mathbf{b_C}$	$\mathbf{b_{BP\ \beta=0.995/\lambda}}$	$\mathbf{b_{BC}}$	$\mathbf{b_{HUB}}$	$\mathbf{b_{AUTH}}$	$\mathbf{b_{IND}}$
RE	139,399	+ (9,622)	+ (862,109)	+ (514)	- (764,100)	+ (25,239)	- (8,407)	+ (13,881)
ROA	2.5538	+ (5.5918)	+ (237)	+ (0.4013)	- (344)	+ (4.387)	- (6.6679)	+ (8.9973)
AT	1.4113	- (0.1307)	+ (57.187)	- (0.0061)	- (24.1776)	- (0.0154)	- (0.0975)	+ (0.3211)
OP	-656,656	+ (3,071,353)	- (35,012,964)	+ (70,389)	- (9,113,010)	- (2,126,930)	- (1,641,619)	+ (730,949)
OP ex. Out.	-155,681	+ (3,930,707)	- (91,548,234)	+ (110,936)	+ (4,455,408)	- (2,692,765)	- (2,464,836)	+ (657,210)
DDR	6.6967	- (1.9445)	- (178)	- (0.1160)	+ (172)	- (1.6302)	+ (2.2455)	- (1.9694)
PFR	93	- (144)	+ (7,035)	+ (3.3248)	- (5,130)	+ (311)	+ (11.5574)	+ (203)
PFR ex. Out.	14.1160	+ (16.0235)	+ (1,180)	+ (0.9238)	- (1,230)	+ (6.8658)	- (16.8147)	+ (25.8063)

The different regression coefficients indicate the effect of the network position properties (independent variables, regressors) on Y (dependent variable, regressand). Due to the different units of measure of the independent variables, one cannot compare the individual regression parameters b_1 up to b_7 presented in Table 60 directly. By the use of standardisation according to Equation 12, we calculate the so-called standardised regression coefficients (beta values). As we eliminate the different measurement dimensions, we can compare the beta values. Nevertheless, we maintain the substantive significance of individual regression parameters for the purpose of predictability.

$$\widetilde{b_j} = b_j \cdot \frac{standard\ deviation\ of\ X_j}{standard\ deviation\ of\ Y}$$

Equation 12: Standardisation of the Regression Coefficients
(Backhaus, 2011, p. 70)

We divide the additional review of the quality of the regression function into two parts, namely (i) the global review, and (ii) the review of each regression coefficient:

- The global review shows how well the model explains the dependent variable Y.
- The review of each regression coefficient shows how individual regression coefficients contribute to the explanation of the dependent variable Y.

Our global review is based on the multiple coefficient of determination R^2 and the so-called F-statistic.

Table 61 shows the first part of our results of the review. R^2 expresses the proportion of explained variance relative to the total variance. R^2 is also known as the goodness of fit because it explains the quality of the regression function with respect to the empirical data. As a normalised value, the multiple coefficient of determination lies between 0 and 1. The results for (i) RE, (ii) ROA, (iii) OP, (iv) OP excluding the outlier and (v) PFR excluding the outlier clearly stand out. The proportions of these results range from 0.755 up to 0.939. This means that the corresponding models explain up to 93.9 % of the total variance.

In order to determine whether the particular model has validity beyond the given sample, we use the F statistic. Besides the scattering of the results, the F-statistic takes into account the size of the sample allowing for a statement on the significance of the model to be made. Following Backhaus (2011, p. 76), we verify whether we can use the estimated regression function (based on the given sample), as a realisation of a true function with unknown parameters to explain a causal relationship in the population.

We perform the verification of the hypothesis H0 (no significant correlation) using an F-test illustrated by Equation 13. The variable n equals the sample size and k equals the number of independent variables.

$$F = \frac{R^2 \cdot (n - k - 1)}{(1 - R^2) \cdot k}$$

Equation 13: Calculation of the F-Value (Bortz, 1999, p. 433)

Based on the value of F, we verify whether the selected regression model has an explanatory value for the dependent variable Y (regressand). We test whether several variables x_i (regressors) together have a significant impact on the regressand. We check the value of F against an F-table at a certain significance level. Bortz (1999, pp. 776–781) provides an appropriate F-table. Pr > F expresses the observed significance level or p-value. The p-value is the smallest fixed level at which we can reject the hypothesis H0. If we accept a level up to 10 %, the hypothesis H0 is rejected for the models of (i) RE, (ii) ROA and (iii) OP. At this point, a level of up to 10 % is sufficient, because the F-statistic is the starting point for optimisation of the different models. The optimised model should then be confirmed on a 5 % level.

Table 61: Multiple Linear Regression Results Including all Independent Variables

	R^2	**F**	**Pr > F**	**Formulation of Hypothesis H0**	
RE	0.755	3.088	8 %	$H0: p > 10\,\%$	**H1**
ROA	0.872	3.890	10 %	$H0: p > 10\,\%$	**H1**
AT	0.415	0.506	80 %	$H0: p > 10\,\%$	H0
OP	0.939	8.845	3 %	$H0: p > 10\,\%$	**H1**
OP ex. Outlier	0.899	3.823	15 %	$H0: p > 10\,\%$	H0
DDR	0.540	0.671	70 %	$H0: p > 10\,\%$	H0
PFR	0.625	0.952	55 %	$H0: p > 10\,\%$	H0
PFR ex. Outlier	0.800	1.711	36 %	$H0: p > 10\,\%$	H0

Following the global review, we now answer the question about the role of individual predictors by a two-sided t-test for each regression coefficient. Our aim is to verify how individual regression coefficients contribute to the explanation of the dependent variable. It is obvious that this test is only useful if the entire model has been confirmed previously through the F-statistic. We calculate the t-value according to Equation 14 where b_j is the standardised correlation coefficient of each independent variable and s_{bj} is the standard error of b_j.

$$t = \frac{b_j}{s_{bj}}$$

Equation 14: t-value of Standardised Correlation Coefficient (Backhaus, 2011, p. 81)

We also calculate the t-value using the statistic software XLSTAT. Pr > | t | expresses the probability associated with significance or p-value. The p-value indicates the likelihood of obtaining such a sample result (or an even more extreme) if the hypothesis H0 is true. The smaller the p-value, the more unlikely it is to get such a result if the hypothesis H0 is true. Thus, the smaller the p-value the stronger the evidence for the alternative hypothesis.

Table 62 provides an overview for the beta values of our three most significant models (RE, ROA and OP). Based on this information, we can now optimise the models: meaning that for all independent variables where we cannot ascertain a significant contribution, the independent variables are removed from the model.

Table 62: Significance of the Standardised Regression Coefficients (All Beta Values)

	β_{AS}	**Pr >|t|**	β_{C}	**Pr >|t|**	$\beta_{BP\beta=0.995/\lambda}$	**Pr >|t|**	β_{BC}	**Pr >|t|**	β_{HUB}	**Pr >|t|**	β_{AUTH}	**Pr >|t|**	β_{IND}	**Pr >|t|**
RE	0.595	43 %	1.404	57 %	1.176	7 %	-2.254	33 %	0.715	18 %	-0.537	20 %	0.467	8 %
ROA	0.731	42 %	0.804	73 %	1.995	5 %	-2.101	37 %	0.279	63 %	-0.894	8 %	0.630	4 %
OP	1.346	8 %	-0.398	81 %	1.174	7 %	-0.186	90 %	-0.454	28 %	-0.739	5 %	0.172	31 %

5.6.1 Revenue per Employee Model

With respect to the dependant variable RE, we can see that independent variables like AS or C fade into the background. Although the simple linear regression confirmed a significant correlation between AS and RE, the meaning of AS is reduced if we take a holistic view. The strongest evidence against the hypothesis H0 (H0: $t < t_{theoretic}$) is determined for standardised regression coefficients of $BP_{\beta=0.995/\lambda}$, BC, HUB, AUTH and IND. Our first optimised model then looks like the results presented by Table 63.

Table 63: Multiple Linear Regression Results Including 5 Independent Variables (RE Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
RE	0.716	4.535	2 %	$H0: p > 5\,\%$	H1

A p-value of 2 % strongly supports our model. Nevertheless, if we verify the contribution of individual correlation coefficients shown by Table 64, a further optimisation might be possible.

Table 64: Significance of the Standardised Regression Coefficients (5 Beta Values, RE Model)

$\beta_{BP\beta=0.995/\lambda}$	Pr >|t|	β_{BC}	Pr >|t|	β_{HUB}	Pr >|t|	β_{AUTH}	Pr >|t|	β_{IND}	Pr >|t|
1.236	3 %	-0.735	16 %	1.084	0 %	-0.228	30 %	0.344	10 %

A model in which AUTH is omitted results in Table 65. The value of R^2 is slightly smaller (0.678 compared to 0.716). However, all independent variables contribute to the model, which is illustrated by Table 66.

Table 65: Multiple Linear Regression Results Including 4 Independent Variables (RE Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
RE	0.678	5.274	2 %	$H0: p > 5\,\%$	H1

Table 66: Significance of the Standardised Regression Coefficients (4 Beta Values, RE Model)

$\beta_{BP\beta=0.995/\lambda}$	Pr > |t|	β_{BC}	Pr > |t|	β_{HUB}	Pr > |t|	β_{IND}	Pr > |t|
1.259	3 %	-0.880	9 %	1.108	0 %	0.338	11 %

It is important to consider that R^2 equals the multiple correlation coefficient. The multiple correlation coefficient is higher if more independent variables are part of the model. Although some independent variables may only add a small contribution towards explaining the whole model, their correlation coefficients lead to a higher R^2. Consequently a smaller result for R^2 is no contradiction if the explanation of the model based on the independent variables is improved. In our case of RE, a comparison of the so-called adjusted coefficient of determination calculated by the use of Equation 15 confirms our statement. The variable J in this formula equals the number of independent variables (regressors). K equals the sample size, consequently K - J - 1 expresses the number of degrees of freedom.

$$R^2_{adj.} = R^2 - \frac{J \cdot (1 - R^2)}{K - J - 1}$$

Equation 15: Adjusted Coefficient of Determination (Backhaus, 2011, p. 76)

The adjusted coefficient of determination R^2 with 4 independent variables is 0.550 compared to 0.558 for 5 independent variables. Given the small difference, we optimised the model for the dependent variable RE influenced by some independent variables (network position properties). Table 67 shows the final model. A positive development for economic performance expressed by RE results in particular from higher values in $BP_{\beta=0.995/\lambda}$, HUB and IND.

Table 67: Final Model for the Dependent Variable RE

RE =	146,554 +(550 · $\mathbf{BP_{\beta=0.995/\lambda}}$) - (298,220 · **BC**) + (39,134 · **HUB**) + (10,041 · **IND**)

If reliance had been placed solely on the simple linear regression and the most significant results, a summarised multiple linear regression targeting to show the different influences of the independent variables would have resulted in a model of poorer quality. In the Appendix A13, we provide a model for RE based on AS, C (the most popular centrality measure) and HUB, for the purpose of completeness.

5.6.2 Return on Assets Model

Another important result is our model of the dependent variable ROA. The simple linear regression confirmed a significant result for the independent variable $BP_{\beta=0.995/\lambda}$. The results of the multiple linear regression including all independent variables confirm the importance of $BP_{\beta=0.995/\lambda}$. According to Table 62, we determine the strongest evidence against the hypothesis H0 (H0: $t < t_{theoretic}$) for standardised regression coefficients of $BP_{\beta=0.995/\lambda}$, AUTH and IND. We present the result of the optimised model in Table 68.

Table 68: Multiple Linear Regression Results Including 3 Independent Variables (ROA Model)

DV	**R^2**	**F**	**Pr > F**	**Formulation of Hypothesis H0**	
ROA	0.714	6.671	1 %	$H0: p > 5\,\%$	**H1**

A p-value of 1 % strongly supports our model. In addition, if we verify the contribution of individual correlation coefficients it shows that no further optimisation is needed. All independent variables contribute to the model illustrated by Table 69.

Table 69: Significance of the Standardised Regression Coefficients
(3 Beta Values, ROA Model)

$\beta_{BP\beta=0.995/\lambda}$	Pr >|t|	β_{AUTH}	Pr >|t|	β_{IND}	Pr >|t|
0.873	0 %	-0.557	3 %	0.479	4 %

The adjusted coefficient of determination R^2 for 3 independent variables is 0.607 compared to 0.648 including all independent variables. Given the reduction of independent variables and the small difference between the two adjusted coefficients of determination, we optimised the model for the dependent variable ROA influenced by some independent variables (network position properties). Table 70 shows the final model. A positive development for economic performance expressed by ROA results in particular from higher values in $BP_{\beta=0.995/\lambda}$ and IND. The negative result for AUTH contradicts the assumption that diversity in product flows on the supplier side is positive.

Table 70: Final Model for the Dependent Variable ROA

ROA =	3.0713 + (0.1756 · $\mathbf{BP_{\beta=0.995/\lambda}}$) - (4.1549 · **AUTH**) + (6.8416 · **IND**)

The same fact we already recognised for the model RE also applies to the ROA model: if we had relied on nothing more than the simple linear regression and its most significant results, a summarised multiple linear regression with the aim to show the different influences of the independent variables would have resulted in a model of poorer quality. In the Appendix A13, we provide as well a model for ROA based on AS, C (the most popular centrality measure) and HUB, for the purpose of completeness.

5.6.3 Operating Profit Model

Our third important result is the model for the dependent variable OP. By simple linear regression we found significant results for the independent variable AS. In addition, we identified several measures of centrality to be significant. C and $BP_{\beta=0.995/\lambda}$ are highlighted. The correlation OP influenced by HUB as the diversity on the customers' side also proved to be significant. The results of the multiple linear regression including all independent variables confirm the importance of AS and $BP_{\beta=0.995/\lambda}$. According to Table 62, we determine the strongest evidence against the hypothesis H0 (H0: $t < t_{theoretic}$) for the standardised regression coefficients of AS, $BP_{\beta=0.995/\lambda}$ and AUTH. We consider the HUB result as not significant enough. Table 71 presents the results of the optimised model.

Table 71: Multiple Linear Regression Results Including 3 Independent Variables (OP Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
OP	0.890	21.509	0 %	$H0: p > 5\,\%$	**H1**

A p-value of nearly 0 % (0.03 %) provides very strong support for our model. If we verify the contribution of individual correlation coefficients, it turns out that no further optimisation is needed. All independent variables contribute to the model, as illustrated by Table 72.

Table 72: Significance of the Standardised Regression Coefficients (3 Beta Values, OP Model)

β_{AS}	Pr > |t|	$\beta_{BP\beta=0.995/\lambda}$	Pr > |t|	β_{AUTH}	Pr > |t|
0.454	1 %	0.897	0 %	-0.425	3 %

The adjusted coefficient of determination R^2 for 3 independent variables is 0.848 compared to 0.833 including all independent variables. Given this small difference between the two adjusted coefficients of determination, we also optimised the model for the dependent variable OP influenced by some independent variables (network position properties). Table 73 shows our final model. A positive development for economic performance expressed by OP results in particular from higher values in AS and $BP_{\beta=0.995/\lambda}$. Again, the negative result for AUTH contradicts the assumption that diversity in product flows on the supplier side is positive.

Table 73: Final Model for the Dependent Variable OP

OP =	-30,619 + (1,035,419 · **AS**) + (53,769 · $\mathbf{BP_{\beta=0.995/\lambda}}$) -(943,645 · **AUTH**)

With respect to the dependent variable OP, we also performed the simple linear regression without a possible outlier. In case of the multiple linear regression, the exclusion of a possible outlier does not really matter. If we perform a multiple linear regression for the dependent variable OP excluding the outlier, the results point into the same direction as if the outlier were included. In the Appendix A13, we provide a multiple linear regression model for OP without the outlier.

Finally, the same fact already recognised for the models RE and ROA, also applies to the initial OP model. Relying only on the simple linear regression and its most significant results, a summarised multiple linear regression would not have the same quality. In the Appendix A13, we provide an additional multiple linear regression model for OP based on AS, C (the most popular centrality measure) and HUB.

5.7 Results for Multiple Linear Regressions

Based on multiple linear regression we developed the conclusive performance measurement models. The multiple linear regression allowed us to include several independent variables in just one model. The results confirmed the three most significant results identified by simple linear regression. We identified significant results with respect to RE, ROA and OP. Thus, performance in the sense of profitability stands out in particular.

Through the analysis of the individual independent variables for their influence, we could optimise our multivariate models. Table 74 shows the summarised results.

Table 74: Three Most Significant Test Results by Means of Multiple Linear Regression
* = statistically significant at 5 % level, ** = statistically significant at 1 % level

Response	**Predictors**						
	AS	**C**	**BP**$_{\beta=0.995/\lambda}$	**BC**	**HUB**	**AUTH**	**IND**
RE	-	-	1.259*	-0.880	1.108**	-	0.338
ROA	-	-	0.873**	-	-	-0.557*	0.479*
OP	0.454**	-	0.897**	-	-	-0.425*	-

Asking for the best fitting model, OP seems to be the most promising solution. The adjusted R^2 indicate that 85 % of the vulnerability in OP are explained by AS, BP and AUTH (Section 5.6.3), compared to 71 % in ROA explained by BP, AUTH and IND (Section 5.6.2), and 55 % in RE explained by BP, BC, HUB and IND (Section 5.6.1).

Looking at Figure 53 we recognise a correlation between ROA and OP. Using the number of employees (see Appendix A4) as a control variable, we verify our findings. We think that the solution for OP is too much dependent on the size of a company. The verification of the statistical association between the number of employees and both DVs (ROA and OP) indicates a correlation coefficient of only 0.03 for ROA compared to 0.61 for OP. Thus, we identify the ROA model as the most reliable network oriented performance measurement model.

6 Implications

By confirming the statistically significant association between different network position properties and several financial performance measures, we have answered our research question stated in chapter 3.4, page 70. Based on our findings, we want to emphasise the implications of our study more fully. There are implications for business as well as for research.

In terms of business, Section 6.1 informs on a new network-related component besides traditional performance measurement based on financial data. This enables a company to improve performance by means of a continuous strategy rethinking and by following recommendations for action. Acknowledging the aim to "(1) provide information that allows the firm to identify the strategies offering the highest potential for achieving the firm's objectives, and (2) align management processes, such as target setting, decision-making, and performance evaluation, with the achievement of the chosen strategic objectives" (Ittner, Larcker & Randall, 2003, p. 715), we inform on contemporary performance measurement.

In order to come to an even more general solution, we are convinced, that the research field of network analysis in the supply chain context benefits from additional research. Section 6.2 points out why our research may serve as a blueprint for further research. We mainly recognise implications for carrying out similar research (i) in a larger context, (ii) with respect to other (non-) manufacturing industries, and (iii) in the light of a longitudinal study.

6.1 Advancement of Performance Measurement

Our thesis is based on the understanding that in a globalised world a company can no longer be considered in isolation or as part of an individual supply chain. Instead, one has to regard companies within a network of supply chains. This strong belief in the importance of networks and the dependency of interactions correlates with a current turning point in the general understanding of performance measurement.

In their extensive literature review on contemporary performance measurement Franco-Santos, Lucianetti and Bourne (2012) write that "more research in this area (note: inter-firm performance) is required especially given the importance of buyer–supplier relationships in our current business environment" (Franco-Santos et al., 2012, p. 97).

Using a variety of statistical instruments, we examined what characteristics of a company's network position influences the economic performance of that company. To determine the degree of implication, we first draw on the proposed framework for contemporary performance measurement (Figure 54).

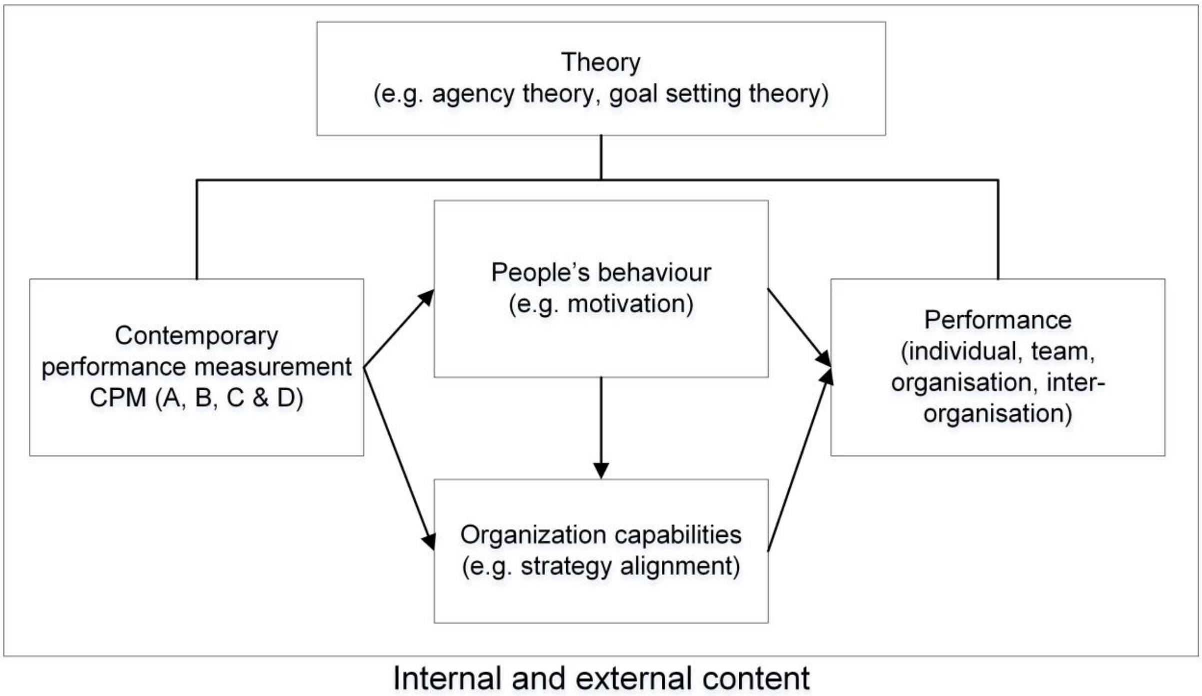


Figure 54: Framework for the Impact of Contemporary Performance Measurement (Franco-Santos et al., 2012, p. 84)

The results of the in-depth analysis of the strongest or most influencing factors (Section 5.4 and Section 5.7) indicates several times: (i) strong positive results for $BP_{\beta=0.995/\lambda}$, and (ii) negative results for AUTH on performance.

- The positive results for $BP_{\beta=0.995/\lambda}$ confirm that Bonacich power, which gives "a higher score to a firm directly connected to several other well-connected entities, making this focal firm both central and powerful" (Bellamy & Basole, 2013, p. 239), clearly influences performance. In other words, Bonacich power reduces the importance of the own degree centrality in favour of the centrality of the connected nodes. We can conclude that the economic performance of a focal company is linked to the centrality (degree centrality) of its neighbours. In line with the positive result for HUB, it is best to be connected to well-connected customers, rather than to be well-connected oneself.
- The negative results for AUTH suggest that it is disadvantageous to have diversified relationships with few suppliers in the network. As our industry of focus is very competitive, the suppliers do not depend on the specific node. Thus, the focal companies (manufacturing companies) obviously cannot expect positive effects because of diversified relationships for a variety of product types. Recalling Bonacich (1987) on the subject of connections to well-connected nodes, it seems more promising if focal companies try to play off many possible suppliers against each other. In line with our in-depth discussion of BP regarding $\beta < 0$ (Section 5.3.2), focal companies should

prefer to increase their number of different suppliers, rather than taking risks of strong dependencies.

In their work, Bellamy and Basole (2013) describe Bonacich power as a "well-known measure not yet exploited in operations and SCM literature" (Bellamy & Basole, 2013, p. 239). In the light of this statement, our results emphasise the timeliness of our thesis and the investigation of the supply chain network in general.

As demonstrated, a focal company benefits from selective connectedness, which is why the strategic focus is to be set on building strong relationships with well-connected customers. By providing strategic recommendations, we recognise the need for targeted action by distinguishing between customers and suppliers.

- It is very likely that strengthening relationships with main customers to reduce fluctuations allows a company to improve its performance. If companies wish to strengthen certain relationships, they should primarily focus on their main customers determined by revenue share. Based on our study, we recommend that having a clear focus on the strongest relationships works best in combination with efforts that ensure open communication and information exchange on a higher level, such as the sharing of stock levels. Improved information exchange between business partners will reduce fluctuations across the supply chain and strengthen the relationships even more. The reduction of fluctuations will eventually improve the overall performance of the individual supply chain consisting of suppliers, focal companies and customers with benefits for all participants.
- Besides stronger relationships, companies benefit from being more central within the network of supply chains. At first, a central position is associated with many incoming and outgoing relationships to suppliers and customers. We recognise this so-called degree centrality as a result of great demand for being an expert, or having the ability to fulfil the requirements of various markets. Furthermore, studying Bonacich power we identify most promising advantages if a company's business partners are themselves well-connected ($\beta > 0$). The innovative capacity of the individual company is certainly one factor influencing both degree centrality as well as Bonacich power.
- While our results do not show a strong impact on performance, if companies are diversified across different industries, the diversity of the individual relationships with regard to product type diversity is relevant. In case a focal company (ego) relies on customers (hubs) buying different product types of that focal company, the performance of the focal company gets improved. Thus, it seems advantageous if different products

are sold to major customers. This is consistent with the results concerning strength of links and our knowledge of Bonacich power.

To summarise and to open up our research on the usability for companies, we propose that companies should enrich their performance measurement tools and include an external network perspective besides an internal financial perspective. Our findings are in line with Franco-Santos et al. (2012) who write that "a contemporary performance measurement system exists if financial and non-financial performance measures are used to operationalize strategic objectives" (Franco-Santos et al., 2012, p. 80).

In terms of contemporary performance measurement the internal financial perspective may consist of the financial performance measures which we use as dependent variables of our statistical analysis. As illustrated, these financial performance measures allow a comprehensive performance analysis on the level of internal evaluation.

The additional network perspective aims to allow further insights into assessing the position in the scale-free supply chain network. Due to $BP_{\beta=0.995/\lambda}$ as our most promising result on network positioning, companies obviously benefit from the identification of well-connected business partners which should be the particular relationships worth to be strengthened. In this context, we recommend to replace the traditional pipe thinking (supplier, manufacturer, and customer) by the management of nonlinear networks respectively ecosystems. For the purpose of contemporary performance measurement, we enable "the organization to perform and gain competitive advantages (e.g., strategic alignment, organizational learning)" (Franco-Santos et al., 2012, p. 80).

Setting the focus on the reliability of the own company and the institutionalisation of cooperation are appropriate measures to strengthen particular relationships across the network. As with Christopher (2011), we argue that successful supply chain integration is all about "the prime objective of improving the speed of response and the reliability of that response" (Christopher, 2011, p. 227).

Based on our findings we state that both, (i) the reliability of the own company and (ii) the level of cooperation, help to strengthen relationships with main business partners. This finally improves performance.

Firstly, measures that quantify reliability of buyer-supplier relationships are (i) innovativeness, (ii) in time and in quantity logistics managed by a high level of IT integration, (iii) quality assurance determined by service level agreements, certification processes and supplier audits and (iv) transparency in terms of pricing and offers (Janker, 2008). The inclusion of such measures into performance analysis eventually drives the reliability of the own company what is a major cornerstone of strategic rethinking toward an increase of business with well-connected business partners. As we present, a focal company seeking to be a valuable node for its partners can improve its performance by such means of comprehensive performance analysis.

Secondly, for reasons of relationships upstream and downstream the supply chain, we concentrate on institutionalising vertical cooperation, meaning cooperation on different levels of the supply chain (Lange, 2010, p. 15). Following Theurl and Schweinsberg (2004, pp. 25–26), we distinguish the level of cooperation because of (i) a formal agreement, (ii) a contract, (iii) a participation and (iv) a joint venture. As a higher level of cooperation also increases the interest for success on both sides, a stronger cooperation with main business partners certainly strengthens relationships for reasons such as higher interdependencies and mutual investments.

Figure 55 summarises our results and assigns the outcomes to the critical path of the initially performed morphological analysis (Section 2.3.3).

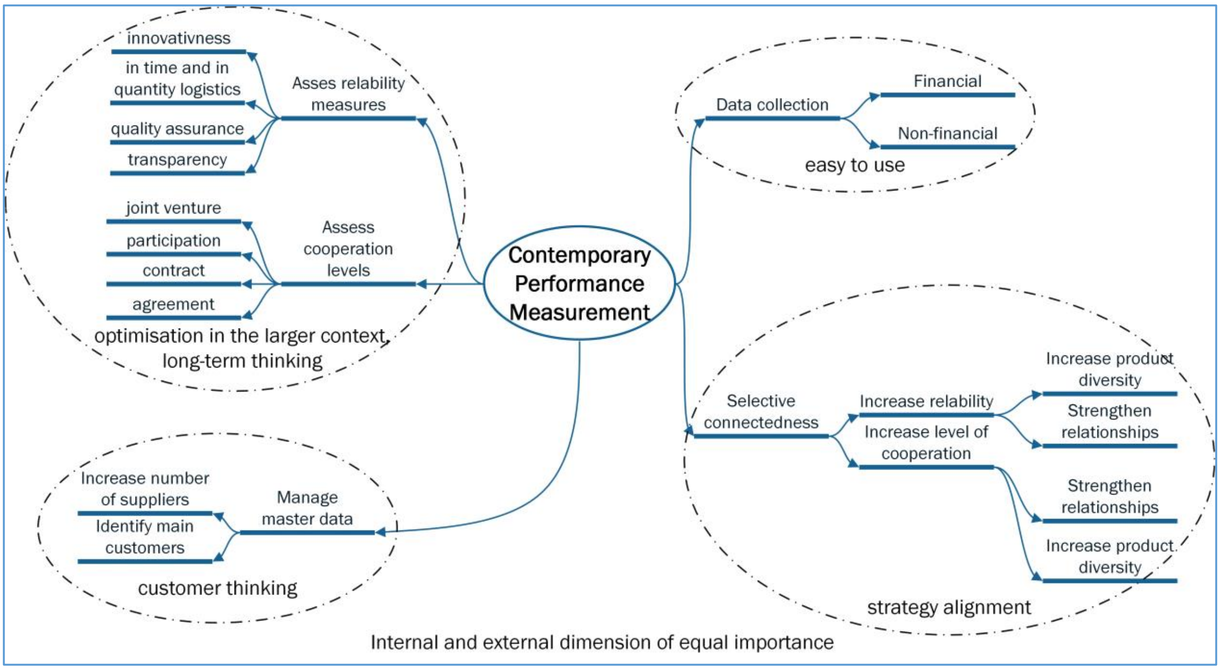


Figure 55: Implications for Contemporary Performance Measurement

Recalling the framework for contemporary performance measurement (Figure 54), we classify our findings as a system of type A. As with Franco-Santos et al. (2012, p. 82):

- Financial and non-financial performance measures are implicitly or explicitly linked to strategy.
- We inform decision-making and evaluational organisational performance.

We can extract the main attributes / actions and group them into (i) people's behaviour (customer thinking), (ii) performance (inter-organisational, long-term thinking in the larger context), (iii) and organisational capabilities (strategy alignment).

Thus, the application of social network theory to the supply chain network allows us to inform on continuous strategy rethinking and recommendations for action. In this sense, our implications are also applicable even for companies not having a clear network insight. We can state that companies should analyse their own relationships with regard to partners who are worth to concentrate on. Our study suggests that appropriate measures to facilitate developing these relations are the strength of the relationship based on cash flows, the diversity of supplied product types on the customer side and the estimated connectedness of the partners.

6.2 Blueprint for Network Research

Given the previously discussed implications in Section 6.1 the present study contributes to knowledge of performance measurement in an industrial context. With respect to supply chain management, our study is one of the first that integrates gained insight from conceptual work on supply chain network architecture into performance measurement. Thereby, our methodological approach provides implications to theory.

We develop a new methodology that allows us to merge a number of ego-networks into one supply chain network (egocentric network study). Based on this section of the scale-free supply chain network, we transfer social network analysis to supply chain management. So we are able to collect information of network positioning coming from patterns of connectedness. In addition to the network position properties, we collect performance data for each focal company using business report analysis and comprehensive financial performance measures.

As both, the collected network data as well as the financial performance data are quantitative, metric data, we test hypotheses for influences of independent variables on dependent variables by means of linear regression. Finally, we develop comprehensive statistical models using multiple linear regression. By means of multiple linear regression, we not only integrate several network position properties into one model, but also evaluate each property for its individual influence on a dependent variable.

By taking our methodological approach as a blueprint for further network oriented research, we think that additional research in the field of our study can contribute to knowledge. We note four main points as recommendations for further research:

- We are convinced that our methodological approach is transferable to other manufacturing supply chains. It would be very interesting to see whether our results can be confirmed. We focus on converters in the plastics industry, which is one typical supply industry. The evaluation of other manufacturing industries might add value to come to an even more general solution of performance measurement in the context of supply chain networks. Probably, our results are also transferable to non-manufacturing supply chains, provided that there exist in these supply chains common business partners between focal companies and a sufficient number of similar focal companies.

- By using our newly developed software tool, we create an egocentric network based on 15 comparable companies and their business partners. This results in a network of $v = 448$ vertices. In case one has the opportunity to create an even larger network, this might add value in order to generalise our findings.
- Further, we assume that a network study that goes beyond suppliers, focal companies and customers can add value. If the opportunity exists to create a network of supply chains that also includes all the relationships (network flows) of the suppliers and all the relationships (network flows) of the customers, one could also analyse these companies. However, we think it is probably not realistic to do this on the level of our quantitative analysis, because data access becomes even more difficult. All companies need to be confident regarding the anonymity and confidentiality by encrypting their data.
- A longitudinal study of an egocentric network would also offer new insights. Our study focuses on a single point in time. In case data can be collected, one could create several networks over a longer period. It might be interesting to carry out our research over a period of 3 to 5 years. Besides the data collection, another difficulty of such study would be to have relationships between companies that persist over this period. One can only compare different networks over a longer period if the companies within this supply chain networks are the same. This means both new as well as cancelled relationships between companies need to be sorted out. Otherwise, the statistics would be distorted.

7 Conclusions

In order to inform on a new perspective in performance measurement, we introduced a specific methodology. Supported by the development of a software tool which not only processes real-time data, but also creates networks for examination, our data analysis shows the impact of network position on economic performance. The data analysis on the given level of detail is only possible because of this new conceptual work which visualises a section of the scale-free supply chain network.

To study this kind of network, we chose the instrument of social network analysis. Social network analysis not only provides a holistic network view, but also allows to collect quantitative data of network positioning. As with Ahrens (2009), the network itself has no main objective, it merely links individual actors with different objectives. Social network analysis allows to go beyond the analysis of dyadic relationships, which is why it seemed to be the best instrument for the present case.

Among others, important contributions to knowledge describing the innovative nature of our study are:

- the development of a new conceptual work,
- the transfer of social network analysis on the supply chain network for an industry-specific case (egocentric network study),
- the quantitative measurement of the network position and
- the study of the correlation between properties of a company’s network position and its economic performance determined by various financial performance measures.

Based on our findings, we informed on a network perspective in performance measurement. The discussion about the implications for business shows how this adds to practice. This is of particular importance, because even if companies recognise the importance of their connectedness, they usually have no opportunity to assess it directly.

With respect to theory and in order to create a more general solution, this research might serve as a blueprint to study other networks. The implications for theory indicate, that there are different opportunities to take this research forward. However, we recognise that data collection is certainly the biggest challenge. One possible best-case scenario might be the opportunity to study an industry-specific supply chain network over 5 years, based on real-time data of a sample of more than 15 ego-networks, including overlapping connections and relationships that persist over this period of time.

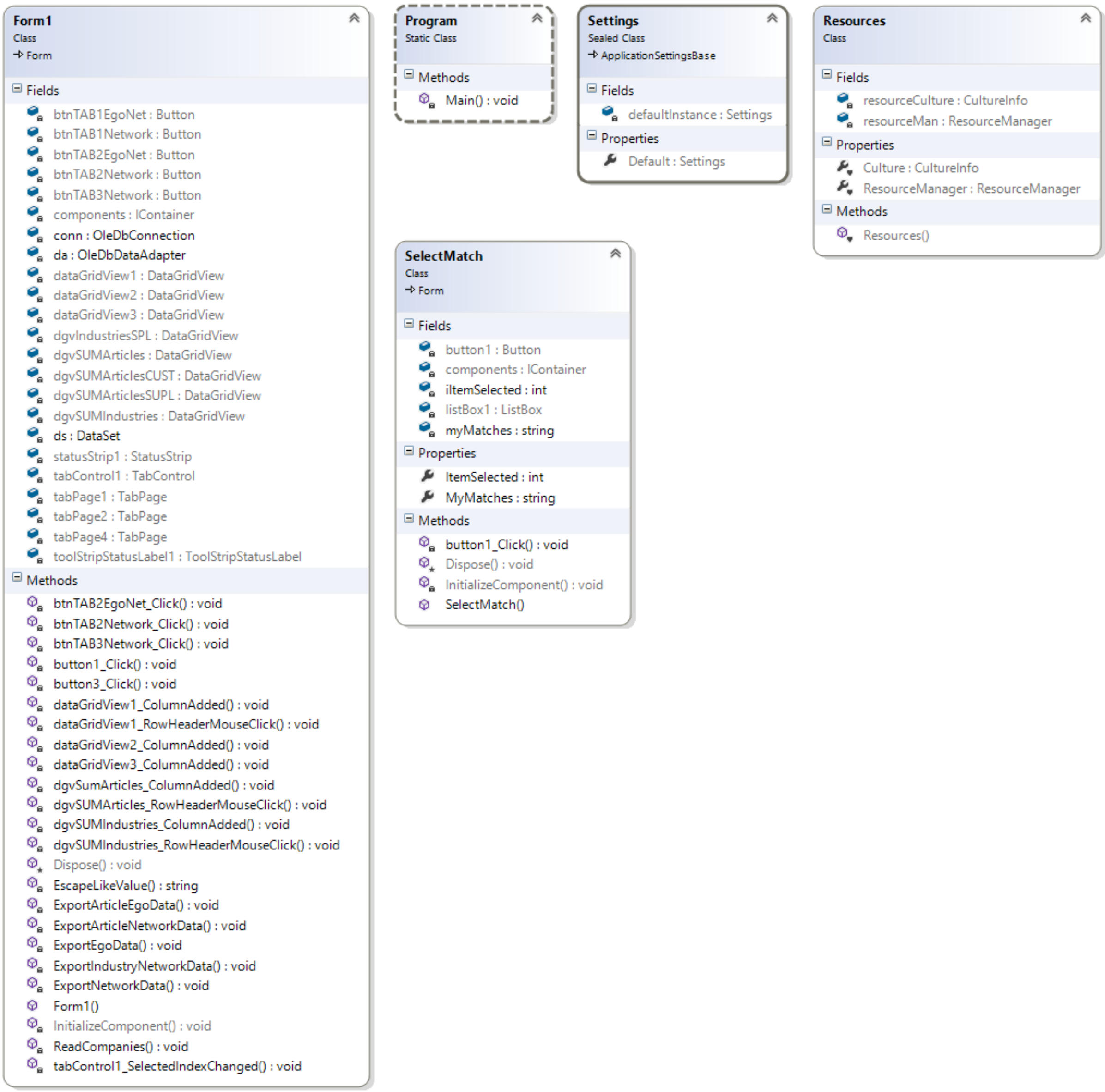
To conclude, we rate the application of social network analysis for the supply chain network as a success. Based on new conceptual work, we overcome the analysis of individual company-specific ego-networks. Thereby, we can show a link between network position and economic performance.

The results of the in-depth analysis of network position characteristics influencing financial performance measures add to managerial practice in the light of network oriented performance measurement. Thus, our study is a contribution to close a gap in performance measurement which results from the increasing importance of supply chain networks.

We are convinced that nowadays companies must rethink their performance measurement tools accompanied by strategic decisions in the light of network participation and mutual dependencies across many supply chains. Thus, it might also be worth to examine whether our findings can be transferred into business software. Companies would certainly benefit from software that acknowledges a clear network orientation.

Appendices

A1. The Developed Software Network Creator



Graphical Representation of the Source Code (Class Diagram)

A2. Quick Test

Quick Test Focal Company 1

FOC1	**FY1**		
Equity	1,187.028	Operating capacity	17,073
Total assets	9,134.66	Interest on debts	151.221
Cash position	491.184	Profit before tax	-193.29
Debt	6,047.70	Cash flow	532.116
Equity ratio (%)	13	Rating	3
Debt repayment period (years)	10	Rating	3
Return on assets (%)	0	Rating	5
Cash flow performance (%)	3	Rating	4
FOC1	**FY2**		
Equity	1,338.249	Operating capacity	19,045
Total assets	7,830.55	Interest on debts	177.372
Cash position	421.827	Profit before tax	-270.434
Debt	5,298.28	Cash flow	531.83
Equity ratio (%)	17	Rating	3
Debt repayment period (years)	9	Rating	3
Return on assets (%)	-1	Rating	5
Cash flow performance (%)	3	Rating	4
Results FY1 and FY2			
Intermediate result: Financial stability			3
Intermediate result: Profitability			4.5
Final Result			3.75

Quick Test Focal Company 2

FOC2	FY1		
Equity	2,478.66	Operating capacity	30,953
Total assets	14,926.536	Interest on debts	449.115
Cash position	1,225.686	Profit before tax	471.855
Debt	12,043.104	Cash flow	1,600.896
Equity ratio (%)	17	Rating	3
Debt repayment period (years)	7	Rating	3
Return on assets (%)	6	Rating	4
Cash flow performance (%)	5	Rating	3
FOC2	**FY2**		
Equity	3,033.52	Operating capacity	30,486
Total assets	16,077.46	Interest on debts	415.005
Cash position	1,072.191	Profit before tax	744.338
Debt	12,505.43	Cash flow	1,878.16
Equity ratio (%)	19	Rating	3
Debt repayment period (years)	6	Rating	3
Return on assets (%)	7	Rating	4
Cash flow performance (%)	6	Rating	3
Results FY1 and FY2			
Intermediate result: Financial stability			3
Intermediate result: Profitability			3.5
Final Result			3.25

Quick Test Focal Company 3

FOC3	**FY1**		
Equity	2,650.347	Operating capacity	12,507
Total assets	7,015.29	Interest on debts	131.892
Cash position	416.142	Profit before tax	880.038
Debt	3,903.321	Cash flow	932.34
Equity ratio (%)	38	Rating	1
Debt repayment period (years)	4	Rating	2
Return on assets (%)	14	Rating	2
Cash flow performance (%)	7	Rating	3
FOC3	**FY2**		
Equity	3,102.873	Operating capacity	12,507
Total assets	6,497.07	Interest on debts	144.399
Cash position	462.759	Profit before tax	1,313.028
Debt	2,889.08	Cash flow	1,262.79
Equity ratio (%)	48	Rating	1
Debt repayment period (years)	2	Rating	1
Return on assets (%)	22	Rating	1
Cash flow performance (%)	10	Rating	1
Results FY1 and FY2			
Intermediate result: Financial stability			1.25
Intermediate result: Profitability			1.75
Final Result			1.5

Quick Test Focal Company 4

FOC4	FY1		
Equity	5,953.332	Operating capacity	13,644
Total assets	7,325.691	Interest on debts	835.695
Cash position	2,525.277	Profit before tax	2231.931
Debt	727.68	Cash flow	1,573.608
Equity ratio (%)	81	Rating	1
Debt repayment period (years)	-1	Rating	1
Return on assets (%)	42	Rating	1
Cash flow performance (%)	12	Rating	1
FOC4	**FY2**		
Equity	5,621.328	Operating capacity	15,918
Total assets	7,264.86	Interest on debts	835.695
Cash position	1,575.882	Profit before tax	2,322.543
Debt	764.47	Cash flow	1,655.14
Equity ratio (%)	77	Rating	1
Debt repayment period (years)	0	Rating	1
Return on assets (%)	43	Rating	1
Cash flow performance (%)	10	Rating	1
Results FY1 and FY2			
Intermediate result: Financial stability			1
Intermediate result: Profitability			1
Final Result			1

Quick Test Focal Company 5

FOC5	FY1		
Equity	17,426.799	Operating capacity	67,160.316
Total assets	46,727.289	Interest on debts	1,847.625
Cash position	694.707	Profit before tax	7,251.786
Debt	22,932.153	Cash flow	9,661.089
Equity ratio (%)	37	Rating	1
Debt repayment period (years)	2	Rating	1
Return on assets (%)	19	Rating	1
Cash flow performance (%)	14	Rating	1
FOC5	**FY2**		
Equity	16,630.899	Operating capacity	63,767.508
Total assets	46,326.77	Interest on debts	1,508.799
Cash position	710.625	Profit before tax	3,563.624
Debt	26,339.29	Cash flow	7,207.23
Equity ratio (%)	36	Rating	1
Debt repayment period (years)	4	Rating	2
Return on assets (%)	11	Rating	3
Cash flow performance (%)	11	Rating	1
Results FY1 and FY2			
Intermediate result: Financial stability			1.25
Intermediate result: Profitability			1.5
Final Result			1.375

Quick Test Focal Company 6

FOC6	**FY1**		
Equity	4,989.156	Operating capacity	48,255.417
Total assets	15,363.144	Interest on debts	297.894
Cash position	467.307	Profit before tax	1,678.212
Debt	9,391.62	Cash flow	1,731.651
Equity ratio (%)	32	Rating	1
Debt repayment period (years)	5	Rating	3
Return on assets (%)	13	Rating	2
Cash flow performance (%)	4	Rating	4
FOC6	**FY2**		
Equity	5,563.34	Operating capacity	45,691.482
Total assets	17,349.85	Interest on debts	397.95
Cash position	179.646	Profit before tax	635.071
Debt	10,880.80	Cash flow	737.662
Equity ratio (%)	32	Rating	1
Debt repayment period (years)	15	Rating	4
Return on assets (%)	6	Rating	4
Cash flow performance (%)	2	Rating	4
Results FY1 and FY2			
Intermediate result: Financial stability			2.25
Intermediate result: Profitability			3.5
Final Result			2.875

Quick Test Focal Company 7

FOC7	**FY1**		
Equity	5,163.474	Operating capacity	60,059.751
Total assets	35,516.97	Interest on debts	1,666.842
Cash position	39.795	Profit before tax	426.217
Debt	27,010.84	Cash flow	2,358.737
Equity ratio (%)	15	Rating	3
Debt repayment period (years)	11	Rating	3
Return on assets (%)	6	Rating	4
Cash flow performance (%)	4	Rating	4
FOC7	**FY2**		
Equity	6,558.061	Operating capacity	65,243.334
Total assets	31,415.25	Interest on debts	1,393.962
Cash position	23.877	Profit before tax	2,063.073
Debt	21,183.84	Cash flow	3,769.86
Equity ratio (%)	21	Rating	2
Debt repayment period (years)	6	Rating	3
Return on assets (%)	11	Rating	3
Cash flow performance (%)	6	Rating	3
Results FY1 and FY2			
Intermediate result: Financial stability			2.75
Intermediate result: Profitability			3.5
Final Result			3.125

Quick Test Focal Company 8

FOC8 FY1			
			not available
FOC8 FY2			
			not available

Quick Test Focal Company 9

FOC9 FY1			
			not available
FOC9 FY2			
			not available

Quick Test Focal Company 10

FOC10	**FY1**		
Equity	13,753.152	Operating capacity	46,732.974
Total assets	23,535.9	Interest on debts	145.536
Cash position	366.114	Profit before tax	9,229.029
Debt	7,604.256	Cash flow	10,031.751
Equity ratio (%)	58	Rating	1
Debt repayment period (years)	1	Rating	1
Return on assets (%)	40	Rating	1
Cash flow performance (%)	21	Rating	1
FOC10	**FY2**		
Equity	17,070.918	Operating capacity	50,296.332
Total assets	24,950.40	Interest on debts	46.617
Cash position	1,520.169	Profit before tax	11,116.01
Debt	5,174.39	Cash flow	11,569.36
Equity ratio (%)	68	Rating	1
Debt repayment period (years)	0	Rating	1
Return on assets (%)	45	Rating	1
Cash flow performance (%)	23	Rating	1
Results FY1 and FY2			
Intermediate result: Financial stability			1
Intermediate result: Profitability			1
Final Result			1

Quick Test Focal Company 11

FOC11	**FY1**		
Equity	17.055	Operating capacity	9,005.04
Total assets	2,900.487	Interest on debts	121.659
Cash position	31.836	Profit before tax	86.412
Debt	2,792.472	Cash flow	221.715
Equity ratio (%)	1	Rating	4
Debt repayment period (years)	12	Rating	3
Return on assets (%)	7	Rating	4
Cash flow performance (%)	2	Rating	4
FOC11	**FY2**		
Equity	69.357	Operating capacity	9,655.404
Total assets	3,574.85	Interest on debts	142.125
Cash position	133.029	Profit before tax	-15.380
Debt	2,949.55	Cash flow	240.42
Equity ratio (%)	2	Rating	4
Debt repayment period (years)	12	Rating	3
Return on assets (%)	4	Rating	4
Cash flow performance (%)	2	Rating	4
Results FY1 and FY2			
Intermediate result: Financial stability			3.5
Intermediate result: Profitability			4
Final Result			3.75

Quick Test Focal Company 12

FOC12	**FY1**		
Equity	3,500.823	Operating capacity	18,192
Total assets	26,868.447	Interest on debts	577.596
Cash position	2.274	Profit before tax	-696.981
Debt	22,880.988	Cash flow	3,491.727
Equity ratio (%)	13	Rating	3
Debt repayment period (years)	7	Rating	3
Return on assets (%)	0	Rating	5
Cash flow performance (%)	19	Rating	1
FOC12	**FY2**		
Equity	2,458.194	Operating capacity	17,055
Total assets	23,251.62	Interest on debts	470.718
Cash position	1.137	Profit before tax	-1,088.849
Debt	20,306.18	Cash flow	2,942.79
Equity ratio (%)	11	Rating	3
Debt repayment period (years)	7	Rating	3
Return on assets (%)	-3	Rating	5
Cash flow performance (%)	17	Rating	1
Results FY1 and FY2			
Intermediate result: Financial stability			3
Intermediate result: Profitability			3
Final Result			3

Quick Test Focal Company 13

FOC13	**FY1**		
Equity	14,658.204	Operating capacity	61,003.461
Total assets	30,545.505	Interest on debts	261.51
Cash position	1,523.58	Profit before tax	2,993.721
Debt	10,977.735	Cash flow	4,868.634
Equity ratio (%)	48	Rating	1
Debt repayment period (years)	2	Rating	1
Return on assets (%)	11	Rating	3
Cash flow performance (%)	8	Rating	2
FOC13	**FY2**		
Equity	15,579.174	Operating capacity	64,757.835
Total assets	32,103.65	Interest on debts	466.17
Cash position	1,523.58	Profit before tax	3,402.366
Debt	11,230.82	Cash flow	5,598.32
Equity ratio (%)	49	Rating	1
Debt repayment period (years)	2	Rating	1
Return on assets (%)	12	Rating	2
Cash flow performance (%)	9	Rating	2
Results FY1 and FY2			
Intermediate result: Financial stability			1
Intermediate result: Profitability			2.25
Final Result			1.625

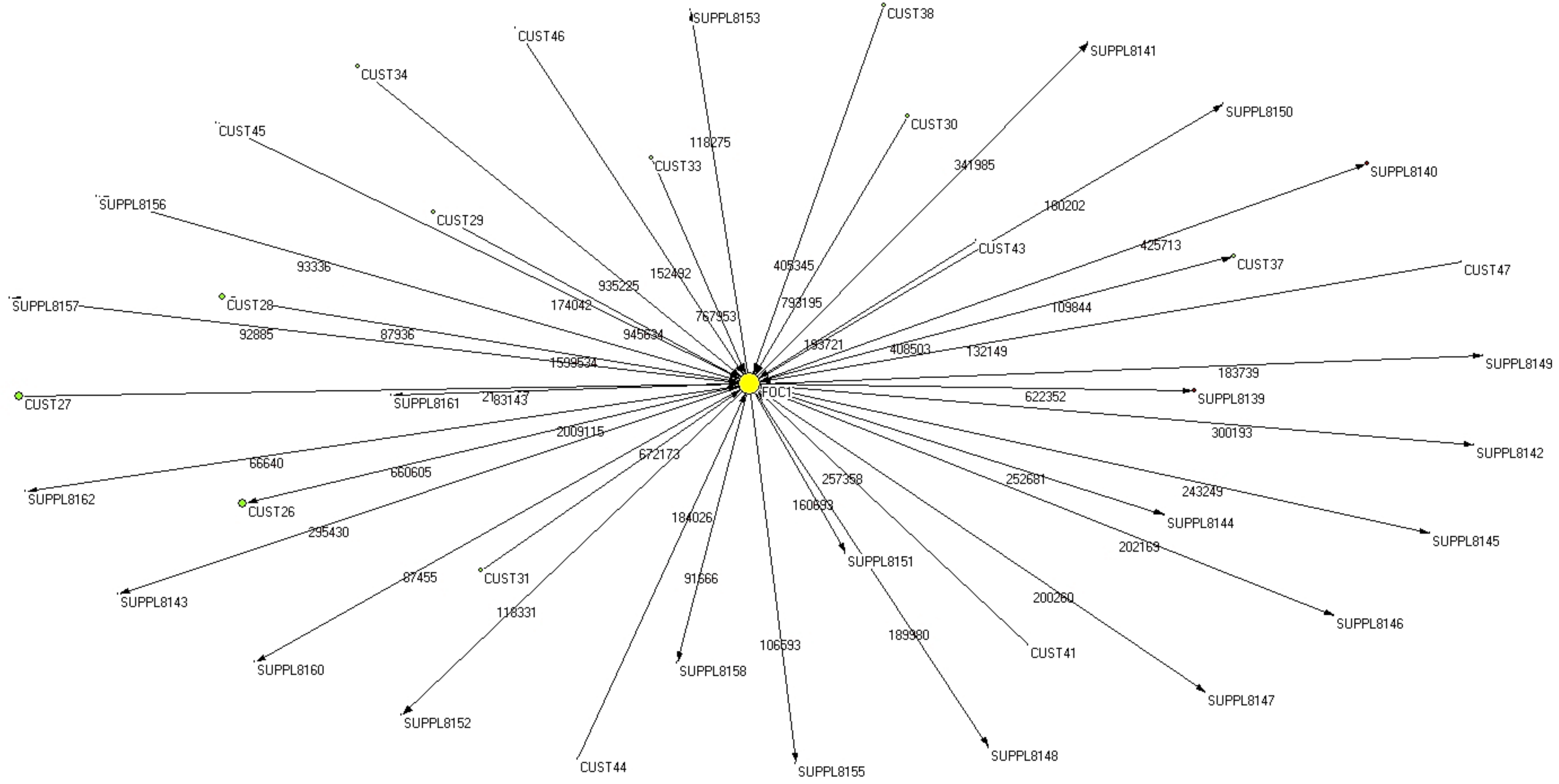
Quick Test Focal Company 14

FOC14 FY1			
			not available
FOC14 FY2			
			not available

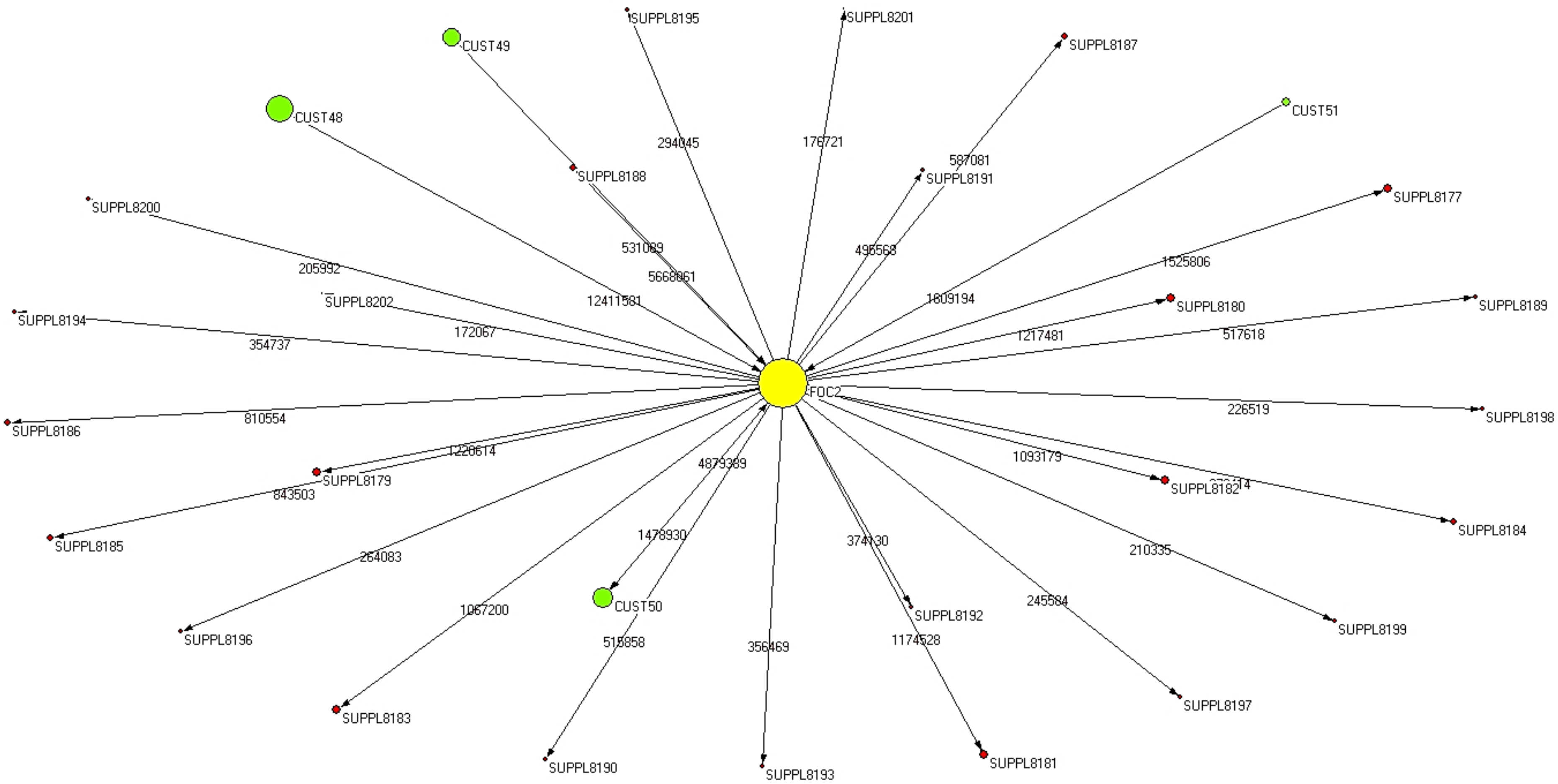
Quick Test Focal Company 15

FOC15	**FY1**		
Equity	6,427.461	Operating capacity	17,359.716
Total assets	8,692.365	Interest on debts	43.206
Cash position	1,639.554	Profit before tax	607.158
Debt	877.764	Cash flow	1,192.713
Equity ratio (%)	74	Rating	1
Debt repayment period (years)	-1	Rating	1
Return on assets (%)	7	Rating	4
Cash flow performance (%)	7	Rating	3
FOC15	**FY2**		
Equity	6,819.726	Operating capacity	18,119.232
Total assets	9,693.72	Interest on debts	17.055
Cash position	2,502.537	Profit before tax	606.999
Debt	1,501.97	Cash flow	1,394.24
Equity ratio (%)	70	Rating	1
Debt repayment period (years)	-1	Rating	1
Return on assets (%)	6	Rating	4
Cash flow performance (%)	8	Rating	2
Results FY1 and FY2			
Intermediate result: Financial stability			1
Intermediate result: Profitability			3.25
Final Result			2.125

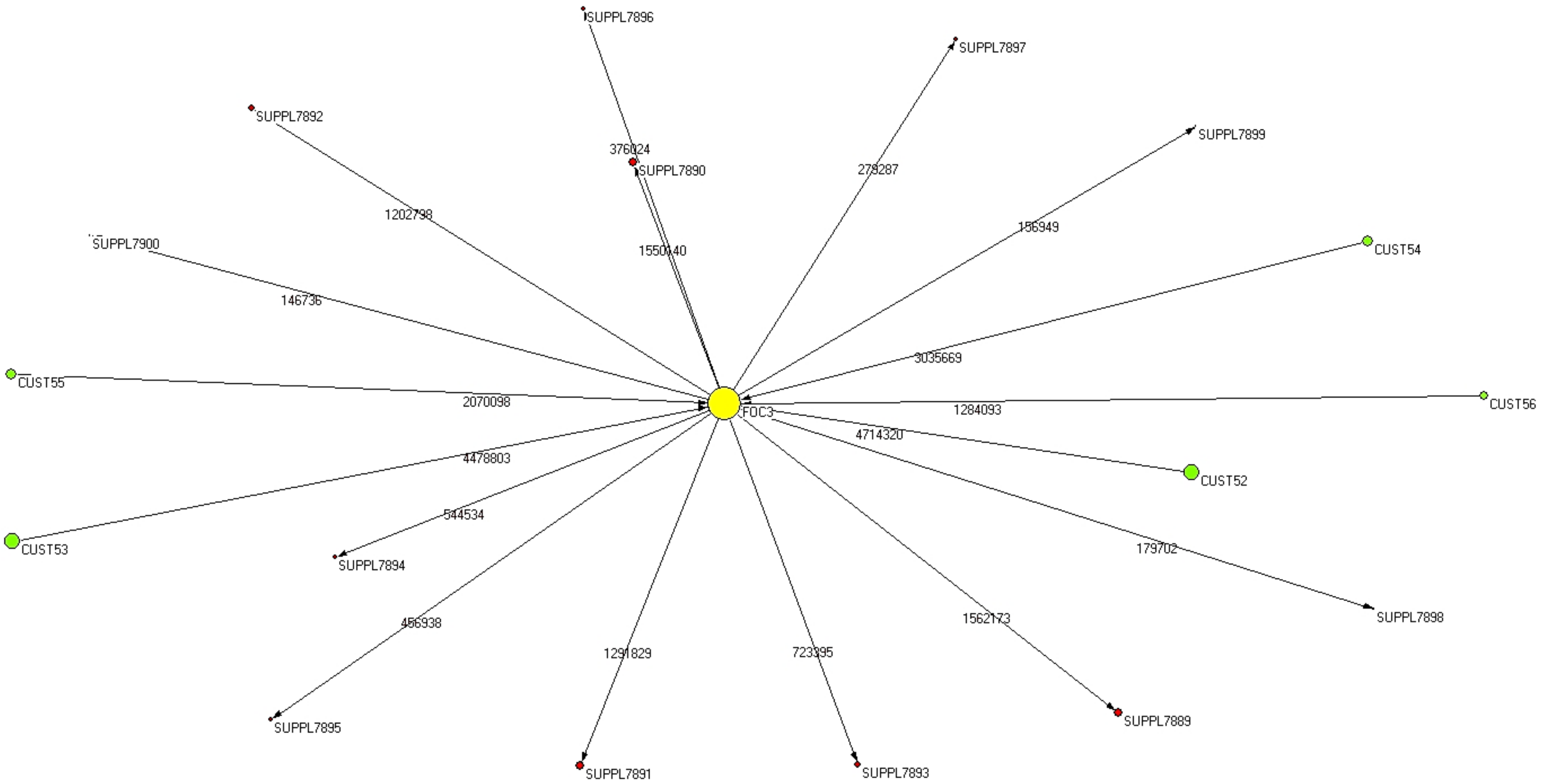
A3. Ego-networks



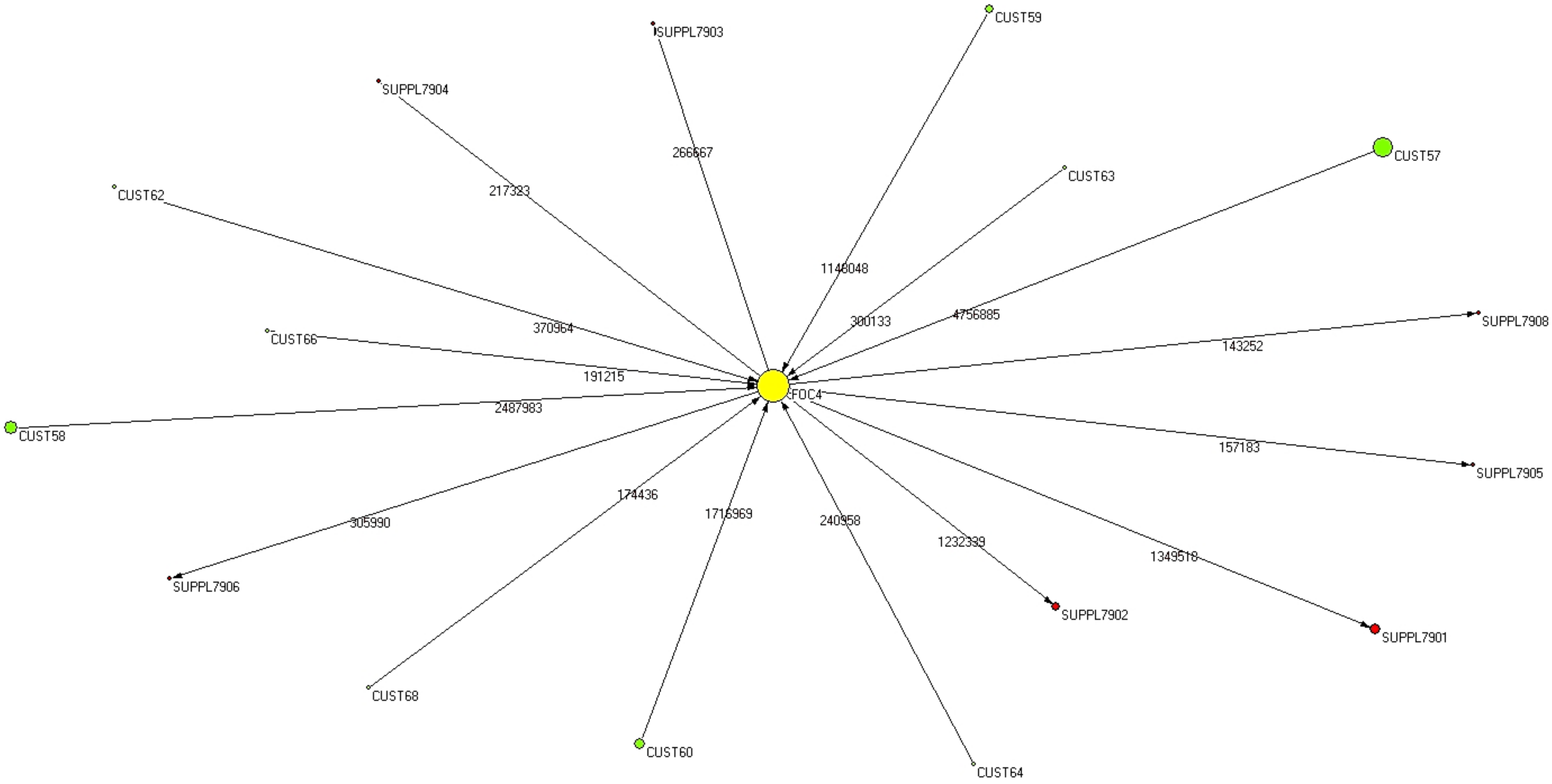
Ego-network Focal Company 1



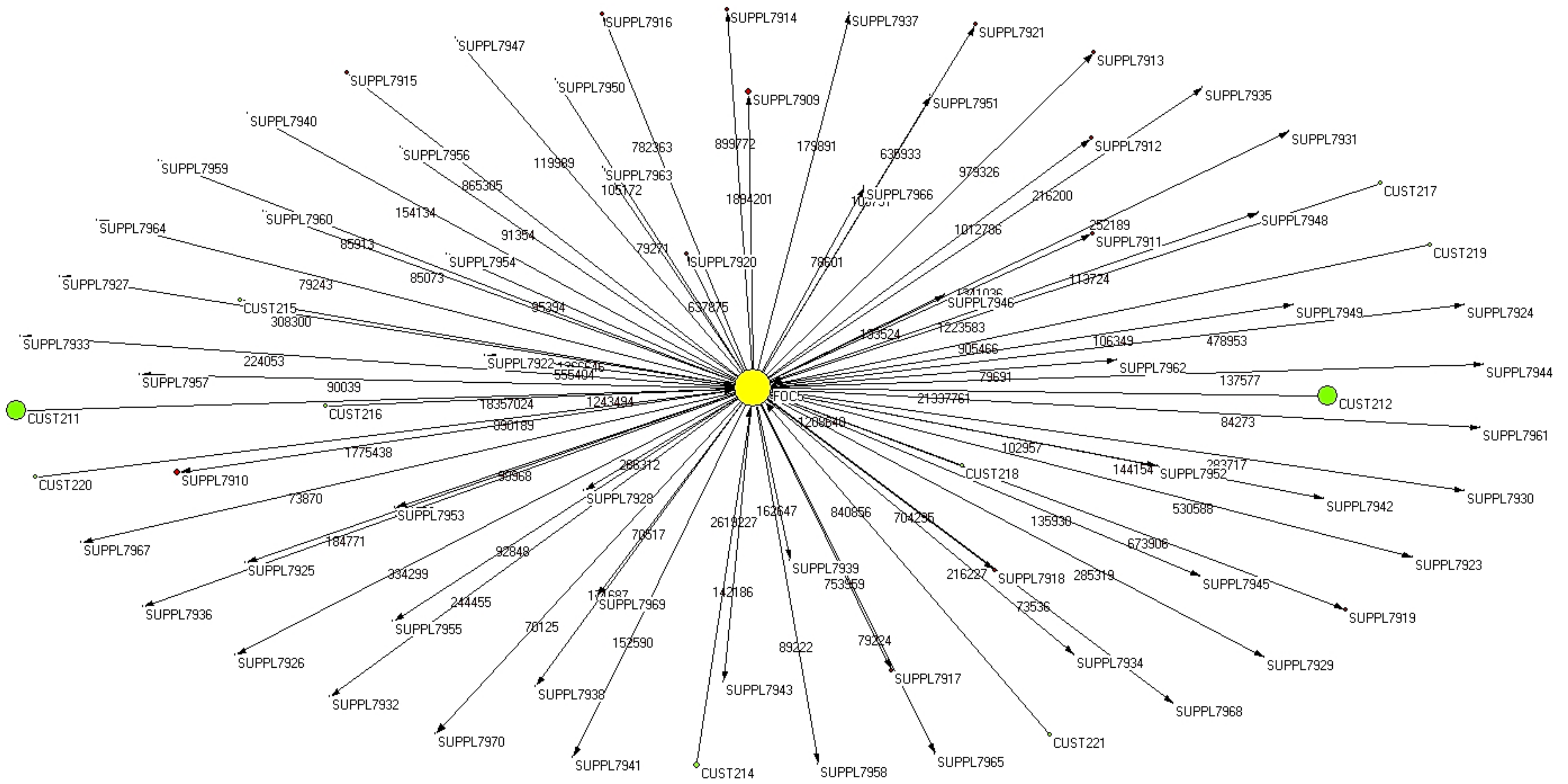
Ego-network Focal Company 2



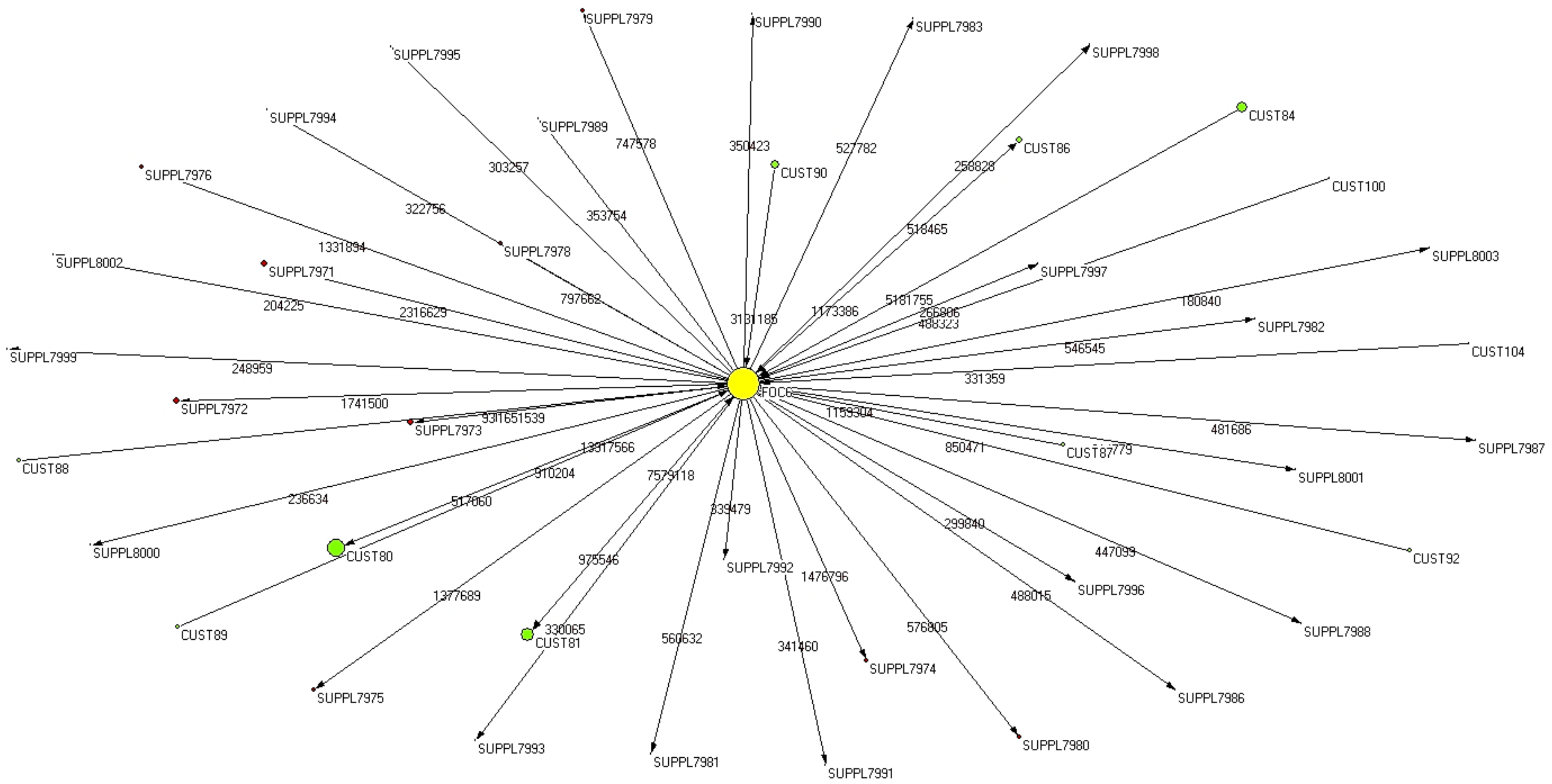
Ego-network Focal Company 3



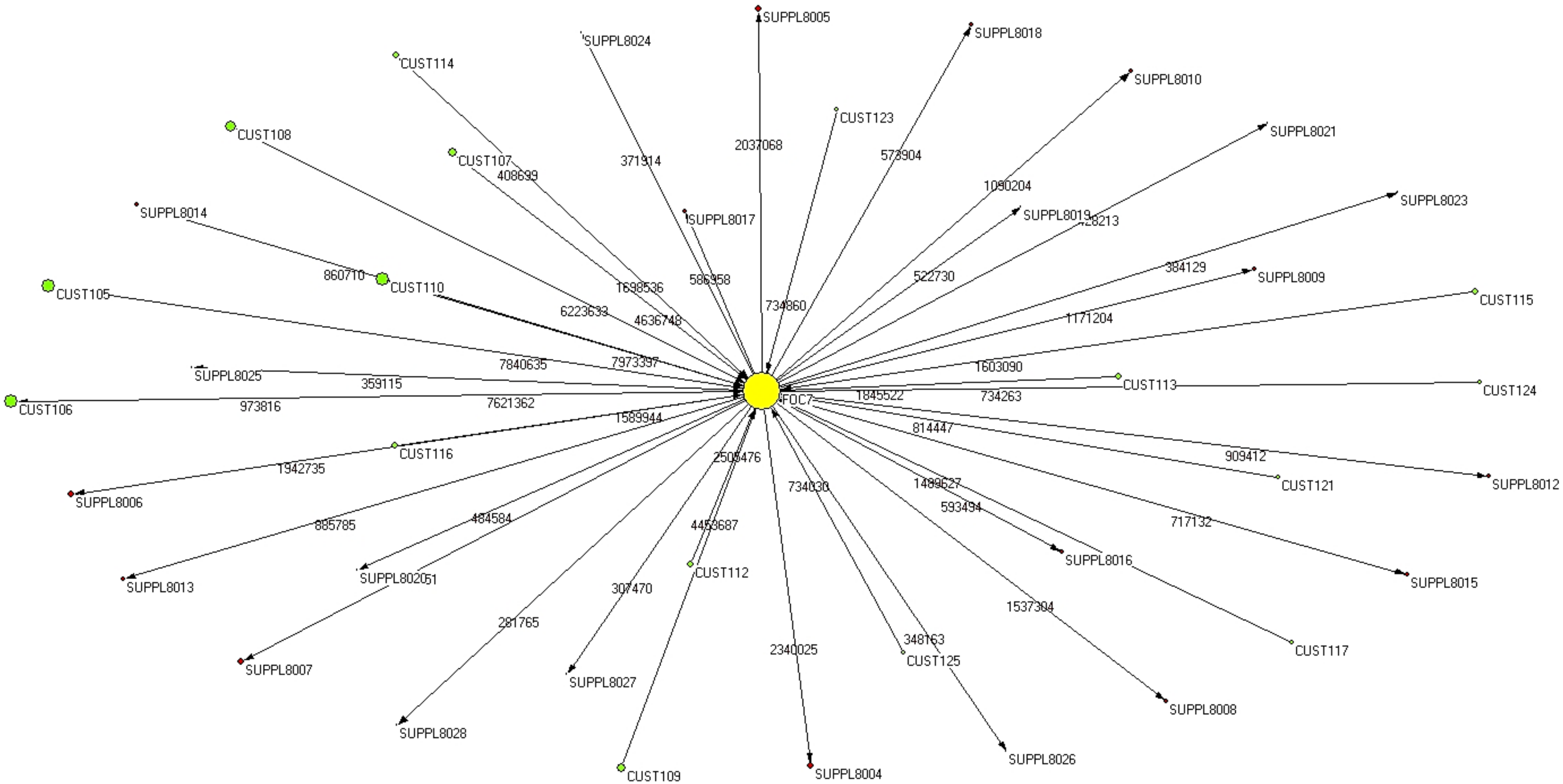
Ego-network Focal Company 4



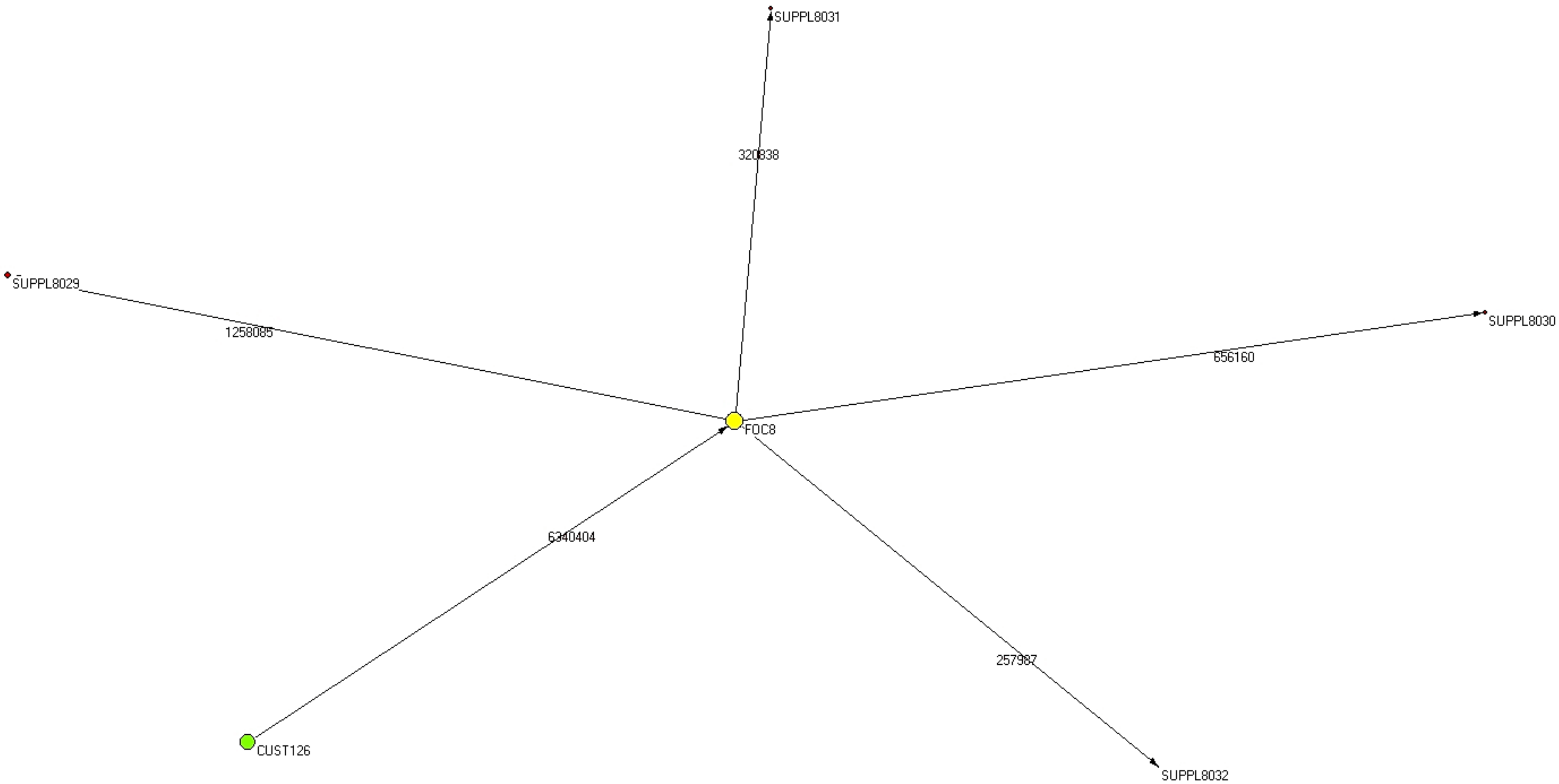
Ego-network Focal Company 5



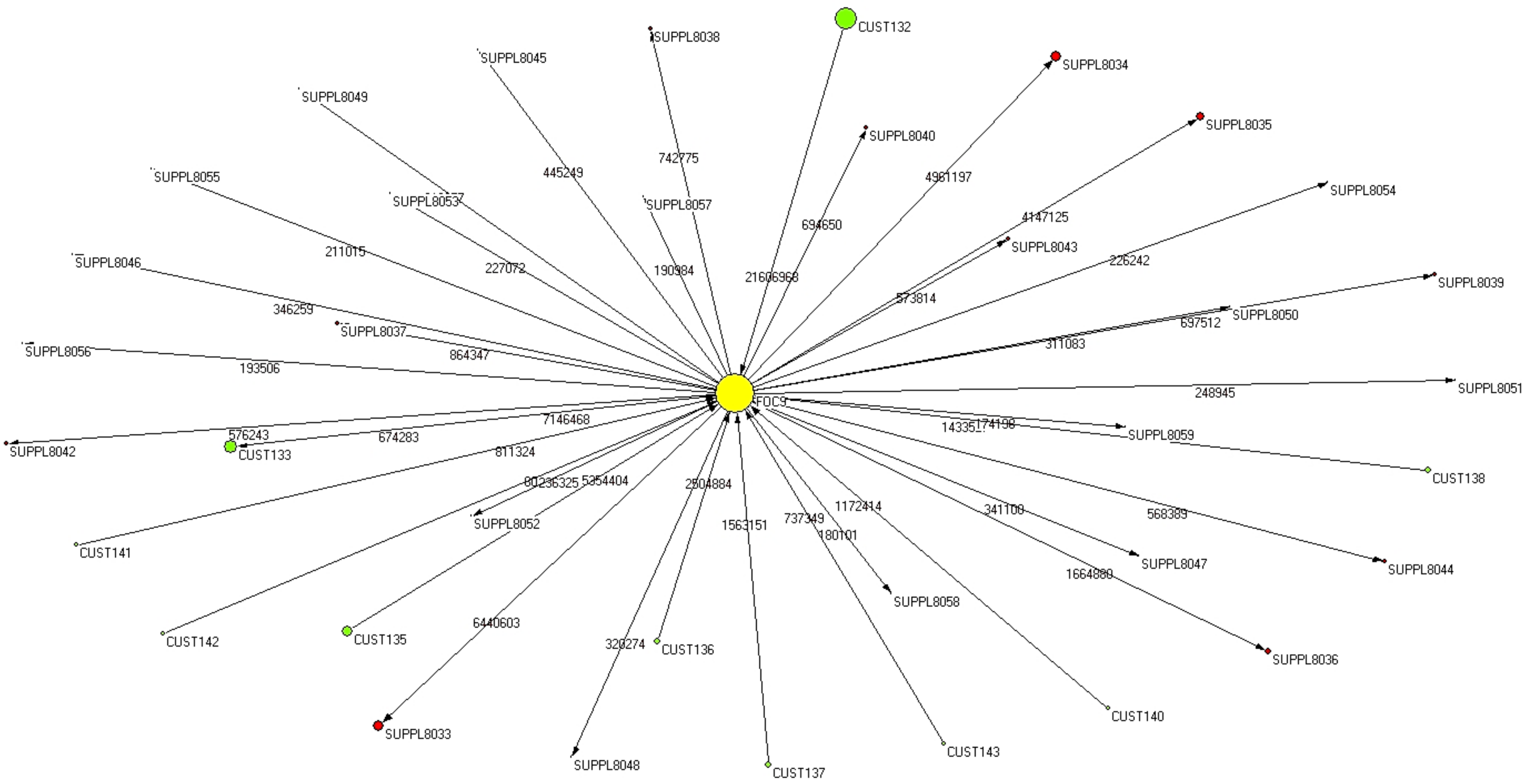
Ego-network Focal Company 6



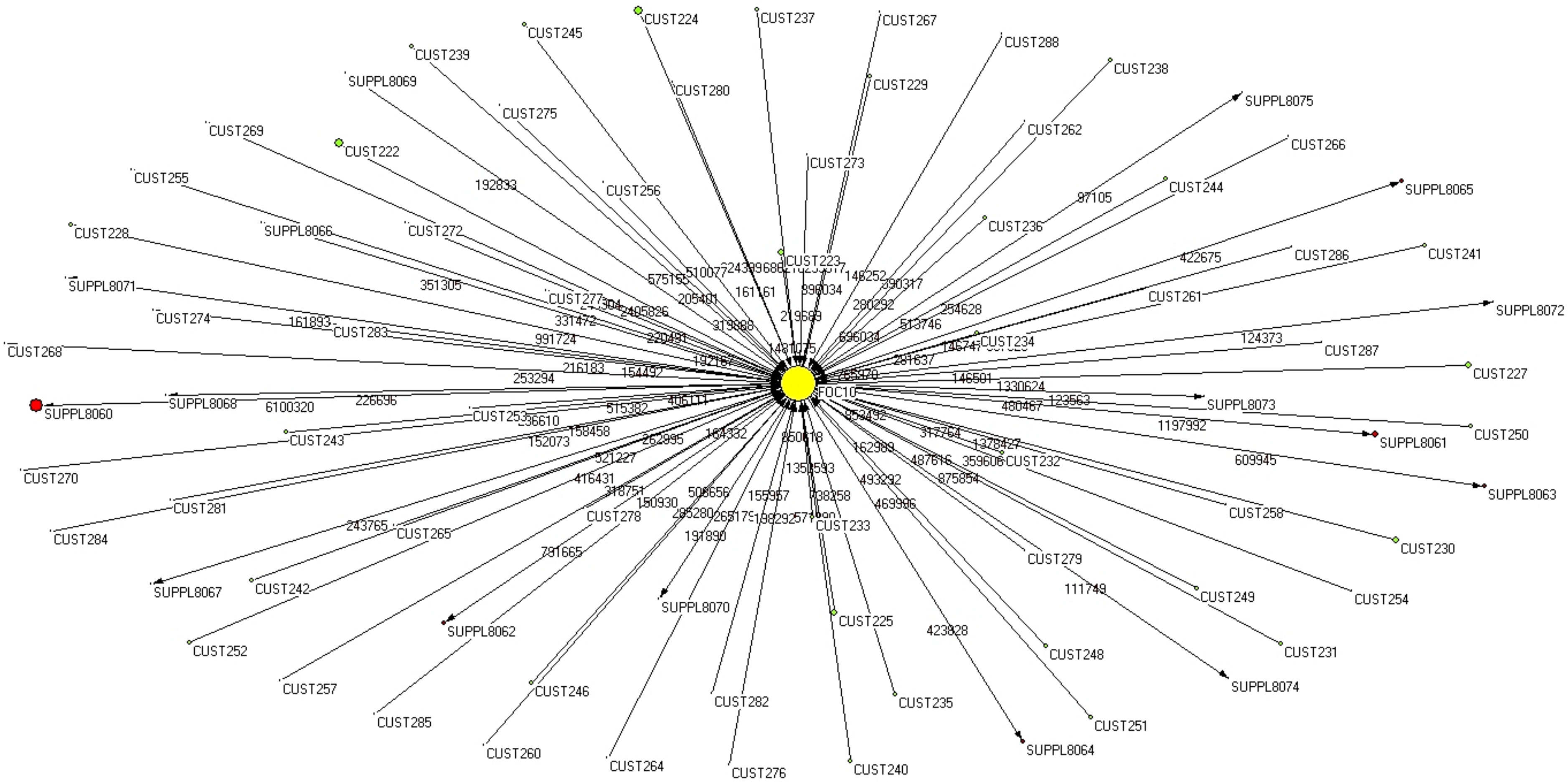
Ego-network Focal Company 7



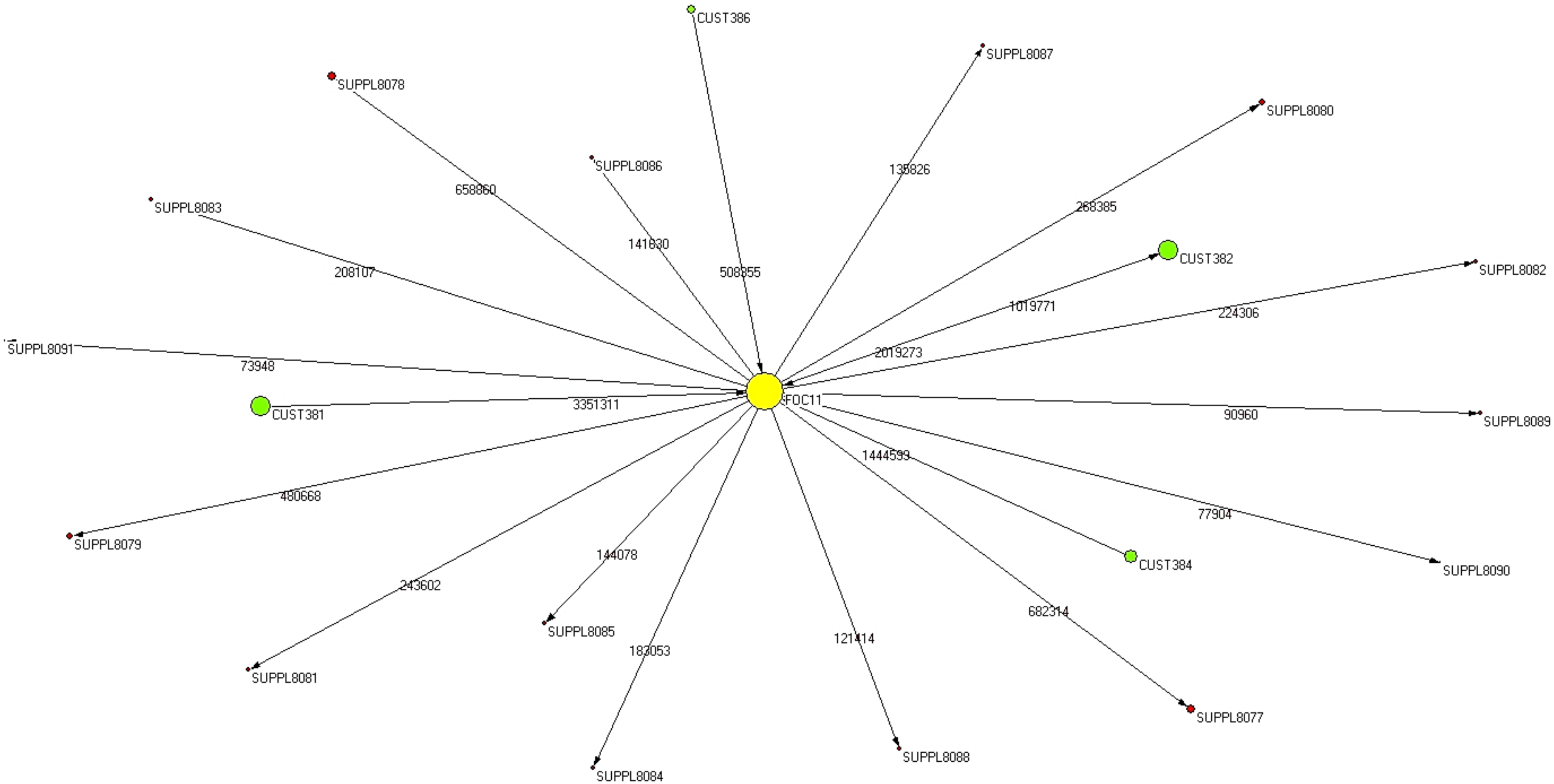
Ego-network Focal Company 8



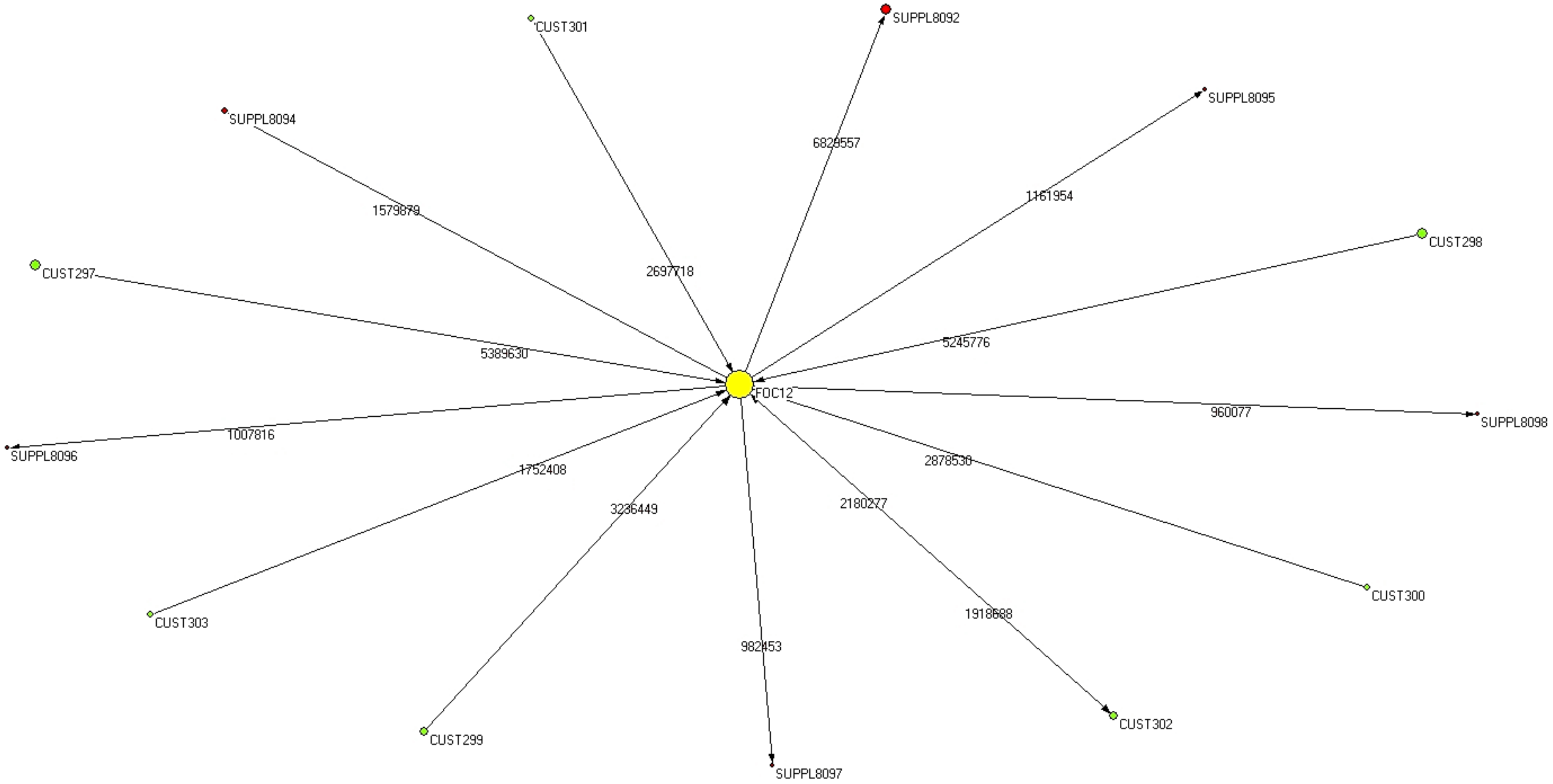
Ego-network Focal Company 9



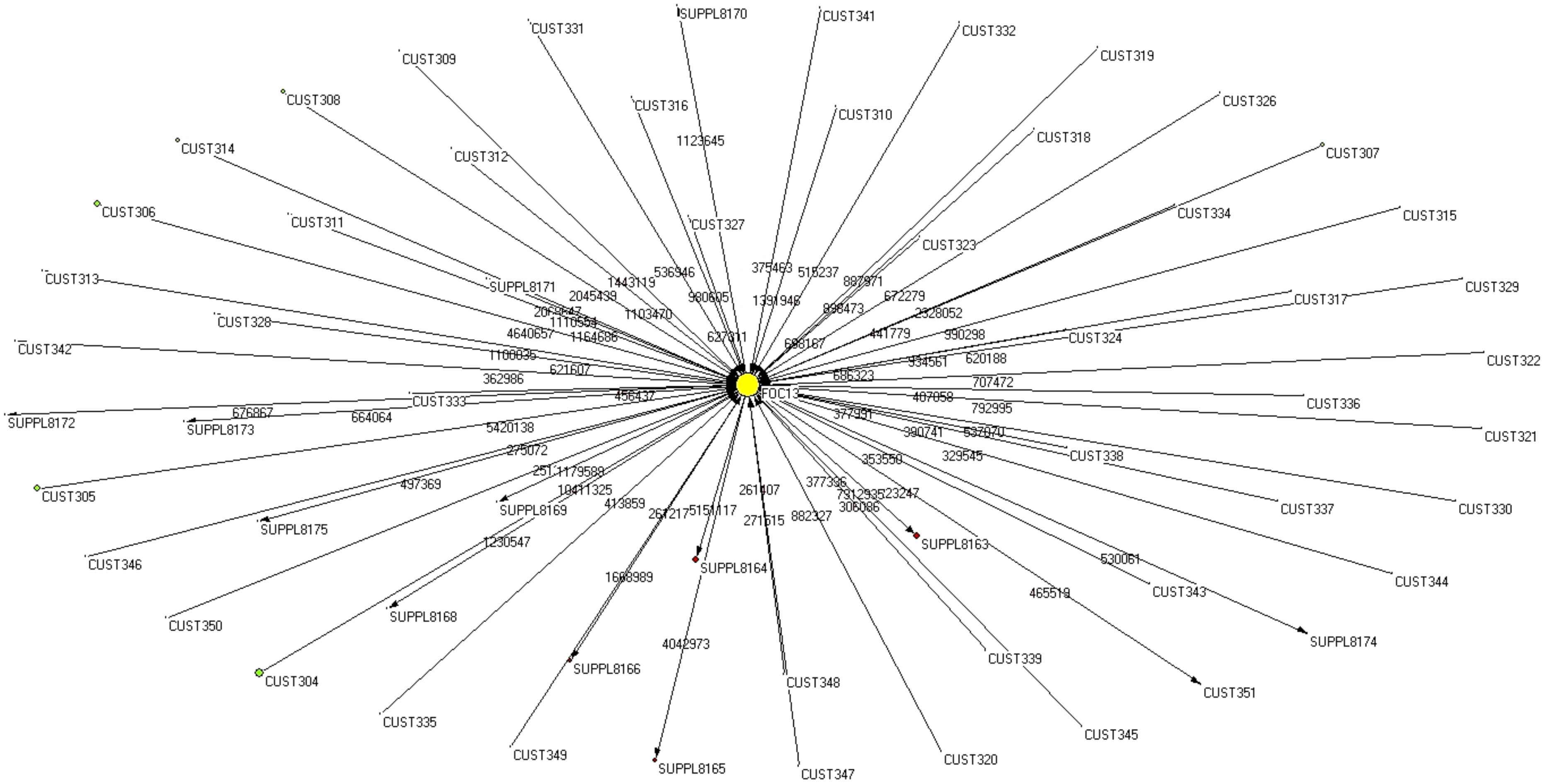
Ego-network Focal Company 10



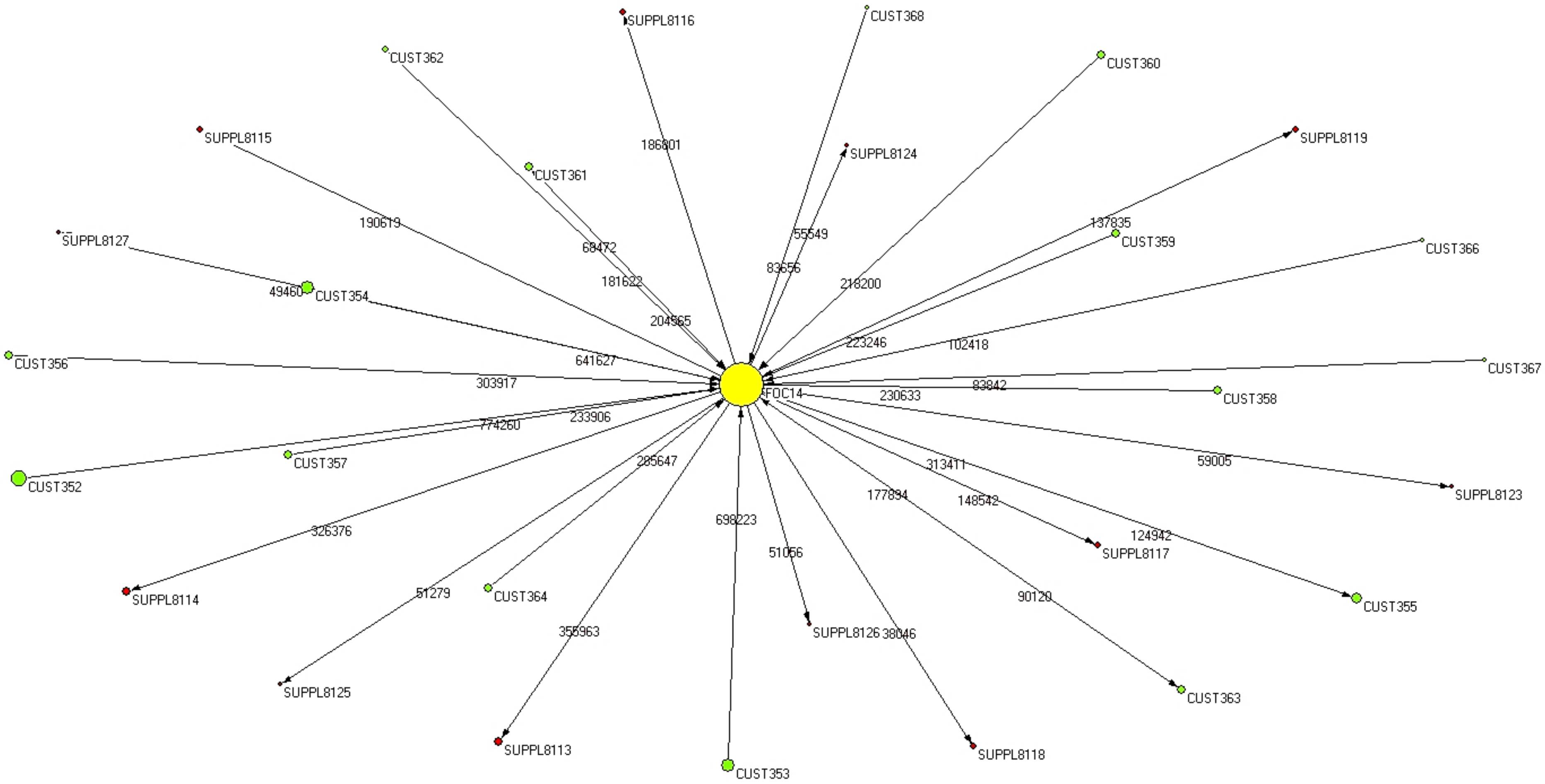
Ego-network Focal Company 11



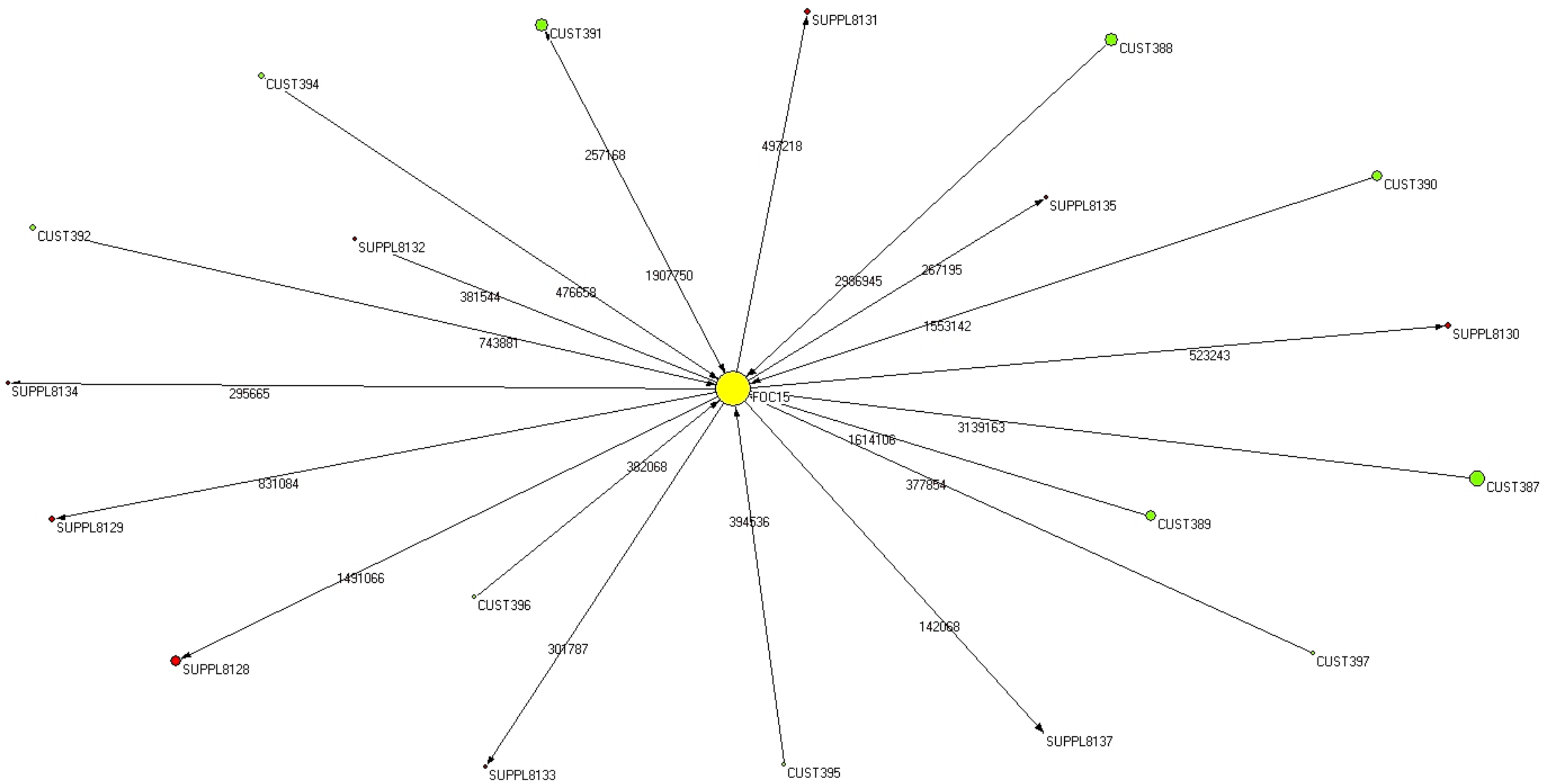
Ego-network Focal Company 12



Ego-network Focal Company 13



Ego-network Focal Company 14



Ego-network Focal Company 15

A4. Performance Indicators

Overview Financial Performance Measures of Focal Company 1

Derivation of Indicators	**Calculation**
Revenue (in thousands)	19,045
Employees	135
Revenue per employee RE (in thousands)	**141.072**
PBIT (in thousands)	-153.127
Depreciation and amortisation (in thousands)	683.825
Operating profit OP (in thousands)	**530.698**
PBT (in thousands)	-270.434
Total assets (in thousands)	7,830.55
Return on assets ROA	**-3.45**
Asset turnover AT	**2.43**
Fixed Assets (in thousands)	4,479.95
Profit fixed asset ratio PFR	**-3.42**
Debts (in thousands)	5,298.28
Cash Flow (in thousands)	531.83
Dynamic debt ratio DDR	**9.96**
Industries (WZ2008)	22290

Overview Financial Performance Measures of Focal Company 2

Derivation of Indicators	**Calculation**
Revenue (in thousands)	30,347
Employees	218
Revenue per employee RE (in thousands)	**139.204**
PBIT (in thousands)	1,159.560
Depreciation and amortisation (in thousands)	1,323.097
Operating profit OP (in thousands)	**2,482.658**
PBT (in thousands)	744.338
Total assets (in thousands)	16,077.46
Return on assets ROA	**4.63**
Asset turnover AT	**1.89**
Fixed Assets (in thousands)	9,847.77
Profit fixed asset ratio PFR	**11.77**
Debts (in thousands)	12,505.43
Cash Flow (in thousands)	1,878.16
Dynamic debt ratio DDR	**6.66**
Industries (WZ2008)	22290

Overview Financial Performance Measures of Focal Company 3

Derivation of Indicators	**Calculation**
Revenue (in thousands)	19,784
Employees	103
Revenue per employee RE (in thousands)	**192.076**
PBIT (in thousands)	1,454.066
Depreciation and amortisation (in thousands)	347.361
Operating profit OP (in thousands)	**1,801.428**
PBT (in thousands)	1,313.028
Total assets (in thousands)	6,497.07
Return on assets ROA	**20.21**
Asset turnover AT	**3.05**
Fixed Assets (in thousands)	1,611.40
Profit fixed asset ratio PFR	**90.24**
Debts (in thousands)	2,889.08
Cash Flow (in thousands)	1,262.79
Dynamic debt ratio DDR	**2,29**
Industries (WZ2008)	22290; 52299; 18120; 33200; 25910; 27900; 27120

Overview Financial Performance Measures of Focal Company 4

Derivation of Indicators	**Calculation**
Revenue (in thousands)	15,918
Employees	80
Revenue per employee RE (in thousands)	**198.975**
PBIT (in thousands)	2,274.404
Depreciation and amortisation (in thousands)	54.088
Operating profit OP (in thousands)	**2,328.492**
PBT (in thousands)	2,322.543
Total assets (in thousands)	7,264.86
Return on assets ROA	**31.97**
Asset turnover AT	**2.19**
Fixed Assets (in thousands)	203.98
Profit fixed asset ratio PFR	**1,115.03**
Debts (in thousands)	764.47
Cash Flow (in thousands)	1,655.14
Dynamic debt ratio DDR	**0.46**
Industries (WZ2008)	22290; 26119; 32990; 25735; 28960

Overview Financial Performance Measures of Focal Company 5

Derivation of Indicators	**Calculation**
Revenue (in thousands)	62,296
Employees	380
Revenue per employee RE (in thousands)	**163.937**
PBIT (in thousands)	5,072.240
Depreciation and amortisation (in thousands)	4,442.881
Operating profit OP (in thousands)	**9,515.121**
PBT (in thousands)	3,563.624
Total assets (in thousands)	46,326.77
Return on assets ROA	**7.69**
Asset turnover AT	**1.34**
Fixed Assets (in thousands)	27,371.22
Profit fixed asset ratio PFR	**18.53**
Debts (in thousands)	26,339.29
Cash Flow (in thousands)	7,207.23
Dynamic debt ratio DDR	**3.65**
Industries (WZ2008)	22290; 13300; 33200; 25610

Overview Financial Performance Measures of Focal Company 6

Derivation of Indicators	**Calculation**
Revenue (in thousands)	43,604
Employees	230
Revenue per employee RE (in thousands)	**189.582**
PBIT (in thousands)	1,032.739
Depreciation and amortisation (in thousands)	163.614
Operating profit OP (in thousands)	**1,196.354**
PBT (in thousands)	635.071
Total assets (in thousands)	17,349.85
Return on assets ROA	**3.66**
Asset turnover AT	**2.51**
Fixed Assets (in thousands)	4,737.19
Profit fixed asset ratio PFR	**21,80**
Debts (in thousands)	10,880.80
Cash Flow (in thousands)	737.66
Dynamic debt ratio DDR	**14.75**
Industries (WZ2008)	22290; 46901; 46902

Overview Financial Performance Measures of Focal Company 7

Derivation of Indicators	**Calculation**
Revenue (in thousands)	64.479
Employees	415
Revenue per employee RE (in thousands)	**155.372**
PBIT (in thousands)	3,457.195
Depreciation and amortisation (in thousands)	2,212.030
Operating profit OP (in thousands)	**5,669.225**
PBT (in thousands)	2,063.073
Total assets (in thousands)	31,415.25
Return on assets ROA	**6.57**
Asset turnover AT	**2.05**
Fixed Assets (in thousands)	18,165.61
Profit fixed asset ratio PFR	**19.03**
Debts (in thousands)	21,183.84
Cash Flow (in thousands)	3,769.86
Dynamic debt ratio DDR	**5.62**
Industries (WZ2008)	25993; 46741; 46902; 22290

Overview Financial Performance Measures of Focal Company 8

Derivation of Indicators	**Calculation**
Revenue (in thousands)	8,027.22
Employees	50
Revenue per employee RE (in thousands)	**160,544**
Industries (WZ2008)	22290; 32990

Overview Financial Performance Measures of Focal Company 9

Derivation of Indicators	**Calculation**
Revenue (in thousands)	40,932
Employees	270
Revenue per employee RE (in thousands)	**151,600**
Industries (WZ2008)	22290; 46901

Overview Financial Performance Measures of Focal Company 10

Derivation of Indicators	**Calculation**
Revenue (in thousands)	49,164
Employees	250
Revenue per employee RE (in thousands)	**196.656**
PBIT (in thousands)	11,162.770
Depreciation and amortisation (in thousands)	3,703.384
Operating profit OP (in thousands)	**14,866.154**
PBT (in thousands)	11,116.007
Total assets (in thousands)	24.950.40
Return on assets ROA	**44.55**
Asset turnover AT	**1.97**
Fixed Assets (in thousands)	12,169.87
Profit fixed asset ratio PFR	**91.72**
Debts (in thousands)	5,174.39
Cash Flow (in thousands)	11,569.36
Dynamic debt ratio DDR	**0.45**
Industries (WZ2008)	22290

Overview Financial Performance Measures of Focal Company 11

Derivation of Indicators	**Calculation**
Revenue (in thousands)	9,665
Employees	60
Revenue per employee RE (in thousands)	**161.075**
PBIT (in thousands)	126.181
Depreciation and amortisation (in thousands)	220.045
Operating profit OP (in thousands)	**346.226**
PBT (in thousands)	-15.380
Total assets (in thousands)	3,574.85
Return on assets ROA	**-0.43**
Asset turnover AT	**2.70**
Fixed Assets (in thousands)	1,136.65
Profit fixed asset ratio PFR	**11.10**
Debts (in thousands)	2,949.55
Cash Flow (in thousands)	240.42
Dynamic debt ratio DDR	**12.27**
Industries (WZ2008)	22290; 25735

Overview Financial Performance Measures of Focal Company 12

Derivation of Indicators	**Calculation**
Revenue (in thousands)	17,908
Employees	126
Revenue per employee RE (in thousands)	**142.125**
PBIT (in thousands)	-618.866
Depreciation and amortisation (in thousands)	4,020.764
Operating profit OP (in thousands)	**3,401.898**
PBT (in thousands)	-1,088.849
Total assets (in thousands)	23,251.62
Return on assets ROA	**-4.68**
Asset turnover AT	**0.77**
Fixed Assets (in thousands)	15,325.69
Profit fixed asset ratio PFR	**-4,04**
Debts (in thousands)	20,306.18
Cash Flow (in thousands)	2,942.79
Dynamic debt ratio DDR	**6.90**
Industries (WZ2008)	22290

Overview Financial Performance Measures of Focal Company 13

Derivation of Indicators	**Calculation**
Revenue (in thousands)	63,922
Employees	261
Revenue per employee RE (in thousands)	**244.912**
PBIT (in thousands)	3,925.354
Depreciation and amortisation (in thousands)	3,540.897
Operating profit OP (in thousands)	**7,466.250**
PBT (in thousands)	3,402.366
Total assets (in thousands)	32,103.65
Return on assets ROA	**10.60**
Asset turnover AT	**1.99**
Fixed Assets (in thousands)	13,824.35
Profit fixed asset ratio PFR	**28.39**
Debts (in thousands)	11,230.82
Cash Flow (in thousands)	5,598.32
Dynamic debt ratio DDR	**2.01**
Industries (WZ2008)	32501; 22290

Overview Financial Performance Measures of Focal Company 14

Derivation of Indicators	**Calculation**
Revenue (in thousands)	6,685,56
Employees	47
Revenue per employee RE (in thousands)	**142.246**
Total assets (in thousands)	2,665.486
Asset turnover	**2,51**
Industries (WZ2008)	22290; 28290; 25735

Overview Financial Performance Measures of Focal Company 15

Derivation of Indicators	**Calculation**
Revenue (in thousands)	14,781
Employees	86
Revenue per employee RE (in thousands)	**171.872**
PBIT (in thousands)	607.592
Depreciation and amortisation (in thousands)	1,002.488
Operating profit OP (in thousands)	**1,610.081**
PBT (in thousands)	606.999
Total assets (in thousands)	9,693.72
Return on assets ROA	**6.26**
Asset turnover AT	**1.52**
Fixed Assets (in thousands)	3,086.19
Profit fixed asset ratio PFR	**19.69**
Debts (in thousands)	1,501.97
Cash Flow (in thousands)	1,394.24
Dynamic debt ratio DDR	**1.08**
Industries (WZ2008)	22290; 32990

A5. Strength of Links Calculation

Strength of Links Calculation Part 1

Cash Flows									
	CUST31	CUST50	CUST56	CUST60	CUST217	CUST84	CUST235	CUST278	CUST306
FOC1	672,173	0	0	0	0	0	0	0	0
FOC2	0	6,358,319	0	0	0	0	0	0	0
FOC3	0	0	1,284,093	0	0	0	0	0	0
FOC4	0	0	0	1,716,969	0	0	0	0	0
FOC5	979,326	0	0	0	1,223,583	0	1,775,438	0	0
FOC6	0	850,471	14,434,626	936,548	0	5,181,755	0	0	0
FOC7	0	0	0	0	7,840,635	0	0	0	0
FOC8	0	0	0	0	0	6,340,404	0	0	0
FOC9	0	0	7,820,751	0	0	0	0	0	0
FOC10	0	0	0	0	0	0	738,258	164,332	0
FOC11	0	0	0	0	0	0	0	0	0
FOC12	0	0	0	0	0	0	0	0	0
FOC13	0	0	0	0	0	0	0	10,411,325	4,640,657
FOC14	0	0	0	0	0	0	0	0	0
FOC15	0	0	0	0	0	0	381,544	0	382,068
SUM	1,651,499	7,208,790	23,539,470	2,653,517	9,064,218	11,522,159	2,895,240	10,575,657	5,022,725

Proportions									
	CUST31	CUST50	CUST56	CUST60	CUST217	CUST84	CUST235	CUST278	CUST306
FOC1	0.407	0	0	0	0	0	0	0	0
FOC2	0	0.882	0	0	0	0	0	0	0
FOC3	0	0	0.055	0	0	0	0	0	0
FOC4	0	0	0	0.647	0	0	0	0	0
FOC5	0.593	0	0	0	0.135	0	0.613	0	0
FOC6	0	0.118	0.613	0.353	0	0.450	0	0	0
FOC7	0	0	0	0	0.865	0	0	0	0
FOC8	0	0	0	0	0	0.550	0	0	0
FOC9	0	0	0.332	0	0	0	0	0	0
FOC10	0	0	0	0	0	0	0.255	0.016	0
FOC11	0	0	0	0	0	0	0	0	0
FOC12	0	0	0	0	0	0	0	0	0
FOC13	0	0	0	0	0	0	0	0.984	0.924
FOC14	0	0	0	0	0	0	0	0	0
FOC15	0	0	0	0	0	0	0.132	0	0.076

Strength of Links Calculation Part 2

Cash Flows									
	CUST312	CUST313	CUST331	CUST334	CUST343	SUPPL8139	SUPPL8142	SUPPL8143	SUPPL8148
FOC1	0	0	0	0	0	622,352	300,193	295,430	189,980
FOC2	0	0	0	0	0	0	0	0	0
FOC3	0	0	0	0	0	376,024	0	0	0
FOC4	0	0	0	0	0	157,183	0	0	0
FOC5	0	0	0	0	0	865,305	753,959	152,590	286,312
FOC6	0	0	0	0	0	353,754	322,756	0	0
FOC7	0	0	717,132	384,129	0	348,163	0	0	1,090,204
FOC8	0	0	0	0	0	320,838	0	0	0
FOC9	0	0	0	0	0	568,389	0	0	0
FOC10	0	0	0	0	0	609,945	0	0	0
FOC11	0	0	0	0	0	121,414	0	480,668	77,904
FOC12	0	0	0	0	0	0	0	0	0
FOC13	1,103,470	1,100,835	536,946	441,779	353,550	0	0	0	0
FOC14	268,014	438,353	0	0	0	0	0	0	0
FOC15	0	0	0	0	2,986,945	831,084	0	0	0
SUM	1,371,484	1,539,188	1,254,078	825,908	3,340,495	5,174,451	1,376,908	928,688	1,644,400

Proportions									
	CUST312	CUST313	CUST331	CUST334	CUST343	SUPPL8139	SUPPL8142	SUPPL8143	SUPPL8148
FOC1	0	0	0	0	0	0.120	0.218	0.318	0.116
FOC2	0	0	0	0	0	0	0	0	0
FOC3	0	0	0	0	0	0.073	0	0	0
FOC4	0	0	0	0	0	0.030	0	0	0
FOC5	0	0	0	0	0	0.167	0.548	0.164	0.174
FOC6	0	0	0	0	0	0.068	0.234	0	0
FOC7	0	0	0.572	0.465	0	0.067	0	0	0.663
FOC8	0	0	0	0	0	0.062	0	0	0
FOC9	0	0	0	0	0	0.110	0	0	0
FOC10	0	0	0	0	0	0.118	0	0	0
FOC11	0	0	0	0	0	0.023	0	0.518	0.047
FOC12	0	0	0	0	0	0	0	0	0
FOC13	0.805	0.715	0.428	0.535	0.106	0	0	0	0
FOC14	0.195	0.285	0	0	0	0	0	0	0
FOC15	0	0	0	0	0.894	0.161	0	0	0

Strength of Links Calculation Part 3

Cash Flows									
	SUPPL8151	SUPPL8152	SUPPL8156	SUPPL8180	SUPPL8182	SUPPL8184	SUPPL8186	SUPPL8187	SUPPL8192
FOC1	160,693	118,331	93,336	0	0	0	0	0	0
FOC2	1,174,528	0	0	1,217,481	1,093,179	878,414	810,554	587,081	374,130
FOC3	156,949	0	0	0	0	0	0	1,202,798	0
FOC4	0	0	0	0	0	0	0	0	0
FOC5	899,772	0	144,154	334,299	0	0	0	0	0
FOC6	341,460	0	0	0	0	0	0	488,015	0
FOC7	0	0	0	0	1,776,051	0	0	0	0
FOC8	0	0	0	0	0	0	0	0	0
FOC9	0	576,243	0	0	0	180,101	0	742,775	6,440,603
FOC10	0	0	423,828	0	0	0	0	0	0
FOC11	0	0	73,948	0	0	0	0	268,385	0
FOC12	0	1,007,816	0	0	0	0	982,453	0	0
FOC13	0	0	0	0	0	0	0	0	0
FOC14	0	0	190,619	0	0	0	0	0	0
FOC15	0	0	0	0	0	0	0	0	0
SUM	2,733,402	1,702,390	925,885	1,551,780	2,869,230	1,058,515	1,793,007	3,289,054	6,814,733

Proportions									
	SUPPL8151	SUPPL8152	SUPPL8156	SUPPL8180	SUPPL8182	SUPPL8184	SUPPL8186	SUPPL8187	SUPPL8192
FOC1	0.059	0.070	0.101	0	0	0	0	0	0
FOC2	0.430	0	0	0.785	0.381	0.830	0.452	0.178	0.055
FOC3	0.057	0	0	0	0	0	0	0.366	0
FOC4	0	0	0	0	0	0	0	0	0
FOC5	0.329	0	0.156	0.215	0	0	0	0	0
FOC6	0.125	0	0	0	0	0	0	0.148	0
FOC7	0	0	0	0	0.619	0	0	0	0
FOC8	0	0	0	0	0	0	0	0	0
FOC9	0	0.338	0	0	0	0.170	0	0.226	0.945
FOC10	0	0	0.458	0	0	0	0	0	0
FOC11	0	0	0.080	0	0	0	0	0.082	0
FOC12	0	0.592	0	0	0	0	0.548	0	0
FOC13	0	0	0	0	0	0	0	0	0
FOC14	0	0	0.206	0	0	0	0	0	0
FOC15	0	0	0	0	0	0	0	0	0

Strength of Links Calculation Part 4

Cash Flows									
	SUPPL7895	SUPPL7902	SUPPL7906	SUPPL7925	SUPPL7927	SUPPL7940	SUPPL7947	SUPPL7968	SUPPL7971
FOC1	0	0	0	0	0	0	0	0	0
FOC2	0	0	0	0	0	0	0	0	0
FOC3	456,938	0	0	0	0	0	0	0	0
FOC4	0	1,232,339	305,990	0	0	0	0	0	0
FOC5	252,189	0	0	344,226	308,300	154,134	119,989	73,536	0
FOC6	0	576,805	0	0	0	339,479	0	0	2,316,629
FOC7	0	586,958	0	0	0	0	0	0	0
FOC8	0	0	0	0	0	0	0	0	1,258,085
FOC9	0	0	0	0	0	0	0	0	0
FOC10	0	6,100,320	0	791,665	0	0	226,696	422,675	0
FOC11	0	0	0	0	0	0	0	0	0
FOC12	0	6,829,557	0	0	0	0	0	0	0
FOC13	0	1,668,989	1,230,547	0	0	0	0	0	0
FOC14	0	0	0	0	0	0	0	0	0
FOC15	0	142,068	0	0	267,195	0	0	0	0
SUM	709,127	17,137,036	1,536,537	1,135,891	575,495	493,613	346,685	496,211	3,574,714

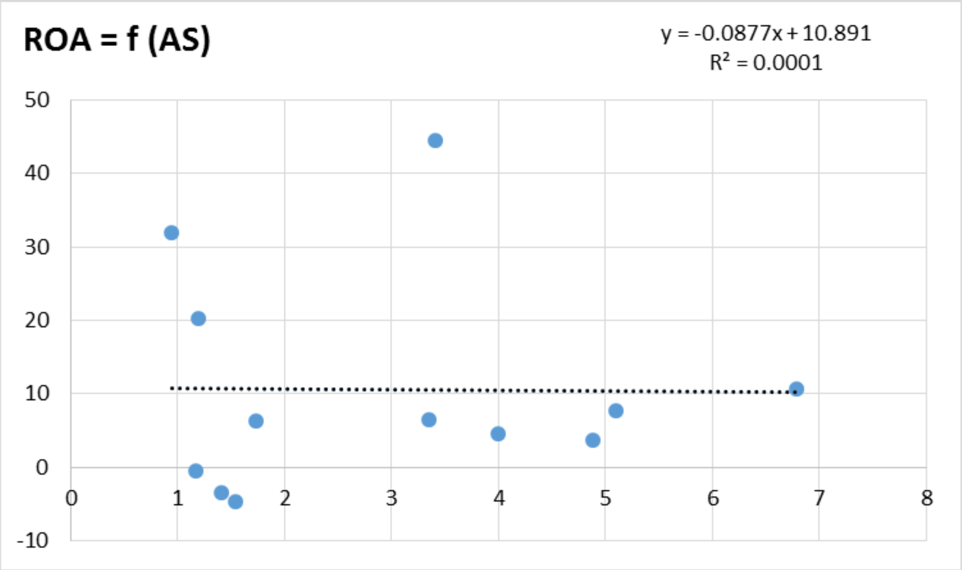
Proportions									
	SUPPL7895	SUPPL7902	SUPPL7906	SUPPL7925	SUPPL7927	SUPPL7940	SUPPL7947	SUPPL7968	SUPPL7971
FOC1	0	0	0	0	0	0	0	0	0
FOC2	0	0	0	0	0	0	0	0	0
FOC3	0.644	0	0	0	0	0	0	0	0
FOC4	0	0.072	0.199	0	0	0	0	0	0
FOC5	0.356	0	0	0.303	0.536	0.312	0.346	0.148	0
FOC6	0	0.034	0	0	0	0.688	0	0	0.648
FOC7	0	0.034	0	0	0	0	0	0	0
FOC8	0	0	0	0	0	0	0	0	0.352
FOC9	0	0	0	0	0	0	0	0	0
FOC10	0	0.356	0	0.697	0	0	0.654	0.852	0
FOC11	0	0	0	0	0	0	0	0	0
FOC12	0	0.399	0	0	0	0	0	0	0
FOC13	0	0.097	0.801	0	0	0	0	0	0
FOC14	0	0	0	0	0	0	0	0	0
FOC15	0	0.008	0	0	0.464	0	0	0	0

Strength of Links Calculation Part 5

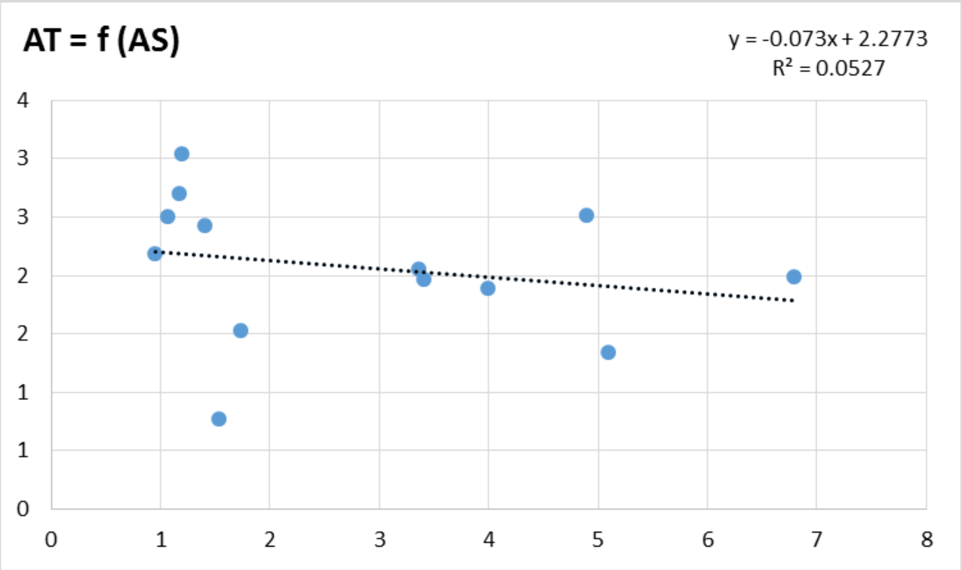
Cash Flows					
	SUPPL7972	SUPPL7988	SUPPL8000	SUPPL8012	SUPPL8054
FOC1	0	0	0	0	0
FOC2	0	0	0	0	0
FOC3	0	0	0	0	0
FOC4	0	0	0	0	0
FOC5	0	0	0	0	0
FOC6	1,741,500	447,099	236,634	0	0
FOC7	0	0	0	909,412	0
FOC8	0	257,987	0	0	0
FOC9	341,100	0	346,259	4,961,197	226,242
FOC10	0	0	0	0	0
FOC11	682,314	144,078	0	0	0
FOC12	0	0	0	0	0
FOC13	0	0	0	7,312,935	1,179,589
FOC14	0	0	355,963	0	0
FOC15	0	0	0	0	0
SUM	2,764,914	849,164	938,856	13,183,544	1,405,831

Proportions					
	SUPPL7972	SUPPL7988	SUPPL8000	SUPPL8012	SUPPL8054
FOC1	0	0	0	0	0
FOC2	0	0	0	0	0
FOC3	0	0	0	0	0
FOC4	0	0	0	0	0
FOC5	0	0	0	0	0
FOC6	0.630	0.527	0.252	0	0
FOC7	0	0	0	0.069	0
FOC8	0	0.304	0	0	0
FOC9	0.123	0	0.369	0.376	0.161
FOC10	0	0	0	0	0
FOC11	0.247	0.170	0	0	0
FOC12	0	0	0	0	0
FOC13	0	0	0	0.555	0.839
FOC14	0	0	0.379	0	0
FOC15	0	0	0	0	0

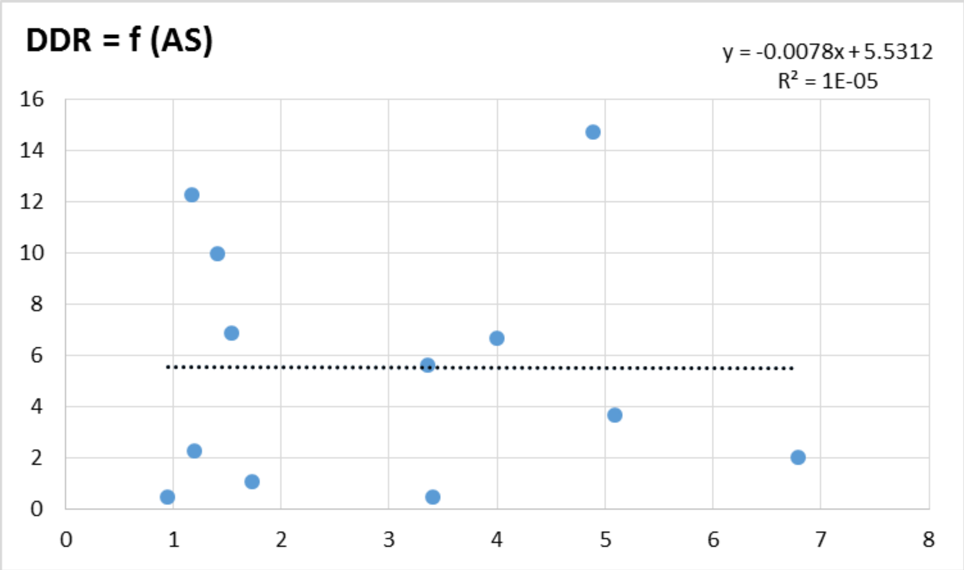
A6. Illustration of the Linear Regression of Hypothesis 1



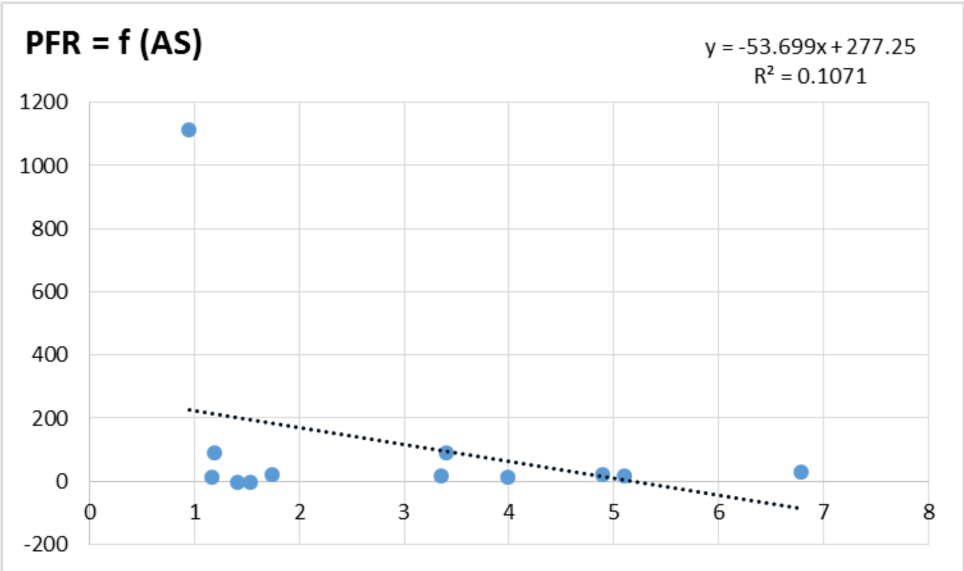
Linear Regression ROA = f(AS)



Linear Regression Asset Turnover = f(AS)

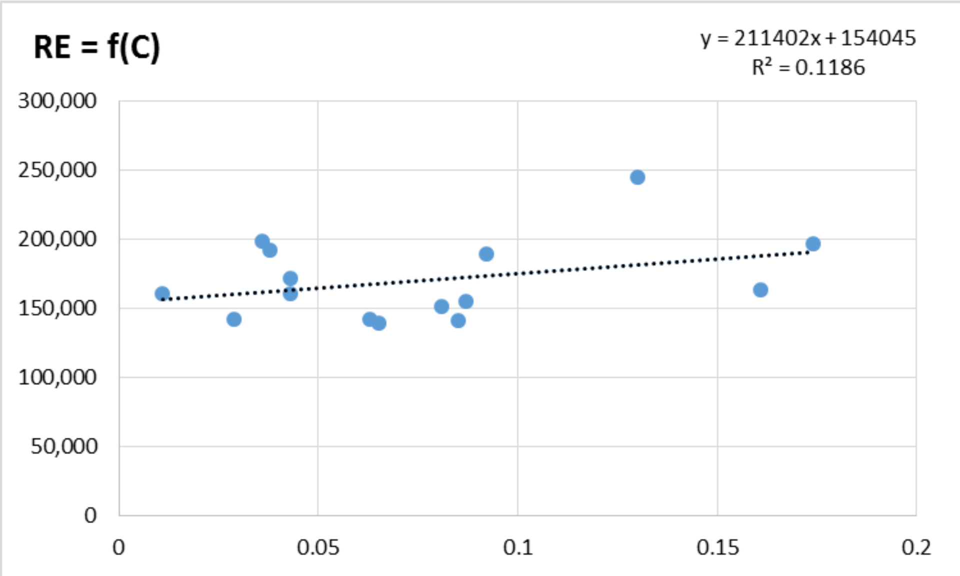


Linear Regression DDR = f(AS)

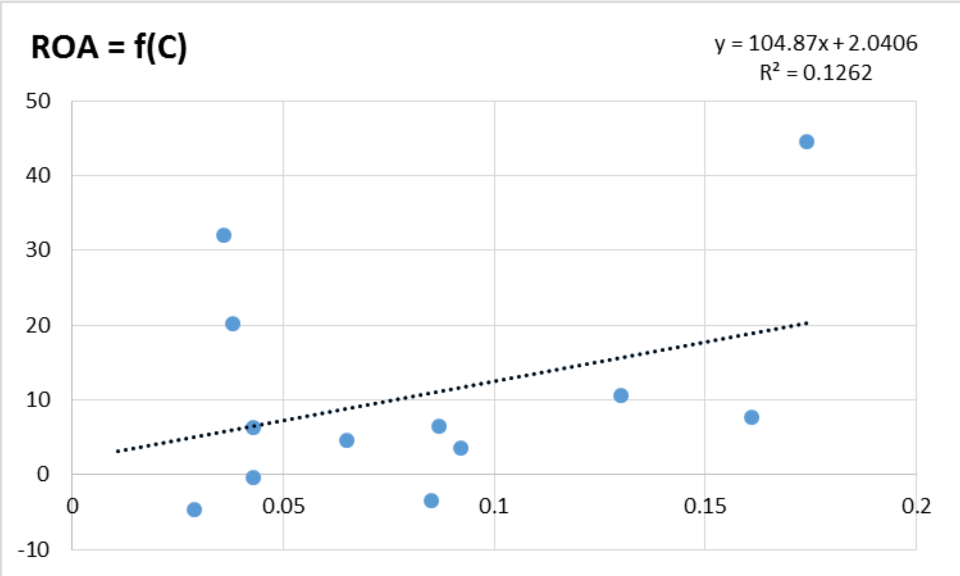


Linear Regression PFR = f(AS)

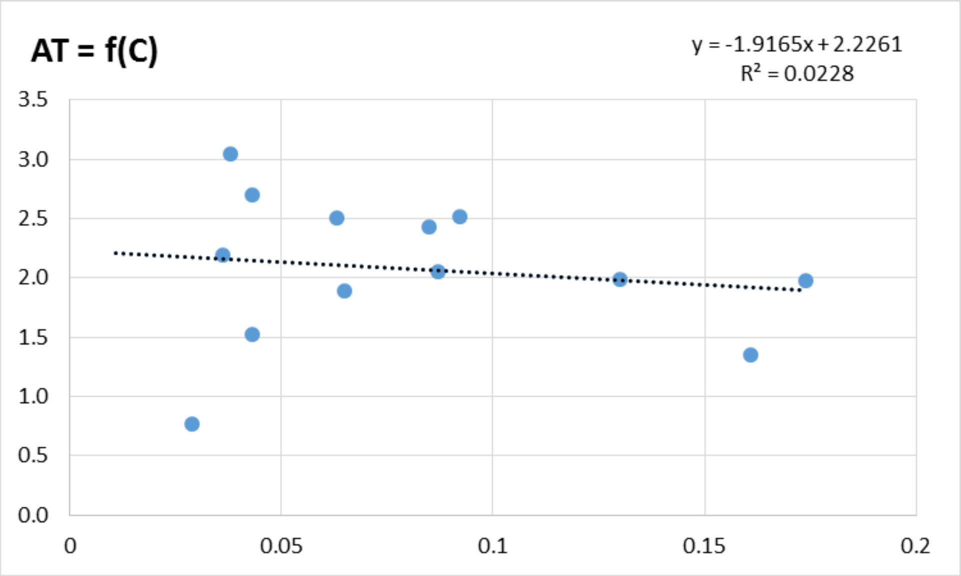
A7. Illustration of the Linear Regression of Hypothesis 2



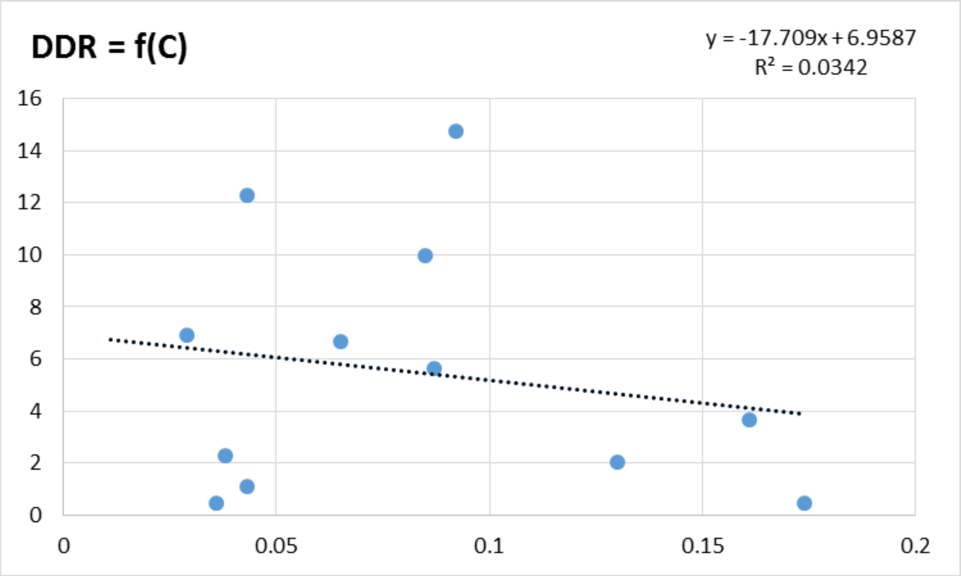
Linear Regression RE = f(C)



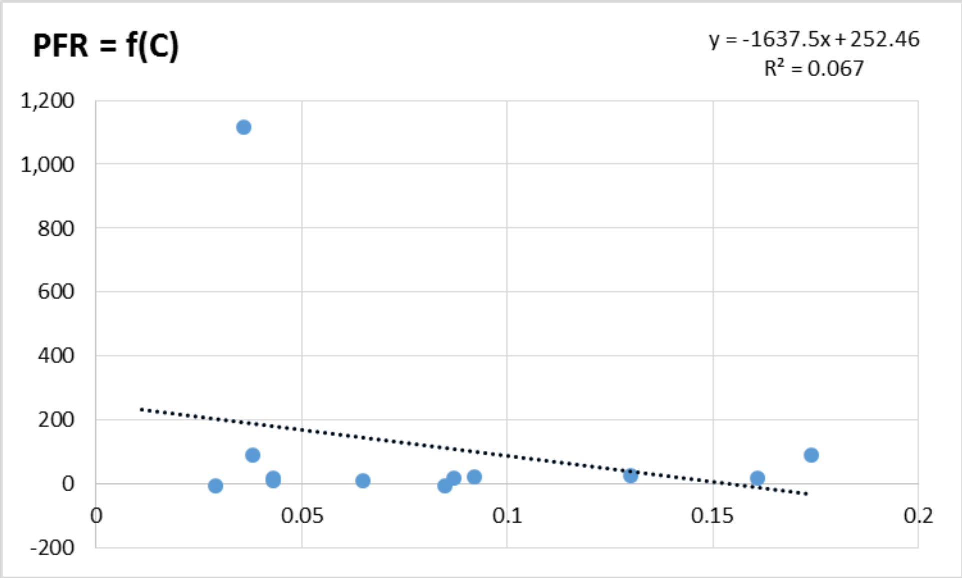
Linear Regression ROA = f(C)



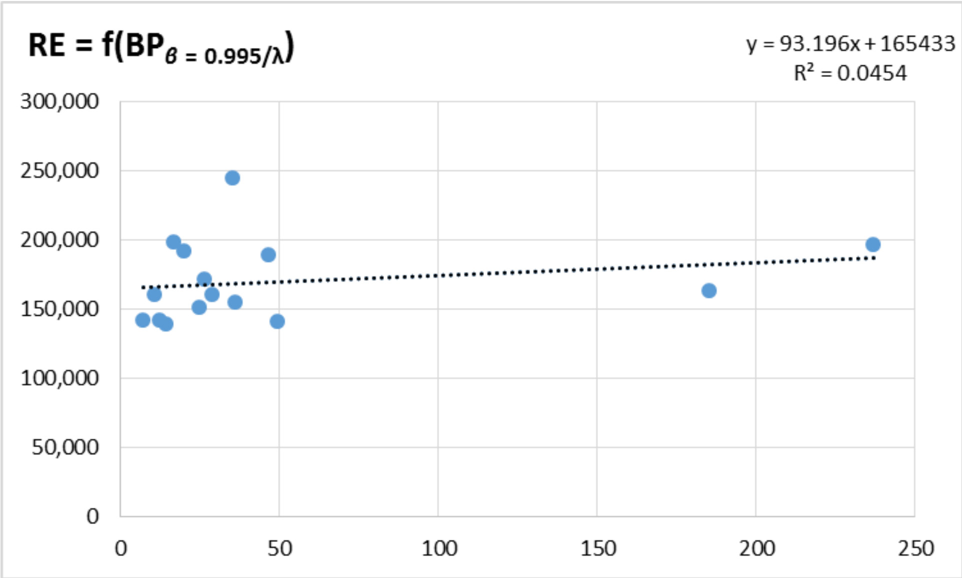
Linear Regression AT = f(C)



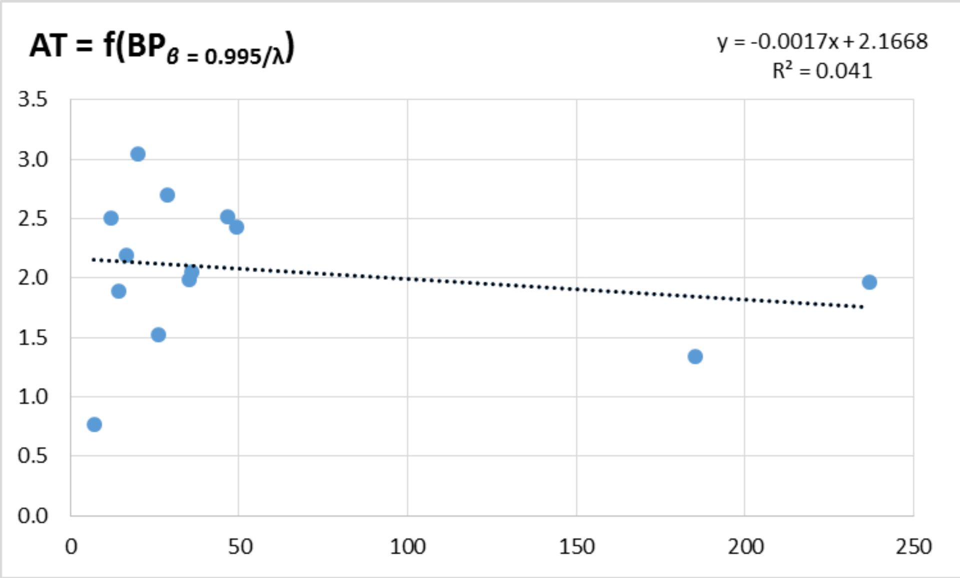
Linear Regression DDR = f(C)



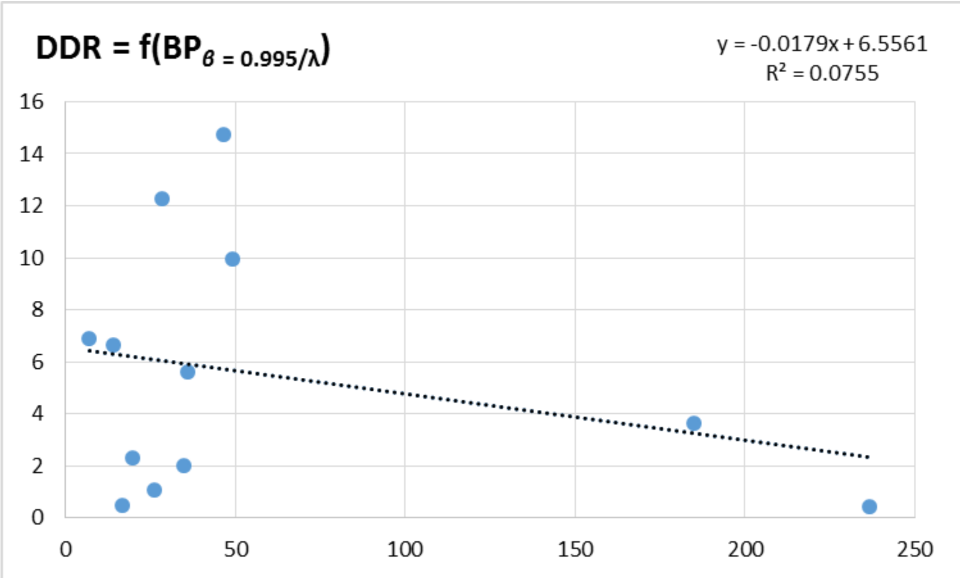
Linear Regression PFR = f(C)



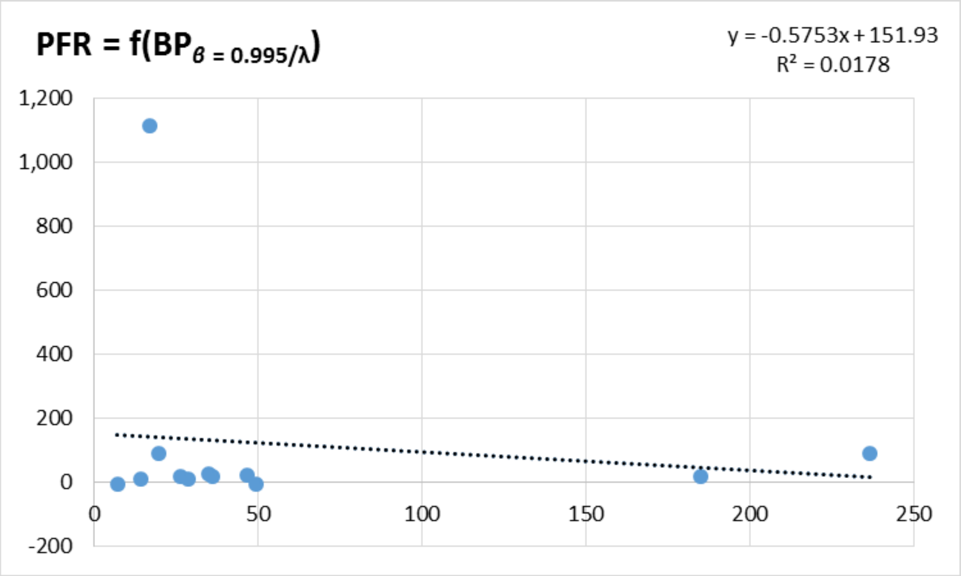
Linear Regression RE = f($BP_{\beta = 0.995/\lambda}$)



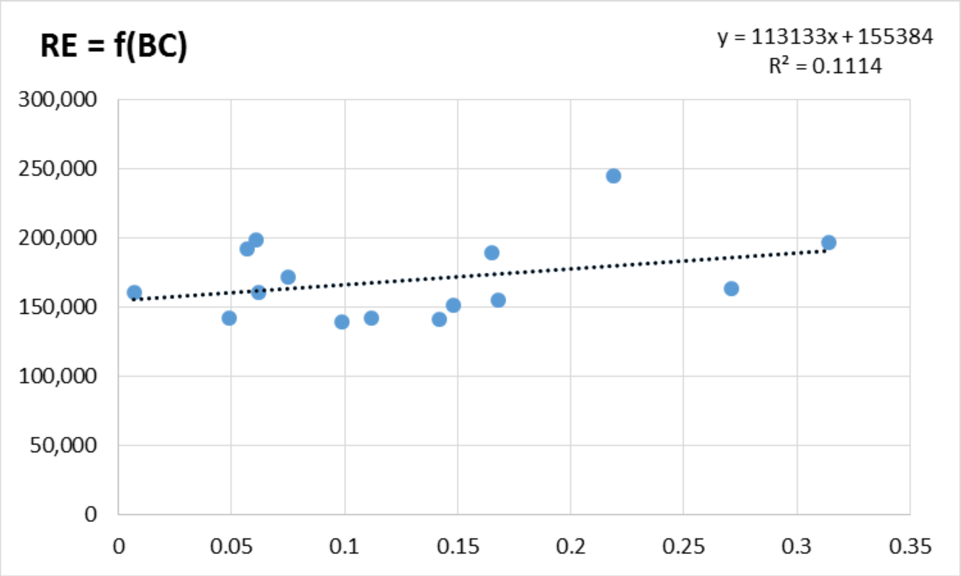
Linear Regression AT = f($BP_{\beta = 0.995/\lambda}$)



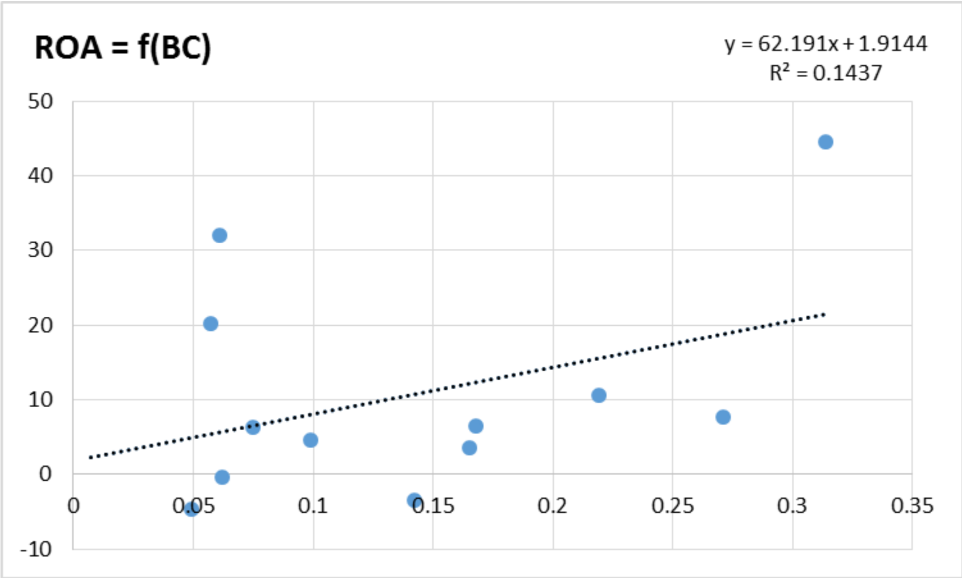
Linear Regression DDR = f($BP_{\beta = 0.995/\lambda}$)



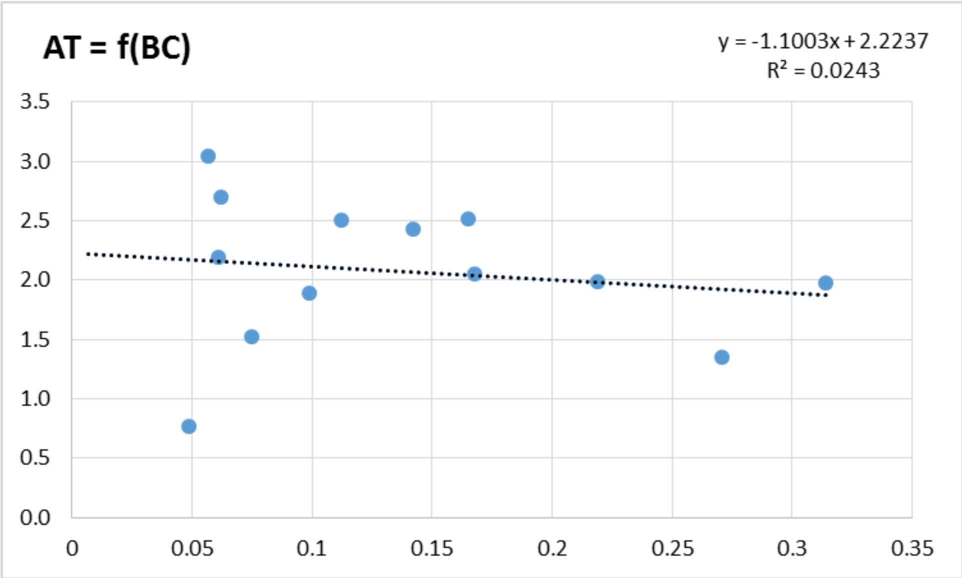
Linear Regression PFR = f($BP_{\beta = 0.995/\lambda}$)



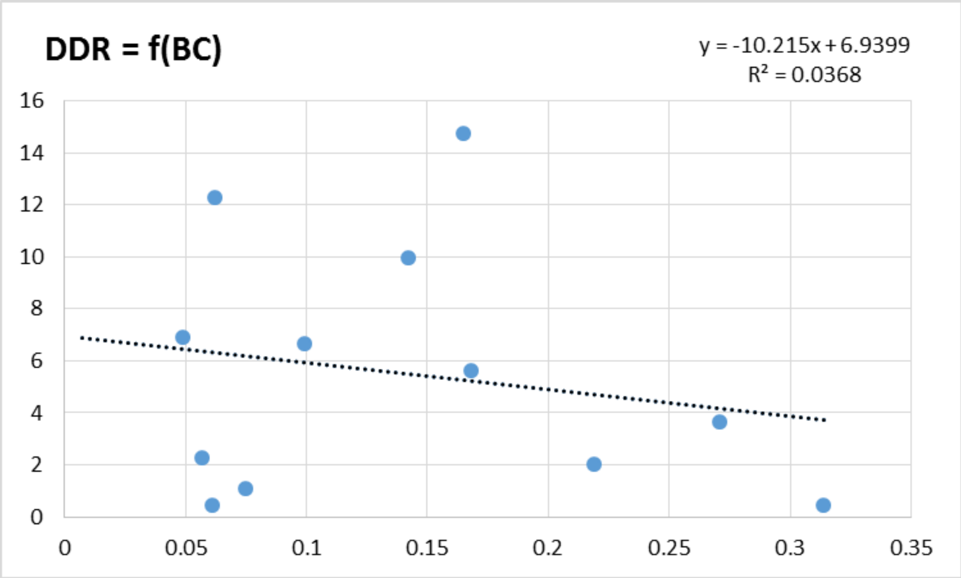
Linear Regression RE = f(BC)



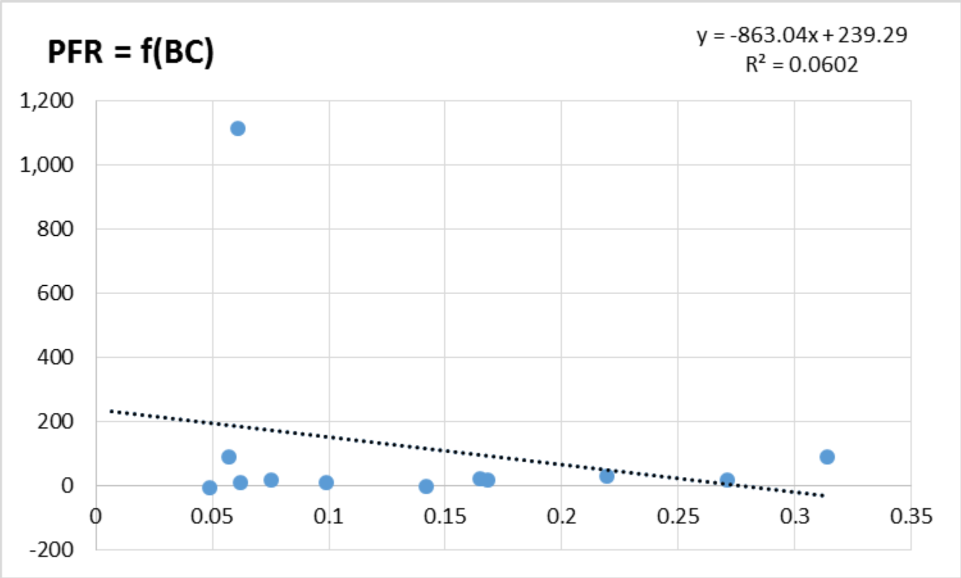
Linear Regression ROA = f(BC)



Linear Regression AT = f(BC)



Linear Regression DDR = f(BC)



Linear Regression PFR = f(BC)

A8. Calculation of Hubs (Sales Orientation)

Calculation of Hubs and Relative Share of Hubs as Part of Diversity

Product Flows (Articles)											
	CUST50	CUST56	CUST60	CUST217	CUST84	CUST278	CUST312	CUST313	CUST306	CUST343	
FOC1	0	0	0	0	0	0	0	0	0	0	
FOC2	22	0	0	0	0	0	0	0	0	0	
FOC3	0	61	0	0	0	0	0	0	0	0	
FOC4	0	0	47	0	0	0	0	0	0	0	
FOC5	0	0	0	12	0	0	0	0	0	0	
FOC6	6	492	52	0	134	0	0	0	0	0	
FOC7	0	0	0	48	0	0	0	0	0	0	
FOC8	0	0	0	0	262	0	0	0	0	0	
FOC9	0	496	0	0	0	0	0	0	0	0	
FOC10	0	0	0	0	0	2	0	0	0	0	
FOC11	0	0	0	0	0	0	0	0	0	0	
FOC12	0	0	0	0	0	0	0	0	0	0	
FOC13	0	0	0	0	0	1,107	77	31	26	1	
FOC14	0	0	0	0	0	0	16	61	0	0	
FOC15	0	0	0	0	0	0	0	0	1	15	
SUM	**28**	**1,049**	**99**	**60**	**396**	**1,109**	**93**	**92**	**27**	**16**	

Proportions											
	CUST50	**CUST56**	**CUST60**	**CUST217**	**CUST84**	**CUST278**	**CUST312**	**CUST313**	**CUST306**	**CUST343**	**SUM**
FOC1	0	0	0	0	0	0	0	0	0	0	**0**
FOC2	0.786	0	0	0	0	0	0	0	0	0	**0.786**
FOC3	0	0.058	0	0	0	0	0	0	0	0	**0.058**
FOC4	0	0	0.475	0	0	0	0	0	0	0	**0.475**
FOC5	0	0	0	0.200	0	0	0	0	0	0	**0.200**
FOC6	0.214	0.469	0.525	0	0.338	0	0	0	0	0	**1.547**
FOC7	0	0	0	0.800	0	0	0	0	0	0	**0.800**
FOC8	0	0	0	0	0.662	0	0	0	0	0	**0.662**
FOC9	0	0.473	0	0	0	0	0	0	0	0	**0.473**
FOC10	0	0	0	0	0	0.002	0	0	0	0	**0.002**
FOC11	0	0	0	0	0	0	0	0	0	0	**0**
FOC12	0	0	0	0	0	0	0	0	0	0	**0**
FOC13	0	0	0	0	0	0.998	0.828	0.337	0.963	0.063	**3.189**
FOC14	0	0	0	0	0	0	0.172	0.663	0	0	**0.835**
FOC15	0	0	0	0	0	0	0	0	0.037	0.938	**0.975**

A9. Calculation of Authorities (Procurement Orientation)

Calculation of Authorities as Part of Diversity (Part 1)

Product Flows (Articles)									
	FOC1	**FOC2**	**FOC3**	**FOC4**	**FOC5**	**FOC6**	**FOC7**	**FOC8**	**FOC9**
CUST56	0	0	0	0	0	58	0	0	95
CUST235	0	0	0	0	16	0	0	0	0
SUPPL8142	29	0	0	0	54	37	0	0	0
SUPPL8139	21	0	19	10	35	24	11	16	27
SUPPL8151	10	9	4	0	22	8	0	0	0
SUPPL8143	10	0	0	0	15	0	0	0	0
SUPPL8156	10	0	0	0	12	0	0	0	0
SUPPL8148	7	0	0	0	20	0	5	0	0
SUPPL8152	3	0	0	0	0	0	0	0	15
SUPPL8180	0	37	0	0	34	0	0	0	0
SUPPL8184	0	5	0	0	0	0	0	0	1
SUPPL8187	0	4	11	0	0	11	0	0	8
SUPPL8182	0	3	0	0	0	0	4	0	0
SUPPL8192	0	2	0	0	0	0	0	0	6
SUPPL8186	0	1	0	0	0	0	0	0	0
SUPPL7895	0	0	1	0	3	0	0	0	0
SUPPL7902	0	0	0	19	0	12	11	0	0
SUPPL7906	0	0	0	3	0	0	0	0	0
SUPPL7947	0	0	0	0	39	0	0	0	0
SUPPL7968	0	0	0	0	20	0	0	0	0
SUPPL7927	0	0	0	0	9	0	0	0	0
SUPPL7925	0	0	0	0	9	0	0	0	0
SUPPL7940	0	0	0	0	1	4	0	0	0
SUPPL7971	0	0	0	0	0	25	0	11	0
SUPPL7972	0	0	0	0	0	20	0	0	4
SUPPL7988	0	0	0	0	0	8	0	3	0
SUPPL8000	0	0	0	0	0	2	0	0	4
SUPPL8012	0	0	0	0	0	0	9	0	14
SUPPL8054	0	0	0	0	0	0	0	0	1

Calculation of Authorities as Part of Diversity (Part 2)

	Product Flows (Articles)						
	FOC10	FOC11	FOC12	FOC13	FOC14	FOC15	SUM
CUST56	0	0	0	0	0	0	153
CUST235	0	0	0	0	0	3	19
SUPPL8142	0	0	0	0	0	0	120
SUPPL8139	2	15	0	0	0	19	199
SUPPL8151	0	0	0	0	0	0	53
SUPPL8143	0	20	0	0	0	0	45
SUPPL8156	4	9	0	0	4	0	39
SUPPL8148	0	10	0	0	0	0	42
SUPPL8152	0	0	10	0	0	0	28
SUPPL8180	0	0	0	0	0	0	71
SUPPL8184	0	0	0	0	0	0	6
SUPPL8187	0	14	0	0	0	0	48
SUPPL8182	0	0	0	0	0	0	7
SUPPL8192	0	0	0	0	0	0	8
SUPPL8186	0	0	1	0	0	0	2
SUPPL7895	0	0	0	0	0	0	4
SUPPL7902	4	0	12	11	0	2	71
SUPPL7906	0	0	0	2	0	0	5
SUPPL7947	39	0	0	0	0	0	78
SUPPL7968	11	0	0	0	0	0	31
SUPPL7927	0	0	0	0	0	1	10
SUPPL7925	3	0	0	0	0	0	12
SUPPL7940	0	0	0	0	0	0	5
SUPPL7971	0	0	0	0	0	0	36
SUPPL7972	0	2	0	0	0	0	26
SUPPL7988	0	1	0	0	0	0	12
SUPPL8000	0	0	0	0	4	0	10
SUPPL8012	0	0	0	10	0	0	33
SUPPL8054	0	0	0	3	0	0	4

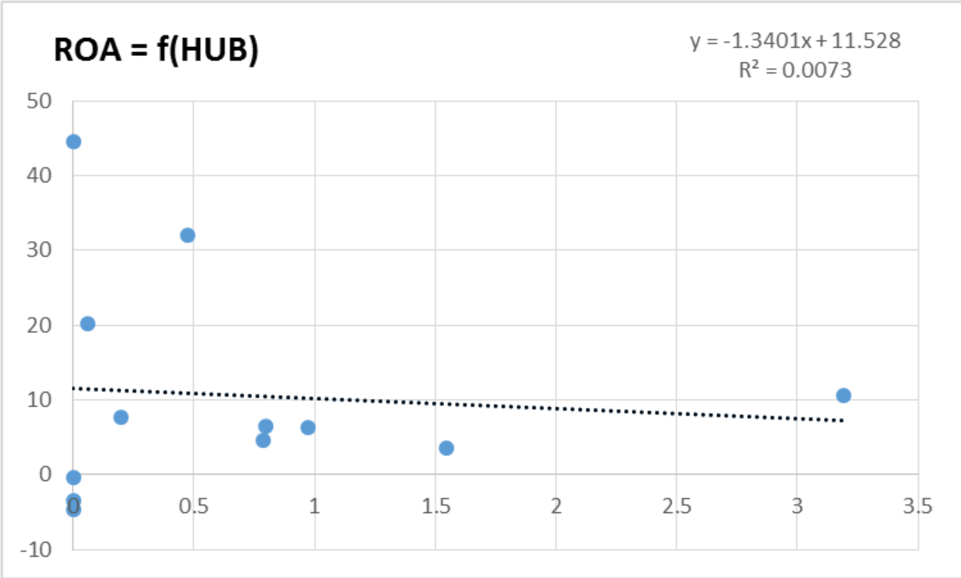
Calculate Relative Share of Authorities (Part 1)

	Proportions							
	FOC1	**FOC2**	**FOC3**	**FOC4**	**FOC5**	**FOC6**	**FOC7**	**FOC8**
	0	0	0	0	0	0.379	0	0
	0	0	0	0	0.842	0	0	0
	0.242	0	0	0	0.450	0.308	0	0
	0.106	0	0.096	0.050	0.176	0.121	0.055	0.080
	0.189	0.170	0.076	0	0.415	0.151	0	0
	0.222	0	0	0	0.333	0	0	0
	0.256	0	0	0	0.308	0	0	0
	0.167	0	0	0	0.476	0	0.119	0
	0.107	0	0	0	0	0	0	0
	0	0.521	0	0	0.479	0	0	0
	0	0.833	0	0	0	0	0	0
	0	0.083	0.229	0	0	0.229	0	0
	0	0.429	0	0	0	0	0.571	0
	0	0.250	0	0	0	0	0	0
	0	0.500	0	0	0	0	0	0
	0	0	0.250	0	0.750	0	0	0
	0	0	0	0.268	0	0.169	0.155	0
	0	0	0	0.600	0	0	0	0
	0	0	0	0	0.500	0	0	0
	0	0	0	0	0.645	0	0	0
	0	0	0	0	0.900	0	0	0
	0	0	0	0	0.750	0	0	0
	0	0	0	0	0.200	0.800	0	0
	0	0	0	0	0	0.694	0	0.306
	0	0	0	0	0	0.769	0	0
	0	0	0	0	0	0.667	0	0.250
	0	0	0	0	0	0.200	0	0
	0	0	0	0	0	0	0.273	0
	0	0	0	0	0	0	0	0
SUM	**1.288**	**2.786**	**0.650**	**0.918**	**7.224**	**4.488**	**1.173**	**0.636**

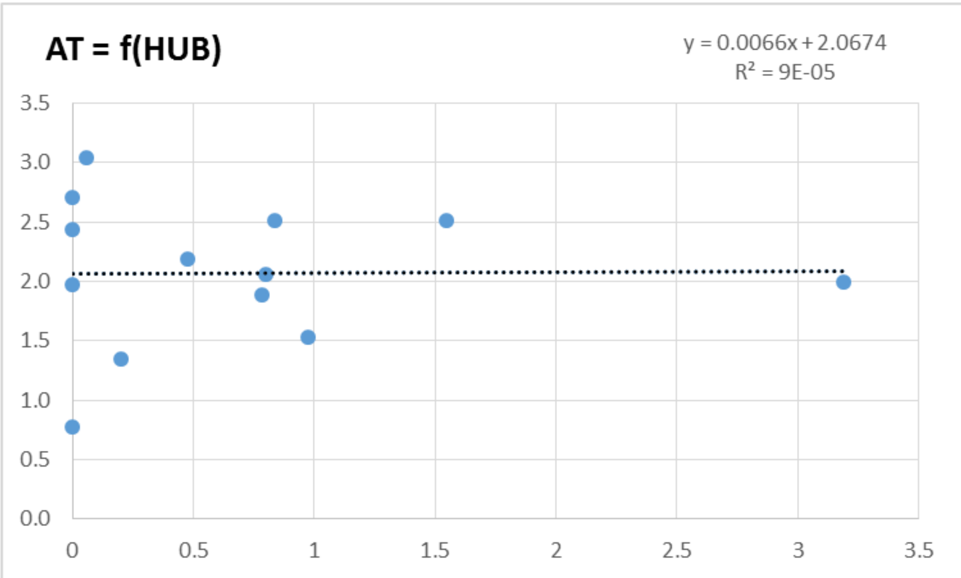
Calculate Relative Share of Authorities (Part 2)

	Proportions						
	FOC9	**FOC10**	**FOC11**	**FOC12**	**FOC13**	**FOC14**	**FOC15**
	0.621	0	0	0	0	0	0
	0	0	0	0	0	0	0.158
	0	0	0	0	0	0	0
	0.136	0.010	0.075	0	0	0	0.096
	0	0	0	0	0	0	0
	0	0	0.444	0	0	0	0
	0	0.103	0.231	0	0	0.103	0
	0	0	0.238	0	0	0	0
	0.536	0	0	0.357	0	0	0
	0	0	0	0	0	0	0
	0.167	0	0	0	0	0	0
	0.167	0	0.292	0	0	0	0
	0	0	0	0	0	0	0
	0.750	0	0	0	0	0	0
	0	0	0	0.500	0	0	0
	0	0	0	0	0	0	0
	0	0.056	0	0.169	0.155	0	0.028
	0	0	0	0	0.400	0	0
	0	0.500	0	0	0	0	0
	0	0.355	0	0	0	0	0
	0	0	0	0	0	0	0.100
	0	0.250	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0.154	0	0.077	0	0	0	0
	0	0	0.083	0	0	0	0
	0.400	0	0	0	0	0.400	0
	0.424	0	0	0	0.303	0	0
	0.250	0	0	0	0.750	0	0
SUM	**3.604**	**1.274**	**1.441**	**1.026**	**1.608**	**0.503**	**0.382**

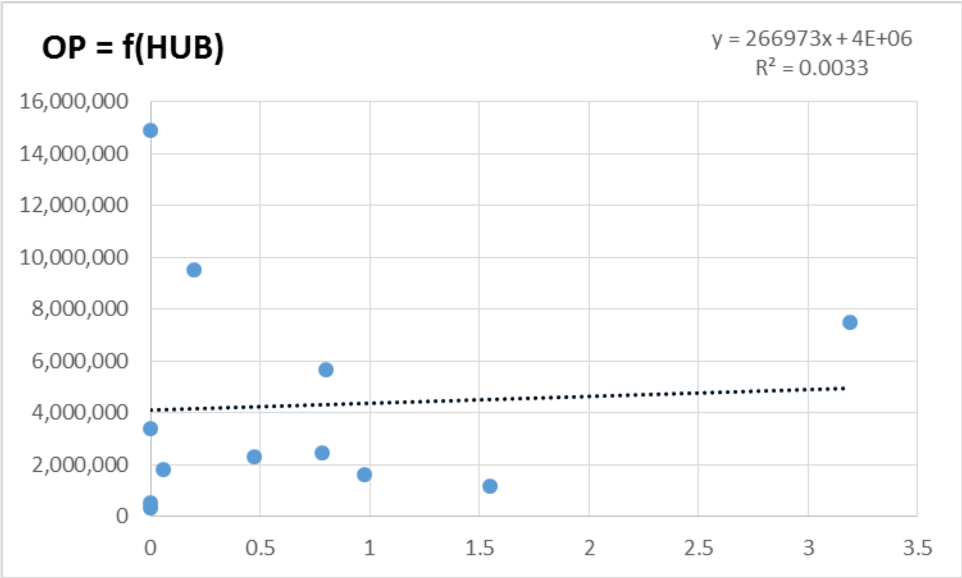
A10. Illustration of the Linear Regression of Hypothesis 3 (Hubs and Authorities)



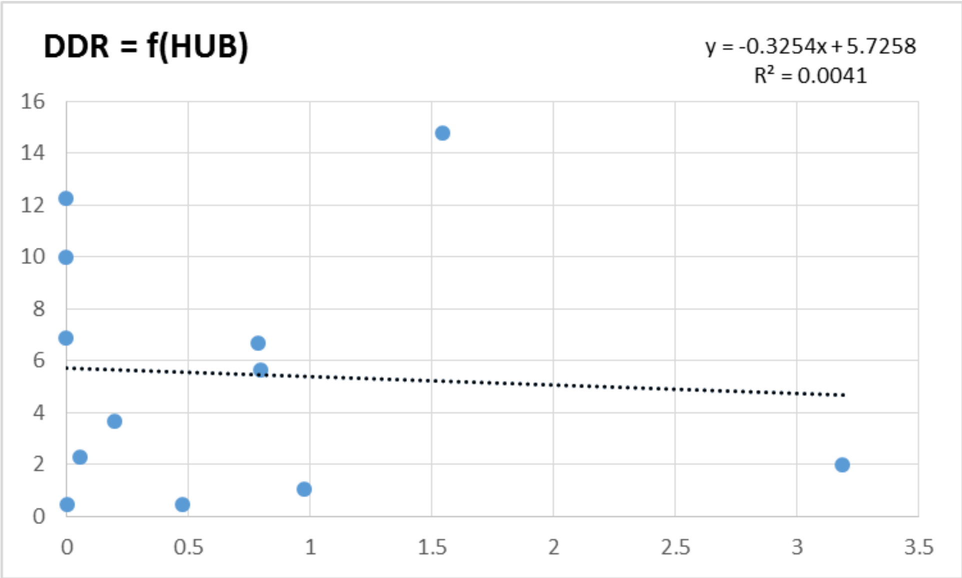
Linear Regression ROA = f(HUB)



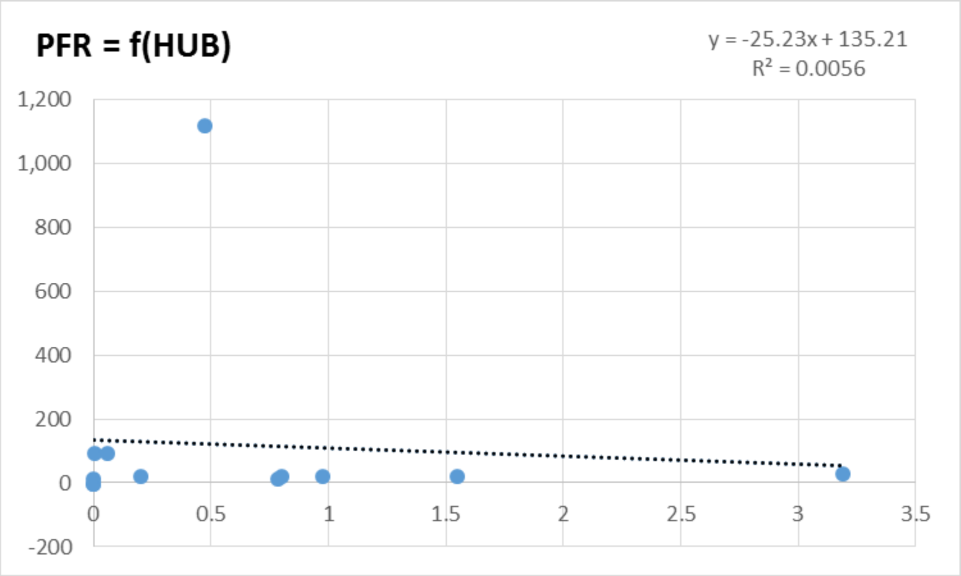
Linear Regression AT = f(HUB)



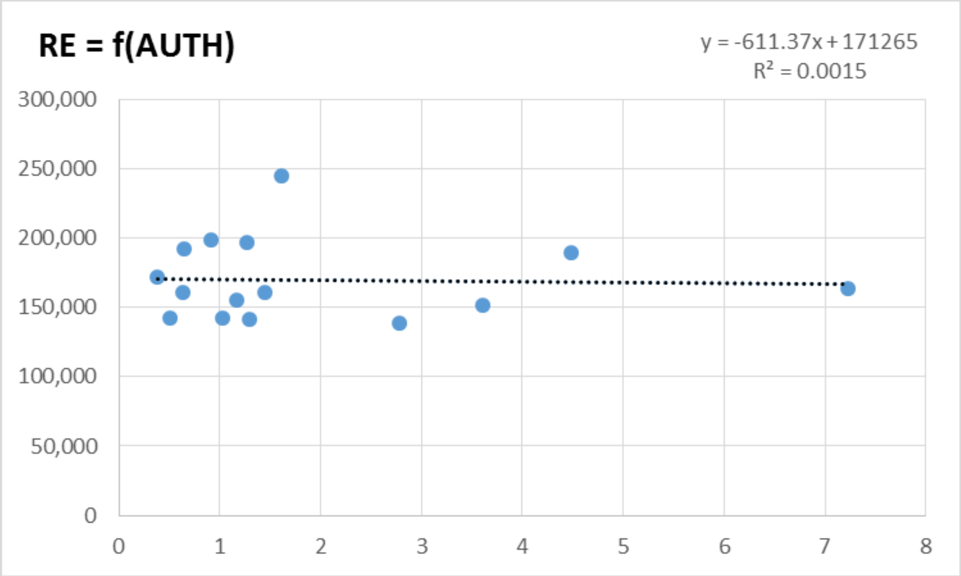
Linear Regression OP = f(HUB)



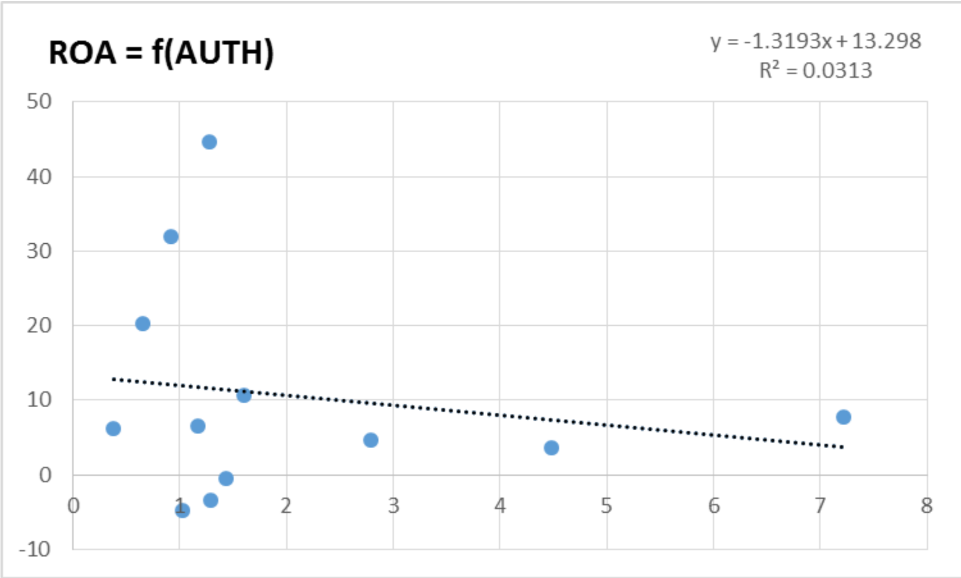
Linear Regression DDR = f(HUB)



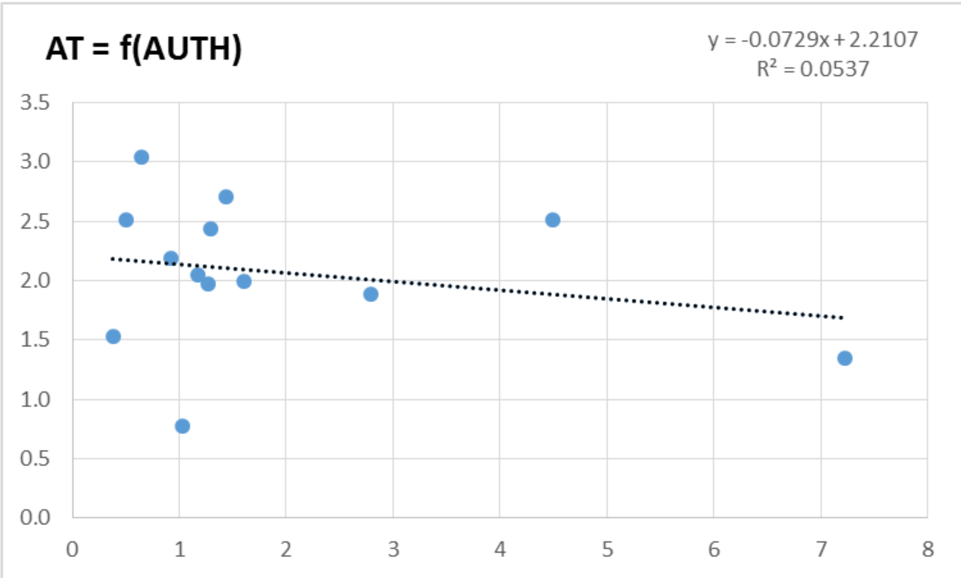
Linear Regression PFR = f(HUB)



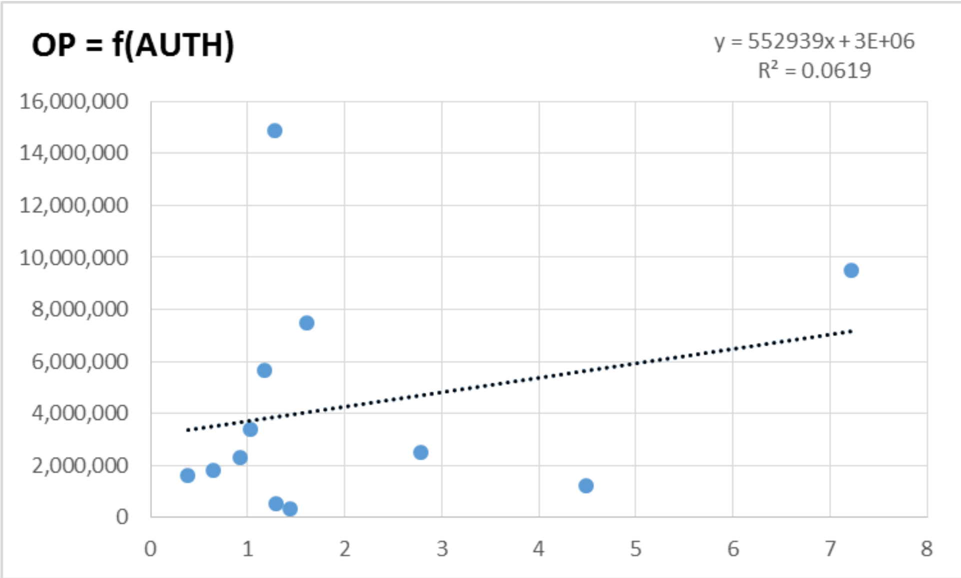
Linear Regression RE = f(AUTH)



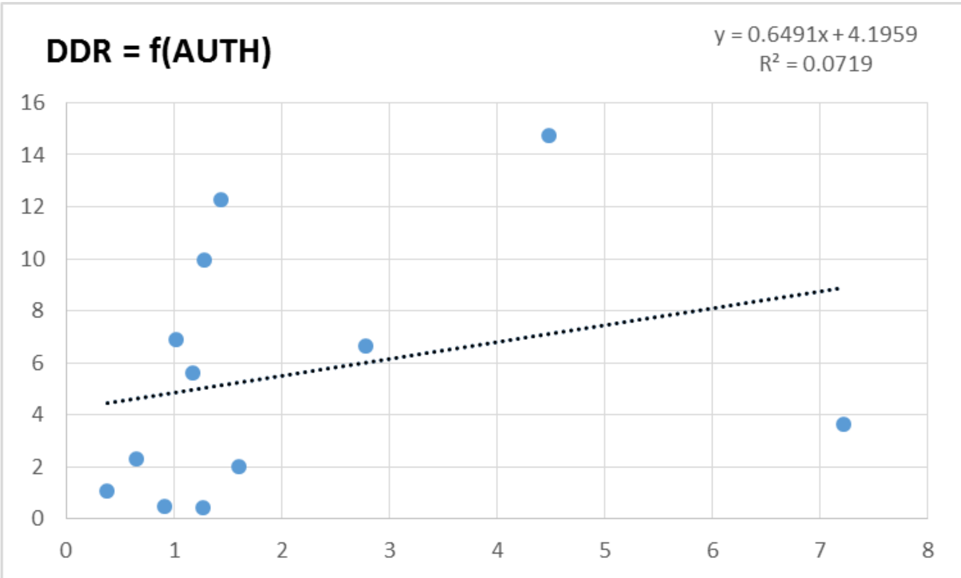
Linear Regression ROA = f(AUTH)



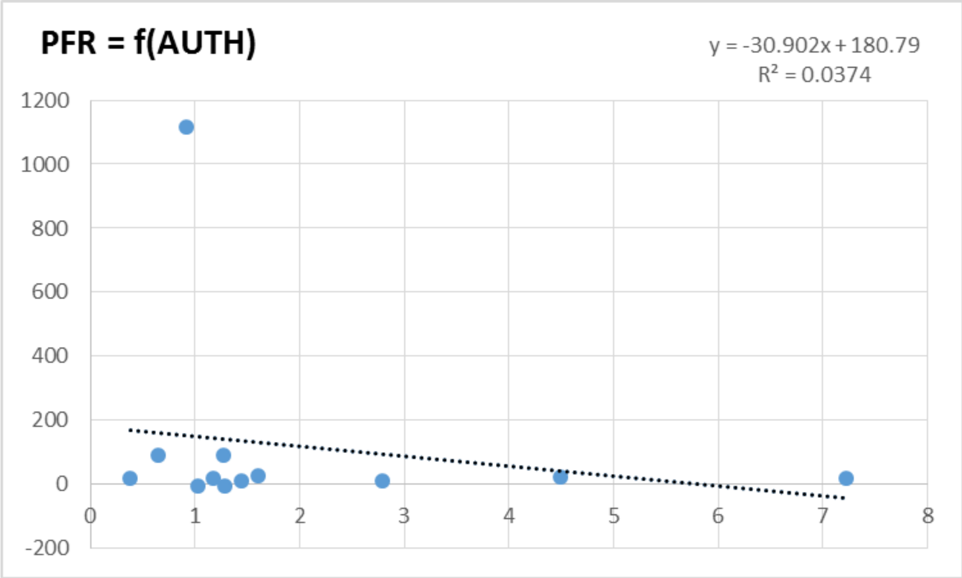
Linear Regression AT = f(AUTH)



Linear Regression OP = f(AUTH)



Linear Regression DDR = f(AUTH)



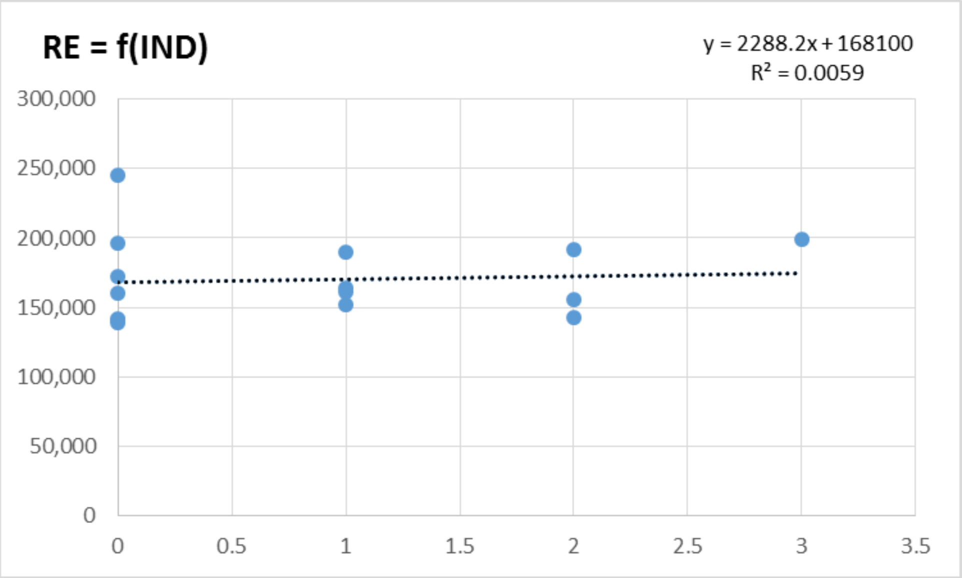
Linear Regression PFR = f(AUTH)

A11. Classification of Industries

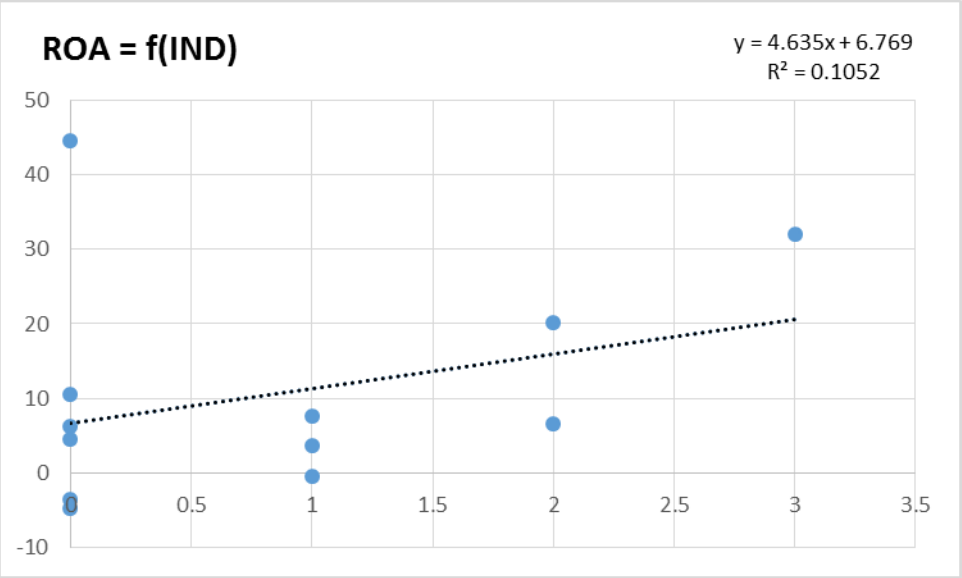
Overview of Classification of Industries of the Focal Companies
(Statistisches Bundesamt, 2008)

COMPANY_ID	CODE	Description for classification	Status
FOC1	22290	Plastics	
FOC2	22290	Plastics	
FOC3	22290	Plastics	
FOC3	52299	Services and Transport	minor role
FOC3	18120	Printed Products	minor role
FOC3	33200	Repair and Installation of Machinery	minor role
FOC3	25910	Metal goods	
FOC3	27900	Electronic components	
FOC3	27120	Electronic components	already named
FOC4	22290	Plastics	
FOC4	26119	Electronic components	
FOC4	32990	Other goods	not specific
FOC4	25735	Metal goods: Construction of tools	
FOC4	28960	Construction of Machinery	
FOC5	22290	Plastics	
FOC5	13300	Finishing of textiles and clothing	minor role
FOC5	33200	Repair and Installation of Machinery	minor role
FOC5	25610	Metal goods Surface finishing and heat treatment	
FOC6	22290	Plastics	
FOC6	46901	Wholesale of finished or unfinished goods	
FOC6	46902	Wholesale of finished or unfinished goods	already named
FOC7	25993	Metal goods	
FOC7	46741	Wholesale of finished or unfinished goods	
FOC7	46902	Wholesale of finished or unfinished goods	already named
FOC7	22290	Plastics	
FOC8	22290	Plastics	
FOC8	32990	Other goods	not specific
FOC9	22290	Plastics	
FOC9	46901	Wholesale of finished or unfinished goods	
FOC10	22290	Plastics	
FOC11	22290	Plastics	
FOC11	25735	Metal goods	
FOC12	22220	Plastics	
FOC13	32501	Medical products	minor role
FOC13	22290	Plastics	
FOC14	22290	Plastics	
FOC14	28290	Construction of Machinery	
FOC14	25735	Metal goods: Construction of tools	
FOC15	22290	Plastics	
FOC15	32990	Other goods	not specific

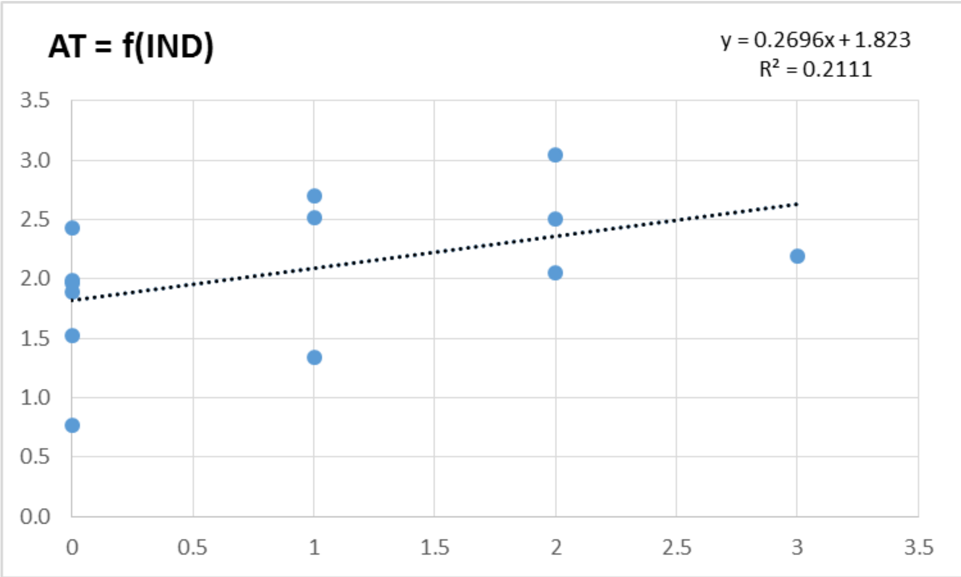
A12. Illustration of the Linear Regression of Hypothesis 3 (Industries)



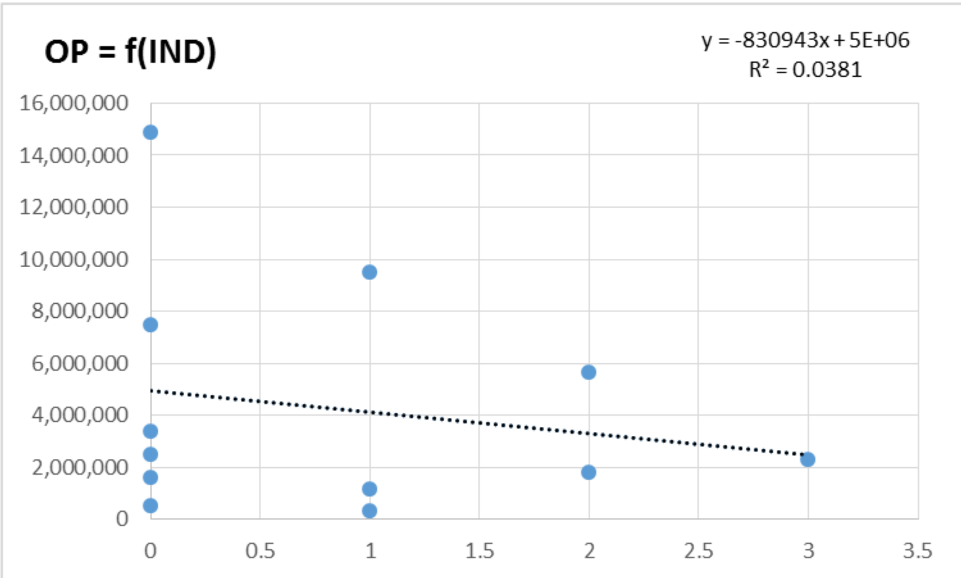
Linear Regression RE = f(IND)



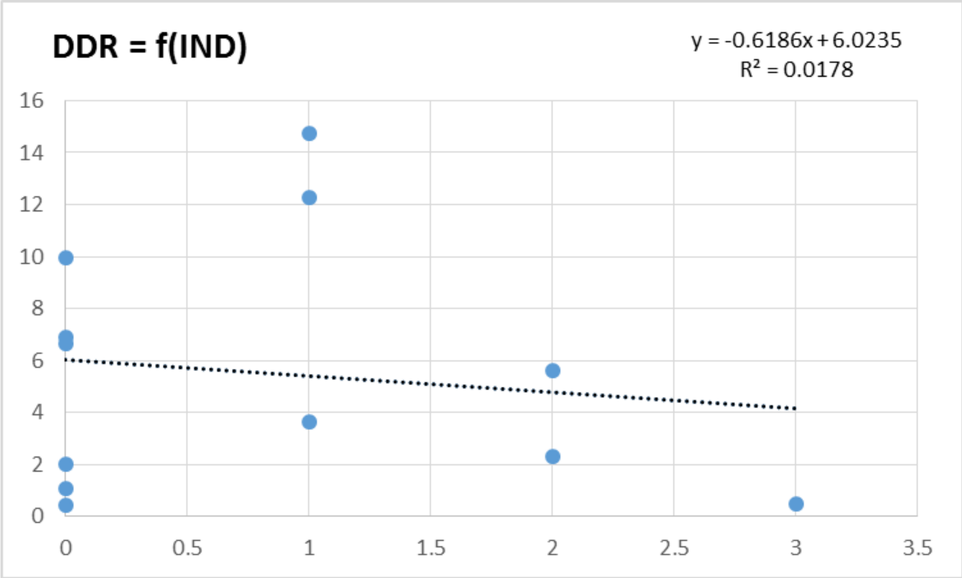
Linear Regression ROA = f(IND)



Linear Regression AT = f(IND)



Linear Regression OP = f(IND)



Linear Regression DDR = f(IND)

A13. Multiple Linear Regression based on the Significant Results of the Simple Linear Regression

Multiple Linear Regression Results Including 3 Independent Variables
(RE Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
RE	0.457	3.09	7 %	$H0: p > 10\ \%$	H1

Significance of the Standardised Regression Coefficients
(3 beta Values, RE Model)

β_{AS}	Pr > |t|	β_{C}	Pr > |t|	β_{HUB}	Pr > |t|
-0.413	44 %	0.489	24 %	0.790	5 %

Multiple Linear Regression Results Including 3 Independent Variables
(ROA Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
ROA	0.354	1.459	30 %	$H0: p > 10\ \%$	H0

Significance of the Standardised Regression Coefficients
(3 beta Values, ROA Model)

β_{AS}	Pr > |t|	β_{C}	Pr > |t|	β_{HUB}	Pr > |t|
-1.189	16 %	1.088	7 %	0.544	34 %

Multiple Linear Regression Results Including 3 Independent Variables
(OP Models)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
OP	0.742	7.652	1 %	$H0: p > 10\ \%$	H1
OP ex. O.	0.605	3.571	8 %	$H0: p > 10\ \%$	H1

Significance of the Standardised Regression Coefficients
(3 beta Values, OP Models)

β_{AS}	Pr > |t|	β_{C}	Pr > |t|	β_{HUB}	Pr > |t|
-0.197	69 %	0.992	2 %	-0.018	96 %
0.380	61 %	0.524	34 %	-0.164	72 %

Multiple Linear Regression Results Including 3 Independent Variables
(OP ex. O. Model)

DV	R^2	F	Pr > F	Formulation of Hypothesis H0	
OP ex. O.	0.740	6.658	2 %	$H0: p > 10\ \%$	**H1**

Significance of the Standardised Regression Coefficients
(3 beta values, OP ex. O. Model)

β_{AS}	Pr > |t|	$\beta_{BP\beta=0.995/\lambda}$	Pr > |t|	β_{AUTH}	Pr > |t|
0.714	2 %	0.976	4 %	-0.738	13 %

References

Ahrens, S. (2009). Soziale Netzwerktheorie. In M. Schwaiger & A. Meyer (Eds.), *Theorien und Methoden der Betriebswirtschaft* (1st ed., pp. 299–314). München: Vahlen, Franz.

Ahuja, G., Soda, G., & Zaheer, A. (2012). The Genesis and Dynamics of Organizational Networks. *Organization Science*, *23*(2), 434–448. doi:10.1287/orsc.1110.0695

Allee, V. (2000). RECONFIGURING THE VALUE NETWORK. *Journal of Business Strategy*, *21*(4), 36–39. doi:10.1108/eb040103

Arndt, H. (2006). *Supply-Chain-Management: Optimierung logistischer Prozesse* (3., aktualisierte und überarb. Aufl). *Lehrbuch*. Wiesbaden: Gabler.

Association of Plastics Manufacturers. (2011). *Plastics - the Facts 2011: An analysis of European plastics production, demand and recovery for 2010*. Retrieved 15.09.2012, from http://www.plasticseurope.org/documents/document/20111107101127-final_pe_factsfigures_uk2011_lr_041111.pdf

Association of Plastics Manufacturers. (2015). *Plastics - the Facts 2014/2015: An analysis of European plastics production, demand and waste data*. Retrieved 01.07.2015, from http://www.plasticseurope.de/cust/documentrequest.aspx?DocID=62506

Backhaus, K. (2011). *Multivariate Analysemethoden: Eine anwendungsorientierte Einführung* (13., überarb. Aufl). *Springer-Lehrbuch*. Berlin [u.a.]: Springer.

Barabási, A.-L., & Albert, R. (1999). Emergence of Scaling in Random Networks. *Science*, *286*(5439), 509–512. doi:10.1126/science.286.5439.509

Basole, R. C., Rouse, W. B., McGinnis, L. F., Bodner, D. A., & Kessler, W. C. (2011). Models of Complex Enterprise Networks. *Journal of Enterprise Transformation*, *1*(3), 208–230. doi:10.1080/19488289.2011.601397

Beamon, B. M. (1998). Supply Chain Design and Analysis: Models and Methods. *International Journal of Production Economics*, 55(3), 281–294. doi:10.1016/S0925-5273(98)00079-6

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, *19*(3), 275–292. doi:10.1108/01443579910249714

Bellamy, M. A., & Basole, R. C. (2013). Network analysis of supply chain systems: A systematic review and future research. *Systems Engineering*, *16*(2), 235–249. doi:10.1002/sys.21238

Bisnode Deutschland GmbH. (2015). Retrieved 15.02.2015, from http://www.bisnode.de/uber-uns-kontakt/unternehmensprofil/

Bititci, U. S. (2015). *Managing business performance: The science and the art* (1. publ). Chichester [u.a.]: Wiley.

Bititci, U. S., Carrie, A. S., & McDevitt, L. (1997). Integrated performance measurement systems: a development guide. *International Journal of Operations & Production Management*, *17*(5), 522–534. doi:10.1108/01443579710167230

Bititci, U., Garengo, P., Dörfler, V., & Nudurupati, S. (2012). Performance Measurement: Challenges for Tomorrow *International Journal of Management Reviews*, *14*(3), 305–327. doi:10.1111/j.1468-2370.2011.00318.x

Blackstone, J. H. (2008). *APICS dictionary* (12th ed). Athens, GA: APICS.

Bolstorff, P., Poluha, R. G., & Rosenbaum, R. G. (2007). *Spitzenleistungen im Supply Chain Management: Ein Praxishandbuch zur Optimierung mit SCOR*. Berlin: Springer.

Bonacich, P. (1972). Factoring and weighting approaches to status scores and clique identification. *The Journal of Mathematical Sociology*, *2*(1), 113–120. doi:10.1080/0022250X.1972.9989806

Bonacich, P. (1987). Power and Centrality: A Family of Measures. *American Journal of Sociology*, *92*(5), 1170–1182. doi:10.2307/2780000

Borgatti, S. P., & Everett, M. G. (1992). Notions of Position in Social Network Analysis. *Sociological Methodology*, *22*, 1–35. doi:10.2307/270991

Borgatti, S. P., & Li, X. U. (2009). On social network analysis in a supply chain context. *Journal of Supply Chain Management*, *45*(2), 1–17. doi:10.1111/j.1745-493X.2009.03166.x

Borgatti, S. P., & Lopez-Kidwell, V. (2011). Network Theory. In J. Scott & P. J. Carrington (Eds.), *Social network analysis. A handbook of* (pp. 40–54). London, Thousand Oaks, Calif, New Delhi: SAGE.

Borgatti, S. P., Everett, M. G., & Johnson, J. C. (2013). Analyzing social networks. Los Angeles [i.e. Thousand Oaks, Calif.], London: Sage Publications.

Bortz, J. (1999). *Statistik: Für Sozialwissenschaftler* (5., vollst. über). Berlin: Springer.

Bourne, M., Mills, J., Wilcox, M., Neely, A., & Platts, K. (2000). Designing, implementing and updating performance measurement systems. *International Journal of Operations & Production Management*, *20*(7), 754–771. doi:10.1108/01443570010330739

Bovet, D., & Martha, J. (2000). *Value nets: Breaking the supply chain to unlock hidden profits*. New York: Wiley.

Buhman, C., Kekre, S., & Singhal, J. (2005). Interdisciplinary and Interorganizational Research: Establishing the Science of Enterprise Networks. *Production and Operations Management*, *14*(4), 493–513. doi:10.1111/j.1937-5956.2005.tb00236.x

Bundeszentrale für politische Bildung. (2009). *Zahlen und Fakten - Globalisierung*. Retrieved 1.5.2014, from http://www.bpb.de/system/files/pdf/8ME2U0.pdf

Burt, R. S. (1978). A structural theory of interlocking corporate directorates. *Social Networks*, *1*(4), 415–435. doi:10.1016/0378-8733(78)90006-0

Burt, R. S. (1987). Social Contagion and Innovation: Cohesion versus Structural Equivalence. *American Journal of Sociology*, *92*(6), 1287–1335. doi:10.2307/2779839

Burt, R. S. (1992). *Structural holes: The social structure of competition*. Cambridge, MA, London: Harvard University Press.

Cagnazzo, L., Taticchi, P., & Brun, A. (2010). The role of performance measurement systems to support quality improvement initiatives at supply chain level. *International Journal of Productivity and Performance Management*, *59*(2), 163–185. doi:10.1108/17410401011014249

Capgemini. (2008). *2016 Future Supply Chain: Global Commerce initiative*. Retrieved 23.08.2014, from http://supplychainmagazine.fr/TOUTE-INFO/ETUDES/GCI_Capgemini-SC2016.pdf

Caplice, C., & Sheffi, Y. (1995). A Review and Evaluation of Logistics Performance Measurement Systems. *The International Journal of Logistics Management*, *6*(1), 61–74. doi:10.1108/09574099510805279

Carter, C. R., Ellram, L. M., & Tate, W. (2007). THE USE OF SOCIAL NETWORK ANALYSIS IN LOGISTICS RESEARCH. *Journal of Business Logistics*, *28*(1), 137–168. doi:10.1002/j.2158-1592.2007.tb00235.x

Chan, F. T., & Qi, H. J. (2003). An innovative performance measurement method for supply chain management. *Supply Chain Management: An International Journal*, *8*(3), 209–223. doi:10.1108/13598540310484618

Chen, I., Paulraj, A., & Lado, A. (2004). Strategic purchasing, supply management, and firm performance. *Journal of Operations Management*, *22*(5), 505–523. doi:10.1016/j.jom.2004.06.002

Chenhall, R. H. (2005). Integrative strategic performance measurement systems, strategic alignment of manufacturing, learning and strategic outcomes: an exploratory study. *Accounting, Organizations and Society*, *30*(5), 395–422. doi:10.1016/j.aos.2004.08.001

Choi, T. Y., & Kim, Y. (2008). Structural embeddedness and supplier management: a network perspective *Journal of Supply Chain Management*, *44*(4), 5–13. doi:10.1111/j.1745-493X.2008.00069.x

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management*, *19*(3), 351–366. doi:10.1016/S0272-6963(00)00068-1

Christopher, M. (1998). *Logistics and supply chain management: Strategies for reducing cost and improving service* (2nd ed). London: Financial Times/Pitman.

Christopher, M. (2011). *Logistics & supply chain management* (4th ed). Harlow, England, New York: Financial Times Prentice Hall.

Cohen, J. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed). Mahwah, N.J: L. Erlbaum Associates.

Cook, K. S., Emerson, R. M., Gillmore, M. R., & Yamagishi, T. (1983). The Distribution of Power in Exchange Networks: Theory and Experimental Results. *American Journal of Sociology*, *89*(2), 275–305. doi:10.2307/2779142

Deyhle, A. (2008). *Controller-Handbuch* (6th ed.). *Controlling pockets: Vol. 5*. Offenburg, Wörthsee: Verl. für ControllingWissen.

Drucker, P. F. (1998). Management's New Paradigms. *Forbes*, pp. 158–177.

DW Journal (Producer). (2013). *Global operating system: What will the software of the future look like?* Interview SAP CEO Jim Hagemann Snabe.

Eccles, R. G. (1991). The Performance Measurement Manifesto. *Harvard Business Review*, *69*(1), 131–137, from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib,cookie,ip,url,uid&db=buh&AN=9102251664&custid=s2888710

EFQM. (1999). *The EFQM Excellence Model*. Retrieved 26.5.2014, from http://www.efqm.org/the-efqm-excellence-model

Erickson, B. H. (1988). The relational basis of attitudes. In B. Wellman & S. D. Berkowitz (Eds.), *Structural analysis in the social sciences: Vol. 2. Social structures. A network approach* (pp. 99–122). Cambridge [Cambridgeshire], New York: Cambridge University Press.

Estampe, D., Lamouri, S., Paris, J.-L., & Brahim-Djelloul, S. (2013). A framework for analysing supply chain performance evaluation models. *International Journal of Production Economics*, *142*(2), 247–258. doi:10.1016/j.ijpe.2010.11.024

Ford Motor Company. (2008). *Business Plan - Submitted to the Senate Banking Committee*. Retrieved 26.07.2013, from http://www.banking.senate.gov/public/_files/Brfg12308AutoPRESENTATIONOFFORDMOTORCOMPANY122_SenateFinal_.pdf

Forrester, J. W. (1961). *Industrial dynamics*. [Cambridge, Mass.]: M.I.T. Press.

Franco-Santos, M., Lucianetti, L., & Bourne, M. (2012). Contemporary performance measurement systems: A review of their consequences and a framework for research. *Management Accounting Research*, *23*(2), 79–119. doi:10.1016/j.mar.2012.04.001

Freeman, L. C. (1977). A Set of Measures of Centrality Based on Betweenness. *Sociometry*, *40*(1), 35–41. doi:10.2307/3033543

Freeman, L. C., Roeder, D., & Mulholland, R. R. (1979). Centrality in social networks conceptual clarification. *Social Networks*, *1(3)*, 215-239. doi:10.1016/0378-8733(78)90021-7

Friedkin, N. E. (1984). Structural Cohesion and Equivalence Explanations of Social Homogeneity. *Sociological Methods & Research*, *12*(3), 235–261. doi:10.1177/0049124184012003001

Fruchterman, Thomas M. J., & Reingold, E. M. (1991). Graph drawing by force-directed placement. *Software: Practice and Experience*, *21*(11), 1129–1164. doi:10.1002/spe.4380211102

Gabler Wirtschaftslexikon. (2014). Performance measurement. In Springer Gabler Verlag (Ed.), *Gabler Wirtschaftslexikon.* Retrieved 24.08.2014, from http://wirtschaftslexikon.gabler.de/Archiv/140765/performance-measurement-v4.html

Garcia Sanz, F. J. (2007). Ganzheitliche Beschaffungsstrategie als Gestaltungsrahmen der globalen Netzwerkintegration in der Automobilindustrie. In Garcia Sanz, Francisco J, K. Semmler, & J. Walther (Eds.), *Die Automobilindustrie auf dem Weg zur globalen Netzwerkkompetenz. Effiziente und flexible Supply Chains erfolgreich gestalten* (pp. 3–23). Berlin: Springer.

Gomes, C. F., Yasin, M. M., & Lisboa, J. V. (2004). A literature review of manufacturing performance measures and measurement in an organizational context: a framework and direction for future research. *Journal of Manufacturing Technology Management*, *15*(6), 511–530. doi:10.1108/17410380410547906

Granovetter, M. S. (1973). The Strength of Weak Ties. *American Journal of Sociology*, *78*(6), 1360–1380. doi:10.2307/2776392

Gunasekaran, A., & Kobu, B. (2007). Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. *International Journal of Production Research*, *45*(12), 2819–2840. doi:10.1080/00207540600806513

Gunasekaran, A., Patel, C., & Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management*, *21*(1/2), 71–87. doi:10.1108/01443570110358468

Harland, C. M., Lamming, R. C., Zheng, J., & Johnsen, T. E. (2001). A Taxonomy of Supply Networks. *The Journal of Supply Chain Management*, *37*(4), 21–27. doi:10.1111/j.1745-493X.2001.tb00109.x

Harrington, H. J. (1991). Improving business processes. *The TQM Magazine*, *3*(1). doi:10.1108/eb059514

Hassan, Mohsen M. D. (2006). Engineering supply chains as systems. *Systems Engineering*, *9*(1), 73–89. doi:10.1002/sys.20042

Hieber, R., & Schönsleben, P. (2002). *Supply chain management: A collaborative performance measurement approach*. Zürich/Singen: vdf, Hochschulverl. an der ETH.

Hochhold, S., & Rudolph, B. (2009). Principal-Agent-Theorie. In M. Schwaiger & A. Meyer (Eds.), *Theorien und Methoden der Betriebswirtschaft* (1st ed., pp. 131–145). München: Vahlen, Franz.

Huan, S. H., Sheoran, S. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management: An International Journal*, *9*(1), 23–29. doi:10.1108/13598540410517557

Ittner, C. D., Larcker, D. F., & Randall, T. (2003). Performance implications of strategic performance measurement in financial services firms. *Accounting, Organizations and Society*, *28*(7-8), 715–741. doi:10.1016/S0361-3682(03)00033-3

Janker, C. G. (2008). *Multivariate Lieferantenbewertung*. Wiesbaden: Gabler.

Jarillo, J., & Stevenson, H. H. (1991). Co-operative strategies—The payoffs and the pitfalls. *Long Range Planning*, *24*(1), 64–70. doi:10.1016/0024-6301(91)90025-J

Kamada, T., & Kawai, S. (1989). An algorithm for drawing general undirected graphs. *Information Processing Letters*, *31*(1), 7–15. doi:10.1016/0020-0190(89)90102-6

Kaplan, R. S., & Norton, D. P. (1992). *The balanced scorecard: Measures that drive performance.*

Kim, Y., Choi, T. Y., Yan, T., & Dooley, K. (2011). Structural investigation of supply networks: A social network analysis approach. *Journal of Operations Management*, *29*(3), 194–211. doi:10.1016/j.jom.2010.11.001

Kippenberger, T. (1996). The performance pyramid. *The Antidote*, *1*(1), 10–11. doi:10.1108/EUM0000000006389

Klibi, W., Martel, A., & Guitouni, A. (2009). *The design of robust value-creating supply chain networks: A critical review*. *[Document de travail]: CIRRELT-2009-34*. Montréal: CIRRELT.

Koch, E. (2014). *Globalisierung: Wirtschaft und Politik*. Wiesbaden: Springer Fachmedien Wiesbaden.

Koch, R. (1999). *The 80/20 principle: The secret of achieving more with less* (1st Currency paperback ed.). New York: Currency.

Kralicek, P. (2009). *Bilanzen lesen - Eine Einführung: Keine Angst vor Kennzahlen* (1. Auflage). *New Business Line*. München: Redline Verlag.

Kurien, G. P., & Qureshi, M. N. (2011). Study of performance measurement practices in supply chain management. *International Journal of Business, Management and Social Sciences*, *2*(4), 19–34. Retrieved 27.07.2013, from http://www.ijbmss-ng.com/ijbmss-ng-vol2-no4-pp19-34.pdf

Lambert, D. M., & Pohlen, T. L. (2001). Supply Chain Metrics. *The International Journal of Logistics Management*, *12*(1), 1–19. doi:10.1108/09574090110806190

Lambert, D. M., Cooper, M. C., & Pagh, J. D. (1998). Supply Chain Management: Implementation Issues and Research Opportunities. *The International Journal of Logistics Management*, *9*(2), 1–20. doi:10.1108/09574099810805807

Lange, K. (2010). Kooperationen in der Automobilindustrie – Analyse und Systematisierung. *Arbeitspapiere (Workingpapers) des Instituts für Genossenschaftswesen der Westfälischen Wilhelms-Universität Münster*, (94). Retrieved 01.11.2015, from https://www.econstor.eu/dspace/bitstream/10419/55808/1/687704510.pdf

Lin, N. (1982). Social resources and instrumental action. In P. V. Marsden & N. Lin (Eds.), *Sage focus editions: Vol. 57. Social structure and network analysis* (pp. 131–145). Beverly Hills: Sage Publications.

Lin, N. (2001). *Social capital: A theory of social structure and action*. *Structural analysis in the social sciences: Vol. 19*. Cambridge, New York: Cambridge University Press.

Lin, N., & Dumin, M. (1986). Access to occupations through social ties. *Social Networks*, *8*(4), 365–385. doi:10.1016/0378-8733(86)90003-1

Lorrain, F., & White, H. C. (1971). Structural equivalence of individuals in social networks. *The Journal of Mathematical Sociology*, *1*(1), 49–80. doi:10.1080/0022250X.1971.9989788

Lowson, B., King, R., & Hunter, A. (1999). *Quick response: Managing the supply chain to meet consumer demand*. Chichester, West Sussex, England: Wiley.

MacBryde, J., Shepherd, C., & Günter, H. (2006). Measuring supply chain performance: current research and future directions. *International Journal of Productivity and Performance Management*, *55*(3/4), 242–258. doi:10.1108/17410400610653219

Maier, M. W. (2006). System and software architecture reconciliation. *Systems Engineering*, *9*(2), 146–159. doi:10.1002/sys.20050

Markovsky, B., Willer, D., & Patton, T. (1988). Power Relations in Exchange Networks. *American Sociological Review*, *53*(2), 220–236. doi:10.2307/2095689

Maskell, B. H. (1991). *Performance measurement for world class manufacturing: A model for American companies*. Cambridge, Mass: Productivity Press.

Melnyk, S. A., Bititci, U., Platts, K., Tobias, J., & Andersen, B. (2014). Is performance measurement and management fit for the future? *Management Accounting Research*, *25*(2), 173–186. doi:10.1016/j.mar.2013.07.007

Merchant, K. A., & Van der Stede, Wim A. (2007). *Management control systems: Performance measurement, evaluation and incentives* (2nd ed). Harlow, England, New York: Financial Times/Prentice Hall.

Min, H., & Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers & Industrial Engineering*, *43*(1-2), 231–249. doi:10.1016/S0360-8352(02)00066-9

Mizruchi, M. S. (1996). What Do Interlocks Do? An Analysis, Critique, and Assessment of Research on Interlocking Directorates. *Annual Review of Sociology*, *22*, 271–298. doi:10.2307/2083432

Morgan, C. (2007). Supply network performance measurement: future challenges? *The International Journal of Logistics Management*, *18*(2), 255–273. doi:10.1108/09574090710816968

Neely, A., Gregory, M., & Platts, K. (1995). Performance measurement system design: A literature review and research agenda. *International Journal of Operations & Production Management*, *15*(4), 80–116. doi:10.1108/01443579510083622

Neumair, S.-M., & Haas, H.-D. (2014). Embeddedness. In Springer Gabler Verlag (Ed.), *Gabler Wirtschaftslexikon.* Retrieved 24.08.2014, from http://wirtschaftslexikon.gabler.de/Archiv/9040/embeddedness-v6.html

Nooy, W. d., Mrvar, A., & Batagelj, V. (2011). *Exploratory social network analysis with Pajek* (Rev. and expanded 2nd ed). New York: Cambridge University Press.

Nudurupati, S. S., Bititci, U. S., Kumar, V., & Chan, F. (2011). State of the art literature review on performance measurement. *Computers & Industrial Engineering*, *60*(2), 279–290. doi:10.1016/j.cie.2010.11.010

Oke, A., & Idiagbon-Oke, M. (2010). Communication channels, innovation tasks and NPD project outcomes in innovation-driven horizontal networks. *Journal of Operations Management*, *28*(5), 442–453. doi:10.1016/j.jom.2010.01.004

Ortega, Máximo J. (2006). Supply Chain Software: Are We Using the Right Tools? Investigación Multidisciplinaria, *Spring 2006 4*(1), 49-69.

Papakiriakopoulos, D., & Pramatari, K. (2010). Collaborative performance measurement in supply chain. *Industrial Management & Data Systems*, *110*(9), 1297–1318. doi:10.1108/02635571011087400

Pathak, S. D., Day, J. M., Nair, A., Sawaya, W. J., & Kristal, M. M. (2007). Complexity and Adaptivity in Supply Networks: Building Supply Network Theory Using a Complex Adaptive Systems Perspective *Decision Sciences*, *38*(4), 547–580. doi:10.1111/j.1540-5915.2007.00170.x

Pettigrew, A. M. (1992). *Fundamental themes in strategy process research*. *Strategic management journal: v. 13, special issue*. Chichester, New York: Wiley.

Piontek, J. (2009). *Bausteine des Logistikmanagements: [Supply-chain-Management ; E-logistics ; Logistikcontrolling ; Online-Version inklusive]* (3., vollst. überarb. und erw. Aufl). *NWB Studium*. Herne: nwb.

Podolny, J. M. (2001). Networks as the Pipes and Prisms of the Market. *American Journal of Sociology*, *107*(1), 33–60. doi:10.1086/323038

Polanyi, K. (1944). *The great transformation*. New York: Rinehart.

Quatember, A. (2011). *Statistik ohne Angst vor Formeln: Das Studienbuch für Wirtschafts- und Sozialwissenschaftler* (3., aktualisierte Aufl). *Wirtschaft*. München [u.a.]: Pearson Studium.

Ritchey, T. (1998). *General Morphological Analysis: A general method for non-quantified modelling*. Retrieved 30.08.2014, from http://www.swemorph.com/pdf/gma.pdf

Robins, G. (2015). *Doing social network research: Network-based research design for social scientists*. Los Angeles, Calif: SAGE.

Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed). New York, London: Free Press; Collier Macmillan.

Rolstadas, A. (1998). Enterprise performance measurement. *International Journal of Operations & Production Management*, *18*(9/10), 989–999. doi:10.1108/01443579810225577

Rolstadas, A., Andersen, B., Browne, J., & Devlin, J. (2004). *Performance Measurement: The ENAPS Approach*. Retrieved 26.02.2013, from http://www.prestasjonsledelse.net/publikasjoner/Performance%20Measurement%20The%20ENAPS%20Approach.pdf

Saunders, M., Lewis, P., & Thornhill, A. (2015). *Research methods for business students* (Seventh edition). New York: Pearson Education.

Schönsleben, P. (2011). *Integrales Logistikmanagement*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Scott, J. (1986). *Capitalist property and financial power: A comparative study of Britain, the United States, and Japan*. Brighton, Sussex: Wheatsheaf Books.

Sihn, W., & Aupperle, G. (1995). *Unternehmensmanagement im Wandel: Erfolg durch Kunden-, Mitarbeiter- und Prozessorientierung*. München, Wien: Hanser.

Simatupang, T. M., & Sridharan, R. (2002). The Collaborative Supply Chain. *The International Journal of Logistics Management*, *13*(1), 15–30. doi:10.1108/09574090210806333

Simmel, G., & Wolff, K. H. (1950). *The Sociology of Georg Simmel. Translated, Edited, and With an Introd. by Kurt H. Wolff*. Glencoe, Ill., Free Press.

Sink, D. S., & Tuttle, T. C. (1989). *Planning and measurement in your organization of the future*. Norcross, Ga: Industrial Engineering and Management Press.

Snyder, D., & Kick, E. L. (1979). Structural Position in the World System and Economic Growth, 1955-1970: A Multiple-Network Analysis of Transnational Interactions. *American Journal of Sociology*, *84*(5), 1096–1126. doi:10.2307/2778218

Statistisches Bundesamt. (2008). *Klassifikation der Wirtschaftszweige*. Retrieved 05.06.2015, from https://www.destatis.de/DE/Methoden/Klassifikationen/GueterWirtschaftklassifikationen/Content75/KlassifikationWZ08.html

Stier, W. (1999). *Empirische Forschungsmethoden: Mit 53 Tabellen (2., verb. Aufl).* Springer-Lehrbuch. Berlin [u.a.]: Springer.

Strogatz, S. H. (2001). Exploring complex networks. *Nature*, *410*(6825), 268, from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib,cookie,ip,url,uid&db=aph&AN=4185535&custid=s2888710

Supply chain Council. (2010). *SCOR model reference: Supply chain operations reference model*. Cypress Tex: Supply chain Council, Inc.

Suwignjo, P., Bititci, U., & Carrie, A. (2000). Quantitative models for performance measurement system. *International Journal of Production Economics*, *64*(1-3), 231–241. doi:10.1016/S0925-5273(99)00061-4

Tandler, S. M. (2013). *Supply Chain Safety Management*. Wiesbaden: Springer Fachmedien Wiesbaden.

Theurl, T., & Schweinsberg, A. (2004). *Neue kooperative Ökonomie: Moderne genossenschaftliche Governancestrukturen*. *Ökonomik der Kooperation: Bd. 2*. Tübingen: Mohr Siebeck.

Ungar, L., Craven, M., Gunopulos, D., & Eliassi-Rad, T. (Eds.) 2006. *the 12th ACM SIGKDD international conference.*

van Hoek, R. I. (1998). “Measuring the unmeasurable” - measuring and improving performance in the supply chain. *Supply Chain Management: An International Journal*, *3*(4), 187–192. doi:10.1108/13598549810244232

Voluntary Interindustry Commerce Standards. (2004). *Collaborative Planning, Forecasting and Replenishment (CPFR®): The CPFR Model - An overview*.

Wallman, S. (1984). *Eight London households*. London, New York: Tavistock Publications.

Wareham, J., Mathiassen, L., Rai, A., Straub, D., & Klein, R. (2005). The business value of digital supply networks: A program of research on the impacts of globalization. *Journal of International Management*, *11*(2), 201–227. doi:10.1016/j.intman.2005.03.007

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. *Structural analysis in the social sciences: Vol. 8*. Cambridge, New York: Cambridge University Press.

Webster, M. (2002). Supply system structure, management and performance: a conceptual model. *International Journal of Management Reviews*, *4*(4), 353–369. doi:10.1111/1468-2370.00092

Wuchty, S. (2001). Scale-free behavior in protein domain networks. *Molecular biology and evolution*, *18*(9), 1694–1702.