Pricing Model of a Two-Sided Market Cloud Manufacturing Platform

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M. Sc. Larissa Eger
geb. in Hildesheim

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Hauptreferent:	Prof. Dr. Kai Furmans
Korreferent:	Prof. Dr. Frank Schultmann

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Kurzfassung

Der Einfluss der Digitalisierung verändert traditionelle Unternehmen ständig. Durch die Schaffung neuer digitaler Geschäftskonzepte verwandeln sich viele traditionelle Märkte in Plattformmärkte. B2B-Märkte beginnen langsam, die Potenziale von Plattformkonzepten zu nutzen, die in C2C-Märkten bereits fest verankert sind. Im Bereich der Fertigungsindustrie zeigen erste Prognosen, dass Cloud Manufacturing (CMfg) Konzepte aufgrund ihrer Potenziale an Relevanz gewinnen werden. Die Grundlage für die Etablierung einer stabilen CMfg-Plattform ist das Verständnis der Komplexität von CMfg-Plattformgeschäftsmodellen durch die Untersuchung ihrer zugrundeliegenden Netzwerkeffekte.

Die Entwicklung eines CMfg-Preismodells für einen zweiseitigen Markt ist die Grundlage einer stabilen CMfg-Plattform und ist das Forschungsziel dieser Arbeit. Da eine Plattform mit der Käufer- und der Anbieterseite interagiert, sollte der Preisansatz das Kundenverhalten beider Seiten berücksichtigen. Beide Marktseiten benötigen eine ausgewogene Anzahl von Teilnehmern der Gegengruppe, was die Komplexität des CMfg-Preismodells erhöht. Ändert sich eine Marktseite der Plattform, ist die andere Marktseite indirekt betroffen und ändert sich ebenfalls. Eine zweiseitige Marktpreisstruktur kann die Anzahl der Kunden beeinflussen und gleichzeitig den Gesamtgewinn der CMfg-Plattform steigern.

Die für die Entwicklung eines CMfg-Plattformpreismodells relevanten bestimmenden Faktoren müssen identifiziert und analysiert werden. Die Eigenschaften der CMfg-Plattform werden benötigt, um die Anforderungen an ein CMfg-Preismodell abzuleiten. Es wird eine Literaturanalyse nach der Methodik des morphologischen Kastens durchgeführt, um den Stand der Literatur von zweiseitigen Märkten zu untersuchen. Die im morphologischen Kasten enthaltenen

Preisbildungsansätze werden anhand der identifizierten Bestimmungsfaktoren von Preismodellen für zweiseitige Märkte kategorisiert und in sechs Cluster eingeteilt.

Anschließend wird ein grundlegendes zweiseitiges Marktmodell für die Entwicklung eines CMfg-Plattformpreismodells ausgewählt. Die erforderlichen Input- und Outputfunktionen des Preismodells werden definiert. Das ausgewählte Basismodell wird weiterentwickelt, um die erforderlichen Ausgabewerte auf der Grundlage von Algorithmen zu berechnen. Basierend auf den bisherigen Ergebnissen wird ein CMfg-Plattformpreismodell erarbeitet. Das entwickelte CMfg-Preismodell basiert auf Berechnungsalgorithmen, die die Eingangsparameter des Modells in die relevanten Ausgangsfunktionen übertragen. Diese beinhalten transaktionsbasierte Gebühren für beide Marktseiten, die Anzahl der Teilnehmer auf beiden Marktseiten und den gesamten Plattformgewinn.

Die Einblicke in das Preismodell der CMfg-Plattform werden auf der Grundlage analytischer und numerischer Analysen des entwickelten CMfg-Preismodells gewonnen. Die Methoden der Differentialrechnung und der statistischen Versuchsplanung werden angewandt, um die Beziehung zwischen den Input- und den Output-Parametern zu analysieren. Die Variation der Input-Parameter des CMfg-Preismodells wirkt sich auf den Gesamtgewinn der Plattform aus, welches für die Etablierung einer wirtschaftlichen, funktionalen Plattform elementar ist. Es wird ein Ausblick auf einen dynamischen Modellierungsansatz gegeben, um weitere Einblicke in die Komplexität eines zweiseitigen CMfg-Marktpreismodells zu gewinnen. Die zentralen Treiber für die Etablierung einer CMfg-Plattform werden diskutiert, einschließlich eines Praxisbeispiels, als eine ersten Indikation für eine allgemeine Anwendbarkeit des Ansatzes, außerhalb von CMfg. Abschließend werden weitere Forschungsbereiche vorgestellt, um tiefere Einblicke in die Komplexität eines zweiseitigen Marktpreismodells zu gewinnen.

Abstract

The influence of digitalisation constantly changes traditional businesses. By creating new digital business concepts, many markets transform into platform businesses. B2B markets are slowly starting to use the potentials of platform concepts, which are already ingrained within C2C markets. Within the manufacturing branch, first prognoses state that cloud manufacturing (CMfg) concepts will increase their relevance due to their potentials for this market. The foundation of establishing a stable CMfg platform is to understand the complexities of CMfg platform business models by examining their underlying network effects.

Therefore, the development of a two-sided market CMfg pricing model is required for the establishment of a CMfg platform, which is the research objective of this thesis. Since a platform interacts with the buyer and supplier market sides, the pricing approach should include the customer behaviour of both. Both market sides require a specific, balanced number of opposite group participants to join the CMfg platform, which increases the complexity of the CMfg pricing model. If one market side of the platform changes, the other market side is indirectly affected and changes as well. A two-sided market pricing structure impacts the number of customers and simultaneously optimises the total profit of the CMfg platform.

The determining factors of two-sided market pricing models have to be identified, to analyse, which are essential for the development of a CMfg platform pricing model. The characteristics of the CMfg platform are needed to determine the requirements of a CMfg pricing model. A literature analysis is conducted according to the methodology of the morphological box to examine the state of the art of two-sided market literature. The pricing approaches included in the morphological toolbox are categorised by the identified determining factors of two-sided market pricing models and sorted into six clusters.

Next, a basic two-sided market model is selected for the development of a CMfg platform pricing model. The required input and output functions of the pricing model are defined. Building on the basic model, advancements are made to modify the pricing model to calculate the required output values based on the developed algorithms. Based on the previous results, a CMfg platform pricing model is developed. The developed CMfg pricing model is based on calculation algorithms, which transfer the input parameters of the model into the relevant output functions, including the transaction-based fees for both market sides, the number of both market side participants and the total platform profit.

Insights into the CMfg platform pricing model are derived based on analytical and numerical analysis of the developed pricing model. Methods of differential calculus and the statistical experimental design are executed to analyse the relationship between the input and the output parameters. The variation of the input parameters of the CMfg affects the total platform profit, which is elementary to establishing an economically viable, functioning platform. An outlook on dynamic effects is presented to gain further insights into the complexity of a CMfg two-sided market pricing model. The central drivers for the establishment of a CMfg platform are discussed, including a first indication of general applicability of the approach, to an example in practice, outside of CMfg. Last, further research areas are presented to gain deeper insights into the complexity of a two-sided market pricing model.

Contents

Glossary of Notation

Variables

S	Suppliers	31
B	Buyers	31
n^{S}	Number of suppliers	31
n^{B}	Number of buyers	31
b^{S}	Benefit of suppliers	31
b^{B}	Benefit of buyers	31
p^{S}	Transaction-based price of suppliers	31
p^{B}	Transaction-based price of buyers	31
$V_{\mathrm{t}}^{\mathrm{S}}$	Volume of transactions of suppliers	31
$V_{\mathrm{t}}^{\mathrm{B}}$	Volume of transactions of buyers	31
c_{t}	Transaction-based cost	32
Π^{P}	Total platform profit	32
$\mathbf{Net}_{\mathrm{S}}$	Net profit of suppliers	32
$\mathbf{Net}_{\mathrm{B}}$	Net profit of buyers	32
i	Type of platform users	32
B^{S}	Membership benefit of suppliers	32

B^{B}	Membership benefit of buyers	32
j	Type of platform	32
P^{S}	Membership fees of suppliers	32
P^{B}	Membership fees of buyers	32
u^{S}	Utility function of suppliers	32
u^{B}	Utility function of buyers	32
$\phi(u)^{\mathrm{S}}$	Demand function of the supplier utility function	33
$\phi(u)^{\mathrm{B}}$	Demand function of the buyer utility function	33
$c_{\mathrm{m}}^{\mathrm{S}}$	Per supplier costs	33
$c_{\mathrm{m}}^{\mathrm{B}}$	Per buyer costs	33
η	Number of products	33
$\theta_{\mathrm{h}}^{\mathrm{B}}$	Horizontal differentiation of buyers	33
π	Profit function of suppliers	34
$\theta_{\mathrm{m}}^{\mathrm{B}}$	Horizontal differentiation of the marginal buyer	34
$F(\theta_{\mathrm{h}}^{\mathrm{B}})$	Cumulative distribution function of buyers	34
$\theta_{\mathrm{h}}^{\mathrm{S}}$	Horizontal differentiation of suppliers	34
r	Stand-alone platform value	38
k	Type of suppliers	41
p^{r}	Volume and price of sold slots	41
$V_{\mathrm{m}}^{\mathrm{B}}$	Variety of the purchased products	45
γ_{p}	Platform differentiation	45
G_{η}	Product bundle	45
D^{B}	Total demand of buyers	45

d^{B}	Demand per buyer	45
p_{γ}	Price of variety	45
t	Distance parameter on the linear city	45
K^{S}	Fixed cost of production of suppliers	45
γ_{η}	Differentiation of products	46
u^{0}	Baseline utility	46
q	Quality	46
q_1	Quality on platform 1	46
q_2	Quality on platform 2	46
$\theta_{\mathrm{v}}^{\mathrm{B}}$	Vertical differentiation of buyers	47
n_{e}	Expected number of participants	47
P_1^{B}	Membership fees of buyers on platform 1	47
P_2^{B}	Membership fees of buyers on platform 2	47
$(x, x-1)$	Extreme point location on the linear city	45
I	Idiosyncratic component	50
$\theta_{\mathrm{v}}^{\mathrm{S}}$	Vertical differentiation of suppliers	50
c^{τ}	Opportunity costs	53
$n_{\mathbf{SH}}^{\mathrm{B}}$	Number of single-homing buyers	53
$n_{\mathbf{MH}}^{\mathrm{B}}$	Number of multi-homing buyers	53
$c_{\mathrm{t}}^{\mathrm{S}}$	Transport costs of the suppliers on the linear city	53
λ^{B}	Number of exclusive buyers	54
b_{d}	Diminishing benefit per user	55
$c_{\mathrm{t}}^{\mathrm{B}}$	Transport costs of the buyers on the linear city	55

Δ^{S}	Current location of the suppliers on the linear city	55
Δ^{B}	Current location of the buyers on the linear city	55
$\left(1 - n_{\mathrm{s}}^{\mathrm{S}}\right)$	Small number of suppliers	57
$\left(1 - n_{\mathrm{s}}^{\mathrm{B}}\right)$	Small number of buyers	57
$(\alpha < 1)$	Trading volume of a small buyer with a regular supplier	57
$(\beta < 1)$	Trading volume of a regular buyer and a small supplier	57
P_{w}	Price wholesale	59
c_{η}	Cost per product of the supplier	59
P_{p}	Posted platform price	59
D^{S}	Total demand of suppliers	59
γ_{v}	Product variety	66
V^{P}	Total profit of customers	72
$\theta_{\mathrm{H}}^{\mathrm{B}}$	Upper limit of buyers	73
ϵ_{F}	Elasticity of the buyer market side	74
$\theta_{\mathrm{H}}^{\mathrm{S}}$	Upper limit of suppliers	74
$H(\theta_{\mathrm{h}}^{\mathrm{S}})$	Cumulative distribution function of suppliers	74
$\theta_{\mathrm{m}}^{\mathrm{S}}$	Horizontal differentiation marginal supplier	74
ϵ_{H}	Elasticity of the supplier market side	74
$\epsilon_{V}^{\mathrm{P}}$	Elasticity of the total profit	76
λ	Ratio of the two market sides	77
m^{S}	Market potential of suppliers	81
m^{B}	Market potential of buyers	81
$\eta_{\max}$	Maximal number of products	81

$\eta_{\min}$	Minimum number of products	82
$\eta_{\mathrm{equ.}}$	Number of suppliers in an equilibrium	84
a_{G}	Value product bundle	101
$time$	Time of each period	136
p^{D}	Price discrimination	139

Abbreviations

CMfg	Cloud manufacturing	2
SMEs	Small and medium enterprises	7
MaaS	Manufacturing-as-a-service	8
CC	Cloud computing	12
AAS	Assembly assistance systems	20
MP	Monopoly	35
DP	Duopoly	35
OP	Oligopoly	35
SH	Single-home	35
MH	Multi-home	35
MF	Membership fees	35
TbF	Transaction-based fees	35
iC	Intra-platform competition	35
V	Product variety	35
Gr	Separation into groups	35
homo	Homogeneous	36
hetero	Heterogeneous	36
MU	Monetary units	126

1 Introduction

„*Change is the only constant*.“
— Heraclitus, Greek Philosopher

Over the last decades, the influence of digitalisation is constantly changing traditional businesses. Companies have to adapt to new manufacturing conditions and customer requirements. New business fields are established by reorganising business models of manufacturing companies to include digital opportunities. In Germany, 96% of the manufacturing companies envision a large growth potential of digitalisation (Berg 2020). Larger companies already invest around 30% of their total turnover into digital technologies to handle new digital requirements (Speck 2023).

Additionally, by creating new digital business concepts and fields, more and more markets now rely on internet-based platforms. Platform business models operate as catalysts for the digital change of companies (Stölzle and Häberle 2021). Within the C2C market, digital solutions such as Airbnb and Uber transform traditional market concepts into digital platform concepts. These platform concepts are used to capture market share.

Platforms deliver value by connecting buyers and suppliers (Blaurock et al. 2018). Their business concepts enable them to connect different market sides to develop a differentiated market offer to their members without owning the assets (Lauchenauer 2023). According to Koenen and Heckler (2020), over 50% of German companies see an enormous potential in digital platforms to improve their own company. Especially, a wider variety of products and the generation of new customers are attractive opportunities for the participating buyers and suppliers (Parker et al. 2017).

Furthermore, B2B platforms are slowly changing traditional businesses by developing concepts for companies to interact with each other by participating on a platform. Cloud manufacturing (CMfg) platforms have a major impact on traditional businesses, these platforms focus on the development of inter-company supply chains by matching machine capacities of their participating companies. Manufacturing companies enter the CMfg platform as buyers or suppliers of machine capacities. If companies within a production network cannot utilise their entire production capacity, they can provide these to other companies via CMfg platforms (Lauchenauer 2023). Capacity suppliers can offer their unused production capacity to expand their income sources, build new business relationships, or adapt to future market developments and requirements. Buyers profit from short-notice, demand-based supply networks of production capacities, which leads to minimising shortages and high downtime costs. First predictions state that CMfg platforms will further increase their relevance due to their value proposition within the manufacturing market (Wiesner et al. 2020).

In conclusion, a CMfg marketplace is a promising approach, which creates new business opportunities for the participating companies and similarly develops new business models for the platform. The first CMfg platform businesses are established in the market, while only few manufacturing companies are integrating them into their business strategy so far. Therefore, research is required to understand the potentials of the concepts, the establishment of and participation on CMfg platforms.

1.1 Problem Description

A central aspect of a CMfg platform is to establish a pricing mechanism which enables the platform to generate a total profit and be competitive. Since a platform interacts with the buyer and supplier market sides, the pricing approach should include the customer behaviour of both. Due to network effects, both market sides require a specific number of opposite group participants to join the CMfg platform, which increases the complexity of the CMfg pricing model. If one market side of the platform changes, the other market side is indirectly affected and changes as well. The two-sided CMfg platform pricing approach requires a balanced number of both market side participants. The pricing structure affects the number of customers and simultaneously optimises the total profit of the CMfg platform.

Therefore, the development of a CMfg pricing model is required for the establishment of a CMfg platform. A two-sided market pricing approach can support the CMfg platform in its management decisions to balance demand and supply on the platform. Since theoretical CMfg pricing models to support management in choosing a suitable pricing strategy do not exist, these decisions need to be accompanied by corresponding mathematical models. In addition, there are no empirical data sets available to examine the effects of price changes to derive generally valid correlations. A two-sided market CMfg platform pricing model will support the management decisions of the CMfg platform, since the influences of network effects are included in the approach. A change of one parameter can affect the entire model so that the understanding of the dependencies of the two market sides is elementary to manage the CMfg pricing platform; leading to the research aim of this thesis, which is to develop a CMfg pricing model.

1.2 Research Aim

This thesis aims to develop a pricing model for a two-sided market CMfg platform by focusing on the following three research questions:

1. Which determining factors of two-sided market pricing models are essential to develop a CMfg platform pricing model?

Identifying the determining factors is essential for developing a CMfg pricing model, since they define the fundamental modelling framework. The determining factors of the pricing model need to be identified and clustered by examining the theoretical and practical concepts, the framework, and the business model of CMfg platforms. Based on the determined concepts of the CMfg platform, a morphological analysis of existing two-sided market pricing approaches examines general modelling strategies, which are the foundation to developing a CMfg pricing model.

2. How is a two-sided market pricing structure modelled for a CMfg platform?

Based on the identified determining factors, the pricing model of the CMfg platform is developed, including the requirements of the buyer and supplier market sides. First, a basic two-sided market model is introduced by including the required input and output functions of the CMfg pricing model. Second, the CMfg pricing model considers the utility of both market sides and the profit function of the CMfg platform. The pricing model considers the influences of both market sides of the CMfg platform, to gain a deeper understanding of the underlying network effects between the two market sides, calculating the transaction-based fees, the number of both market side participants and the total platform profit.

3. What insights into the CMfg platform pricing model can be ascertained?

After developing the CMfg pricing model, an analytical and numerical analysis is conducted. Methods of differential calculus and the statistical experimental design are executed to analyse the relationship between the input and the output parameters. Every input parameter defines a specific effect of the CMfg pricing model. The variation of the input parameters of the CMfg affects the total platform profit, which is elementary to establishing an economically viable, functioning platform.

Additionally, a first impression of the inclusion of dynamic effects is presented to gain a deeper understanding of the CMfg pricing structure. The results of the analysis of the static and the dynamic CMfg pricing model are fundamental to derive recommendations for CMfg platforms.

1.3 Organisation of the Thesis

This thesis structures the three central research questions into nine chapters. Chapter 1 presents the motivation and research aim of this thesis. The introduction is followed by Chapter 2 to analyse and determine the conceptual characteristics of CMfg platforms. Chapter 3 presents the modelling approaches of two-sided market pricing models, to deduce the determining factors of the CMfg pricing model, answering the first research question.

Chapter 4 presents a basic pricing model approach, which is the foundation for developing the static two-sided market pricing approach for CMfg in Chapter 5. This pricing approach responds to research question two. Chapter 6 conducts an analytical and numerical analysis of the developed pricing model to gain a deeper understanding of the impacts of the underlying network effects. Chapter 7 presents a first outlook of implementing dynamic effects into the developed CMfg pricing model.

Chapter 8 replies to research question three and derives recommendations from the analysis for the practical implementation of a CMfg platform, including a first indication of general applicability outside of CMfg. Chapter 9 summarises the results of the thesis and identifies further research areas. Figure 1.1 illustrates the organisation of this thesis.

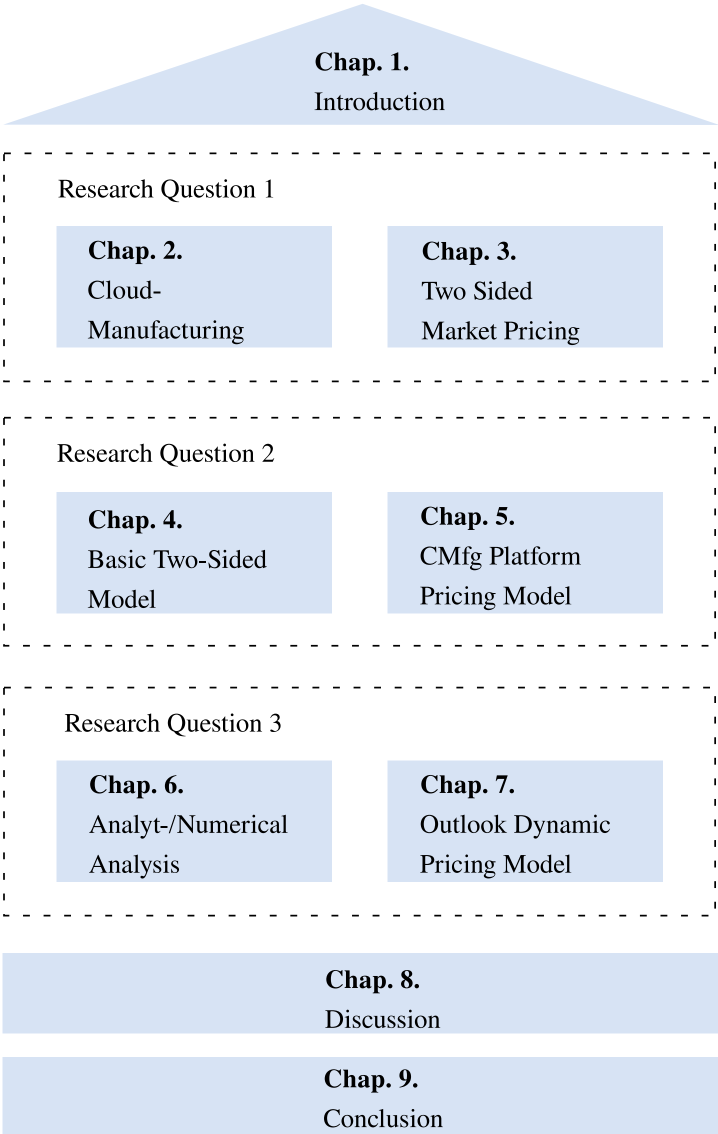

Figure 1.1: Organisation of the Thesis

2 Cloud Manufacturing

The value of manufacturing companies is being defined by their production capability of physical products. According to Botzkowski (2017), the value of manufacturing companies shifts from physical products towards dynamic value creation networks through digital progress and technological developments. Ematinger (2018) identifies that digital transformation within manufacturing companies is the foundation to participate in cross-company digital concepts. Hunke et al. (2017) determine that based on technological development, manufacturing companies transform by adapting platform solutions such as CMfg into their traditional business models. A core aspect of the CMfg platform is that it enables manufacturing companies to share and acquire unused production capacities. The capability of the CMfg platform aligns flexible, agile and cross-company production supply chains to address the increasing demand for smaller lot sizes, short-term notice production offers and individual customer demands (Wiesner et al. 2020).

The Statistisches Bundesamt (2023) states that the European market of manufacturing companies of machine tools is highly fragmented. Small and medium enterprises (SMEs) in the German manufacturing sector have a share of around 98% (Bundesministerium für Wirtschaft und Energie 2016). As a result, manufacturing companies are confronted with huge efforts to identify suitable partners for collaboration. The combination of new technological developments and differentiated market situations leads to enormous growth potential for CMfg platforms (Huang et al. 2013).

Based on the potential of B2B platforms, CMfg platforms are examined in detail in the following. The CMfg platform concepts consider the perspective of buyers, suppliers, and the platform itself. The two-market sides can interact with each other by participating on the CMfg platform, as displayed in Figure 2.1.

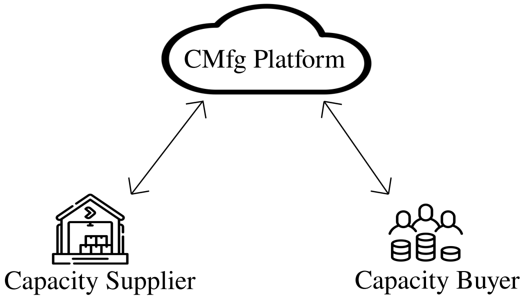

Figure 2.1: Two-Sided Market CMfg Platform Model

The capacity supplier of a CMfg platform offers dynamic production capacities. The CMfg platform offers Manufacturing-as-a-service (MaaS) so that products are collaboratively realised by including smaller manufacturers (Rauschecker et al. 2011). The supplier market side benefits from additional revenue based on utilising unused production capacity and by establishing new business opportunities. The CMfg platform offers the manufacturing capacities of the supplier market side to the buyer market side. The buyer side demands production capacities at short notice due to an unexpected increase in demand or because of capacity shortages. Fast responses to uncertain, fluctuating customer demands and the production of smaller lot sizes are handled more efficiently within CMfg concepts (Wiesner et al. 2020). The platform matches the required capacities to the customer requests of the buyers, who select from different offers based on quality, cost, and delivery time (Täuscher and Laudien 2018, Kaufmann 2015). The capacity buyer requires customised products based on CAD files or technical drawings for example so that the manufacturing capacities of the CMfg need to be highly individualised and differentiated. The variety of the manufacturing capacities is based on the capabilities of the capacity suppliers. The capacity buyers of the platform are distinguished by their individual utility expectations regarding the CMfg platform. The participating companies of the CMfg platform can join the platform as a capacity supplier and buyer at the same time (Wu et al. 2014) as shown by Figure 2.2.

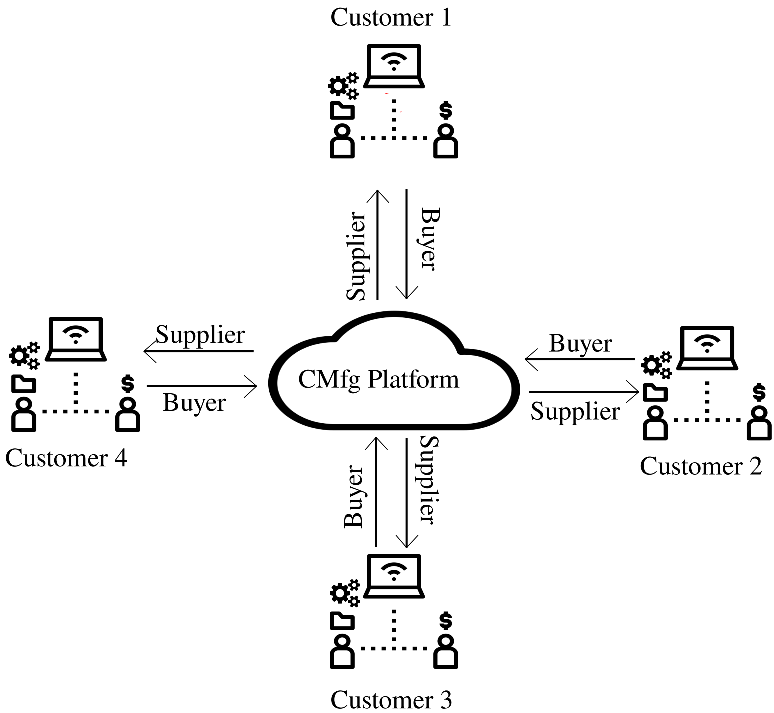

Figure 2.2: Customers of the Two-Market Sides of a CMfg Platform

In summary, the CMfg platform concept establishes a unique model for matching production capacities of cross-company production networks (Charro and Schaefer 2018). Through interactions of both market sides, a benefit for both sides is generated (Wiesner et al. 2020). Due to the complexity of CMfg platforms, a structured approach is required to examine the specifics of CMfg as displayed in Figure 2.3.

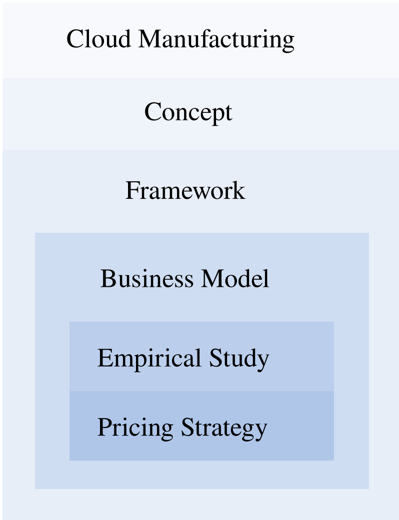

Figure 2.3: Structure of the Cloud Manufacturing Analysis

Firstly, an overview of the different concepts of CMfg is described from a theoretical and practical perspective. Secondly, a framework is developed based on the presented CMfg concepts to obtain a general structure of the characteristics of CMfg platforms.

The identified characteristics of the framework are the foundation to develop a CMfg business model, including the specifics of the platform economy. An empirical study analyses the results of the framework and the business model to gain a first validation of the developed approaches. Finally, the pricing strategy as part of the business model is examined.

2.1 Concepts

Platform concepts evolve to be the most distinctive business models in the digital world (Blaurock et al. 2018). Theoretical concepts to determine their potentials are examined in this section. Since the platform participants own the resources and not the platform itself, the structure of traditional businesses is changed by separating ownership and control of resources and capacities, which achieves a faster growth rate and transforms significant business structures of many industries. Due to the potentials of CMfg concepts, their market development in the production sector leads to a higher increase in CMfg and MaaS solutions within recent years, which drives fundamental CMfg concepts in literature and practice (Tao et al. 2011, Parker et al. 2017).

2.1.1 In Theory

The new potentials of the CMfg platform are examined by the literature developing theoretical CMfg platform concepts. The foundation for CMfg platform businesses are the network effects between the different market sides, which are fundamental for successfully establishing a platform. Network effects are differentiated into intra-platform and inter-platform competition. Intra-platform competition analyses the competition within the same market side group, whereby the participants influence each other positively and negatively (Zhang and Nie 2021). The CMfg platform gains beneficial market information due to an extreme information asymmetry of itself and its participants. The market transparency is based on technologies, which connect participants of the manufacturing companies and their capacities in an interactive ecosystem (Parker et al. 2017).

Adamson et al. (2017) determine that the motivation for participation in cloud concepts include various new potentials by resource and information sharing. Wu et al. (2013a) define the concept of CMfg as a customer-oriented ecosystem in which participants configure and select manufacturing capacities. Wu et al. (2013b) analyse the elementary characteristics of theoretical CMfg concepts. A relevant element is the transformation of hierarchical manufacturing towards a customer-oriented supply chain, by developing a flexible supply chain based on the capacities and demands of participants (Charro and Schaefer 2018). An agile customer-orientated supply chain increases productivity and reduces cost by enhancing production capacities for the buyers. Based on flexibility, CMfg platform offers a temporary, re-configurable and dynamic supply chain by manufacturing small lot sizes, reducing downtime and responding to demands instantly (Ren et al. 2015). Access to a variety of manufacturing capacities enables the CMfg platform to provide manufacturing opportunities, which are not accessible in traditional manufacturing settings (Ralph and Stockinger 2010). Novel manufacturing opportunities for SMEs are encouraged by the aggregation of manufacturing capacities to form virtual factories so that even smaller companies can offer collaborative manufacturing capacities for larger capacity requests which they can not manage individually (Adamson et al. 2017).

Moreover, manufacturing companies transform their businesses by mapping and abstracting from physical manufacturing to virtual capacities. Virtualisation of production capacities examines the sharing and establishing of service-oriented manufacturing for the CMfg participants (Ren et al. 2017). Cloud computing (CC) assists companies to generate transparency of manufacturing capacities (Adamson et al. 2017). CC enables the support of on-demand services with significant reliability, scalability, and accessibility in a CMfg platform environment (Xun 2012). Due to the enormous development of information, manufacturing and management technologies, the requirements for manufacturing change so that companies are facing growing global competition and increasing customer requests for highly differentiated products (Tao et al. 2017). CMfg platforms combine manufacturing capacities into cloud services, according to the capabilities of the suppliers, through the development of service-oriented manufacturing concepts (Tao et al. 2011).

According to Henzel and Herzwurm (2018) the concept of CMfg platforms is involved in the entire life cycle of manufactured products since the required capacities of the manufactured goods are affected by their current life cycle stage. CMfg platforms enabled by CC examine different types of manufacturing resources as services for all product life cycle phases (Adamson et al. 2017). Manufacturing companies can scale their capacities up to and down by joining the CMfg platform, which includes instant pricing for capacity buyers (Hasan and Starly 2020). Additionally, transient and dynamic demands are adjustable under temporary demand peaks caused by unpredictable increases in customer demands (Wu et al. 2013a).

Next, after examining theoretical concepts of CMfg platforms, the market situation in practice is described in the following section, to gain an impression of the current CMfg platform market situation.

2.1.2 In Practice

The theoretical impacts of CMfg platform businesses are analysed in practice to understand the current manufacturing market situation. Helo and Hao (2017) examine manufacturing companies in the sheet metal industry, which start to establish CMfg concepts for customers in the automotive and aerospace sectors. The developed information technology tools combined with management concepts provide a practical solution to the changing business fields. Production steps within sheet metal manufacturing include laser cutting and sheet metal handling systems, which are highly automated manufacturing technologies. The degree of automation technology is essential for managing the manufacturing capacities within cloud services (Ralph and Stockinger 2010).

In comparison to traditional manufacturing processes, the CMfg platform connects cross-company production capacities of the suppliers to establish transparency of the available capabilities (Wiesner et al. 2020). According to Lerch and Jäger (2020) one-third of the manufacturing industries currently participate in CMfg platform concepts. For example, Ellwein et al. (2018) develop a platform framework named the "Rent'n'Produce" platform, which focuses on connecting manufacturing resources of SMEs through cloud technology. Their platform framework defines a standard for manufacturing companies, enabling them to participate in the concept. A survey is conducted by them to understand the requirements and challenges of the SMEs to participate on a CMfg platform. The dominating factor for the companies to join the concept is the increasing market pressure followed by the possibility to increase capacity utilisation, to self-promote their own business or to simplify the communication between manufacturing companies. The interface of the CMfg platform needs to be available for all participants and to be user-friendly. The participants of the survey are concerned of potential barriers, such as the lack of standardisation, the acceptance of the workforce and if the platform can reach the critical mass of participants to generate benefits for the users.

Colombo et al. (2019) present the project "Production harmonizEd Reconfiguration of Flexible Robots and Machinery", which focuses on different case studies of the transformation of existing manufacturing systems toward plug-and-produce manufacturing ecosystems. They include the challenges of a global view of various production scenarios by enabling the integration of existing manufacturing systems. As a result, the gained knowledge is put into practice.

Apart from the presented concepts, the establishment of CMfg platforms is driven by start-ups, which are the first industrial applications of the CMfg concepts. The CMfg operators offer different services, such as brokering services and collaboration support to their participants (Wirtz 2019). An example is Laserhub (2023), which provides basic marketplace services requiring manual entry and order acceptance. In comparison, Xometry (2023), Fictiv (2023) and 3D Hubs (2023) offer a higher degree of automation by including instant pricing. Their platform participants still need to enter and accept the orders through a web portal. A more advanced CMfg platform is KREATIZE (2023), which anonymously matches customer orders with the available production capacities of the suppliers. The presented platforms are differentiated by their billing model and how suppliers manifest themselves on the platform. The suppliers can stay anonymous or appear publicly during the entire matching and manufacturing processes on the CMfg platform.

These presented platforms enable the participants to share their production capacities but do not prove a fully integrated customer-to-customer supply chain integrating manufacturing, transport and assembly capacities (Dümmel and Eger 2021). In addition, the existing platforms do not use the possibilities of the production ecosystems by combining the production capacity of individual suppliers to align cross-company supply chains by multi-sharing the production orders (Wiesner et al. 2020). The presented theoretical and practical concepts of the CMfg platform give a first impression of the specifics of two-sided market platform concepts for manufacturing companies to enable the development of a framework in the following chapter.

2.2 Framework

For the digital transformation of manufacturing companies, a structured analysis of platform concepts is essential. The structuring of the concepts is based on the development of a CMfg framework. The majority of the existing frameworks for establishing CMfg approaches focus on the IT architecture of the platform and the offered service components, but not on the conceptual requirements of the CMfg platform. In addition, there are many approaches for structuring and developing traditional business models, which do not sufficiently take into account the relevant aspects of the platform economy (Banerjee and Majumdar 2020). These concepts often require preliminary information, which is not included in the business model itself.

Consequently, a general framework for a systematic approach to structurally support manufacturing companies during their digital transformation is required (Riemensperger and Falk 2020). The first step for manufacturing companies to revise, expand or redesign their current businesses is to define a framework that analyses basic rules and conditions for establishing CMfg platforms. A framework including the relevant areas of the platform economy is the foundation of the development of a platform business model (Parker et al. 2017, Li et al. 2020, Chen et al. 2016). Four areas are identified, which contain the specific requirements of CMfg platforms to structure the elements of the platform. Table 2.1 shows these characteristics and their areas.

Table 2.1: CMfg Platform Framework

Characteristics	**Areas**
Platform	Open vs. closed platform, platform deployment time, platform availability, platform deployment channel
Market	Market situation, market areas, dependency of suppliers, market reach, market segments, market developments
Customer	Two-sided market, target group (B2B,B2C), critical mass of participants
Price	Pricing model (transaction-based vs. membership)

The four areas are identified according to the requirements of the presented CMfg concepts. The first framework area are the platform characteristics, which define the transformation of traditional business models into cloud based business models. Since CMfg platform concepts change traditional markets, their effects on the market need to be considered, which forms the second area of the framework, considering the market characteristics. The CMfg platform considers the two market sides of the capacity suppliers and buyers, which have different motivations to participate on the CMfg platform so that the two market sides have to be classified by the third area determining the customer characteristics. Last, the price characteristics of the CMfg platform are examined, since the new CMfg business model needs to be economically stable.

The first framework area of the platform characteristics includes the aspect of openness. Since the participants of the CMfg are assumed to complete a registration process to enter the platform, the participation is restricted to members providing credit ranking, certificates, and manufacturing capabilities (Hui 2011, Parker et al. 2017). A CMfg platforms can provide their services immediately or use a defined time frame for a market launch. The deployment time to integrate a manufacturing company into the CMfg platform depends on the lead time for the connection of the systems and is considered to be high. The CMfg platform availability should initially be regional, country- and sector-specific to limit the arising complexity, which is essential to estimate the number of platform participants (Wiesner et al. 2020). The interaction of the CMfg platform with their participants is based on different channels such as mobile applications, web platforms or other digital connections (Eger and Wiesner 2021).

The second characteristic of the framework is the market characteristic. The market situation of the existing CMfg platforms is described as an oligopoly, since they only slightly differ in their specialised areas. As a newly founded CMfg platform should offer an end-to-end, agile and flexible supply chain, it could be considered a monopoly (Wiesner et al. 2020). Within platform economics, it is advisable to address market areas that do not have complete market coverage (Parker et al. 2017). Another aspect is the dependence of the participants on the availability of the capacities due to their locations. If, for example, the participants are dependent on local production capabilities or the products are subjected to enormous time pressure, the orders are not tendered worldwide. For the establishment of a CMfg platform, the market reach should be limited to regional areas at the beginning (Zhan et al. 2011). The advantage is that the supply chains between individual production steps are significantly less complex (Eger and Wiesner 2021). The market segmentation of the CMfg platform should be focused on the mass market since the differentiation of the offered capacities can be configured wider, since the production orders are individually processed by manufacturing capacity suppliers using differentiated production processes. The digitalisation level within the industry is relevant for participating on the CMfg platform. The degree of digitalisation in manufacturing enterprises is advanced, as many digital techniques are already applied (Leyh and Bley 2016).

The third characteristic that platform economics considers the network effects of two market sides. The customer benefit contains the perspective of the suppliers and the buyers (Armstrong 2006). Considering both market sides is a crucial aspect while establishing a platform, which is not considered in traditional business model approaches. The customer benefits of the supplier market side arise primarily from the expansion of their business models and the generation of additional revenues for underutilised production capacities. From the buyer perspective, essential aspects for participation are that capacity shortages are compensated, technical disruptions are counteracted and fluctuating demand is absorbed (Behrens and Wiesner 2021). The target group of the production platform is the B2B sector, since the legal requirements for private customer groups contain a higher degree of complexity (Wiesner et al. 2020). If the critical mass of the CMfg platform exhibits a sufficient number of participants on both market sides, transactions between the participants are coordinated by the platform. It is elementary to consider the required number of participants when developing the CMfg platform (Parker et al. 2017).

The fourth characteristic considers the applied pricing model. The customers of the platform are charged by transaction or pay membership fees for their participation (Armstrong 2006). A combination of both would also be conceivable. Since this thesis focuses on the pricing structure of the CMfg in detail, it is referred to Section 2.5 for a detailed view on the specifics of the pricing approach of the CMfg platform.

Based on the presented results, a transfer of the identified framework areas contributes to simplifying the development of the CMfg business model. Due to the analysis of the framework, the business model of a CMfg platform is developed in the following section based on the identified requirements of the presented framework (Eger and Wiesner 2021).

2.3 Business Model

The developed CMfg framework structures the CMfg concepts so that a CMfg business model is developed including the results of the four framework areas. Within the traditional business world, contract manufacturing companies generate their income by the number of products sold, which need to cover their production expenses (Wiesner et al. 2014). With their current business model, the manufacturing machines produce according to their customer demand and not their capacity. The costs of idle times of the production machines are simply added to the product prices (Vogel-Heuser et al. 2017). Consequently, the development of a CMfg platform concept assists manufacturing companies using the possibilities of the digital world by including strategic digital transformation approaches into their traditional business model (Remane et al. 2017). Much effort is required to develop these concepts and tools that allow sharing resources to match their supply and demand (Baalsrud Hauge et al. 2014). This trend is leading to an expansion of the business models of the manufacturing companies and the establishment of new business areas, allowing them to benefit from the potential of CMfg production platforms (Parker et al. 2017). The central value provided by a CMfg platform is to create a dynamic, automated marketplace for production capacities among the participants. This will increase efficiency, reduce product life cycle costs and enable optimal resource utilisation, in response to customer-generated tasks with variable demand (Wu et al. 2013a, Xu et al. 2014). Unused manufacturing capacity is offered on platforms providing access to new customer groups (Blaurock et al. 2018).

The developed CMfg structure in Section 2.2 identifies the preliminary requirements to establish a CMfg business model. The possibilities provided for companies like machine manufacturers, contract manufacturers or companies with limited production capacities are that they can adapt to new business fields by providing individual customer solutions to complex demands collaboratively through a CMfg business model. The collaboration of manufacturing offers combined production capacities of SMEs by providing solutions for complex problems, through the platform. Collaborating with other manufacturers increases the possibilities of each producer to be matched by forming a virtual factory by offering the combined available production capacities (Opresnik and Taisch 2015). Matching algorithms provide suggestions for optimal value chains for a specific product, while quality is tracked throughout the manufacturing process (Wiesner et al. 2020). A higher degree of machine capacity is reached by data analysis identifying suitable production demands, which leads to cost benefits for suppliers and buyers (Kaufmann 2015). As a result, the effects of digitalisation and data analysis methods change the traditional business model of manufacturing companies (Loebbecke and Picot 2015).

Furthermore, many approaches conceptually support the development of business models, such as the Business Model Canvas by Osterwalder and Pigneur (2010) or the St. Gallen Business Model Configurator by Gassmann et al. (2017), which are classified as standard tools within traditional business model generation. A detailed analysis of a CMfg platform, based on the Business Model Canvas, can be found in Wiesner et al. (2020). First digital business model approaches are developed, for example by Kotarba (2018), to include the specifics of platform concepts into the business model of the manufacturing companies. Täuscher and Laudien (2018) analysed a variety of online marketplace business models to determine the relevant aspects of a platform business model by clustering business model elements such as their dimensions, value creation, delivery, and capture. The results are the first indication of the relevant business model areas to be considered for platform businesses (Bundesministerium für Wirtschaft und Energie 2016).

In addition to the business model concept, several partners establishing the platform and implementing the derived business model are required. It is essential to involve affiliated manufacturing companies to automate capability and capacity reporting. The same applies to IT companies, providing the interfaces between the platform and the enterprise information systems. Payment and insurance suppliers support the financial aspects (Wiesner et al. 2020).

The business model of the CMfg needs to consider the entire supply chain so that assembly and transport capacities are integrated alongside production capacities. Assembly assistance systems (AAS) are a technology which ensures the assembly quality within the processes. The integration of assembly services into a platform tends to increase the complexity of the processes because individual assembly requirements of customised products are considered. If assembly services are integrated, the buyer has to transmit detailed product information to the platform. The assembly supplier receives product information, which automatically derives work instructions from the information through the support of AAS. The possibilities of AAS enable outsourced assembly services through the CMfg platform. An order is divided among different capacity suppliers through multi-sourcing, with one supplier responsible for the production of the components and another for the assembly services (Wiesner et al. 2020). This enhances the capacity variety of the production platforms by including assembled products, which significantly increases the benefits of the participating customers (Dümmel and Eger 2021).

Besides the manufacturing companies, a CMfg platform can also include logistic processes to transport the produced goods from the capacity supplier to the buyers (Borgi et al. 2017). The necessary ad-hoc transport relationships are provided by including the capacities of logistics service suppliers. The CMfg platform registers individual service suppliers, purchases contingents or cooperates with existing logistics services platforms. These three variants of the inclusion of shipping capacity are analysed by Eger et al. (2022) in detail according to technical, legal and economic aspects. As a result, the CMfg platform benefits by connecting directly to a logistic services platform to provide the required shipping capacities to create collaborative and short notice cross-company supply chains (Eger et al. 2022). Figure 2.4 presents the different suppliers of manufacturing, assembly and transport capacities, which provide an End-2-End supply chain for their customers.

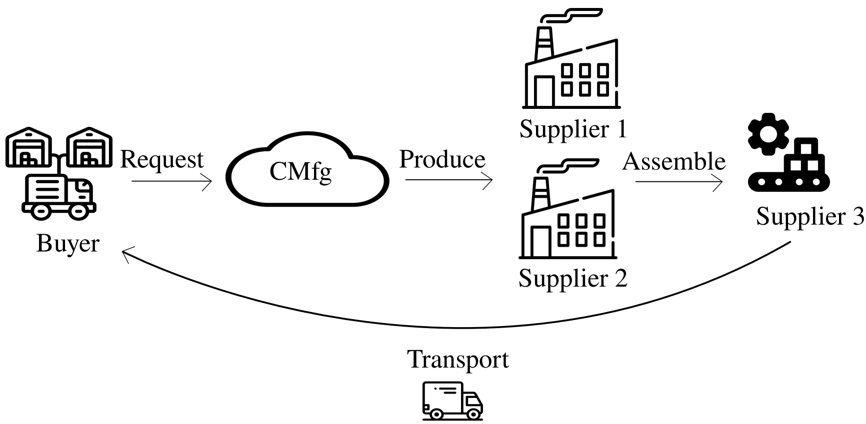

Figure 2.4: Multi-Sourced End-2-End Supply Chain

The pricing structure of the developed CMfg concept is another element of the CMfg platform business model. It defines the success of the economic efficiency of the CMfg platform and is the foundation for the successful establishment of long-term business concepts. The CMfg platform costs include the maintenance and further technical developments of the platform, the support of existing participants and the acquisition of new participants. Different income streams of the business model such as entrance fees, marketing strategies and promotions of third party suppliers are considered to cover the costs. Since the pricing model is one of the central components of the business, the pricing structure is analysed in further detail in this thesis. The first step of this analysis is the conduction of an empirical study to gain deeper insights, as presented in the following section.

2.4 Empirical Research

Behrens and Wiesner (2021) analyse the requirements of a CMfg platform by conducting an empirical study focusing on the results of the developed framework and business model to examine the potentials of CMfg platforms. The target group of the empirical study are manufacturing companies from the automotive or metalworking industry, which potentially would participate on a CMfg platform. The empirical study is conducted during the COVID-19 pandemic, which affects the research results. The effects of the COVID-19 pandemic disrupt components of the value network and highlight dependencies on external suppliers (Golan et al. 2020). The demand of the manufacturing companies for a CMfg platform is based on the need to have a tool to react to the uncertainties and changing environmental conditions of the pandemic. The relevance for digitalisation concepts within companies leads to a rapid change within the market (Schnelle et al. 2021). Due to the effects of the COVID-19 pandemic, the potentials of platform concepts increase the acceptance of manufacturing companies to participate or establish CMfg concepts, because the COVID-19 pandemic effects can be mitigated by participation in manufacturing platforms (Sarkis et al. 2020).

A total of 44 manufacturing companies participate in the empirical study. Only 16% of the study participants have prior experience using digital platforms in a B2B context. The study participants can choose to respond to the study questions from the perspective of a capacity supplier or buyer. Two-thirds of the study participants answer from the perspective of capacity suppliers and one-third of the perspective of buyers (Behrens and Wiesner 2021).

The results of the study show that the buyer market side requests product variety from which they select a capacity supplier according to their requirements. The platform should offer a high level of trustworthiness (27.7%) and a high level of delivery reliability (27.7%). According to Kendall-Tau-b, it is statistically shown that with a very high significance (r=0.761, p=0.001, N=17), a strong positive correlation between the availability of capacities and delivery reliability exists. The delivery reliability also increases with an increase in the availability of production capacities. This correlation has a positive effect on the participation of the buyers since the two criteria, availability and delivery reliability, are decisive for the buyers and correlate strongly with each other (Behrens and Wiesner 2021).

Furthermore, the results show that capacity suppliers register on a dynamic production platform to offer available machine capacities (25%) and establish new customer relationships (21%). On average, the suppliers expect additional revenue of about 28% through platform participation. In addition to the production capacities offered, the suppliers would use the potentials of services such as higher quality standards (27%) or manufacturing processes (22%) to improve the current order situation and generate additional revenue. The CMfg platform manages the general pricing structure of the manufacturing capacities. The CMfg platform ensures the coverage of the marginal costs of the capacity suppliers by allowing them to propose price ranges. The platform derives the total price for the manufacturing capacities from the price proposal and according to customer demand (Behrens and Wiesner 2021).

Another aspect of a successful implementation of a CMfg platform is the integration of customer evaluations. The customer reviews combined with the hard facts of the rendered services affect the rating to increase the service performance. Data-driven information is included by analysing tracking and quality data of the manufacturing processes and service delivery (Behrens and Wiesner 2021).

For the CMfg platform itself, it is elementary that the platform operates economically. The CMfg platform can set membership fees or fees for every individual transaction on the platform. The empirical study establishes that the majority of suppliers and buyers generally accept user fees and determines that participants prefer a transaction fee over fixed membership fees, as shown by Figure 2.5 (Behrens and Wiesner 2021).

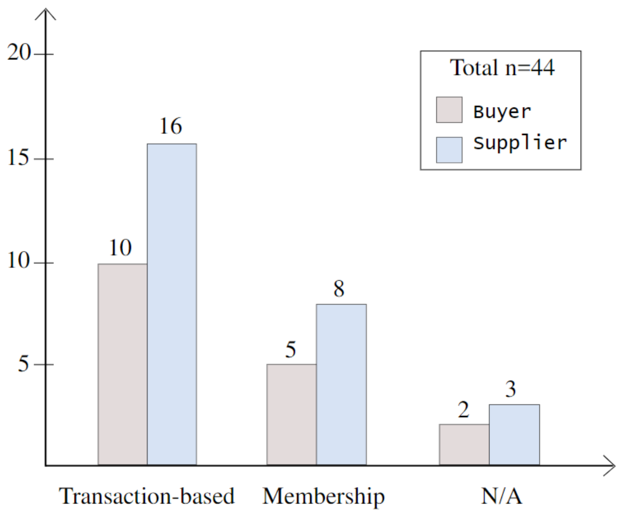

Figure 2.5: Transaction-based vs. Membership Fees

The buyers accept transaction costs per order at a mean value of 3.29% of the total order price. The suppliers suggest a percentage fee of 3.81% on average per transaction on the CMfg platform. The participating buyers accept the increase of the transaction fees if the availability of the offered capacity is increasing at the same time (r=0.519, p=0.015, N=17). While establishing a CMfg platform, it can provide its services for free to reach the critical mass of participants faster. In this regard, 21.1% of suppliers indicated that a discount of transaction fees is among the main reasons for entering CMfg platforms during the COVID-19 pandemic. The request for production capacity correlates positively with the transaction costs of the CMfg platform, according to Kendall-Tau-b. As soon as the order situation of the capacity suppliers increases, they would accept an increase in transaction fees by the CMfg platform (r=0.414, p=0.013, N=27). (Behrens and Wiesner 2021) According to the results of the empirical study, a first impression on the complexity of the two-sided market pricing structures is shown so that the following research of this thesis will focus on the specifics of the CMfg pricing model.

2.5 Pricing Strategy

The CMfg platform has to generate a positive total profit surplus to be economically successful. Based on the results of the previous sections, the fundamentals for developing a CMfg platform pricing approach are deduced. The pricing structure of a CMfg is based on the interactions of the two market sides of the platform. Information asymmetry exists between the CMfg platform and its participants so that the information provided by the CMfg platform enables the participants to interact with each other.

According to Armstrong (2006) the pricing approach of two-sided markets is based on the number of participants of both market sides. The utility of the buyer market side to participate on the platform is dependent on the number of participants of the supplier market side and vice versa. A balanced number of both participant sides is elementary to match the supplier to the buyer market side. Each participant of the platform is charged an entrance fee, enabling the participant to interact with the opposite market side (Wiesner et al. 2020). The entrance fees of a CMfg platform can be fixed or transaction-based, or a mixture of both. The empirical research of Chapter 2.4 suggests transaction-based fees are the favourable entrance fees for CMfg businesses. The provided utility is elementary to determine the CMfg platform entrance fees. If the utility of the participants increases, the total amount of platform entrance fees increases, leading to a growth of the profit of the platform (Hagiu 2004).

Consequently, establishing a CMfg platform is challenging. For a balanced interaction of both market sides and to balance the number of participants, a two-sided market CMfg pricing model has to be defined. The first step to develop a two-sided market pricing model is to include the identified conceptual requirements of a CMfg platform, determined by this chapter, to the existing two-sided market pricing model. Therefore, the state-of-the-art of two-sided market literature is analysed by Chapter 3.

2.6 Summary

Summarised, this chapter presents the following fundamentals of CMfg platforms:

- Platform concepts change traditional business concepts.
- Enormous growth potential of CMfg platforms in the next few years is foreseen.
- The foundation for CMfg platform businesses are the network effects between the different market sides.
- CMfg platform concepts consider the perspectives of buyers, suppliers, and the platform itself.
- The two-market sides can interact with each other by participation on the CMfg platform.
- The supplier market side benefits from additional revenue from unused production capacities and the realisation of new business opportunities.
- The buyer market side demands production capacities at short notice with fast responses to uncertain, fluctuating demands and the production of smaller lot sizes.
- A framework analyses the specifics of the platform economics to identify the fundamental information necessary to develop a CMfg platform business model.
- An empirical study gives the first impression on the practical requirements of the CMfg pricing model.
- For a balanced interaction of both market sides participants, a two-sided market CMfg pricing model has to be defined.

3 Two-Sided Market Pricing Models

The pricing mechanism is the foundation of the CMfg platform to be economically sustainable. Based on the determined requirements of the CMfg platform in Chapter 2, the elements of a CMfg pricing model will be identified in this chapter to answer the first research question by examining the state-of-the-art of two-sided market literature.

Before examining the two-sided market literature, a selection of one-sided pricing models is presented to gain a complete overview of the state-of-the-art of CMfg platform approaches. The one-sided market literature already analyses the application of pricing approaches for the CMfg platform in detail. For example, Truong-Huu and Tham (2013) develop a game-theoretic model for a dynamic pricing approach, which determines the competition between the platform suppliers and buyers by modelling a dynamic pricing game using a Markov chain. Liu and Wang (2020) focus on developing a novel approach of a game-theoretic model to allocate fair resource scheduling of the buyers and suppliers capacity. Mihailescu and Teo (2010) develop an auction-based model to assign dynamic pricing of the platform members by modelling the participants as rational members with an individual level of information. Xu and Li (2013) establish a stochastic pricing algorithm based on a revenue management framework to introduce the potential of dynamic pricing. Li et al. (2020) use a fuzzy approach to evaluate the dynamic matching of the prices of a CMfg market. A genetic model approach is modelled by Macias and Guitart (2011), which iterates from an elementary pricing function to an advanced pricing structure by continuously improving the dynamic pricing model.

The presented approaches are based on a one-sided market modelling framework, considering the specifics of manufacturing. In contrast to these approaches, a two-sided market framework is differentiated by the interaction of two market sides with two different customer groups instead of one market side (Wright 2004). Network effects can be considered within these models. It is essential to understand the challenges of transferring one-sided market pricing approaches into two-sided market pricing models by gaining a deeper understanding of the interdependence between the modelling methods. Wright (2004) defines eight challenges of aligning the model frameworks, such as the connection of market power and price-cost margins. He deduces that a direct transfer of the concepts is not desirable and two-sided market approaches require differentiated and systematic pricing approaches.

In conclusion, the modelling of a two-sided market pricing mechanism is more complex than the presented one-market sided approaches due to the determining factors of the market and the influences of the network effects of the two market sides. Platforms enable the interaction of the participants of both groups (Evans and Schmalensee 2013), which leads to network effects between the two groups (Hagiu 2004). Because of the network effects, it is essential to establish a pricing approach of the CMfg platform using a two-sided pricing approach. The network effects consider the interactions of enrolled members on both sides of the CMfg platform and the impact of the implementation of entrance fees (Rochet and Tirole 2003). Both market sides obtain value from interacting with the opposite market side through the platform (Wright 2004). Besides, the benefit of group members increases with the number of other group members within the same group consuming the same product (Katz and Shapiro 1985). Since a one-sided market approach can not handle the characteristics of the market requirements, the development of the CMfg pricing model will be based on two-sided market approaches to accurately model the CMfg platform requirements. The fundamental literature approaches are presented in Section 3.1 to understand the modelling approaches of the two-sided market pricing mechanism.

3.1 Fundamental Literature Approaches

The analysis of two-sided market pricing approaches begins with the rise of platform concepts. The new platform concepts lead to the development of two-sided market pricing models. The fundamental two-sided market models within the literature are presented by Figure 3.1.

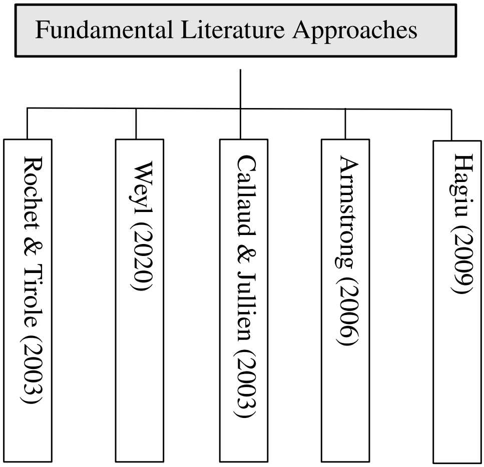

Figure 3.1: Fundamental Literature Approaches

These five pricing approaches of the two-sided market literature are described in the following. One of the fundamental approaches is developed by Rochet and Tirole (2003), who allocate the interactions of suppliers (S) and buyers (B) by applying transaction-based entrance fees. The models combine the two market sides, including the number of suppliers (n^{S}) and the number of buyers (n^{B}). The benefit of suppliers (b^{S}) and the benefit of buyers (b^{B}) arise by interacting with each other through the platform. The prices set by the platform for transaction-based price of suppliers (p^{S}) and transaction-based price of buyers (p^{B}). The total number of transactions on the platform is defined by the volume of transactions of suppliers ($V_{\mathrm{t}}^{\mathrm{S}}$) and the volume of transactions of buyers ($V_{\mathrm{t}}^{\mathrm{B}}$). The network effects influence the gross profit of the buyer (b^{B} - p^{B}) $\cdot\, n^{\mathrm{S}}$, which is dependent on the number of group members on the other side. The number of suppliers and buyers on the platform are independent of each other.

$$\begin{aligned} n^{\mathrm{S}} &= b^{\mathrm{S}} \geq p^{\mathrm{S}} = V_{\mathrm{t}}^{\mathrm{S}} \cdot p^{\mathrm{S}} \\ n^{\mathrm{B}} &= b^{\mathrm{B}} \geq p^{\mathrm{B}} = V_{\mathrm{t}}^{\mathrm{B}} \cdot p^{\mathrm{B}} \end{aligned} \tag{3.1}$$

The total platform profit (Π^{P}) is composed of the benefits of both groups minus the transaction-based cost (c_{t}) of the platform multiplied by the profit of the transaction-based fees for the volume of transactions.

$$\Pi^{\mathrm{P}} = \left(p^{\mathrm{B}} + p^{\mathrm{S}} - c_{\mathrm{t}}\right) \cdot \left(V_{\mathrm{t}}^{\mathrm{B}} + V_{\mathrm{t}}^{\mathrm{S}}\right) \tag{3.2}$$

Weyl (2010) expands the pricing approach of Rochet and Tirole (2003) by considering the influences of both sides heterogeneity by determining user-specific transaction-based fees. The net profit of suppliers ($\mathrm{Net}_{\mathrm{S}}$) and the net profit of buyers ($\mathrm{Net}_{\mathrm{B}}$) of the type of platform users (i) displays the individual benefit and price structure of each user i. The total number of interactions on the platform generates the membership benefit of suppliers (B^{S}) and the membership benefit of buyers (B^{B}) of each user i. The transaction costs for the user are measured by p^{S} and p^{B}.

$$\begin{aligned} \mathrm{Net}_i^{\mathrm{B}} &= B_i^{\mathrm{B}} + b_i^{\mathrm{B}} \cdot n^{\mathrm{S}} - p^{\mathrm{B}}\left(n^{\mathrm{S}}\right), \quad i \in \mathbb{N} \\ \mathrm{Net}_i^{\mathrm{S}} &= B_i^{\mathrm{S}} + b_i^{\mathrm{S}} \cdot n^{\mathrm{B}} - p^{\mathrm{S}}\left(n^{\mathrm{B}}\right), \quad i \in \mathbb{N} \end{aligned} \tag{3.3}$$

Caillaud and Jullien (2003) focus on the analysis of the chicken-and-egg-problem of the platform, which can be traced back to the necessity of an equal volume of registrations of the buyer and supplier market side. The net profit of suppliers and the net profit of buyers on a platform type of platform (j) contains the transaction-based prices p^{S} and p^{B} and the fixed membership fees of suppliers (P^{S}) and the fixed membership fees of buyers (P^{B}). The utility function of suppliers (u^{S}) and the utility function of buyers (u^{B}) measure the curve progression of the benefit to participate on the platform in regard to the transaction-based fees charged by the platforms j.

$$\begin{aligned} \text{Net}^{\text{S}} &= n_j^{\text{B}} \cdot b^{\text{S}} \cdot u^{\text{S}} \left(1 - p_j^{\text{S}}\right) - P_j^{\text{S}}, \quad j = 1, 2 \\ \text{Net}^{\text{B}} &= n_j^{\text{S}} \cdot b^{\text{B}} \cdot u^{\text{B}} \left(1 - p_j^{\text{B}}\right) - P_j^{\text{B}}, \quad j = 1, 2 \end{aligned} \tag{3.4}$$

Armstrong (2006) is the first author who analyses fixed membership fees for suppliers P^{S} and buyers P^{B}. He models the net profit for both market sides, which can obtain the benefit b^{S} or b^{B} by participating on the platform.

$$\begin{aligned} \text{Net}^{\text{S}} &= b^{\text{S}} \cdot n^{\text{B}} - P^{\text{S}} \\ \text{Net}^{\text{B}} &= b^{\text{B}} \cdot n^{\text{S}} - P^{\text{B}} \end{aligned} \tag{3.5}$$

Due to the indirect network effects, the benefit of the participants is based on the interaction with the other market side. The total number of participants of the two market sides is essential for the approach, since each participant of each market side is charged with the calculated membership fee of the platform. The demand function of the supplier utility function ($\phi(u)^{\text{S}}$) and the demand function of the buyer utility function ($\phi(u)^{\text{B}}$) describe the number of the participants n^{S} and n^{B} of one group for a given level of utility u^{S} and u^{B}.

$$\begin{aligned} n^{\text{S}} &= \phi^{\text{S}} \left(u^{\text{S}}\right) \\ n^{\text{B}} &= \phi^{\text{B}} \left(u^{\text{B}}\right) \end{aligned} \tag{3.6}$$

The per supplier costs (c_{m}^{S}) and the per buyer costs (c_{m}^{B}) are considered to define the total profit of the platform.

$$\begin{aligned} \Pi^{\text{P}} = {} & \phi^{\text{S}} \left(u^{\text{S}}\right) \left[b^{\text{S}} \phi^{\text{B}}(u^{\text{B}}) - u^{\text{S}} - c_{\text{m}}^{\text{S}}\right] \\ & + \phi^{\text{B}}(u^{\text{B}}) \left[b^{\text{B}} \phi^{\text{S}} \left(u^{\text{S}}\right) - u^{\text{B}} - c_{\text{m}}^{\text{B}}\right] \end{aligned} \tag{3.7}$$

Hagiu (2009) bases his analysis on the previous pricing approach, since he also includes fixed membership fees in his model. He focuses on the impacts of differentiated number of products (η) and horizontal differentiation of buyers

($\theta_{\mathrm{h}}^{\mathrm{B}}$) to determine the net profit of the buyers by considering fixed membership fees.

$$\mathrm{Net}^{\mathrm{B}} = u^{\mathrm{B}}(\eta) - P^{\mathrm{B}} - \theta_{\mathrm{h}}^{\mathrm{B}}, \quad \theta_{\mathrm{h}}^{\mathrm{B}} \in (0,1) \tag{3.8}$$

Similar to the calculation of the net profit of the buyers, the net profit of the suppliers also considers fixed membership fees. The profit function of suppliers (π) is multiplied by the cumulative distribution function of buyers ($F(\theta_{\mathrm{h}}^{\mathrm{B}})$) of the horizontal differentiation of the marginal buyer ($\theta_{\mathrm{m}}^{\mathrm{B}}$) to model the benefit of participating on the platform of the supplier market side. The membership fees of the supplier market side P^{S} are subtracted by the horizontal differentiation of suppliers ($\theta_{\mathrm{h}}^{\mathrm{S}}$) to generate the net profit of the suppliers.

$$\mathrm{Net}^{\mathrm{S}} = \pi(\eta) \cdot F\left(\theta_{m}^{\mathrm{B}}\right) - P^{\mathrm{S}} - \theta_{\mathrm{h}}^{\mathrm{S}}, \quad \theta_{\mathrm{m}}^{\mathrm{B}}, \theta_{\mathrm{h}}^{\mathrm{S}} \in (0,1) \tag{3.9}$$

A fundamental assumption of his pricing approach is that each supplier sells exactly one product so that the number of products equals the number of suppliers. The total profit of the platform is affected by the total number of participants on the platform and the number of membership fees.

$$\Pi^{\mathrm{P}} = P^{\mathrm{B}} \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) + P^{\mathrm{S}} \cdot \eta \tag{3.10}$$

The presented pricing approaches form the foundation of the modelling framework of the two-sided market pricing literature by including indirect network effects into their pricing structure. They serve as the basis for expanding and developing two-sided market pricing models.

3.2 Morphological Analysis

The fundamental literature of two-sided market approaches is expanded to analyse specific requirements of the underlying applications and dependencies within the pricing models. The similarities of the pricing approaches of Section 3.1 are

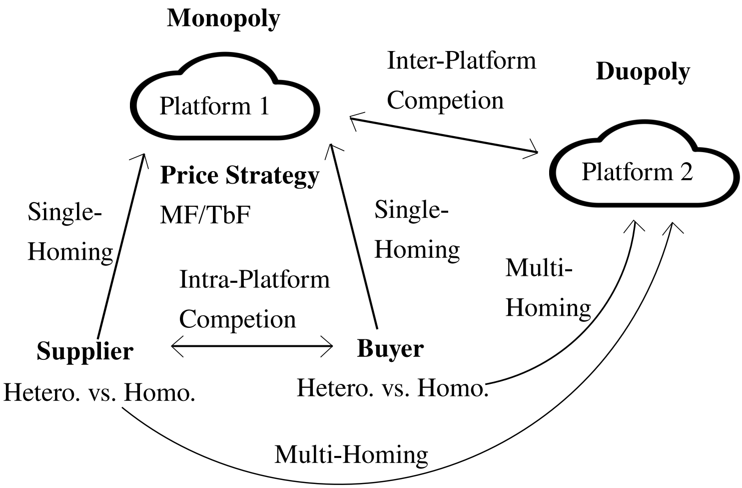

Figure 3.2: Determining Factors of the CMfg Two-Sided Market Approaches

analysed to identify the determining factors of two-sided market models. Based on this analysis, eight determining factors are identified. Figure 3.2 summarises these factors of the pricing approach.

The first determining factor describes the market situation of the pricing model of the CMfg platform, which influences the modelling framework for the remaining determining factors. The market situation can be modelled as monopoly (MP), duopoly (DP) or oligopoly (OP). Depending on this, the homing strategies of the participants between the different platforms are examined. In a monopoly market, the customer can only single-home (SH). In a duopoly or oligopoly market situation, the two-market groups can individually be modelled to Single- or multi-home (MH). The platform can choose to set entrance fees, differentiated into membership fees (MF), transaction-based fees (TbF) or a combination of both.

Another criterion is the intra-platform competition (iC) within one market side group. Other aspects are the product variety (V) offered by the CMfg platform and the separation into groups (Gr) on one market side. If customers are separated into groups, they are considered to be homogeneous (homo) within their group but heterogeneous (hetero) across different groups. The last two determining factors of the analysis are the heterogeneity and homogeneity of the buyer and supplier market side, which affect the complexity of the pricing approaches. Based on the identified determining factors, the expansion of the two-sided market factors can be clustered into six categories:

- Intra-platform competition
- Heterogeneity vs. homogeneity
- Homing strategies
- Separation into market groups
- CMfg pricing approaches
- Supplementary approaches

Next, the two-sided market literature is systematically analysed by categorising the literature into clusters based on the determining factors. Since only two approaches concentrate on the specifics of the CMfg platform market, pricing models are analysed to understand the general modelling approach of two-sided market pricing models. A first impression of the existing literature of two-sided market pricing models is presented by Liu et al. (2018). In contrast, and as an expansion to their examination, the two-sided market pricing approaches are clustered based on the identified determining factors. A morphological analysis, based on Ritchey (2018), is conducted to categorise the selected pricing approaches. The elements of the mathematical models are discussed in-depth and accordingly prepared to gain a detailed understanding of the approaches. A unified notation is introduced to compare the pricing approaches and to standardise them. A standard modelling procedure for each cluster is developed. This is the foundation to model a two-sided market pricing approach for a CMfg platform. A total number of 73 articles are identified, which contain the required determining factors. Only 37 of the articles include all eight determining factors in their pricing model. Since the modelling of the eight determining factors is

Table 3.1: Literature Review of Two-Sided Market Pricing Models

Cluster Pricing Models	Identified Models	Selected Models
Intra-platform competition	22	9
Heterogeneity vs. homogeneity	21	12
Homing strategies	7	5
Separation into market groups	2	2
CMfg pricing approaches	12	2
Supplementary approaches	9	7
Total number of pricing models	73	37

elementary to develop a CMfg pricing approach, the analysis will focus on the 37 articles and disregard the other 36 articles. The assignment of the articles to the individual clusters can be found in Table 3.1 (Tranfield et al. 2003).

The identified 37 pricing models are analysed in detail beginning with Section 3.2.1. The pricing approaches base their pricing model on the framework of the underlying market situation. Each cluster examines the assigned pricing approaches in order from monopoly to duopoly to oligopoly. Similarly, each pricing model bases its pricing strategy on membership, transaction-based or mixed fees. The effects of the market situations and the pricing strategy are already considered in all six clusters. The impacts of product variety are closely related to the introduction of heterogeneity, these factors will be analysed together. The target of the morphological analysis is to generate transparency of the relevant determining factors of the pricing models and understand how the components are connected and influence each other. Due to the complexity of the modelling approaches, some analysed articles consider more than one category. For this reason, these approaches are clustered based on the determining factor that has a significant effect on the pricing model.

3.2.1 Intra-Platform Competition

Intra-platform competition considers participants, which are not only interested in the other market side members, but also interested in participants of the same market group. This factor examines the competition between participants of one market side leading to negative network effects within the own group (Hagiu 2004). Nine pricing approaches are selected to analyse the impacts of intra-platform competition on the two-sided market pricing model. These approaches fulfil the requirements of the morphological analysis by containing the relevant determining factors.

The results of the morphological analysis can be found in Table 3.2. The majority of the approaches in the existing literature are modelled in the market situation of a monopoly. All pricing models only consider single-homing participants. Most of the models determine a fixed membership fee pricing structure. Half of the approaches contain differentiated products, and none of the models examine the effects of separation into groups. Pricing models with homogeneous or heterogeneous supplier and buyer market sides are analysed to the same extent.

The pricing approach of Belleflamme and Peitz (2019a) contains aspects of intra-platform competition on the supplier market side by expanding the pricing model of Hagiu (2009). They analyse the two-sided market pricing mechanism, considering a market situation with only one existing platform. In the monopoly market situation with fixed membership fees, they examine the intra-platform competition only on the supplier market side.

The net profit of the buyer market side and the net profit of the supplier market side include the stand-alone platform value (r) of the platform as well as the functions π (n^{S},n^{B}) and u^{B} (n^{S},n^{B}), which model the benefit of the interaction between the two market sides.

$$\begin{aligned} \mathrm{Net}^{\mathrm{B}} &= r^{\mathrm{B}} + u^{\mathrm{B}}\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) - P^{\mathrm{B}} \\ \mathrm{Net}^{\mathrm{S}} &= r^{\mathrm{S}} + \pi\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) - P^{\mathrm{S}} \end{aligned} \tag{3.11}$$

Table 3.2: Morphological Analysis for Pricing Models Including Intra-Platform Competition

Publication	Determining Factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Belleflamme (2019)	MP	SH(S,B)	MF(S,B)	✓	✓	-	homo	hetero
Angelini (2019)	MP	SH(S,B)	MF(S,B),TbF(S)	✓	✓	-	homo	hetero
Lin (2014)	MP	SH(S,B)	MF(S,B)	✓	-	-	hetero	homo
Kurucu (2008)	MP	SH(S,B)	MF(S,B)	✓	-	-	hetero	hetero
Nocke (2007)	MP	SH(S,B)	TbF(S)	✓	✓	-	hetero	hetero
Belleflamme (2009)	DP	SH(S,B)	MF(S,B)	✓	-	-	homo	homo
Belleflamme (2016)	DP	SH(S,B)	MF(S,B)	✓	✓	-	hetero	hetero
Bardey (2014)	DP	SH(S,B)	MF(S,B)	✓	-	-	homo	homo
Li (2011)	MP	SH(S,B)	MF(S,B)	✓	-	-	homo	homo

The profit function of the platform consists of the number of suppliers and buyers multiplied by their membership fees, minus the cost per supplier and buyer.

$$\Pi^{\mathrm{P}} = n^{\mathrm{B}} \left(P^{\mathrm{B}} - c_{\mathrm{m}}^{\mathrm{B}} \right) + n^{\mathrm{S}} \left(P^{\mathrm{S}} - c_{\mathrm{m}}^{\mathrm{S}} \right) \tag{3.12}$$

Angelini et al. (2019) follow the approach of the previous authors by determining the effects of intra-platform competition on the supplier market side for a monopoly market situation. Their model is based on the utility and profit functions introduced in the Equations 3.11. Additionally, they introduce investment costs for the development and maintenance of a platform. By introducing investment costs, they consider the relevance of constant quality improvements of the platform and their effects on the two customer groups.

In contrast to the previous models, the pricing approach of Lin et al. (2014) are not dependent on the interaction of the two market sides, but on all market components as a whole. In fact, the pricing model is managed through a change of parameters, which leads to an adoption of platform entry fees. Their model includes positive indirect network effects by Equation 3.13 and negative intra-platform competition by Equation 3.14, which emphasises that the platform can manage network effects by influencing the number of buyers through an according pricing mechanism.

$$\frac{\mathrm{Net}^{\mathrm{s}} (\pi)}{n^{\mathrm{B}}} > 0 \tag{3.13}$$

$$\frac{\mathrm{Net}^{\mathrm{s}} (\pi)}{n^{\mathrm{B}}} < 0, \tag{3.14}$$

Another approach is developed by Kurucu (2008) who analyses the negative intra-platform competition of an online dating platform. Particularly, he models the net profit of both market sides similarly to analyse their behaviour, which is differentiated by their type. The net profit considers positive cross-group effects of the interaction with participants of the other market side. The intra-platform competition is modelled by a high ratio of own group participants in comparison to participants of the other market side.

$$\mathrm{Net}^{\mathrm{B}} = \left(n^{\mathrm{B}}\right)^{y} \cdot \left(\frac{n^{\mathrm{B}}}{n^{\mathrm{S}}}\right)^{1-y} - P^{\mathrm{B}} \tag{3.15}$$

Nocke et al. (2007) introduce a pricing approach of a theoretical framework containing an ownership structure, in which the suppliers can purchase predefined trading spots on a platform. The net profit of the type of suppliers (k) depends on the current volume and price of sold slots (p^{r}).

$$\mathrm{Net}_{\mathrm{k}}^{\mathrm{S}} = n_{\mathrm{i}}^{\mathrm{B}} \cdot \pi_{\mathrm{k}}^{\mathrm{S}} - P^{\mathrm{S}}\left(n_{\mathrm{k}}^{\mathrm{S}}\right) - p^{\mathrm{r}}, \quad k, i \in \mathbb{N} \tag{3.16}$$

This influences the number of every paid single spot and models the intra-platform competition of the suppliers regarding platform spots.

Belleflamme and Toulemonde (2009) are among the first authors to model a two-sided market pricing strategy of a duopoly market situation while including the effects of intra-platform competition. They differentiate their analysis by considering one platform with no entrance fees and one platform with membership fees. The platform participants of both groups only single-home. The basic assumption is that due to positive inter-platform interactions, the utility functions are increasing through an increasing number of members of the other group.

$$\begin{aligned} u^{\mathrm{B}}\left(n^{\mathrm{B}}, n^{\mathrm{S}+1}\right) > u^{\mathrm{B}}\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) \\ u^{\mathrm{S}}\left(n^{\mathrm{B}+1}, n^{\mathrm{S}}\right) > u^{\mathrm{S}}\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) \end{aligned} \tag{3.17}$$

In addition to the positive inter-platform competition, the utility functions also include the negative intra-platform competition between members of the same group.

$$\begin{aligned} u^{\mathrm{B}}\left(n^{\mathrm{B}+1}, n^{\mathrm{S}}\right) &\leq u^{\mathrm{B}}\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) \\ u^{\mathrm{S}}\left(n^{\mathrm{B}}, n^{\mathrm{S}+1}\right) &\leq u^{\mathrm{S}}\left(n^{\mathrm{B}}, n^{\mathrm{S}}\right) \end{aligned} \tag{3.18}$$

As members prefer to interact on a platform with a lower number of participants of their own group, intra-platform competition can be referred to as intra-group rivalry.

Belleflamme and Toulemonde (2016) model a duopoly market situation. The framework of the pricing game is defined by asymmetric equilibrium. Changes in the interaction between suppliers and buyers affect the modelling framework and hence the equilibrium prices. As a result, it is proved that platforms prefer no variety of products, while the participants of platforms favour a higher differentiation. Since the platform business model is based on the entrance fees of the two market sides, the platform has to balance their own preference to reduce the variety with the varying demand of their customers to increase their total profit.

Besides, Bardey et al. (2014) examine a duopoly market situation, focusing on the health and education sector requirements. The model measures negative network effects by the intensity of competition on one market side regarding a predefined quality on the other market side. In contrast to common pricing approaches, intra-platform competition negatively affects the buyer but not the supplier market side.

Li et al. (2011) analyse the specific application of an e-marketplace by examining a pricing approach in a monopoly market situation. They determine the impacts of intra-platform competition by proceeding similarly to the previous authors. They also include a decreasing profit function by an increasing number of suppliers. The demand and profit functions are analysed and compared to conventional businesses so that the platform can maximise its revenue strategy.

In summary, they examine practical strategies for e-marketplaces based on the theoretical studies of the pricing mechanism.

All presented pricing models include intra-platform competition by considering the ratio of same group participants to participants of the other market side. Next, the influences of heterogeneity and homogeneously are analysed.

3.2.2 Heterogeneity versus Homogeneity

The pricing mechanism of two-sided market models assumes that the buyer and supplier market side participants are homogeneous, to simplify the models. Further, to increase the accuracy of the models, heterogeneity of horizontal and vertical differentiated customer groups is added into the pricing models. Twelve pricing models are analysed, which include heterogeneous and homogeneous differentiation in their pricing models. The results of the morphological analysis of these pricing models are presented by Table 3.3.

The majority of the pricing approaches in the existing literature consider a single-homing strategy. All models include membership fees for at least one market side, most even for both market sides. Only two articles include intra-platform competition, and no approach examines the impacts of separation into groups. All pricing approaches analyse the influence of at least one heterogeneous market side, half of the approaches model heterogeneity on the supplier and buyer market side.

One of the first approaches to include heterogeneity is modelled by Viecens (2009), who expands the pricing approach of Hagiu (2009). She provides a pricing model of a monopoly market situation, in which the pricing strategy of the platform depends on the pricing strategy of the producers and the taste for variety by the buyers.

Table 3.3: Morphological Analysis for Pricing Models Including Heterogeneity versus Homogeneity Pricing Approaches

Publication	Determining Factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Viences (2009)	MP	SH(S,B)	MF(S,B),TbF(B)	✓	✓	-	homo	hetero
Galeotti (2009)	MP	SH(S,B)	MF(S,B)	✓	✓	-	homo	hetero
Roger (2017)	DP	SH(S,B)	MF(S,B)	-	✓	-	homo	hetero
Salim (2010)	DP	SH(S,B)	MF(S,B)	-	✓	-	hetero	hetero
Gabszewicz (2004)	DP	SH(S,B)	MF(S,B)	-	✓	-	hetero	hetero
Gabszewicz (2012)	DP	MH(S,B)	MF(S,B)	-	✓	-	hetero	hetero
Gabszewicz (2014)	DP	SH(B),MH(S)	MF(S,B)	-	✓	-	hetero	hetero
Ribeiro (2016)	DP	MH(S,B)	MF(S,B)	-	✓	-	hetero	hetero
Zennyo (2016)	DP	SH(B),MH(S)	MF(B),TbF(S)	-	✓	-	hetero	hetero
Chakravorti (2006)	DP	SH(B),MH(S)	MF(B),TbF(S)	-	✓	-	hetero	hetero
Argenziano (2008)	DP	SH(S),MH(B)	MF(S,B)	-	✓	-	hetero	hetero
Tan (2017)	OP	SH(S,B)	MF(S,B)	-	✓	-	homo	homo

The net profit of the buyer market side includes their preference for the variety of the purchased products ($V_{\mathrm{m}}^{\mathrm{B}}$), which affects the progression of the utility function of the buyers. The platform differentiation (γ_{p}) is multiplied by the distance parameter on the linear city (t). d'Aspremont et al. (1979) define the linear city as the distribution of the customers between $[0, 1]$, which are modelled as the extreme point location on the linear city ($(x, x-1)$). For travelling along the linear city, the distance parameter t is considered. The net profit of the buyer market side is calculated by subdividing γ_{p} and t from the utility of the buyers.

$$\mathrm{Net}^{\mathrm{B}} = u^{\mathrm{B}}\left(V_{\mathrm{m}}^{\mathrm{B}}\right) - \gamma_{\mathrm{p}} \cdot t \tag{3.19}$$

The total demand of buyers (D^{B}) is dependent on the variety of the products within their product bundle (G_{η}) including the variety of the products, the membership fees of the sellers and the price of variety (p_{γ}). The demand per buyer (d^{B}) can be zero for no demand or 1 so that this buyer demands every product of the platform.

$$D^{\mathrm{B}} = \frac{1}{\gamma_{\mathrm{p}}} G_{\eta}\left(V_{\mathrm{m}}^{\mathrm{B}}, P^{\mathrm{S}}, \sum_{\gamma=1}^{V_{\mathrm{m}}^{\mathrm{B}}} p_{\gamma}\right), \quad d^{\mathrm{B}} \in [0, 1] \tag{3.20}$$

The modelling of the optimal product bundle of the customer is a unique extension of common pricing mechanisms. The net profit of each supplier k is dependent on the demand of buyers, the fixed cost of production of suppliers (K^{S}) and the membership fees of the suppliers.

$$\mathrm{Net}_{\mathrm{k}}^{\mathrm{S}} = \pi_{\mathrm{k}}^{\mathrm{S}} \cdot D^{\mathrm{B}} - K^{\mathrm{S}} - P^{\mathrm{S}}, \quad k \in \mathbb{N} \tag{3.21}$$

In conclusion, the decision of the buyer side to purchase on the platform is highly dependent on the price structure of the producer, which defines the platform profit function.

$$\Pi^{\mathrm{P}} = P^{\mathrm{B}} \cdot D^{\mathrm{B}} + P^{\mathrm{S}} \cdot n^{\mathrm{S}} \tag{3.22}$$

Galeotti and Moraga-Gonzalez (2009) analyse a pricing approach of a monopoly market situation. The producers are assumed to be horizontally differentiated and compete with their pricing structures. The homogeneous buyers of the platform are interested in differentiated products and choose the products accordingly to maximise their utility. Later in the article, they relax their assumption so that outside trading without platform participation is possible.

The two-sided market model of Roger (2017) introduces a pricing mechanism including heterogeneity by modelling vertically differentiated products in a duopoly market. The pricing mechanism covers the special application of the newspaper industry and includes a competition of both market sides. The platform customers either want to purchase a newspaper or advertise their products or services in the newspaper. Each of the two platforms j produces a newspaper, which homogeneous readers demand. Horizontally differentiated advertisers can demand an advertising spot in the newspaper. The net profit of the customers include the differentiation of products (γ_η) as a quality measurement for each product.

$$\mathrm{Net}^{\mathrm{B}} = \gamma_\eta \cdot b^{\mathrm{B}} - P_{\mathrm{j}}^{\mathrm{B}}, \quad \mathrm{j} = 1, 2;\ \gamma_\eta \in (0, 1) \tag{3.23}$$

The two platforms compete directly for participants from both groups, which is significant for the single-homing behaviour of the participants. If it is possible to generate a larger share for one platform on the buyer market side, it is assumed that more advertisers from the other side prefers to participate on this platform.

Salim (2010) introduces a pricing model in a duopoly market situation, including incentives for the producer market side to offer a wide range of differentiated products. The net profit of the buyer market side contains a baseline utility (u^0), which measures a benefit of the buyer by joining the platform. The total degree of quality (q) of both platforms j combined and the quality degree of the quality on platform 1 (q_1) and the quality on platform 2 (q_2) separately is also included in the net profit of buyers.

$$\mathrm{Net}_{\mathrm{j}}^{\mathrm{B}} = u^0 + 2 \cdot q_{\mathrm{j}} \cdot n_{\mathrm{j}}^{\mathrm{S}} + (q_1 + q_2) \cdot \left(1 - n_{\mathrm{j}}^{\mathrm{S}}\right), \quad j = 1, 2 \tag{3.24}$$

This differentiation in quality can lead to investment motivation to further expand the variety of products.

Gabszewicz and Wauthy (2004) model a duopoly market situation with a vertically differentiated framework by considering the effects of product differentiation through inter-network effects. The model analyses the perceived value of inter-platform network effects of heterogeneously differentiated group members by the vertical differentiation of buyers ($\theta_{\mathrm{v}}^{\mathrm{B}}$). Besides, the modelling approach considers two different homing strategies. The first homing strategy only allows participants of both sides to single-home by including the expected number of participants (n_{e}). The net profit of this strategy determines the utility for the buyer market side to only participate on one platform.

$$\mathrm{Net}^{\mathrm{B}} = \theta_{\mathrm{v}}^{\mathrm{B}} \cdot n_{\mathrm{e}}^{\mathrm{S}} - p^{\mathrm{B}}, \quad \theta_{\mathrm{v}}^{\mathrm{B}} \in (0,1) \tag{3.25}$$

The second strategy enables both sides to multi-home. The net profit includes the benefit the buyer expects by participating on both platforms, minus the fixed membership fees of buyers on platform 1 (P_1^{B}) and fixed membership fees of buyers on platform 2 (P_2^{B}).

$$\mathrm{Net}^{\mathrm{B}} = \theta_{\mathrm{v}}^{\mathrm{B}} \cdot n_{\mathrm{j}}^{\mathrm{S}} - P_1^{\mathrm{B}} - P_2^{\mathrm{B}}, \quad \mathrm{j} = 1, 2,\ \theta_{\mathrm{v}}^{\mathrm{B}} \in (0,1) \tag{3.26}$$

Gabszewicz and Wauthy (2014) expand their price model by comparing two different strategies to solve the duopoly competition. The equilibrium price is determined by an analysis based on the network size and by considering a price-based approach. The net profit function is applied for the analysis of both strategies.

$$\begin{aligned} \mathrm{Net}^{\mathrm{B}} &= \theta_{\mathrm{v}}^{\mathrm{B}} \cdot n_{\mathrm{j}}^{\mathrm{S}} - P_j^{\mathrm{B}}, \quad \mathrm{j} = 1, 2;\ \theta_{\mathrm{v}}^{\mathrm{B}} \in (0,1) \\ \mathrm{Net}^{\mathrm{S}} &= \theta_{\mathrm{v}}^{\mathrm{B}} \cdot n_{\mathrm{j}}^{\mathrm{B}} - P_j^{\mathrm{S}}, \quad \mathrm{j} = 1, 2;\ \theta_{\mathrm{v}}^{\mathrm{B}} \in (0,1) \end{aligned} \tag{3.27}$$

Gabszewicz and Wauthy (2012) also develop a different pricing approach by including horizontal and vertical differentiation. They introduce a variation of the Hotelling model, in which the density of the participating firms is different on each market side and participants are located at the extreme points $[0, 1]$ by $(x, x - 1)$ of the linear city (Jeitschko et al. 2018). Figure 3.3 shows the linear city on which the participating firms X_{n} are distributed.

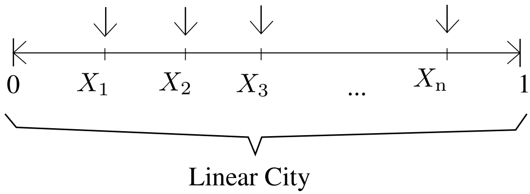

Figure 3.3: Linear City of a Two-Sided Market Pricing Model

Both market sides can travel along the linear city by paying linear transportation costs to get closer to their designated platform. The asymmetry in the participating density represents the vertical differentiation of the platform participants.

Ribeiro et al. (2016) introduce a pricing mechanism that aligns the aspects of the pricing model of the previous authors with the pricing approach of Armstrong (2006). The horizontal and vertical differentiation of the model of Gabszewicz and Wauthy (2012) is extended by the assumption that membership fees of one market side increase if the fees of the other market side decrease to balance the number of customers of both market sides. The pricing approach considers that the lower quality firm interacts more competitively due to a lower average participant density, combined with an increasing marginal participant density. In equilibrium, the platform contains higher quality products with a greater market share. The sold number of products is higher on a platform that offers lower quality products, summarised with its stand-alone platform value r. The net profit of the buyer market side includes the extreme point location on the linear city $(x, x - 1)$.

$$\begin{aligned} \mathrm{Net}_1^{\mathrm{B}}(x) &= r^{\mathrm{B}} + b^{\mathrm{B}} \cdot n_1^{\mathrm{S}} - p_1^{\mathrm{B}} - x \\ \mathrm{Net}_2^{\mathrm{B}}(x) &= r^{\mathrm{B}} + b^{\mathrm{B}} \cdot n_2^{\mathrm{S}} - p_2^{\mathrm{B}} - (1 - x) \end{aligned} \tag{3.28}$$

The net profit of the suppliers is similar to the buyer net profit.

Zennyo (2016) analyses a pricing mechanism of a duopoly market situation. The two platforms are separated into platforms, which either offer high-quality or low-quality devices. Platforms determine the prices of the offered hardware devices for the buyer market side. Also, software producers develop software according to the offered hardware and are charged a royalty rate by the platform. The net profit of the buyer market side includes the vertical differentiation of buyers and is independent of the low- and high-quality hardware devices and the developed software.

$$\mathrm{Net}_{\mathrm{j}}^{\mathrm{B}} = \theta_{\mathrm{v}}^{\mathrm{B}} \cdot q_{\mathrm{j}} + b^{\mathrm{B}} \cdot n^{\mathrm{S}} - P_{\mathrm{j}}^{\mathrm{B}}, \quad \mathrm{j} = 1, 2;\ \theta_{\mathrm{v}}^{\mathrm{B}} \in (0, 1) \tag{3.29}$$

As the hardware devices can change in quality, the hardware prices are chosen asymmetrically. The royalty fees for the developer are charged symmetrically, so that in equilibrium a platform offering lower-quality products could receive a higher profit share than the rival platform. The higher development costs are based on the complex software development for high-quality devices.

Chakravorti and Roson (2006) formulate a two-sided market pricing model for a competitive payment network. The pricing mechanism focuses on the individual benefit of each customer, which is created by the product differentiation on both market sides. Their net profit contemplates the impact of the network-specific benefit for each payment service and each participant i of the buyer and supplier market side.

$$\begin{aligned} \mathrm{Net}^{\mathrm{B}} &= \max\{0, b_{1,\mathrm{i}}^{\mathrm{B}}, n_2^{\mathrm{S}} - P_1^{\mathrm{B}}, b_{2,\mathrm{i}}^{\mathrm{B}}, n_2^{\mathrm{S}} - P_2^{\mathrm{B}}\} \\ \mathrm{Net}^{\mathrm{S}} &= \max\{0, \left(b_{1,\mathrm{i}}^{\mathrm{S}} - P_1^{\mathrm{S}}\right) \cdot n_1^{\mathrm{B}}\} + \max\{0, \left(b_{2,\mathrm{i}}^{\mathrm{S}} - P_2^{\mathrm{S}}\right) \cdot n_2^{\mathrm{B}}\} \end{aligned} \tag{3.30}$$

Through the analysis of various market equilibria, the competition leads to a definite increase of welfare for all participants of the payment network. By expanding the pricing model, similar results are achieved by establishing differentiated payment instruments. As a result, marginal prices are calculated, which provide details of pricing effects on both market sides.

Argenziano (2008) models a pricing approach of a duopoly market situation, including product differentiation. The net profit of the buyer market side contains differentiation in $\theta_{\mathrm{v}}^{\mathrm{B}}$ and the idiosyncratic component (I).

$$\mathrm{Net}_{\mathrm{j}}^{\mathrm{B}} = \theta_{\mathrm{v,j}}^{\mathrm{B}} + I_{\mathrm{j}} + \eta_{\mathrm{j}} - P^{\mathrm{B}}, \quad j = 1, 2,\ \theta_{\mathrm{v}}^{\mathrm{B}} \in (0, 1) \tag{3.31}$$

Idiosyncratic defines that products reach a specific quality required by the buyers. The equilibrium pricing allocation considers indispensable and sufficient requirements, which are formulated for predetermined prices. The definition of requirements for the pricing model sets reliable assumptions for the network. The equilibria differ due to the level of asymmetry of the two-sided market pricing model. One of the reasons for the platform asymmetry is found in the similarity of platform participants. Besides, firms can align their product prices so that firms with higher quality products obtain a larger profit share. As a result, the asymmetry of the pricing mechanism decreases.

Tan and Zhou (2017) pioneer a two-sided market pricing approach for an oligopoly market situation. The pricing model focuses on the specific tastes of both market sides by considering intra- and inter-platform effects. In an asymmetric market situation with full market coverage, a simple price symmetry equilibrium is analysed. The net profit of the buyer market side includes the degree of product differentiation.

$$\mathrm{Net}_{\mathrm{j}}^{\mathrm{B}} = u^{0} + r_{\mathrm{j}}^{\mathrm{B}} + u^{\mathrm{B}}\left(V_{\mathrm{m,j}}^{\mathrm{B}}\right) - P_{\mathrm{j}}^{\mathrm{B}}, \quad j \in \mathbb{N} \tag{3.32}$$

Platforms are able to subsidise a market side by decreasing the membership fees of this market side. With an increase in competition among platforms, the effects of the production differentiation and the cross-subsidy decline.

In summary, vertical and horizontal differentiation of customers as well as product variety is introduced by multiple approaches into the pricing mechanism. Most of the presented approaches include the impacts of the vertical differentiation of suppliers ($\theta_{\mathrm{v}}^{\mathrm{S}}$) and buyers $\theta_{\mathrm{v}}^{\mathrm{B}}$ as well as the horizontal differentiation of suppliers $\theta_{\mathrm{h}}^{\mathrm{S}}$, and buyers $\theta_{\mathrm{h}}^{\mathrm{B}}$. The integration of these parameters into the net profit of buyer and supplier is defined as one standard approach for the inclusion of differentiation.

$$\begin{aligned} \mathrm{Net}^{\mathrm{B}} &= \theta_{\mathrm{v}}^{\mathrm{B}} \cdot u\left(\eta^{\mathrm{B}}\right) - P^{\mathrm{B}} - \theta_{\mathrm{h}}^{\mathrm{B}}, \quad \theta_{\mathrm{v}}^{\mathrm{B}},\, \theta_{\mathrm{h}}^{\mathrm{B}} \in (0,1) \\ \mathrm{Net}^{\mathrm{S}} &= \theta_{\mathrm{v}}^{\mathrm{S}} \cdot \pi\left(\eta^{\mathrm{S}}\right) \cdot F\left(\theta_{m}^{\mathrm{B}}\right) - P^{\mathrm{S}} - \theta_{\mathrm{h}}^{\mathrm{S}}, \quad \theta_{\mathrm{m}}^{\mathrm{B}},\, \theta_{\mathrm{v}}^{\mathrm{S}},\, \theta_{\mathrm{h}}^{\mathrm{S}} \in (0,1) \end{aligned} \tag{3.33}$$

The vertical differentiation influences the progression of the utility function and the profit function. They show a stronger increase of their net profit when $\theta_{\mathrm{v}}^{\mathrm{S}}$ and $\theta_{\mathrm{v}}^{\mathrm{B}}$ takes a value closer to 1 and a stronger decrease when $\theta_{\mathrm{h}}^{\mathrm{S}}$ and $\theta_{\mathrm{h}}^{\mathrm{B}}$ is closer to 0. This is based on the assumption that the participants value a heterogeneous customer structure higher than homogeneous customer types. The horizontal differentiation $\theta_{\mathrm{h}}^{\mathrm{S}}$ and $\theta_{\mathrm{h}}^{\mathrm{B}}$ represents the differentiation of the customers on the platform. Consequently, the combination of the parameters $\theta_{\mathrm{v}}^{\mathrm{S}}$, $\theta_{\mathrm{v}}^{\mathrm{B}}$, $\theta_{\mathrm{h}}^{\mathrm{S}}$ and $\theta_{\mathrm{h}}^{\mathrm{B}}$ determine the vertical and horizontal differentiation of the platform.

3.2.3 Homing Strategies

In a two-sided market situation with more than one platform, customers of both market sides can choose their homing strategy. They decide to either participate exclusively by single-homing or interact with more than one platform by multi-homing (Armstrong 2006). Through the pricing approach of the platform, it is beneficial for the two market sides to adapt a homing strategy based on the behaviour of the other market side. Table 3.4 contains the morphological analysis of five articles, which focus their pricing approach on the influences of the homing strategy. A fundamental precondition to effectively analyse homing strategies is that all models are based on a duopoly market situation. The morphological analysis shows that none of the presented approaches includes transaction-based fees, impacts of intra-platform competition or separation into groups due to the increase of complexity these aspects would have on the pricing approaches. The majority of the models assume differentiated products. All pricing models analyse the implications of at least one heterogeneous market side.

Table 3.4: Morphological Analysis for Pricing Models Including Homing Strategies

Publication	Determining Factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Belleflamme (2019b)	DP	SH(S,B)	MF(S,B)	-	✓	-	hetero	hetero
	DP	SH(B),MH(S)	MF(S,B)	-	✓	-	hetero	hetero
Armstrong (2007)	DP	SH(B),MH(S)	MF(S,B)	-	✓	-	hetero	homo
Choi (2010)	DP	SH(B),MH(S)	MF(S)	-	✓	-	homo	hetero
	DP	MH(S,B)	MF(S)	-	✓	-	homo	hetero
Jeitschko (2020)	DP	SH(S,B),MH(S,B)	MF(S,B)	-	-	-	hetero	hetero
Rasch (2007)	DP	SH(S),MH(B)	MF(S,B)	-	✓	-	hetero	homo

Belleflamme and Peitz (2019b) formulate a pricing approach based on the model of Armstrong (2006). They analyse the impacts of differentiated homing strategies towards the price structure, the revenue of the platform and the profit of the participants. The supplier and buyer market side are indifferent to joining platform 1 or 2 due to an equal value of r and opportunity costs (c^{τ}) so that different homing strategies are analysed based on the distributions of participants.

$$\begin{aligned} r_1^{\mathrm{S}} - c^{\tau} \cdot x^{\mathrm{S}} &= r_2^{\mathrm{S}} - c^{\tau} \cdot \left(1 - x^{\mathrm{S}}\right) \\ r_1^{\mathrm{B}} - c^{\tau} \cdot x^{\mathrm{B}} &= r_2^{\mathrm{B}} - c^{\tau} \cdot \left(1 - x^{\mathrm{B}}\right) \end{aligned} \tag{3.34}$$

Platforms are assumed to be located on the extreme points $(x, x-1)$ of the linear city and the participants are uniformly distributed. Due to this assumption, single-homing participants of both market sides register equally on the platform in equilibrium. In the more complex case, in which one side of the market is enabled to multi-home, platforms compete to attract the multi-homing market side to join the platform exclusively. The reason for this is, to gain a benefit by generating a market situation similar to a monopoly market.

Armstrong and Wright (2007) analyse a two-sided market pricing approach in a duopoly market situation. The supplier market side considers the platform as homogeneous and the buyer market side as heterogeneous. The impacts of the homing strategies is analysed through the net profit of the suppliers. The net profit of the supplier on platform 1 includes the number of single-homing buyers ($n_{\mathrm{SH}}^{\mathrm{B}}$) of platform 1 and the number of multi-homing buyers ($n_{\mathrm{MH}}^{\mathrm{B}}$).

The net profit of platform 2 includes the buyers, who are single-home on platform 2 while there are also a number of multi-homing buyers. The net profit of a supplier who multi-homes includes the membership fees for both platforms and the numbers of single-homing buyers of both platforms. In addition, the transport costs of the suppliers on the linear city ($c_{\mathrm{t}}^{\mathrm{S}}$) are considered by the pricing model.

$$
\begin{aligned}
\mathrm{Net}_1^{\mathrm{S}} &= r^{\mathrm{S}} - P_1^{\mathrm{S}} - c_{\mathrm{t}}^{\mathrm{S}} \cdot x + b^{\mathrm{S}} \cdot \left(n_{\mathrm{SH},1}^{\mathrm{B}} + n_{\mathrm{MH}}^{\mathrm{B}}\right) \\
\mathrm{Net}_2^{\mathrm{S}} &= r^{\mathrm{S}} - P_2^{\mathrm{S}} - c_{\mathrm{t}}^{\mathrm{S}} \cdot (1-x) + b^{\mathrm{S}} \cdot \left(n_{\mathrm{SH},2}^{\mathrm{B}} + n_{\mathrm{MH}}^{\mathrm{B}}\right) \\
\mathrm{Net}_{1,2}^{\mathrm{S}} &= r^{\mathrm{S}} - P_1^{\mathrm{S}} - P_2^{\mathrm{S}} - c_{\mathrm{t}}^{\mathrm{S}} + b^{\mathrm{S}} \cdot \left(n_{\mathrm{SH},1}^{\mathrm{B}} + n_{\mathrm{SH},2}^{\mathrm{B}} + n_{\mathrm{MH}}^{\mathrm{B}}\right)
\end{aligned} \tag{3.35}
$$

Typical for analysing a duopoly market situation, the platform levies marginal membership fees on the buyer side of the market to increase their participation. Due to positive network effects, the number of buyers increases the willingness of suppliers to join the platform. The platform increases the membership fees to the supplier market side to subsidise the buyer side. Even though the membership fees are high for the supplier side, the suppliers still want to participate on the platform to interact with the buyer market side. The platform can provide exclusive contracts to sign up suppliers to participate on one platform to prevent multi-homing. Accordingly, the pricing game changes because the supplier market side participates on one platform exclusively so that the buyer market side has stronger preferences to join the platform, which contains a higher number of suppliers. On the contrary, the platform extracts more revenue from the buyer market by charging premium prices.

Choi (2010) analyses a pricing model containing multi-homing impacts, which considers tying effects by modelling an number of exclusive buyers (λ^{B}). Due to tying, platforms can offer customers access to platform-specific products, which increases the profit of the platform suppliers. Besides, tying increases the motivation of platform participants to multi-home. First, under tying only buyers are allowed to multi-home and the supplier market side remains single-homing. Second, this assumption is relaxed so that both market sides are allowed to multi-home.

$$
n_{\mathrm{MH}}^{\mathrm{B}} = \frac{\lambda^{\mathrm{B}} \cdot b^{\mathrm{B}} - P^{\mathrm{B}}}{\gamma_{\eta}} \tag{3.36}
$$

Jeitschko and Tremblay (2020) analyse a pricing model in which both market sides select their homing strategy endogenously. It is also conceivable that all producers single-home and customers select a mixed strategy with a net profit of the single-homing market side and a net profit of the multi-homing market side. The possibility of the pricing model to compare different homing-strategies creates the opportunity to evaluate the different market behaviours of the participants, which enhances the social welfare of the participants and platforms and results in a diminishing benefit per user (b_{d}).

$$\mathrm{Net}^{\mathrm{B}} = r^{\mathrm{B}} + b^{\mathrm{B}}\left(n^{\mathrm{S}}\right) \cdot n^{\mathrm{B}} - P^{\mathrm{B}} \tag{3.37}$$

$$\mathrm{Net}^{\mathrm{B}}_{1,2} = \left(1 + b^{\mathrm{B}}_{\mathrm{d}}\right) \cdot r^{\mathrm{B}} + b^{\mathrm{B}}\left(n^{\mathrm{S}}\right) \cdot n_{\mathrm{MH}} - P^{\mathrm{B}}_{1} - P^{\mathrm{B}}_{2} \tag{3.38}$$

Rasch (2007) develops a pricing approach by comparing the revenue share of a single-homing and a multi-homing market side. The net profit for the buyer market side is calculated based on single homing buyers. By travelling on the linear city the current location of the buyers on the linear city (Δ^{B}) is changed. The transport costs of the buyers on the linear city ($c^{\mathrm{B}}_{\mathrm{t}}$) is subdivided to calculate the net profit of the buyers. The net profit of a single-homing supplier includes the current location of the suppliers on the linear city (Δ^{S}) and their transportation costs on the linear city $c^{\mathrm{B}}_{\mathrm{t}}$.

$$\mathrm{Net}^{\mathrm{B}} = u^{0} + b^{\mathrm{B}} \cdot n^{\mathrm{S}} - P^{\mathrm{B}} - c^{\mathrm{B}}_{\mathrm{t}} \cdot \Delta^{\mathrm{B}}. \tag{3.39}$$

$$\mathrm{Net}^{\mathrm{S}} = u^{0} + b^{\mathrm{S}} \cdot n^{\mathrm{B}} - P^{\mathrm{S}} - c^{\mathrm{S}}_{\mathrm{t}} \cdot \Delta^{\mathrm{S}} \tag{3.40}$$

The net profit of a multi-homing supplier is subdivided by the membership fees of both platforms.

$$\mathrm{Net}^{\mathrm{S}}_{1,2} = u^{0} + b^{\mathrm{S}} - P^{\mathrm{S}}_{1} - P^{\mathrm{S}}_{2} - t^{\mathrm{S}}. \tag{3.41}$$

The pricing model can be adjusted if the supplier market side is only single-homing and the buyer market side applies a mixed homing strategy. In contrast to common approaches, which analyse the revenue generation through high membership fees on the multi-homing side of the market, this approach focuses on a different strategy. As soon as single-homing participants join one platform, the platform obtains the market power to connect the multi-homing participants.

It is common to locate platforms on the extreme points of a linear city $(x, x-1)$ considering the different pricing approaches and their homing strategies. A uniformly distributed customer can participate on one platform by travelling a distance of $t \cdot x$ and on the other platform by travelling $t \cdot (1-x)$. If participants register on a platform, they can interact with the participants of the other market side, which are also registered on this platform. If customers are multi-homing by registering on both platforms, they can interact with a larger number of other market side participants. However, the customers have to pay the membership fees set by both platforms so that it has to be examined individually for each pricing approach if the multi-homing strategy is beneficial for one or two market sides.

3.2.4 Separation into Market Groups

An expansion of two-sided market pricing models is the consideration of separated customer groups of one market side, since one market side participants are assumed to be heterogeneous in general but homogeneous within a customer group. The participants of the same market group are now categorised by their group-specific customer behaviour. Separated customer groups are only discussed in a few publications, as shown in Table 3.5. The two approaches are modelled in a duopoly market situation, based on different homing strategies and entrance fees. Suppliers and buyers both are considered to be either homogeneous or heterogeneous.

Reisinger (2014) analyses a pricing model in a duopoly market situation, which combines membership with transaction-based fees. Due to the complexity of the pricing mechanism, the merger of two different revenue strategies results in multiple equilibria. Two modelling frameworks are analysed. Firstly, homogeneous trading behaviour and secondly, a trading behaviour including heterogeneity on both market sides. A combination of the heterogeneous participants into the existing homogeneous pricing game is conducted. As a result, the incorporation of heterogeneity leads to an unambiguous equilibrium. Besides, aspects of the separation into groups are introduced into the heterogeneous pricing game by separating the two market sides into a small number of suppliers ($\left(1 - n_{\mathrm{s}}^{\mathrm{S}}\right)$) and a small number of buyers ($\left(1 - n_{\mathrm{s}}^{\mathrm{B}}\right)$) as well as into regular supplier n^{S} and buyer n^{B} groups. The trading volume of regular suppliers and buyers corresponds to the trading volume of the homogeneous pricing model. Accordingly, the model considers the trading volume of a small buyer with a regular supplier $((\alpha < 1))$, the trading volume of a regular buyer and a small supplier $((\beta < 1))$ and the trading volume of a regular buyer and a small supplier is $(\beta < 1)$ and $(\alpha \cdot \beta < \alpha, \beta)$ if both groups members are of small trading behaviour.

Filistrucchi and Klein (2015) describe a duopoly market situation including subdivided groups on one market side. The pricing model focuses on newsletter advertisements. The advertising is not only dependent on the number of newsletter readers, but also their characteristics. Newsletter publishers affect the composition of the newsletter readers due to their income structure, whereby the readers are separated according to high and low income. For this reason, the pricing approach also indicates the influences of differentiated trading behaviour within groups of the same market side.

The integration of separation into market groups allows conducting a more accurate analysis of a pricing mechanism because the behaviour of different customer groups are analysed. Integrating the effects of separation into groups is based on considering differentiated functions of the net utility or profit for a specific customer group. For example, the utility functions of one customer group increase or decrease stronger than the utility function of another group. A reason for this is that the groups value the interactions on the platform differently.

Table 3.5: Morphological Analysis for Pricing Models Including Separation into Market Groups

Publication	Determining Factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Reisinger (2014)	DP	SH(S,B)	MF,TbF(S,B)	✓	✓	✓	hetero	hetero
	DP	SH(B),MH(S)	MF,TbF(S,B)	-	-	✓	homo	homo
Filistrucchi (2015)	DP	MH(S,B)	MF(S,B)	-	-	✓	hetero	hetero

Table 3.6: Morphological Analysis for Pricing Models Including CMfg Pricing Approaches

Publication	Determining Factors							
	Determining factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Peng (2017)	MP	SH(S,B)	MF(S)	-	-	-	homo	homo
Pan (2019)	MP	SH(S,B)	MF(S)	-	-	✓	homo	homo

3.2.5 CMfg Pricing Approaches

Based on the literature research, only two publications are identified, which fulfil the required determining factors of the morphological analysis for the specific application of CMfg platforms. The two pricing models based their approaches on the assumption of a monopoly market situation, including fixed membership fees with homogeneous buyers and suppliers. None of the approaches considers intra-platform competition or product variety. Pan et al. (2019) analyse the effect of separation into groups. The results of the morphological analysis can be found in Table 3.6.

Peng et al. (2017) investigate a monopoly platform by focusing their analysis on the results of an empirical study of the pricing strategy of Amazon. They combine the findings of evaluating the pricing data of Amazon with a stochastic pricing model and a revenue management approach. The net profit of the supplier market side is assumed to be generated in their pricing approach by advertising their product capacity modelled as total demand of suppliers (D^{S}) towards the platform at a price wholesale (P_{w}), which is subtracted by the cost per product of the supplier (c_η).

$$\mathrm{Net}^{\mathrm{S}} = V_{\mathrm{t,j}}^{\mathrm{S}} \cdot \left(D^{\mathrm{S}}\right) \cdot \left(P_{\mathrm{w}} - c_\eta\right), \quad j \in \mathbb{N} \tag{3.42}$$

Correspondingly, the platform is purchasing the offered product capacity at a posted platform price (P_{p}) and is providing them towards the buyer market side and with this generating the profit of the platform.

$$\Pi^{\mathrm{P}} = V_{\mathrm{j}}^{\mathrm{S,t}} \cdot \left(D^{\mathrm{S}}\right) \cdot \left(P_{\mathrm{p}} - P_{\mathrm{w}}\right), \quad j \in \mathbb{N} \tag{3.43}$$

Because the supplier market side is not directly interacting with the buyer market side, the pricing model can be simplified to two one-sided market pricing models. This is because the platform interacts with both market sides separately so that network effects are not considered in the pricing approach. Since the influences of network effects are the fundamentals of a two-sided market pricing approach, this approach will not be considered further.

Pan et al. (2019) analyse a monopolistic market situation of a CMfg platform. They develop a pricing approach including one platform, a group of customers and two groups of capacity suppliers. The net profit of the customer includes the capacities offered by supplier one and supplier two.

$$\text{Net}^{\text{B}} = b^{\text{B}} \cdot \left(D^{\text{B}}_{\text{S},1} + D^{\text{B}}_{\text{S},2}\right) + P^{\text{B}} \tag{3.44}$$

The pricing approach works according to an opposite method because rather than following the standards of common two-sided market approaches, they start their investigation to examine the maximum prices. The platform determines the profit maximising membership fees. A hotelling game is performed by the capacity supplier, adjusted to the utility of the customers. The production capacity distribution of the CMfg platform is determined. The pricing approach is based on the assumption that the maximising prices are known. The objective of a two-sided market pricing mechanism is to define a pricing structure considering network effects, which increase the profits of the platform and the benefits of the customer groups. The presented pricing approaches are not fulfilling these conditions so that they will be neglected.

3.2.6 Supplementary Approaches

Supplementary pricing models are analysed in the following, due to the complexity and variations of two-sided markets. The morphological analysis of this cluster includes seven pricing models, exhibiting the differences of their determining factors. The results of this analysis can be found in Table 3.7. Most of the approaches are analysed in a duopoly market and they consider a single-homing strategy. The pricing structure examines fixed membership, transaction-based fees and a mixture of pricing strategies. Only one approach considers intra-platform competition, three approaches analyse product variety and none of the approaches analyses the effects of separation into groups. The pricing approaches include the influences of heterogeneous and homogeneous customer market sides and a mixture of homing strategies.

Table 3.7: Morphological Analysis for Supplementary Pricing Models

Publication	Determining Factors							
Author	Market	Homing	Fees	iC	V	Gr	Buyers	Suppliers
Kung (2017)	MP	SH(S,B)	MF(B),TbF(B)	-	-	-	hetero	hetero
Gans (2012)	MP	SH(S,B)	MF(B),TbF(S)	-	-	-	hetero	homo
Anderson (2019)	MP	SH(S,B)	MF(S),TbF(S)	-	✓	-	hetero	hetero
Chen (2012)	MP	SH(S,B)	MF(S,B)	✓	-	-	hetero	hetero
Weisman (2010)	MP	SH(S,B)	TbF(S,B)	-	-	-	homo	homo
Sokullu (2019)	DP	SH(S),MH(B)	TbF(S)	-	✓	-	homo	hetero
Tsukamoto (2020)	DP	MH(S,B)	MF(S,B)	-	✓	-	hetero	hetero

Kung and Zhong (2017) present a pricing mechanism modelled for grocery delivery in a sharing economy. The platform offers the delivery of groceries to one market group, while the other side of the market provides the delivery service. The pricing model compares three different strategies of membership fees, transaction-based fees and cross-subsidisation. During the cross-subsidisation, the platform charges the customers a membership fee. For a successful interaction, the customer pays a transaction fee for the grocery delivery, compensating the supplier market side by paying per delivery.

Gans (2012) analyses the specific application of mobile platforms by presenting a modelling framework, which increases the variety of mobile applications. The specifics of this approach are that customers can already purchase access to mobile platforms before the price of the applications is specified. The income of the platform is generated on the market side of the application developers.

Anderson and Bedre-Defolie (2019) provide a pricing approach for a monopoly market situation. The pricing model includes a high degree of product varieties following the preferences of the buyer. Accordingly, the degree of variation provided by the platform is analysed to estimate a correlative differentiation standard.

Another approach is provided by Chen and Huang (2012) formulating a monopoly pricing model. They include the impact of the entrance of new participants on the matching probability of the existing platform members. The platform allocates the number of participants of the two market sides and provides the buyers with relevant information on the price structure of the suppliers. Their probability defines the buyers who visit and purchase from each supplier. If no buyer purchases from a supplier, products will remain unsold.

Weisman (2010) analyses a monopoly market situation based on the pricing approach of Rochet and Tirole (2003). In equilibrium, an optimal assignment is estimated by shifting a compute pricing ratio towards the buyer side of the platform. The price elasticity, as well as linear demand, are considered in the pricing approach.

Sokullu (2019) analyses the specific application of a traditional book store and an E-marketplace for books in a duopoly market situation. His research is based on an empirical set of data. The pricing approach assumes that suppliers offer products with identical characteristics. The variety of products leads to an increase of the utility or profit of the customers, until the offered products lead to a disproportional time and cost effort to search the required products on the platform. At a certain number of offered products, the utility of the buyers decreases if the variety further increases.

Tsukamoto (2020) develops a duopoly pricing model based on the pricing approaches of Gabszewicz and Wauthy (2004) and Gabszewicz and Wauthy (2014). The pricing approaches are extended by positive as well as negative network effects on both market sides. Additionally, total market coverage is assumed.

Since the supplementary pricing approaches are based on different assumptions, the modelling approaches diverge widely. In conclusion, the analysis of supplementary pricing approaches is intended to emphasise the transparency and diversity of pricing models.

3.3 Research Gap

The morphological analysis of Section 3.2 examines the interaction of the determining factors and their influences on the pricing approach, which responds to research question one. Based on the determining factors, the central elements of a two-sided market model are identified, as displayed in Figure 3.4. The basic structure of a two-sided market pricing model contains the inputs and outputs of the platform interactions and the buyer and supplier market sides. The benefits of the buyer market side are expressed by their utility function. The profit functions model the profit of the supplier and the platform. Based on the morphological analysis of the literature, the focus of the presented models is to understand the net profit of both market sides, since their benefit is essential

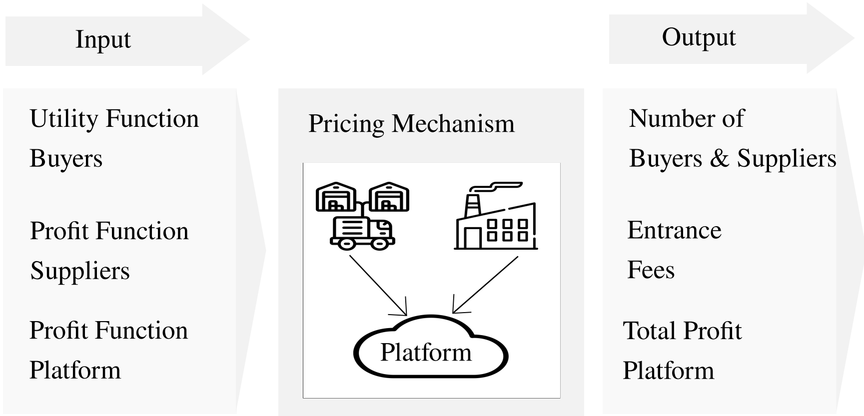

Figure 3.4: CMfg Two-Sided Market Pricing Model

for the platforms to function. The two market sides participate on platforms to increase their net profit by increasing their benefit described by their input functions. For a deeper analysis of the utility and profit functions, functions modelling the curve progressions of u^{B} and π are introduced to simulate the behaviour of the customers and the platform. The total platform profit of the two-sided market model increases if the net profit of both market sides increases, since the output function of the total platform profit is directly linked to the net profit of the participants. Only if both market sides benefit from the participation on the platform, their net profit increases and the platform is able to generate traffic and value for their customers.

Therefore, the platform tries to reach equilibrium pricing by matching capacity suppliers and buyers. Network effects have a significant impact on the equilibrium pricing mechanism of the two-sided market, generated by interactions of the participants of both customer groups. Through the pricing strategy of the platform, the corresponding entrance fees and the number of suppliers and buyers on the platform are defined.

It is an assumption of two-sided pricing models that simplifications need to be made to illustrate complex realities within a model. The production capacities of suppliers and buyers participating on the CMfg platform are central to the operation of the platform. For simplicity, the modeling process uses the number of suppliers and buyers as a proxy for their capacities. This simplification is based on the understanding that the available capacity on the platform is crucial for both market sides to derive benefits from joining. Suppliers bring their production capacities, while buyers bring their demand for these capacities. The ability of the platform to balance these two sides effectively ensures that the capacities of the suppliers are utilized to meet the needs of the buyers. The number of participants, therefore, serves as a proxy for the total available capacity on the platform. A higher number of suppliers generally indicates a greater volume of available production capacity, while a higher number of buyers indicates a stronger demand for these capacities.

Based on a balanced number of participants, a higher matching rate for suppliers and buyers is reached, which leads to more traffic on the platform and affects the platform profit. The pricing approach is essential to support platforms to make beneficial decisions and for being economically sustainable. The platform can regulate the number of participants in equilibrium, which substantially improves the platform matching quality (Behrens and Wiesner 2021).

The morphological analysis examines the determining factors of the selected two-sided pricing models by analysing their findings as a foundation for modelling a pricing mechanism for the CMfg platform. Every single factor of the pricing model changes the required modelling framework by affecting the net profit modelled by the utility and profit functions of both market sides. That is why it is elementary to analyse the determining factors of the pricing models for the development of a CMfg pricing approach. The determining factors of the pricing model need to match the specific requirements of the CMfg platform. Based on the results of the morphological analysis, no approach in the literature fulfils this requirement.

The required determining factors include the market situation, the homing strategy, the type of participation fee, the consideration of intra-platform competition within one market group, the variety of products, the separation into market groups and the heterogeneity and homogeneity of the buyer and supplier market side. Based on the defined specific requirements of a CMfg platform, the development of the CMfg pricing approach is based on a monopoly market situation. The CMfg participants can join the monopoly platform to interact with the other market side so that the customers are single-home. In alliance with existing CMfg literature approaches of for example Zhao et al. (2015), Talukder et al. (2010) and Wei et al. (2018) and the results of the empirical study of Wiesner et al. (2020), the type of participant fee to enter the platform is determined as transaction-based fees. The pricing mechanism needs to estimate the number of transactions of buyers and suppliers because the platform generates revenue on every transaction (Jerath et al. 2010). Intra-platform competition on the supplier market side needs to be considered in the pricing approach to observe the influences of a disproportional increase of capacity suppliers regarding the demand of the buyers. If the demand of the buyers is not balanced to the offered products of the suppliers, the suppliers will start to leave the CMfg platform (Behrens and Wiesner 2021).

Moreover, the product variety of the suppliers needs to be examined within the pricing approach since the buyers have specific requirements regarding the product capacities (Adamson et al. 2017). Product variety (γ_{v}) captures the high specification of high-end resources and includes the individual product requirements of a CMfg platform by influencing the curve progression of the utility and profit function of the two market side groups. The capacity buyer uploads a CAD file containing the production requirements and quality metrics of the requested product. The platform matches the buyer inquiry with a supplier who can fulfil the demand for the product and quality standards. Production capacity is offered to produce this specific part in a defined time frame. A more detailed insight of CMfg processes can be found in Wiesner et al. (2020). The buyer and supplier market sides are heterogeneously differentiated to analyse further complexity within the CMfg market. Vertical differentiation is modelled by $\theta_{\mathrm{v}}^{\mathrm{B}}$ and horizontal differentiation by $\theta_{\mathrm{h}}^{\mathrm{B}}$.

The last defined determining factor is the consideration of separate customer groups on the buyer market side of the CMfg pricing model. The groups of buyers are homogeneous within their groups but show heterogeneous differentiation towards each other. Due to the diversity of the customer requirements, it is more accurate to separate the customer based on their demands, for example, by their company size. Another example is that one group values express delivery by accepting additional costs, while the other does not.

Consequently, a CMfg platform is analysed based on the described pricing approach. The identified requirements need to be introduced in the pricing mechanism. The CMfg platform calculates the number of participants, their transaction-based fees and their total profit. Since no pricing approach in the literature fulfils the analysed requirements, a basic modelling framework is determined in Chapter 4 as the foundation to develop a pricing model for the specification of a CMfg in Chapter 5.

3.4 Summary

Summarised, this chapter presents the following state-of-the-art two-sided market literature:

- In literature, CMfg approaches consider pricing models as one-sided market approaches. These pricing models cannot be transformed into two-sided market approaches due to the complexity of considering two market sides instead of one.
- Since the CMfg platform considers the buyer and supplier market side, a two-sided market pricing approach is required.
- Five pricing approaches are presented to define the determining factors of two-market side approaches.
- The morphological analysis separates the identified 37 articles into 6 sections: Intra-platform competition, heterogeneity versus homogeneity, homing strategies, separation into market groups, CMfg pricing approaches and supplementary approaches.
- Due to the results of the morphological analysis, the input functions and the output values of a two-sided market pricing approach are determined.
- The two market sides participate on the platform to increase their net profit modelled by their input functions. The total platform profit also increases if the net profit of both market sides increases, since the output function of the total platform profit is directly linked to the net profit of the participants.
- Since none of the presented approaches within the literature fulfil the identified requirements of a CMfg platform pricing model, the results are the foundation to develop a CMfg pricing model following the required determining factors.

4 Basic Two-Sided Market Model

Chapter 3 defines the requirements of a two-sided market pricing mechanism for a CMfg platform. Since there is no calculation model within the two-sided market literature, which models a CMfg platform pricing structure, the first step is to select a basic two-sided market modelling approach as the foundation for developing a CMfg pricing model.

Therefore, the first step of this chapter is to examine the literature of pricing approaches of Section 3.1 to select one approach as the basic two-sided market pricing model. The selected pricing model is analysed in detail to gain a deeper understanding of the approach. For a two-sided market pricing model, it is elementary to define an equilibrium for the required output values, as displayed by Figure 3.4. The equilibrium price calculation is examined in detail. Next, advancements to the pricing approach are made to develop a calculation algorithm for calculating the required output values.

4.1 Model Selection

A two-sided market model is selected, which is the foundation for the development of the CMfg pricing model. This is relevant, since the pricing approach of the CMfg platform is based on one of the pricing approaches of Section 3.1. The requirements of the CMfg pricing approach are introduced by expanding an existing two-sided market pricing approach by the required determining factors. The analysis of the literature shows that the adoption of an already existing pricing model to include the defined determining factors is a common procedure. The five approaches are presented in Section 3.1:

- Rochet and Tirole (2003)
- Weyl (2010)
- Caillaud and Jullien (2003)
- Armstrong (2006)
- Hagiu (2009)

The five approaches are analysed based on their characteristics to identify the closest approach to the determined requirements of the CMfg platform. These characteristics include the ability to adjust the approach, the similarities to the requirements of the CMfg pricing approach, and the possibility to include dynamic aspects. The approach of Hagiu (2009) is selected to be the closest approach of the two-sided market pricing models to the required pricing approach of CMfg platforms. Its selection is based on the criteria that horizontal product differentiation is included in the demand and utility functions of the customers and intra-platform competition on the supplier market side. The approach contains the possibility to adjust the entrance fees from fixed membership to transaction-based fees. The customer demand includes the price elasticity of both market sides, which is relevant for the analysis of dynamic effects.

In conclusion, the approach of Hagiu (2009) incorporates modelling characteristics as the basis for developing a CMfg pricing approach. The modelling approach of Hagiu (2009) is described in Section 4.2 and the calculation of the equilibrium price of his model is examined in Section 4.3 to gain a deeper understanding of his model. Based on his model, the pricing approach is extended to fit the requirements of a CMfg pricing approach in Section 4.4. The calculation algorithm of the developed pricing model is presented by Section 4.5. Section 4.6 summarises the components of the adjusted CMfg pricing model.

4.2 Model Description

In the following, the two-sided market pricing model of Hagiu (2009) is described in detail to understand the specifics of the approach. He models a platform between the two market sides of buyers and suppliers, which controls access by setting entrance fees for the participants. A general assumption of his approach is that the number of buyers participating on the platform increases if the product variety also increases.

The profit of suppliers increases by an increasing number of buyers purchasing their products. Section 3.1 determines in Equation 3.8 the net profit of the buyer market side and in Equation 3.9 the net profit of the supplier market side, which is assumed to be equal for every participating buyer and supplier. The net profit of both market sides considers the number of participants, grouped by their membership fee and their costs to participate on the platform. Equation 3.10 defines the platform profit based on the number of participants of both market sides and their membership fees to enter the platform.

Additionally, the pricing model includes the number of products modelled by η, which is assumed to be a continuous variable. The pricing model is based on the assumption that every supplier only offers one product out of η so that the number of suppliers is equal to the number of offered products. Every product of one supplier is assumed to be identical and interchangeable. The preference of product variety is determined by γ_η. With an increase in γ_η, the differentiation of the offered products increases, leading to a higher market share for every single supplier. With a decrease in γ_η, the differentiation of the offered products decreases, which leads to lower market shares for each supplier due to the effects of intra-platform competition between the suppliers.

A central assumption of Hagiu (2009) is that the utility function $u^{\mathrm{B}}(\eta)$ of the buyers strictly increases with an increasing number of products, and every buyer has the same utility from the offered products. The profit functions $\pi(\eta)$ of the suppliers strictly decrease. With an increasing number of suppliers, the intra-platform competition on the supplier market side also increases and the market power of a single supplier decreases. The gross profit of the platform modelled by the total profit of customers (V^{P}) is created by the total benefit generated by the participation of the buyers and suppliers on the platform.

$$V^{\mathrm{P}}(\eta) = u^{\mathrm{B}}(\eta) + \eta \cdot \pi(\eta) \tag{4.1}$$

The curve progression of Equation 4.1 is assumed to have a concave progression based on the progressions of the curves of $u^{\mathrm{B}}(\eta)$ and $\pi(\eta)$. Figure 4.1 displays the correlation of the progressions of the functions $u^{\mathrm{B}}(\eta)$, $\pi(\eta)$ and $V^{\mathrm{P}}(\eta)$. The benefit on the y-axis can be interpreted as the utility of the platform buyers and the profit of the suppliers.

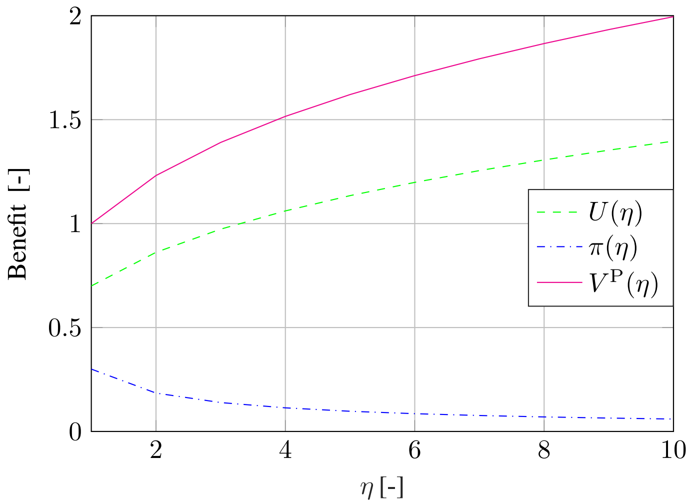

Figure 4.1: Utility and Profit Functions

A relevant aspect of the Hagiu (2009) pricing approach is the integration of horizontal differentiation on both market sides by including the parameters $\theta_{\mathrm{h}}^{\mathrm{B}}$ and $\theta_{\mathrm{h}}^{\mathrm{S}}$. These parameters separate both market side participants horizontally by their costs. The parameter $\theta_{\mathrm{h}}^{\mathrm{B}}$ determines the horizontal differentiation of the buyer market side. The upper limit of buyers ($\theta_{\mathrm{H}}^{\mathrm{B}}$) of the distribution of $F(\theta_{\mathrm{h}}^{\mathrm{B}})$ defines, that the total number of buyers, which gain the benefit of $u^{\mathrm{B}}(\eta)$, join the CMfg platform. The buyers are distributed within the interval of $[0,\ \theta_{\mathrm{H}}^{\mathrm{B}}\ ]$.

In this context, the term characterises that the utility function of each buyer u^{B} is defined based on the costs arising for every specific customer while using the platform. The individual costs include for example learning costs to interact with the platform and all its applications. The parameter $F(\theta_{\mathrm{h}}^{\mathrm{B}})$ is interpreted as the proportion of buyers using the platform because their individual costs are less or equal to $\theta_{\mathrm{h}}^{\mathrm{B}}$. A buyer only participates on the platform if the expected net profit of Equation 3.8 is higher or equal to zero. The last buyer of the distribution of $F(\theta_{\mathrm{h}}^{\mathrm{B}})$, which still benefits from participating, is defined as marginal buyer $\theta_{\mathrm{m}}^{\mathrm{B}}$.

The upper limit $\theta_{\mathrm{H}}^{\mathrm{B}}$ is defined as the maximum number of buyers who participate on the platform. The cumulative distribution of buyers $\theta_{\mathrm{h}}^{\mathrm{B}}$ is defined as $F(\theta_{\mathrm{h}}^{\mathrm{B}})$ with a density function of $f(\theta_{\mathrm{h}}^{\mathrm{B}})$ as shown by Figure 4.2.

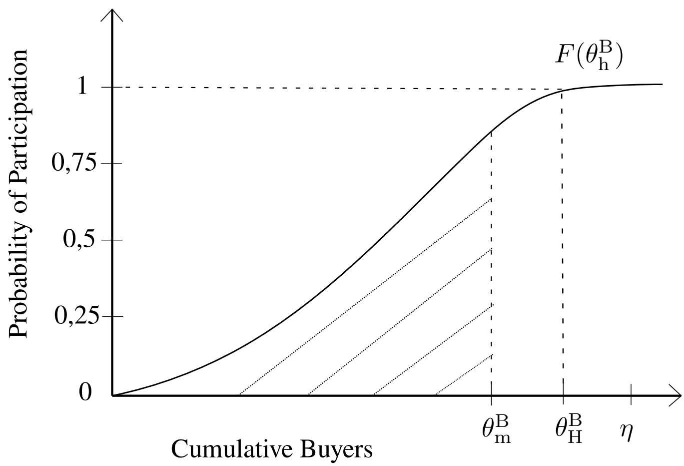

Figure 4.2: Probability of Cumulative Buyers

Based on the introduced functions, the elasticity of the net utility of the buyers is defined.

$$\epsilon_{\mathrm{F}}(\theta_{\mathrm{h}}^{\mathrm{B}}) = \frac{\theta_{\mathrm{h}}^{\mathrm{B}} \cdot f(\theta_{\mathrm{h}}^{\mathrm{B}})}{F(\theta_{\mathrm{h}}^{\mathrm{B}})} > 0 \tag{4.2}$$

The elasticity of the buyer market side (ϵ_F) affects the fixed cost distribution of the buyers in the interval $[0,\, \theta_{\mathrm{H}}^{\mathrm{B}}\,]$. If ϵ_F increases, the cost structure shifts towards the upper limit $\theta_{\mathrm{H}}^{\mathrm{B}}$ leading to an increasing $\theta_{\mathrm{h}}^{\mathrm{B}}$ and lower demand on the buyer market side.

The net profits π of the supplier market side depend on the number of buyers $\theta_{\mathrm{h}}^{\mathrm{B}} \leq \theta_{\mathrm{m}}^{\mathrm{B}}$ participating on the platform. The suppliers consider variable costs of $\theta_{\mathrm{h}}^{\mathrm{S}}$ as the cost of interacting with the platform. Only if the supplier generates a positive net profit, he will participate on the platform. The individual costs of a supplier are composed of the cost to make the product accessible on the platform. The upper limit of suppliers ($\theta_{\mathrm{H}}^{\mathrm{S}}$) of the cumulative distribution function of suppliers ($H(\theta_{\mathrm{h}}^{\mathrm{S}})$) defines, that the total number of suppliers, which gain the benefit of π, participate on the CMfg platform. The last supplier of the distribution, which joins the platform, is modelled as the horizontal differentiation marginal supplier ($\theta_{\mathrm{m}}^{\mathrm{S}}$). The cumulative distribution is determined by $H(\theta_{\mathrm{h}}^{\mathrm{S}})$ and the density function by $h(\theta_{\mathrm{h}}^{\mathrm{S}})$. Equal to the buyer market side, $\theta_{\mathrm{h}}^{\mathrm{S}}$ is distributed on $[0,\, \theta_{\mathrm{H}}^{\mathrm{S}}\,]$ as shown by Figure 4.3.

The parameter $\theta_{\mathrm{h}}^{\mathrm{S}}$ is equal to the inverse function of $H(\theta_{\mathrm{h}}^{\mathrm{S}})$, which models the horizontal differentiation of the supplier market side.

$$\theta_{\mathrm{h}}^{\mathrm{S}} = H^{-1}\,(\eta) \tag{4.3}$$

According to these functions, the elasticity of the supplier market side (ϵ_H) is described. If the elasticity ϵ_H increases, the variable cost of every individual

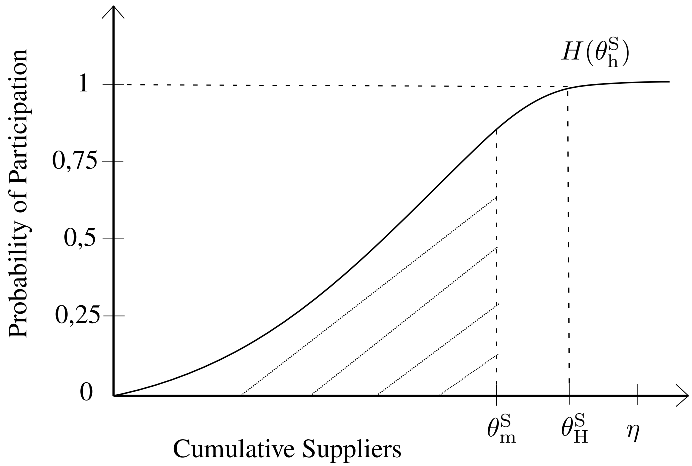

Figure 4.3: Probability of Cumulative Suppliers

supplier increases so that the demand of the supplier to participate on the platform decreases.

$$\epsilon_{\mathrm{H}}(\theta_{\mathrm{h}}^{\mathrm{S}}) = \frac{\theta_{\mathrm{h}}^{\mathrm{S}} \cdot h(\theta_{\mathrm{h}}^{\mathrm{S}})}{H(\theta_{\mathrm{h}}^{\mathrm{S}})} > 0. \tag{4.4}$$

Additionally, Hagiu (2009) introduces the relations of $H(\theta_{\mathrm{h}}^{\mathrm{S}})$ and $F(\theta_{\mathrm{h}}^{\mathrm{B}})$ to calculate the number of participants of both market sides based on the marginal customer and upper limit of customers on the platform.

$$\begin{aligned} F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) &= \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \\ H\left(\theta_{\mathrm{m}}^{\mathrm{S}}\right) &= \left(\frac{\theta_{\mathrm{m}}^{\mathrm{S}}}{\theta_{\mathrm{H}}^{\mathrm{S}}}\right)^{\epsilon_{\mathrm{H}}} \end{aligned} \tag{4.5}$$

The relationship of the buyer and supplier market side is analysed by the progression of the utility and profit functions of both markets sides, which is further characterised by introducing specific functions to define $u^{\mathrm{B}}(\eta)$, $\pi(\eta)$ and

$V^{\mathrm{P}}(\eta)$. For the utility function, a Cobb Douglas function is chosen to model the progression of the benefits of the buyer markets generated by participating on the platform (Cobb and Douglas 1928). The utility function strictly increases, since the net profit $u^{\mathrm{B}}(\eta)$ increases in the number of accessible products.

$$u^{\mathrm{B}}(\eta) = (1 - \gamma_\eta) \cdot \eta^{\gamma_\eta} \tag{4.6}$$

The profit function for each supplier strictly decreases in η due to the intra-platform competition on the supplier market side.

$$\pi(\eta) = \gamma_\eta \cdot \eta^{\gamma_\eta - 1} \tag{4.7}$$

The total profit of both market sides is concave and strictly increases in η at a decreasing rate, because the customers value the 10th product more than the 100th product.

$$V^{\mathrm{P}}(\eta) = \eta^{\gamma_\eta} \tag{4.8}$$

The introduced functions of $u^{\mathrm{B}}(\eta)$, $\pi(\eta)$ and $V^{\mathrm{P}}(\eta)$ specify the progression of the functions of the pricing model and fulfil the requirements of Hagiu (2009).

Equal to the elasticity of both customer market sides, the elasticity of the total profit (ϵ_V^{P}) is defined, which measures the preferences of the customers for product variety.

$$\epsilon_{\mathrm{V}}^{\mathrm{P}}(\eta) = \frac{\eta \cdot V^{\mathrm{P}'}(\eta)}{V^{\mathrm{P}}(\eta)} \in]0, 1[\tag{4.9}$$

The elasticity ϵ_V^{P} directly impacts the progression of $V^{\mathrm{P}}(\eta)$. The higher the value of ϵ_V^{P} the less concave is the progression of $\epsilon_V^{\mathrm{P}}(\eta)$. Figure 4.4 displays the influences of ϵ_V^{P} on the progression of $\epsilon_V^{\mathrm{P}}(\eta)$.

The impact of V^{P} on $V^{\mathrm{P}}(\eta)$ is interpreted as the degree of substitution between the platform suppliers. The closer the value of V^{P} is towards 1, the higher is the differentiation of the suppliers and the smaller the possibility to be substituted.

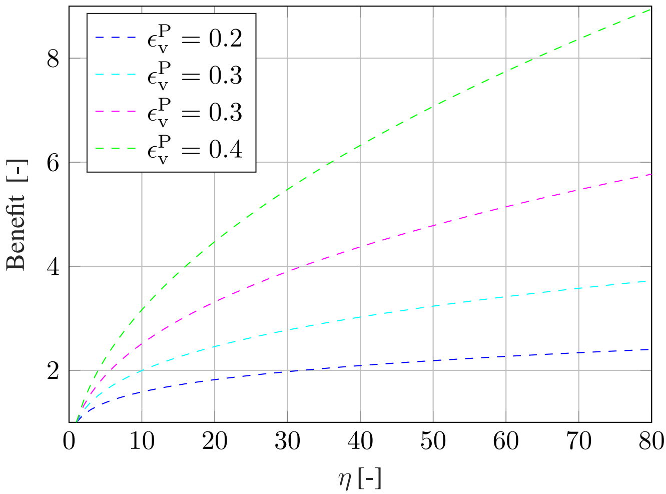

Figure 4.4: Progression of $V^{P}(\eta)$

Moreover, the ratio of the two market sides (λ) is defined by including the profit of the suppliers and the marginal contribution of an additional supplier to gross customer profit.

$$\lambda(\eta) = \frac{\pi(\eta)}{V^{P\prime}(\eta)}. \tag{4.10}$$

The ratio λ represents the market position the suppliers have over the platform buyers. If the ratio λ is high, the platform supplier can extract a higher profit from their products.

The description of the pricing model of Hagiu (2009) underlines the relevance of the different market sides of the pricing approach, which leads to the complexity of two-sided market pricing models. After the detailed examination of the approach, the next step is to analyse the price calculation within the equilibrium state of a platform pricing model.

4.3 Equilibrium Price Calculation

In this section, the equilibrium state of the two-sided market pricing model of Hagiu (2009) is analysed in detail. Platform business models aim to be economically sustainable by trying to maximise the profits generated by the entrance fees of both market sides (Wiesner et al. 2020). The membership fees P^{B} and P^{S} for the buyer and supplier market side are chosen accordingly. Equation 3.10 describes the platform profit, which consists of the number of participants on the buyer $F(\theta_{\mathrm{m}}^{\mathrm{B}})$ and on the supplier market side η multiplied with the respective membership fees P^{B} and P^{S} for both market sides.

The platform profit cannot be maximised by simply increasing the membership fees P^{B} and P^{S} of both market sides, because the increase can also lead to a decrease in the utility and profit function of both market sides. Due to lower benefits for both market sides, a lower number of participants is reached on the platform, which can accelerate the decrease of participants even more.

The elementary aspect to maximise the platform profit is the network effects of both market sides. Consequently, the maximisation of the platform profit has to be based on a balanced number of both market side participants rather than on an increase of platform entrance fees. An equilibrium for suppliers $H(\theta_{\mathrm{m}}^{\mathrm{S}})$ and buyers $F(\theta_{\mathrm{m}}^{\mathrm{B}})$ adopting the platform has to be determined. For the buyer market side, the equilibrium is defined by the determination of the marginal buyer $\theta_{\mathrm{m}}^{\mathrm{B}}$, which has an indifferent utility to participate on the platform.

$$\theta_{\mathrm{m}}^{\mathrm{B}} = u^{\mathrm{B}}(\eta) - P^{\mathrm{B}} \tag{4.11}$$

Equation 4.11 determines the marginal buyer $\theta_{\mathrm{m}}^{\mathrm{B}}$ as a function $\Theta(\eta, P^{\mathrm{B}})$ of the supplier demand and the buyer membership fees. For the supplier market side the equilibrium is reached if the entire opportunities for the supplier to generate profits are exhausted, which determines the number of required products η as a function $N(\theta_{\mathrm{m}}^{\mathrm{B}}, P^{\mathrm{S}})$ of the buyer demand and the membership fees of the supplier market side.

$$\pi(\eta) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - P^{\mathrm{S}} - H^{-1}(\eta) = 0 \tag{4.12}$$

Both equations depend on the membership fees and the number of participants. Based on the network effects, the maximising pricing strategy for the platform has to consider the number of participants and the calculation of the according membership fees.

Therefore, an equation for the platform profit is required, which depends on the parameters $\theta_{\mathrm{m}}^{\mathrm{B}}$ and η instead of P^{B} and P^{S}. The net profit of the buyer market side and the net profit of the supplier market side are adjusted.

$$P^{\mathrm{B}} = u^{\mathrm{B}}(\eta) - \theta_{\mathrm{m}}^{\mathrm{B}} \tag{4.13}$$

$$P^{\mathrm{S}} = \pi(\eta) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - H^{-1}(\eta) \tag{4.14}$$

Equation 4.13 and Equation 4.14 are introduced into Equation 3.10 so that Equation 4.15 is only dependent on the tuple $(\theta_{\mathrm{m}}^{\mathrm{B}}, \eta)$.

$$\Pi^{\mathrm{P}} = \left(u^{\mathrm{B}}(\eta) - \theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) + \eta \cdot \left(\pi(\eta) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - H^{-1}(\eta)\right) \tag{4.15}$$

By introducing Equation 4.1 into Equation 4.15 the expression of the platform profit is further simplified.

$$\Pi^{\mathrm{P}} = \left(V^{\mathrm{P}}(\eta) - \theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - \eta \cdot H^{-1}(\eta) \tag{4.16}$$

As a result, the equilibrium to maximise the platform profit is calculated by the number of both market side participants directly through $(\theta_{\mathrm{m}}^{\mathrm{B}}, \eta)$ instead of an increase of the membership fees $(P^{\mathrm{S}}, P^{\mathrm{B}})$.

Furthermore, the first-order condition determines the equilibrium tuple $(\theta_{\mathrm{m}}^{\mathrm{B}}, \eta)$ for Equation 4.16, which is derived partially by $\theta_{\mathrm{m}}^{\mathrm{B}}$ and η. For the buyer market side, the Equation 4.16 is derived partially by $\theta_{\mathrm{m}}^{\mathrm{B}}$ and set equal to zero. Equation 4.17 is divided by $\theta_{\mathrm{m}}^{\mathrm{B}} \cdot f\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)$. As a result, the number of buyers in equilibrium are defined.

$$f\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot V^{\mathrm{P}}\left(\eta\right) - \left(F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) + \theta_{\mathrm{m}}^{\mathrm{B}} \cdot f\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)\right) \stackrel{!}{=} 0. \tag{4.17}$$

$$\frac{V^{\mathrm{P}}\left(\eta\right)}{\theta_{\mathrm{m}}^{\mathrm{B}}} - \frac{F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)}{\theta_{\mathrm{m}}^{\mathrm{B}} \cdot f\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)} - 1 = 0 \tag{4.18}$$

$$\frac{V^{\mathrm{P}}\left(\eta\right) - \theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{m}}^{\mathrm{B}}} = \frac{1}{\epsilon_{\mathrm{F}}(\theta_{\mathrm{m}}^{\mathrm{B}})}. \tag{4.19}$$

For the supplier market side, Equation 4.16 is derived by η and set equal to zero so that the equilibrium for the supplier market side is defined.

$$V'^{\mathrm{P}}\left(\eta\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - \eta \cdot H^{-1'}\left(\eta\right) - H^{-1}\left(\eta\right) \stackrel{!}{=} 0. \tag{4.20}$$

As a result, Equation 4.19 and Equation 4.20 are only dependent on ($\theta_{\mathrm{m}}^{\mathrm{B}}$, η). Due to these calculations, the corresponding membership fees (P^{S}, P^{B}) for both market sides and the total platform profit can be determined. Since the pricing approach of Hagiu (2009) is developed for theoretical analysis, model advancements are required to transfer his pricing approach so that calculations of the output values can be conducted.

4.4 Model Advancement

The presented pricing model of Hagiu (2009) is adjusted in the following. For calculating the output values of the pricing model, the presented examinations of Section 4.2 and Section 4.3 are expanded by the introduction of a market potential and the calculation of the upper limit and the marginal customers of the pricing approach. In accordance with Staub (2020), the advancements of the pricing approach of Hagiu (2009) are analysed in detail in the following.

Next, the market potential is presented. The distribution functions of $\epsilon_H(\theta_\mathrm{h}^\mathrm{S})$ and $\epsilon_F(\theta_\mathrm{h}^\mathrm{B})$ determine the percentage of participants registered on the platform. They are defined as distribution functions in the range from zero to one. For the calculation of potential customers of both market sides, the market potential of suppliers (m^S) for the supplier market side and the market potential of buyers (m^B) for the buyer market side are introduced. The market potential is interpreted as the market penetration of the platform within a specific market. The purpose of the market potential is to calculate the number of suppliers η and the number of buyers B on the platform.

$$\eta = H\left(\theta_\mathrm{h}^\mathrm{S}\right) \cdot m^\mathrm{S} \tag{4.21}$$

$$B = F\left(\theta_\mathrm{h}^\mathrm{B}\right) \cdot m^\mathrm{B} \tag{4.22}$$

There are 7806 manufacturing companies of metal products within Germany so that the market potential for the CMfg platform is assumed to be between 0 and 7806 participants for both market sides (Opfinger 2018). The presented Equation of Section 4.2 and Section 4.3 also need to be expanded by the market potential.

Furthermore, the upper limits $\theta_\mathrm{H}^\mathrm{B}$ and $\theta_\mathrm{H}^\mathrm{S}$ of the distribution functions $F(\theta_\mathrm{h}^\mathrm{B})$ and $H(\theta_\mathrm{h}^\mathrm{S})$ are determined. Equation 4.19 is used to estimate the upper limit $\theta_\mathrm{H}^\mathrm{B}$ for the buyer market side. Equation 4.19 is rearranged according to $\theta_\mathrm{m}^\mathrm{B}$ so that only depends on the parameter η by a given elasticity value of ϵ_F.

$$\theta_\mathrm{m}^\mathrm{B} = \frac{V^\mathrm{P}(\eta)}{\frac{1}{\epsilon_\mathrm{f}} + 1} \tag{4.23}$$

As the total number of the market potential is defined as 7806 companies, the parameter η is defined as maximal number of products (η_max). Since the suppliers only offer one product η, the maximum number of suppliers is equal to

η_{max}. The maximum value of $\theta_{\mathrm{m}}^{\mathrm{B}}$ is interpreted as $\theta_{\mathrm{H}}^{\mathrm{B}}$ so that by Equation 4.23 the upper limit of $\theta_{\mathrm{H}}^{\mathrm{B}}$ is calculated by substituting the value of $\eta = 7806$ into Equation 4.8. Equation 4.24 summarises the calculation for the upper limit $\theta_{\mathrm{H}}^{\mathrm{B}}$.

$$\theta_{\mathrm{H}}^{\mathrm{B}} = \frac{V^{\mathrm{P}}\left(\eta_{\mathrm{max}}\right)}{\frac{1}{\epsilon_{\mathrm{f}}} + 1} \tag{4.24}$$

Equation 3.9 is used to estimate the upper limit $\theta_{\mathrm{H}}^{\mathrm{S}}$ for the supplier market side and is set equal to zero so that it can be interpreted as the marginal supplier of $\theta_{\mathrm{m}}^{\mathrm{S}}$, since this supplier is indifferent regarding the participation on the platform.

$$\theta_{\mathrm{m}}^{\mathrm{S}} = \pi\left(\eta\right) \cdot F(\theta_{\mathrm{m}}^{\mathrm{B}}) \cdot m^{\mathrm{B}} - P^{\mathrm{S}} \tag{4.25}$$

Under the assumption that the membership fee of the platform equals zero, the parameter $\theta_{\mathrm{m}}^{\mathrm{B}}$ equals the function of $u^{\mathrm{B}}(\eta)$. The marginal supplier is calculated by inserting Equation 4.6 into Equation 4.25 depending on the parameter η.

$$\theta_{\mathrm{m}}^{\mathrm{S}} = \pi\left(\eta\right) \cdot F(u^{\mathrm{B}}(\eta)) \cdot m^{\mathrm{B}} \tag{4.26}$$

The minimum number of products (η_{min}) is set into $\pi(\eta_{\mathrm{min}})$ to analyse the upper limit of the profit of each supplier, which is defined by the minimum number of competing suppliers so that η_{min} equals one supplier. Equation 4.27 models the calculation of the upper limit $\theta_{\mathrm{H}}^{\mathrm{S}}$.

$$\theta_{\mathrm{H}}^{\mathrm{S}} = \pi\left(\eta_{\mathrm{min}}\right) \cdot F(u^{\mathrm{B}}(\eta_{\mathrm{min}})) \cdot m^{\mathrm{B}} \tag{4.27}$$

The introduction of the market potential for both market sides and the determination of the functions for the upper limits are the precondition to calculate the equilibrium of the pricing model. The equilibrium is dependent on the equilibrium tuple of the parameters ($\theta_{\mathrm{m}}^{\mathrm{B}}$, η) so that it is elementary to rearrange Equation 4.16 to be only dependent on one parameter.

Therefore, Equation 4.20 is extended by the market potential. The first derivative of parameter $V^{\mathrm{P}}(\eta)$ of Equation 4.8 leads to Equation 4.29, which is inserted into Equation 4.28 to define Equation 4.30.

$$V^{'\mathrm{P}}(\eta) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} - \eta \cdot H^{-1'}\left(\eta, m^{\mathrm{S}}\right) H^{-1}\left(\eta, m^{\mathrm{S}}\right) \stackrel{!}{=} 0 \tag{4.28}$$

$$V^{'\mathrm{P}}(\eta) = \gamma_{\eta} \cdot \eta^{\gamma_{\eta}-1} \tag{4.29}$$

$$\gamma_{\eta} \cdot \eta^{\gamma_{\eta}-1} \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} - \eta \cdot H^{-1'}\left(\eta, m^{\mathrm{S}}\right) H^{-1}\left(\eta, m^{\mathrm{S}}\right) \stackrel{!}{=} 0 \tag{4.30}$$

Next, the term $F(\theta_{\mathrm{h}}^{\mathrm{B}})$ is adjusted so that Equation 4.5 is introduced into Equation 4.30 leading to Equation 4.31.

$$\gamma_{\eta} \cdot \eta^{\gamma_{\eta}-1} \cdot \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{m}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \cdot m^{\mathrm{B}} = \eta \cdot H^{-1'}\left(\eta, m^{\mathrm{S}}\right) \cdot H^{-1}\left(\eta, m^{\mathrm{S}}\right) \tag{4.31}$$

Based on the assumption of Hagiu (2009) that every supplier is only selling one kind of product to the buyer market side, the number of sold products is equal to the number of suppliers, which is determined by Equation 4.32. This assumption reduces the complexity of the analysis. For a CMfg platform, it can be interpreted that every supplier has only one product they can manufacture. Based on this assumption, Equation 4.33 and Equation 4.34 are determined. Both Equations 4.33 and 4.34 are inserted into Equations 4.35.

$$H\left(\theta_{\mathrm{m}}^{\mathrm{S}}\right) \cdot m^{\mathrm{S}} = \eta \tag{4.32}$$

$$H^{-1}(\eta, m^{\mathrm{S}}) = \left(\frac{\eta}{m^{\mathrm{S}}}\right)^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{H}}^{\mathrm{S}} \tag{4.33}$$

$$H^{-1'}(\eta, m^{\mathrm{S}}) = \frac{1}{m^{\mathrm{S}\,\frac{1}{\epsilon_{\mathrm{H}}}}} \cdot \frac{1}{\epsilon_{\mathrm{H}}} \cdot \eta^{\frac{1}{\epsilon_{\mathrm{H}}}-1} \cdot \theta_{\mathrm{H}}^{\mathrm{S}} \tag{4.34}$$

$$\gamma_\eta \cdot \eta^{\gamma_\eta - 1} \cdot \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{m}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \cdot m^{\mathrm{B}} = \eta \cdot \frac{1}{m^{\mathrm{S}^{\frac{1}{\epsilon_{\mathrm{H}}}}}} \cdot \frac{1}{\epsilon_{\mathrm{H}}} \cdot \eta^{\frac{1}{\epsilon_{\mathrm{H}}} - 1} \cdot \theta_{\mathrm{H}}^{\mathrm{S}} \cdot \left(\frac{\eta}{m^{\mathrm{S}}}\right)^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{H}}^{\mathrm{S}} \tag{4.35}$$

Equation 4.19 is rearranged to Equation 4.36 so that $\theta_{\mathrm{m}}^{\mathrm{B}}$ is inserted into Equation 4.35.

$$\theta_{\mathrm{m}}^{\mathrm{B}} = \frac{V^{\mathrm{P}}(\eta)}{\frac{1}{\epsilon_{\mathrm{F}}} - 1} \tag{4.36}$$

As a result, Equation 4.37 determines the number of suppliers in an equilibrium ($\eta_{\mathrm{equ.}}$), which is only dependent on η.

$$\eta_{\mathrm{equ.}} = \left[\left(\frac{\gamma_\eta \cdot (\epsilon_{\mathrm{F}})^2 \cdot m^{\mathrm{B}}}{(1+\epsilon_{\mathrm{F}})^{\epsilon_{\mathrm{F}}} \cdot (\theta_{\mathrm{H}}^{\mathrm{B}})^{\epsilon_{\mathrm{F}}}}\right) \cdot \left(\frac{m^{\mathrm{H}^{\frac{1}{\epsilon_{\mathrm{H}}}}} \cdot \epsilon_{\mathrm{F}}}{(1+\epsilon_{\mathrm{H}}) \cdot \theta_{\mathrm{H}}^{\mathrm{S}}}\right)\right]^{\frac{\epsilon_{\mathrm{H}}}{2\epsilon_{\mathrm{F}} \cdot (1-\gamma_\eta)}} \tag{4.37}$$

The defined η is inserted into Equation 4.36 so that the value of $\theta_{\mathrm{m}}^{\mathrm{B}}$ is calculated, which is required to calculate the total number of platform buyers. Due to the calculation of the equilibrium tuple, the membership fees for both market sides and the total profit of the platform is determined. The calculation of the different steps of the pricing model is analysed in detail in the following.

4.5 Calculation Algorithm

The calculation algorithm of the two-sided market pricing model has eight steps, which aim to transfer the input functions into the required output values:

- Number of buyers and suppliers [1]
- Entrance fees
- Total platform profit

Figure 4.5 presents the eight steps of the calculation, beginning with Algorithm 1 and resulting in the total platform profit.

Figure 4.5: Calculation Algorithm of the Basic Two-Sided Pricing Model

[1] The number of buyers and suppliers represents their production capacities.

The first step is the calculation of the upper limits of the buyer market side through Algorithm 1.

Algorithm 1 Basic Model Calculation Algorithm Upper Limit Buyer

Require: $\gamma_\eta \in [0,1]$; $\epsilon_\mathrm{F} \in [0,1]$; $\epsilon_\mathrm{H} \in [0,1]$; $m^\mathrm{S} \in \mathbb{N}$; $m^\mathrm{B} \in \mathbb{N}$; $\eta_\mathrm{min} = 1$; $\eta_\mathrm{max} = m^\mathrm{B,S}$

Ensure:

$u^\mathrm{B}(\eta) = (1 - \gamma_\eta) \cdot \eta^{\gamma_\eta}$ ▷ Utility Function Buyers

$\pi(\eta) = \gamma_\eta \cdot \eta^{\gamma_\eta - 1}$ ▷ Profit Function Suppliers

$V^\mathrm{P}(\eta) = \eta^{\gamma_\eta}$ ▷ Total Profit of Both Market Sides

Ensure: ▷ Upper Limit Buyer

if $\frac{V^\mathrm{P}(\eta_\mathrm{max})}{\frac{1}{\epsilon_\mathrm{f}}+1} \leq 1$ **then**

$\theta^\mathrm{B}_\mathrm{H} = \frac{V^\mathrm{P}(\eta_\mathrm{max})}{\frac{1}{\epsilon_\mathrm{f}}+1}$

else

if $\frac{V^\mathrm{P}(\eta_\mathrm{max})}{\frac{1}{\epsilon_\mathrm{f}}+1} > 1$ **then**

$\theta^\mathrm{B}_\mathrm{H} = 1$

end if

end if

As a requirement for the calculation, the input parameters of the pricing model need to be defined based on the value ranges determined by Algorithm 1. Next, the chosen input parameters are used for the calculation of the input functions: utility of buyers, profit function of suppliers and total profit of both market sides.

An iterative algorithm is used to calculate the upper limit of the buyer by inserting the maximum value for $V^{\mathrm{P}}(\eta_{\max})$ as defined in Equation 4.24. Since $\theta_{\mathrm{H}}^{\mathrm{B}}$ can reach a maximum value of 1, the algorithm ensures that the value is within the defined value range. If the calculation of $\theta_{\mathrm{H}}^{\mathrm{B}}$ leads to a higher value for this parameter, the iterative algorithm sets $\theta_{\mathrm{H}}^{\mathrm{B}}$ to one.

After the calculation of the upper limit of the buyer, the upper limit for the supplier is calculated by Algorithm 2.

Algorithm 2 Basic Model Calculation Algorithm Upper Limit Suppliers

Require: $\gamma_\eta \in [0,1]$; $\epsilon_{\mathrm{F}} \in [0,1]$; $\epsilon_{\mathrm{H}} \in [0,1]$; $m^{\mathrm{S}} \in \mathbb{N}$; $m^{\mathrm{B}} \in \mathbb{N}$; $\eta_{\min} = 1$;

$\eta_{\max} = m^{\mathrm{B,S}}$; $\theta_{\mathrm{H}}^{\mathrm{B}} \in [0,1]$

Ensure: ▷ Upper Limit Suppliers

if $\pi(\eta_{\min}) \cdot F\left(\frac{u^{\mathrm{B}}(\eta_{\min})}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \cdot m^{\mathrm{B}} \leq 1$ **then**

$\theta_{\mathrm{H}}^{\mathrm{S}} = \pi(\eta_{\min}) \cdot F\left(\frac{u^{\mathrm{B}}(\eta_{\min})}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \cdot m^{\mathrm{B}}$

else

if $\pi(\eta_{\min}) \cdot F\left(\frac{u^{\mathrm{B}}(\eta_{\min})}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \cdot m^{\mathrm{B}} > 1$ **then**

$\theta_{\mathrm{H}}^{\mathrm{S}} = 1$

end if

end if

Algorithm 2 uses an iterative method to calculate the upper limit of the supplier by inserting the maximum value for $u^{\mathrm{B}}(\eta_{\min})$ as defined in Equation 4.27. Since $\theta_{\mathrm{H}}^{\mathrm{S}}$ can reach a maximum value of one, the algorithm ensures that the value is within the defined value range. If the calculation of $\theta_{\mathrm{H}}^{\mathrm{S}}$ leads to a higher value for this parameter, the iterative algorithm sets $\theta_{\mathrm{H}}^{\mathrm{S}}$ to one.

The upper limits of both algorithms are elementary to calculate the equilibrium number of both market sides. The calculated values are elementary to determine the output values of the remaining six calculation steps, starting with the calculation of the number of suppliers in equilibrium. Equation 4.37 leads to the output value of the equilibrium number participating on the supplier market side. The equilibrium number of the buyer market side is calculated by the determination of $\theta_{\mathrm{m}}^{\mathrm{S}}$ described by Equation 4.36.

Next, the marginal buyer is introduced into Equation 4.5 so that the number of platform buyers in equilibrium is defined. The membership fees of the buyer market side are calculated by Equation 4.13. Equation 4.14 is adjusted to Equation 4.38 so that the membership fees for the supplier market side are determined.

$$P^{\mathrm{S}} = \pi\left(\eta\right) \cdot F\left(\frac{u^{\mathrm{B}}(\eta_{\min})}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} - \left(\frac{\eta}{m^{\mathrm{S}}}\right)^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{H}}^{\mathrm{S}} \tag{4.38}$$

The total platform profit is defined by Equation 3.10 so that both participation numbers are multiplied by the calculated membership fees. An example illustrates the calculation of the input and the output functions and values. The required parameter of γ_{η} is set at 0,3, ϵ_F and ϵ_H are set at 0,1 and the market potential m^{S} and m^{B} at 7806, which is the maximum number of platform customers (Opfinger 2018). Based on the eight calculation steps of the pricing model, the output values are displayed by Table 4.1.

Table 4.1: Example Calculation of Basic Pricing Model

Output Values	**Calculated Values**
Number of suppliers	7185 Suppliers
Number of buyers	7806 Suppliers
Platform fee suppliers	4,24 Monetary units
Platform fee buyers	9,05 Monetary units
Total platform	101.090 Monetary units

Next, it is essential to ensure that the calculated platform profit is clearly defined. The total platform profit is calculated by the number of suppliers and buyers and their prices.

$$\Pi^{\mathrm{P}} = P^{\mathrm{B}} \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} + P^{\mathrm{S}} \cdot \eta \tag{4.39}$$

The calculation of the total platform profit is only dependent on the tuple (η, $\theta_{\mathrm{m}}^{\mathrm{B}}$). Equation 4.39 is reduced by the platform prices, as described by Equation 4.40.

$$\Pi^{\mathrm{P}} = \left(V^{\mathrm{P}}\left(\eta\right) - \theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) - \eta \cdot H^{-1}\left(\eta\right) \tag{4.40}$$

Equation 4.40 is derived by the two parameters (η, $\theta_{\mathrm{m}}^{\mathrm{B}}$). The first partial derivation of η is calculated by Equation 4.41 and the first partial of $\theta_{\mathrm{m}}^{\mathrm{B}}$ is calculated by Equation 4.42.

$$\frac{V^{\mathrm{P}}\left(\eta\right) - \theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{m}}^{\mathrm{B}}} = \frac{1}{\epsilon_{\mathrm{F}}(\theta_{\mathrm{m}}^{\mathrm{B}})} \tag{4.41}$$

$$V'^{\mathrm{P}}\left(\eta\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} - \eta \cdot H^{-1'}\left(\eta\right) - H^{-1}\left(\eta\right) \stackrel{!}{=} 0 \tag{4.42}$$

The zero point of the function is necessary, but not sufficient for an extreme value. The second derivative of Equation 4.40 is required to be calculated for the two parameters (η, $\theta_{\mathrm{m}}^{\mathrm{B}}$), which leads to a $2x2$ Hessian matrix. A Hessian matrix is the second derivative of a function with several variables. The matrix is a $2x2$ matrix since two variables are double partial derived. The $2x2$ matrix with a point x as zero of the first derivative is suspected to be an extreme value exactly if the Hessian matrix is negative at this point. The first and second derivation of the tuple (7185, 7806) leads to a negative value of the Hessian matrix so that the tuple suspected of being an extreme value is indeed an extreme value (Luderer and Würker 2015).

In conclusion, the equilibrium calculation of the model of Hagiu (2009) is adjusted so that the calculation of the output values of the pricing model is executed. The approach has to include the specifics of the CMfg market. For that reason, the basic model is expanded in Chapter 5 by the determining factors defined in Chapter 3.

4.6 Model Overview

The summary of the components of the two-sided pricing model is the basis for the calculation of the required output values as shown by Figure 3.4, including the number of suppliers and buyers, their entrance fees and the total profit of the platform. After introducing all components of the pricing model, a consolidated view of the full model is given:

$$B = F(\theta_{\mathrm{h}}^{\mathrm{B}}) \cdot m^{\mathrm{B}} \tag{4.43}$$

▷ Number of Buyers

$$\eta = H(\theta_{\mathrm{h}}^{\mathrm{S}}) \cdot m^{\mathrm{S}} \tag{4.44}$$

▷ Number of Suppliers

$$\text{Net}^{\text{B}} = u^{\text{B}}(\eta) - P^{\text{B}} - \theta_{\text{h}}^{\text{B}} \tag{4.45}$$

▷ Benefit of Buyers

$$u^{\text{B}}(\eta) = (1 - \gamma_{\eta}) \cdot \eta^{\gamma_{\eta}} \tag{4.46}$$

▷ Utility Function of Buyers

$$\text{Net}^{\text{S}} = \pi(\eta) F\left(\theta_{m}^{\text{B}}\right) \cdot m^{\text{B}} - P^{\text{S}} - \theta_{\text{h}}^{\text{S}} \tag{4.47}$$

▷ Net Profit of Suppliers

$$\pi(\eta) = \gamma_{\eta} \cdot \eta^{\gamma_{\eta} - 1} \tag{4.48}$$

▷ Profit Function of Suppliers

$$V^{\text{P}}(\eta) = u^{\text{B}}(\eta) + \eta \cdot \pi(\eta) \tag{4.49}$$

▷ Utility of Buyers and Suppliers

$$V^{\text{P}}(\eta) = \eta^{\gamma_{\eta}} \tag{4.50}$$

▷ Gross Profit of Buyers and Suppliers

$$V'^{\mathrm{P}}(\eta) = \gamma_\eta \cdot \eta^{\gamma_\eta - 1} \tag{4.51}$$

▷ First Derivation of Gross Profit of Buyers and Suppliers

$$\epsilon_{\mathrm{F}}(\theta_{\mathrm{h}}^{\mathrm{B}}) = \frac{\theta_{\mathrm{h}}^{\mathrm{B}} \cdot f(\theta_{\mathrm{h}}^{\mathrm{B}})}{F(\theta_{\mathrm{h}}^{\mathrm{B}})} > 0 \tag{4.52}$$

▷ Elasticity Buyers

$$F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) = \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \tag{4.53}$$

▷ Number Marginal Buyer

$$\epsilon_{\mathrm{H}}(\theta_{\mathrm{h}}^{\mathrm{S}}) = \frac{\theta_{\mathrm{h}}^{\mathrm{S}} \cdot h(\theta_{\mathrm{h}}^{\mathrm{S}})}{H(\theta_{\mathrm{h}}^{\mathrm{S}})} > 0 \tag{4.54}$$

▷ Elasticity Suppliers

$$H\left(\theta_{\mathrm{m}}^{\mathrm{S}}\right) = \left(\frac{\theta_{\mathrm{m}}^{\mathrm{S}}}{\theta_{\mathrm{H}}^{\mathrm{S}}}\right)^{\epsilon_{\mathrm{H}}} \tag{4.55}$$

▷ Number Marginal Supplier

$$\epsilon_{\mathrm{V}}^{\mathrm{P}}(\eta) = \frac{\eta \cdot V'^{\mathrm{P}}(\eta)}{V^{\mathrm{P}}(\eta)} \in]0,1[\tag{4.56}$$

▷ Degree Substitution Suppliers

$$\lambda(\eta) = \frac{\pi(\eta)}{V'^{\mathrm{P}}(\eta)} \tag{4.57}$$

▷ Market Position of Suppliers

$$\Pi^{\mathrm{P}} = P^{\mathrm{B}} \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} + P^{\mathrm{S}} \cdot \eta \tag{4.58}$$

▷ Total Platform Profit

$$P^{\mathrm{B}} = u^{\mathrm{B}}(\eta) - \theta_{\mathrm{m}}^{\mathrm{B}} \tag{4.59}$$

▷ Membership Fees Buyers

$$P^{\mathrm{S}} = \pi(\eta) \cdot F(\theta_{\mathrm{m}}^{\mathrm{B}}) \cdot m^{\mathrm{B}} - H^{-1}(\eta) \tag{4.60}$$

▷ Membership Fees Suppliers

$$\Pi^{\mathrm{P}} = (V^{\mathrm{P}}(\eta) - \theta_{\mathrm{m}}^{\mathrm{B}}) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} - \eta \cdot H^{-1}(\eta) \tag{4.61}$$

▷ Total Platform Profit

$$\theta_{\mathrm{H}}^{\mathrm{B}} = \frac{V^{\mathrm{P}}(\eta_{\max})}{\frac{1}{\epsilon_{\mathrm{f}}} + 1} \tag{4.62}$$

▷ Upper Limit Buyers

$$\theta_{\mathrm{H}}^{\mathrm{S}} = \pi\left(\eta_{\min}\right) \cdot F(u^{\mathrm{B}}(\eta_{\min})) \cdot m^{\mathrm{B}} \tag{4.63}$$

▷ Upper Limit Suppliers

$$\frac{V^{\mathrm{P}}\left(\eta\right) - \theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{m}}^{\mathrm{B}}} = \frac{1}{\epsilon_{\mathrm{F}}(\theta_{\mathrm{m}}^{\mathrm{B}})} \tag{4.64}$$

▷ First Partial Derivation Buyers

$$V'^{\mathrm{P}}\left(\eta\right) \cdot F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) \cdot m^{\mathrm{B}} - \eta \cdot H^{-1'}\left(\eta\right) - H^{-1}\left(\eta\right) \overset{!}{=} 0 \tag{4.65}$$

▷ First Partial Derivation Suppliers

$$\eta_{\mathrm{equ.}} = \left[\left(\frac{\gamma_{\eta} \cdot (\epsilon_{\mathrm{F}})^{2} \cdot m^{\mathrm{B}}}{(1+\epsilon_{\mathrm{F}})^{\epsilon_{\mathrm{F}}} \cdot (\theta_{\mathrm{H}}^{\mathrm{B}})^{\epsilon_{\mathrm{F}}}}\right) \cdot \left(\frac{m^{\mathrm{H}\,\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \epsilon_{\mathrm{F}}}{(1+\epsilon_{\mathrm{H}}) \cdot \theta_{\mathrm{H}}^{\mathrm{S}}}\right)\right]^{\frac{\epsilon_{\mathrm{H}}}{2\epsilon_{\mathrm{F}} \cdot (1-\gamma_{\eta})}} \tag{4.66}$$

▷ Equilibrium Number of Suppliers

4.7 Summary

Summarised, this chapter presents the following fundamentals of the basic two-sided market model:

- Five fundamental two-sided market pricing models are identified.
- The pricing approach of Hagiu (2009) is selected as the foundation to develop a CMfg pricing model. The reason for the selection is that he integrates horizontal differentiation on both market sides and intra-platform competition on the supplier market side.
- Hagiu (2009) defines demand as elasticity of the customers, which is relevant to expand the model to include dynamic effects into the pricing approach.
- The modelling assumptions of the two-sided market approach are presented in detail.
- Advancements of the pricing approach include the introduction of a market potential, the calculation of upper limits and the calculation of marginal buyer and supplier.
- The calculations of output values are based on a balanced number of participants rather than on the entrance price so that the model is only dependent on the number of participants.
- The developed calculation algorithm transforms the input functions into the output values of the number of suppliers and buyers, their membership fees and the total platform profit.
- Based on the basic two-sided market model, a CMfg pricing model is developed.

5 Static CMfg Platform Pricing Model

The foundation of the CMfg platform is to be financially successful in providing platform services to manufacturing companies. Chapter 2 determines the essential aspects of CMfg concepts, which are the foundation of the establishment of a CMfg platform. Chapter 3 identifies the determining factors of the CMfg pricing by a morphological analysis summarised by the gap analysis of Section 3.3 to identify the requirements of the CMfg pricing model. Chapter 4 models a basic pricing approach, which is essential to develop a calculation algorithm to calculate the number of customers, the entrance fees and the total platform profit.

In this chapter, the approach of Hagiu (2009) is further expanded, while the introduced model assumptions of Chapter 4 remain. The results of Chapter 2 until Chapter 4 are combined to include the theoretical CMfg concept, the determining factors and the basic model approach into the development of the CMfg pricing model. A static pricing approach is developed, focusing on a balanced number of participants to increase the total platform profit.

First, the fields of the basic two-sided market model are identified, which need to be adjusted to fit the identified determining factors of the CMfg platform. Second, the identified model requirements are introduced into the basic two-sided market pricing approach to model the CMfg pricing approach. Third, based on the developed CMfg pricing model, a calculation algorithm is defined to examine the calculation of the equilibrium output values of the CMfg platform. A model overview summarises the CMfg platform pricing model.

Table 5.1: Determining Factors for a CMfg Pricing Model

Determining Factors	Requirements
Market Situation	Platform monopoly
Homing Strategy	Single-homing
Participation Fees	Transaction-based fees
Intra-platform competition	Supplier market side
Product Characteristics	Product variety, differentiation
Separation into market groups	Buyer market side
Supplier market side	Horizontally differentiated
Buyer market side	Horizontally, vertically differentiated

5.1 Model Requirements

The first step for developing a CMfg pricing approach is to identify the requirements of the pricing model. Based on the results of the morphological analysis, the required determining factors of the CMfg pricing model are summarised by Table 5.1.

The CMfg pricing approach is developed for the market situation of a monopoly so that both market sides are single-homing by participating on the CMfg platform. By considering the results of Section 2.4, the CMfg platform provides its services by charging transaction-based entrance fees. The intra-platform competition is analysed on the supplier market side, since the profit function of each supplier decreases if new suppliers enter the CMfg platform (Behrens and Wiesner 2021). As the CMfg platform provides manufacturing, assembly and transportation capacity, the provided capacities are combined into highly individual supply chains to produce customer-specific products of high variety. To include the specifics of different customer groups, the different customer behaviour is modelled by the separation into market groups on the buyer market side.

In addition, the buyer market side is assumed to be horizontally and vertically differentiated to model the specifics of this market side accurately. The supplier market side is assumed to only be horizontally differentiated since the focus of the analysis is based on the intra-platform competition so that these effects are predominantly determined by the CMfg pricing model. After the requirements of the CMfg pricing approach are identified, the foundation for developing the CMfg pricing model is determined.

5.2 Model Development

The development of the CMfg pricing model is based on the identified model requirements. The first determining factors, which will be used to extend the basic pricing model of Hagiu (2009) are the product variety and differentiation. The buyer market side has specific product requirements regarding the production capacities of the platform. The buyer uploads a CAD file or a technical drawing containing the production requirements and quality metrics of the required product on the platform. The platform matches the customer inquiry with a producer who fulfils the requested product and quality standards and offers production capacity to produce this specific product, in a defined time frame. Product variety and differentiation are included in the model to analyse the effects of these requirements.

The capacity buyer values the capabilities of the supplier differently depending on their customer orders. The cloud manufacturing pricing model will include the parameter γ_{v}, which models the preference of the product variety by the buyers. By the increase of γ_{v} the utility and profit function of the platform participants increase. The reason is that the participants have a higher utility or profit if the products match the required manufacturing procedure more precisely. Product variety is interpreted as the differentiation of the product a supplier offers on the CMfg platform. If all suppliers offer the same product, the variety of products for the buyer would be restricted.

The product differentiation of the CMfg platform is based on the offered quality level of the suppliers. The differentiation is modelled by γ_η so that a value close to zero is interpreted as top quality. Similar to the product variety, an increasing γ_η leads to an increase in the utility and profit function of the participants. If γ_η and γ_{v} are modelled close to 1, the function shows a nearly linear progression. If γ_η or γ_{v} increase, the utility of the buyers also increases by the rising benefit of the purchased products.

$$u^{\mathrm{B}}(\eta) = (1 - \gamma_{\mathrm{v}} \cdot \gamma_\eta) \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta)} > 0 \tag{5.1}$$

The higher $\gamma_\eta \cdot \gamma_{\mathrm{v}}$ the less the profit of the suppliers falls, because the intra-platform competition decreases, which is interpreted as the weakening competition on the supplier market side.

$$\pi(\eta) = \gamma_{\mathrm{v}} \cdot \gamma_\eta \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta) - 1} \tag{5.2}$$

The total profit of both market sides increases concavely.

$$V^{\mathrm{P}}(\eta) = \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta)} \tag{5.3}$$

The next determining factors to be examined are the horizontal and vertical differentiation of the buyer market side and the horizontal differentiation of the supplier market side. The impacts of vertical and horizontal differentiation are modelled by $\theta_{\mathrm{h}}^{\mathrm{B}}$, $\theta_{\mathrm{h}}^{\mathrm{S}}$, $\theta_{\mathrm{v}}^{\mathrm{B}}$ and $\theta_{\mathrm{v}}^{\mathrm{S}}$. Horizontal differentiation separates both market side participants horizontally by their costs, as displayed by Figure 4.2 and Figure 4.3. For the buyer market side, the costs can for example include the time to participate on the CMfg platform, to search the matching suggestions of the platform if they fit to their requirements or to interact with new suppliers via the platform. For the supplier market side, the cost can include the set-up costs to register their capacity on the platform or to handle the internal processes within their manufacturing line to produce the products.

Vertical differentiation influences the progression of the utility function and the profit function. They show a higher increase of their net profit when $\theta_{\mathrm{v}}^{\mathrm{B}}$

and $\theta_{\mathrm{v}}^{\mathrm{S}}$ take a value closer to 1 and a higher decrease when $\theta_{\mathrm{v}}^{\mathrm{B}}$ and $\theta_{\mathrm{v}}^{\mathrm{S}}$ are closer to 0. This is based on the assumption that the participants value a heterogeneous customer structure higher than a homogeneous customer structure. The horizontal differentiation $\theta_{\mathrm{h}}^{\mathrm{B}}$ and $\theta_{\mathrm{h}}^{\mathrm{S}}$ represent the differentiation of the customers on the platform. With a high value of $\theta_{\mathrm{h}}^{\mathrm{B}}$ and $\theta_{\mathrm{h}}^{\mathrm{S}}$ the customers are assumed to be horizontally differentiated, which represents the customer-specific willingness to pay to use the platform. Similarly, a low value of $\theta_{\mathrm{h}}^{\mathrm{B}}$ and $\theta_{\mathrm{h}}^{\mathrm{S}}$ represents that more customers will participate.

The basic model of Hagiu (2009) already includes the impacts of horizontal differentiation on both market sides by $\theta_{\mathrm{h}}^{\mathrm{B}}$ and $\theta_{\mathrm{h}}^{\mathrm{S}}$. The pricing mechanism will be expanded by including the vertical differentiation parameter $\theta_{\mathrm{v}}^{\mathrm{B}}$ on the buyer market side. The modelling of vertical differentiation is introduced by multiplying the utility function of the buyer market side with the differentiation factor $\theta_{\mathrm{v}}^{\mathrm{B}}$. The net profit of the buyer market side displays the integration of horizontal differentiation with vertical differentiation.

$$\text{Net}^{\mathrm{B}} = \theta_{\mathrm{v}}^{\mathrm{B}} \cdot u^{\mathrm{B}}(\eta) - P^{\mathrm{B}} - \theta_{\mathrm{h}}^{\mathrm{B}} \tag{5.4}$$

Moreover, vertical differentiation can introduce a value product bundle (a_{G}) in the CMfg pricing model. An empty product basket is modelled with 0 and a full basket with 1 by $\theta_{\mathrm{v}}^{\mathrm{B}}$. The product bundle analyses vertical heterogeneous customer demand so that the net profit of the customer market side is enhanced by $\theta_{\mathrm{v}}^{\mathrm{B}} \cdot u^{\mathrm{B}}(\eta)$. Parameter a_{G} introduces the influence that with $\theta_{\mathrm{v}}^{a_{\mathrm{G}},\mathrm{B}}$, $a_{\mathrm{G}} \in [0,1]$ the benefit of the first product of the product bundle is higher than of the nth product.

A product bundle can contain various products from different suppliers per customer group. For example, products are produced by different manufacturing techniques, such as machines using lasers, laser punching, or die cutting to produce a similar product. Due to the preferences of the buyers, the products of the product bundles are chosen, so that their utility function is dependent on the offered products.

Another determining factor is the separation of customer groups, which is modelled by differentiated customer group utility functions $u^{\mathrm{B}}(\eta)$. The different groups of buyers are homogeneous within their groups, but show heterogeneous differentiation towards each other. It is possible to analyse the utility of different customer types for the offered capacities through the different customer groups. The model separates, for example, by the company size of the buyers, such as enterprise or SME. Another example is that one customer group can value express delivery by accepting additional costs, while the other group does not. From group to group $\theta_{\mathrm{v}}^{\mathrm{B}}$ differs depending on the utility perception.

Since the products of the bundles differentiates between the customer groups, the assumption that every buyer purchases every product can be softened. The total number of products of all customer groups, is defined as the total number of products offered on the platform. Derived from $\theta_{\mathrm{v}}^{\mathrm{B}}$ and $u^{\mathrm{B}}(\eta)$, the horizontal differentiation $\theta_{\mathrm{h}}^{\mathrm{B}}$ and the entrances fees of the buyers P^{B} can be approximated. The net profit of the buyer market side includes vertical differentiation through the implementation of product bundles and the separation into customer groups i.

$$
\begin{aligned}
\mathrm{Net}_1^{\mathrm{B}} &= \left(\theta_{\mathrm{v},1}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \cdot u_1^{\mathrm{B}}(\eta) - P_1^{\mathrm{B}} - \theta_{\mathrm{h},1}^{\mathrm{B}} \\
\mathrm{Net}_2^{\mathrm{B}} &= \left(\theta_{\mathrm{v},2}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \cdot u_2^{\mathrm{B}}(\eta) - P_2^{\mathrm{B}} - \theta_{\mathrm{h},2}^{\mathrm{B}} \\
&\vdots \\
\mathrm{Net}_i^{\mathrm{B}} &= \left(\theta_{\mathrm{v},i}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \cdot u_i^{\mathrm{B}}(\eta) - P_i^{\mathrm{B}} - \theta_{\mathrm{h},i}^{\mathrm{B}}, \quad i \in \mathbb{N}
\end{aligned}
\tag{5.5}
$$

The net profit of the capacity suppliers is modified correspondingly.

$$
\mathrm{Net}^{\mathrm{S}} = \pi(\eta) \cdot \sum_{i=1}^{n} \theta_{\mathrm{v},i}^{\mathrm{B}} \cdot F_i\left(\theta_{\mathrm{m},i}^{\mathrm{B}}\right) - P^{\mathrm{S}} - \frac{\eta}{H(\eta)} \tag{5.6}
$$

The entrance fees of the different customer groups will vary depending on their utility function. The platform profit is modelled.

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{n} P_i^{\mathrm{B}} \cdot F_i\left(\theta_{\mathrm{m},i}^{\mathrm{B}}\right) + \eta \cdot P^{\mathrm{S}}. \tag{5.7}$$

Additionally, the cloud manufacturing pricing model will be based on transaction-based fees for both market sides. According to the empirical research of Behrens and Wiesner (2021), customers prefer transaction-based fees to membership fees. The number of transactions of buyers and suppliers has to be considered to calculate the corresponding transaction-based fees.

The platform profit is calculated based on the number of transactions of both markets sides on the platform. There are $F_i\left(\theta_{\mathrm{m},i}^{\mathrm{B}}\right)$ participants in each buyer group, which each buy $\eta \cdot \theta_{\mathrm{v},i}^{\mathrm{B}}$ products. If the transactions are charged with p^{S}, the total transaction fee per buyer of this particular group can be calculated.

$$P_i^{\mathrm{B}} = p_i^{\mathrm{B}} \cdot \eta \cdot \theta_{\mathrm{v},i}^{\mathrm{B}}. \tag{5.8}$$

The total price of each customer group to participate on the platform includes the transaction-based prices p_i^{B}. The net profit of the buyer market side is modelled for i customer groups.

$$\mathrm{Net}_i^{\mathrm{B}} = \left(\theta_{\mathrm{v},i}^{\mathrm{B}}\right)^{\mathrm{a_G}} \cdot u_i^{\mathrm{B}}(\eta) - \left(p_i^{\mathrm{B}} \cdot \eta \cdot \theta_{\mathrm{v},i}^{\mathrm{B}}\right) - \theta_{\mathrm{h},i}^{\mathrm{B}} \tag{5.9}$$

Similarly to the customer groups, the net profit of the capacity suppliers is modelled by including the number of transactions on the buyer market side, since through their interactions the transactions are directly linked to the sold machine capacities of the suppliers.

$$\mathrm{Net}^{\mathrm{S}} = p^{\mathrm{S}} \cdot \sum_{i=1}^{n} \theta_{\mathrm{v},i}^{\mathrm{B}} \cdot F_i(\theta_{\mathrm{m},i}^{\mathrm{B}}) \tag{5.10}$$

The profit function of the platform is only dependent on the parameters (η, $\theta^{\mathrm{B}}_{\mathrm{m},i}$) and includes the presented determining factors of the CMfg pricing approach. The total profit of the platform is calculated based on the transaction-fees of both market sides.

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{n} \left\{ F_i(\theta^{\mathrm{B}}_{\mathrm{m},i}) \left[\theta^{\mathrm{a_G}}_{\mathrm{v},i} u^{\mathrm{B}}_i(\eta) - \theta^{\mathrm{B}}_{\mathrm{v},i} + \eta\, \pi(\eta) \sum_{j=1}^{m} \theta^{\mathrm{B}}_{\mathrm{v},ij} \right] \right\} - \frac{\eta}{H(\eta)} \tag{5.11}$$

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{n} \left\{ F_i(\theta^{\mathrm{B}}_{\mathrm{m},i}) \left[\sum_{j=1}^{m} V^{\mathrm{P}}_{i,j} - \theta^{\mathrm{B}}_{\mathrm{v},ij} \right] \right\} - \frac{\eta}{H(\eta)} \tag{5.12}$$

In conclusion, the pricing structure of a CMfg platform is analysed more accurately based on the presented two-sided market pricing approach. The input functions of the platform and its participants will be used to calculate the equilibrium number of participants, the optimal transaction-based fees and the total profit of the platform in a monopoly market situation. Next, the developed pricing approach will be transferred into a calculation algorithm to examine the necessary calculation steps of the CMfg pricing approach.

5.3 Calculation Algorithm

The developed CMfg pricing approach of the previous section follows the eight calculation steps displayed by Figure 5.1 to determine the required output values. The aim of the calculation algorithm is to define the total profit of the platform, which is based on an equilibrium number of buyers and suppliers participating on the platform. The calculation algorithm includes eight steps including the algorithm 3, 4, 5 and 6. Based on the calculated values of these algorithms, the values for the number of buyers, the transaction-based fees of both market sides and the total platform profit are calculated.

Figure 5.1: Calculation Algorithm of the Static CMfg Pricing Model

The input parameters of Algorithm 1 are adjusted to define Algorithm 3 including the determining factors of the CMfg platform. Algorithm 1 is extended by the parameter γ_{v} including the product differentiation of the offered production capacities. The input functions of buyers and suppliers are also extended by γ_{v} so that the adjusted CMfg pricing model includes product variety. Algorithm 3 includes the adjusted input functions to calculate the upper limit of the buyer market side.

Similar to the calculations of Algorithm 1, the input parameters of the pricing model are defined by Algorithm 3. Next, the chosen input parameters will be used for the calculation of the input functions utility of buyers, profit function of suppliers and total profit of both market sides considering the influences of γ_{v}. An iterative algorithm is used to calculate the upper limit of the buyer by inserting the maximum value for $V^{\mathrm{P}}(\eta_{\max})$ as defined in Equation 4.24. Since $\theta_{\mathrm{H}}^{\mathrm{B}}$ can reach a maximum value of one, the algorithm ensures that the value is within the defined value range. If the calculation of $\theta_{\mathrm{H}}^{\mathrm{B}}$ leads to a higher value for this parameter, the iterative algorithm sets $\theta_{\mathrm{H}}^{\mathrm{B}}$ to one.

Algorithm 3 CMfg Pricing Model Calculation Algorithm Upper Limit Buyer

Require: $\gamma_\eta \in [0,1]; \gamma_{\mathrm{v}} \in [0,1]; \epsilon_{\mathrm{F}} \in [0,1]; \epsilon_{\mathrm{H}} \in [0,1]; m^{\mathrm{S}} \in \mathbb{N}; m^{\mathrm{B}} \in \mathbb{N};$

$\eta_{\min} = 1; \eta_{\max} = m^{\mathrm{B,S}}$

Ensure:

$u^{\mathrm{B}}(\eta) = (1 - \gamma_{\mathrm{v}} \cdot \gamma_\eta) \cdot \eta^{\gamma_{\mathrm{v}} \cdot \gamma_\eta}$ ▷ Utility Function Buyers

$\pi(\eta) = \gamma_{\mathrm{v}} \cdot \gamma_\eta \cdot \eta^{\gamma_{\mathrm{v}} \cdot \gamma_\eta - 1}$ ▷ Profit Function Suppliers

$V^{\mathrm{P}}(\eta) = \eta^{\gamma_{\mathrm{v}} \cdot \gamma_\eta}$ ▷ Total Profit of Both Market Sides

Ensure: ▷ Upper Limit Buyer

if $\frac{V^{\mathrm{P}}(\eta_{\max})}{\frac{1}{\epsilon_{\mathrm{f}}}+1} \leq 1$ **then**

$\theta_{\mathrm{H}}^{\mathrm{B}} = \frac{V^{\mathrm{P}}(\eta_{\max})}{\frac{1}{\epsilon_{\mathrm{f}}}+1}$

else

if $\frac{V^{\mathrm{P}}(\eta_{\max})}{\frac{1}{\epsilon_{\mathrm{f}}}+1} > 1$ **then**

$\theta_{\mathrm{H}}^{\mathrm{B}} = 1$

end if

end if

After the calculation of the upper limit of the buyer, the upper limit for the supplier is calculated by Algorithm 4.

Algorithm 4 CMfg Pricing Model Calculation Algorithm Upper Limit Suppliers

Require: $\gamma_\eta \in [0,1]$; $\gamma_\mathrm{v} \in [0,1]$; $\epsilon_\mathrm{F} \in [0,1]$; $\epsilon_\mathrm{H} \in [0,1]$; $m^\mathrm{S} \in \mathbb{N}$; $m^\mathrm{B} \in \mathbb{N}$;

$\eta_{\min} = 1$; $\eta_{\max} = m^{\mathrm{B,S}}$; $\theta^\mathrm{B}_\mathrm{H} \in [0,1]$

Ensure: ▷ Upper Limit Suppliers

if $\pi(\eta_{\min}) \cdot F\left(\frac{u^\mathrm{B}(\eta_{\min})}{\theta^\mathrm{B}_\mathrm{H}}\right)^{\epsilon_\mathrm{F}} \cdot m^\mathrm{B} \leq 1$ **then**

$\theta^\mathrm{S}_\mathrm{H} = \pi(\eta_{\min}) \cdot F\left(\frac{u^\mathrm{B}(\eta_{\min})}{\theta^\mathrm{B}_\mathrm{H}}\right)^{\epsilon_\mathrm{F}} \cdot m^\mathrm{B}$

else

if $\pi(\eta_{\min}) \cdot F\left(\frac{u^\mathrm{B}(\eta_{\min})}{\theta^\mathrm{B}_\mathrm{H}}\right)^{\epsilon_\mathrm{F}} \cdot m^\mathrm{B} > 1$ **then**

$\theta^\mathrm{S}_\mathrm{H} = 1$

end if

end if

Equal to the calculations of Algorithm 2, Algorithm 4 uses an iterative method to calculate the upper limit of the supplier by inserting the maximum value for $u^\mathrm{B}(\eta_{\min})$ as defined in Equation 4.27. Since $\theta^\mathrm{S}_\mathrm{H}$ can reach a maximum value of one, the algorithm ensures that the value is within the defined value range. If the calculation of $\theta^\mathrm{S}_\mathrm{H}$ leads to a higher value for this parameter, the iterative algorithm sets $\theta^\mathrm{S}_\mathrm{H}$ to one. The upper limits of both algorithms are elementary to calculate the equilibrium number of both market sides. The calculated values are elementary to determine the output values of the remaining six calculation steps, starting with the calculation of the number of suppliers in equilibrium.

Next, Algorithm 5 calculates the number of suppliers in equilibrium. The first step of the calculation adjusts Equation 4.1 by introducing the presented pricing model advancement of Section 5.2 to form Equation 5.13, which models the total benefits of both market sides.

$$V_{\mathrm{i}}^{\mathrm{P}}(\eta) = (\theta_{\mathrm{v},i}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}(\eta) + (\theta_{\mathrm{v},i}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot \eta \cdot \pi(\eta), \tag{5.13}$$

The first derivative of Equation 5.13 with respect to η leads to Equation 5.14 to identify the indifferent numbers of the marginal supplier.

$$V_{\mathrm{i}}^{\prime\mathrm{P}}(\eta) = \eta \cdot \left((\gamma_\eta \cdot \gamma_{\mathrm{v}})^3 \cdot \left(\theta_{\mathrm{v,i}}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \right) + \left(\frac{2 \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}}{(\gamma_\eta - \gamma_{\mathrm{v}})} \right) \tag{5.14}$$

The number of suppliers in equilibrium contains Equation 5.13 and Equation 5.14.

$$\begin{aligned} \eta_{\mathrm{equ.}} = & \sum_{i=1}^{\mathrm{n}} \cdot V_{\mathrm{i}}^{\prime\mathrm{P}}(\eta) \cdot \frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta)}{\left(\left(1 + \frac{1}{\epsilon_{\mathrm{F,i}}}\right) \cdot \theta_{\mathrm{h,i}}^{\mathrm{B}} \right)^{\epsilon_{\mathrm{F,i}} \cdot m^{\mathrm{B}}}} \\ & - \eta^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot m^{\mathrm{S}\,\frac{-1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}} \cdot \left(\frac{1 + \epsilon_{\mathrm{H}}}{\epsilon_{\mathrm{H}}} \right) \end{aligned} \tag{5.15}$$

Due to the complexity of Equation 5.15 an approximation method is used to calculate the number of participants as explained by Algorithm 5. The Algorithm starts by setting η to one supplier as the starting value for the calculation. An iterative algorithm is used for the calculation to define the number of suppliers in equilibrium by counting up the number of suppliers. The output values for $V_{\mathrm{i}}^{\mathrm{P}}(\eta)$, $V_{\mathrm{i}}^{\prime\mathrm{P}}(\eta)$ and $\eta_{\mathrm{equ.}}$ are calculated for each value of η until the value of η is close to equal to $\eta_{\mathrm{equ.}}$ or the entire market potential of the supplier market side is reached.

Since the number of suppliers can only be interpreted within $\mathbb{N}$, the result of the algorithm can be rounded down or up. Since the effects of the rounding only slightly affects the analysis of the equilibrium calculation, the suppliers will be rounded up to have a constant procedure to only be able to consider numbers of $\mathbb{N}$. The calculation of these parameters is determined by Algorithm 5.

Algorithm 5 CMfg Pricing Model Calculation Algorithm Number of Suppliers

Require: $\gamma_\eta \in [0,1]; \gamma_{\mathrm{v,i}} \in [0,1]; \epsilon_{\mathrm{F,i}} \in [0,1]; \epsilon_{\mathrm{H}} \in [0,1]; m^{\mathrm{S}} \in \mathbb{N}; m^{\mathrm{B}} \in \mathbb{N};$

$\eta_{\min} = 1; \eta_{\max} = m^{\mathrm{B,S}}; \theta_{\mathrm{H}}^{\mathrm{B}} \in [0,1]; \theta_{\mathrm{H}}^{\mathrm{S}} \in [0,1]; \alpha_{\mathrm{G}} \in [0,1];$

$\theta_{\mathrm{v,i}}^{\mathrm{B}} \in [0,1]; \theta_{\mathrm{v}}^{\mathrm{S}} \in [0,1];$

$\eta_{\mathrm{Start}} = 1$ ▷ Start Value of Product Number

Ensure: $V_{\mathrm{i}}^{\mathrm{P}}(\eta) = (\theta_{\mathrm{v,i}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}(\eta) + (\theta_{\mathrm{v,i}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot \eta \cdot \pi(\eta)$

$V_{\mathrm{i}}'^{\mathrm{P}}(\eta) = \eta \cdot \left((\gamma_{\eta,\mathrm{i}} \cdot \gamma_{\mathrm{v,i}})^3 \cdot \left(\theta_{\mathrm{v,i}}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \right) + \left(\frac{2 \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}}{(\gamma_{\eta,\mathrm{i}} - \gamma_{\mathrm{v,i}})} \right)$

$\eta_{\mathrm{equ.}} = \sum_{i=1}^{\mathrm{n}} \cdot V_{\mathrm{i}}'^{\mathrm{P}}(\eta) \cdot \frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta)}{\left(\left(1+\frac{1}{\epsilon_{\mathrm{F,i}}}\right) \cdot \theta_{\mathrm{h,i}}^{\mathrm{B}}\right)^{\epsilon_{\mathrm{F,i}} \cdot m^{\mathrm{B}}}} - \eta^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot m^{\mathrm{S}\frac{-1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}} \cdot \left(\frac{1+\epsilon_{\mathrm{H}}}{\epsilon_{\mathrm{H}}} \right)$

while $\Delta(\eta - \eta_{\mathrm{equ.}}) > 0.01 \wedge \eta < m^{\mathrm{B,S}} + 1$ **do**

$V_{\mathrm{i}}^{\mathrm{P}}(\eta) = (\theta_{\mathrm{v,i}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}(\eta) + (\theta_{\mathrm{v,i}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot \eta \cdot \pi(\eta)$

$V_{\mathrm{i}}'^{\mathrm{P}}(\eta) = \eta \cdot \left((\gamma_{\eta,\mathrm{i}} \cdot \gamma_{\mathrm{v,i}})^3 \cdot \left(\theta_{\mathrm{v,i}}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \right) + \left(\frac{2 \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}}{(\gamma_{\eta,\mathrm{i}} - \gamma_{\mathrm{v,i}})} \right)$

$\eta_{\mathrm{equ.}} = \sum_{i=1}^{\mathrm{n}} \cdot V_{\mathrm{i}}'^{\mathrm{P}}(\eta) \cdot \frac{{}_{\mathrm{i}}^{\mathrm{P}}(\eta)}{\left(\left(1+\frac{1}{\epsilon_{\mathrm{F,i}}}\right) \cdot \theta_{\mathrm{h,i}}^{\mathrm{B}}\right)^{\epsilon_{\mathrm{F,i}} \cdot m^{\mathrm{B}}}} - \eta^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot m^{\mathrm{S}\frac{-1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}} \cdot \left(\frac{1+\epsilon_{\mathrm{H}}}{\epsilon_{\mathrm{H}}} \right)$

$\eta = \eta + 0.01$

end while

$\eta_{\mathrm{equ.}} = \eta - 0.01$ ▷ Equilibrium Number of Suppliers

Lastly, Algorithm 6 calculates the marginal buyer of the buyer market side.

Algorithm 6 CMfg Pricing Model Calculation Algorithm Marginal Buyer

Require: $\gamma_\eta \in [0,1]; \gamma_{\mathrm{v,i}} \in [0,1]; \epsilon_{\mathrm{F,i}} \in [0,1]; \epsilon_{\mathrm{H}} \in [0,1]; m^{\mathrm{S}} \in \mathbb{N}; m^{\mathrm{B}} \in \mathbb{N};$

$\eta_{\min} = 1; \eta_{\max} = m^{\mathrm{B,S}}; \theta_{\mathrm{H}}^{\mathrm{B}} \in [0,1]; \theta_{\mathrm{H}}^{\mathrm{S}} \in [0,1]; \alpha_{\mathrm{G}} \in [0,1];$

$\theta_{\mathrm{v,i}}^{\mathrm{B}} \in [0,1]; \theta_{\mathrm{v}}^{\mathrm{S}} \in [0,1]; \eta_{\mathrm{equ.}} \in \mathbb{N}$ ▷ Suppliers in Equilibrium

Ensure: ▷ Marginal Buyer in Equilibrium

if $\frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta_{\mathrm{equ.}})}{\frac{1}{\epsilon_{\mathrm{F,i}}}} < 1$ **then**

$\theta_{\mathrm{m,i}}^{\mathrm{B}} = \frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta_{\mathrm{equ.}})}{\frac{1}{\epsilon_{\mathrm{F,i}}}}$

else

if $\frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta_{\mathrm{equ.}})}{\frac{1}{\epsilon_{\mathrm{F,i}}}} > 1$ **then**

$\theta_{\mathrm{m,i}}^{\mathrm{B}} = 1$

end if

end if

Following the calculation approaches of Algorithm 1 and 2, Algorithm 6 uses an iterative method to calculate the marginal buyer. Equation 4.36 is adjusted so that $\eta_{\mathrm{equ.}}$ is included for the calculation of the marginal buyer. Since $\theta_{\mathrm{m,i}}^{\mathrm{B}}$ can reach a maximum value of one, the algorithm ensures that the value is within the defined value range. If the calculation of $\theta_{\mathrm{m,i}}^{\mathrm{B}}$ leads to a higher value for this parameter, the iterative algorithm sets $\theta_{\mathrm{m,i}}^{\mathrm{B}}$ to one.

Based on the results of Algorithm 3 through Algorithm 6, the total number of buyers, the transaction-based entrance fees and the total CMfg platform profit are calculated. The equilibrium number of the marginal buyer is used to define the number of buyers in equilibrium by determining the number of buyers within each buyer group, afterwards the number of buyers of each group is summed up so that the total number of buyers is defined.

$$\begin{aligned} B_{\mathrm{i}} &= \left(\frac{\theta_{\mathrm{m,i}}^{\mathrm{B}}}{\theta_{\mathrm{H,i}}^{\mathrm{B}}} \right)^{\epsilon_{\mathrm{F,i}} \cdot m_{\mathrm{i}}^{\mathrm{B}}} \\ B_{\mathrm{total}} &= \sum_{i=1}^{\mathrm{n}} B_{\mathrm{i}} \end{aligned} \tag{5.16}$$

Based on the number of participants, the transaction-based fees of both market sides are calculated. The buyer market side is charged by Equation 5.17 and the supplier market side is charged by Equation 5.18 for each transaction on the platform.

$$p_{\mathrm{i}}^{\mathrm{B}} = \frac{\left(\theta_{\mathrm{v,i}}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \cdot u_{\mathrm{i}}^{\mathrm{B}}(\eta) - \theta_{\mathrm{m,i}}^{\mathrm{B}}}{\eta \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}} \tag{5.17}$$

$$p^{\mathrm{S}} = \pi(\eta) - \frac{\left(\frac{\eta}{m^{\mathrm{B}}}\right)^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}}}{\sum_{i=1}^{\mathrm{n}} \theta_{\mathrm{v,i}}^{\mathrm{B}} \cdot B_{\mathrm{i}}} \tag{5.18}$$

Due to the calculated numbers of buyers and suppliers and their according transactions on the CMfg platform, the total platform profit is defined.

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{\mathrm{n}} p_{\mathrm{i}}^{\mathrm{B}} \cdot B_{\mathrm{i}} \cdot \eta \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}} + p^{\mathrm{S}} \cdot \eta \cdot \sum_{i=1}^{\mathrm{n}} \theta_{\mathrm{v,i}}^{\mathrm{B}} \cdot B_{\mathrm{i}}. \tag{5.19}$$

In conclusion, the defined eight calculation steps of Figure 5.1 lead to the output values for the CMfg platform in accordance with the defined approach stated in Figure 3.4. In the following chapter, a numerical analysis of the static CMfg pricing model will be conducted to gain a deeper understanding of the underlying network effects and the influences between the input and output parameters.

5.4 Model Overview

The developed CMfg pricing model responds to research question two. The summary of the components of the CMfg pricing model is the foundation for the calculation of the required output values as shown by Figure 3.4 based on their input parameters. Based on the developed CMfg pricing model, an analytical and numerical study to analyse the complexity of a two-sided market approach is conducted in Chapter 6. After introducing all components of the pricing model, a consolidated view of the full model is given:

$$u^{\mathrm{B}}(\eta) = (1 - \gamma_{\mathrm{v}} \cdot \gamma_{\eta}) \cdot \eta^{\gamma_{\mathrm{v}} \cdot \gamma_{\eta}} > 0 \tag{5.20}$$

▷ Utility Function of Buyers

$$\pi(\eta) = \gamma_{\mathrm{v}} \cdot \gamma_{\eta} \cdot \eta^{\gamma_{\mathrm{v}} \cdot \gamma_{\eta} - 1} \tag{5.21}$$

▷ Profit Function of Suppliers

$$V^{\mathrm{P}}(\eta) = \eta^{\gamma_{\mathrm{v}} \cdot \gamma_{\eta}} \tag{5.22}$$

▷ Utility of Buyers and Suppliers

$$\mathrm{Net}_{\mathrm{i}}^{\mathrm{B}} = (\theta_{\mathrm{v,i}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot u_{\mathrm{i}}^{\mathrm{B}}(\eta) - P_{\mathrm{i}}^{\mathrm{B}} - \theta_{\mathrm{h,i}}^{\mathrm{B}} \tag{5.23}$$

▷ Benefit of Buyers

$$\mathrm{Net}^{\mathrm{S}} = \pi\left(\eta\right) \cdot (\theta^{\mathrm{B}}_{\mathrm{v},1} \cdot F(\theta^{\mathrm{B}}_{1,\mathrm{m}})) + (\theta^{\mathrm{B}}_{\mathrm{v},2} \cdot F(\theta^{\mathrm{B}}_{2,\mathrm{m}})) - P^{\mathrm{S}} - \frac{\eta}{H\left(\eta\right)} \quad (5.24)$$

▷ Net Profit of Suppliers

$$P^{\mathrm{B}}_{\mathrm{i}} = p^{\mathrm{B}}_{\mathrm{i}} \cdot \eta \cdot \theta^{\mathrm{B}}_{\mathrm{v,i}}. \quad (5.25)$$

▷ Transaction-based Fee Buyers

$$\mathrm{Net}^{\mathrm{B}}_{\mathrm{i}} = (\theta^{\mathrm{B}}_{\mathrm{v,i}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}_{\mathrm{i}}(\eta) - \left(p^{\mathrm{B}}_{\mathrm{i}} \cdot \eta \cdot \theta^{\mathrm{B}}_{\mathrm{v,i}}\right) - \theta_{\mathrm{h,i}} \quad (5.26)$$

▷ Net Profit of Buyers

$$\mathrm{Net}^{\mathrm{S}}_{\mathrm{i}} = p^{\mathrm{B}} \cdot (\theta^{\mathrm{B}}_{\mathrm{v},1} \cdot F_1(\theta^{\mathrm{B}}_{1,\mathrm{m}}) + \theta^{\mathrm{B}}_{\mathrm{v},2} \cdot F_2(\theta^{\mathrm{B}}_{2,\mathrm{m}}) + ... + \theta^{\mathrm{B}}_{\mathrm{v,i}} \cdot F_{\mathrm{i}}(\theta^{\mathrm{B}}_{\mathrm{i,m}})) \quad (5.27)$$

▷ Net Profit of Suppliers

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{n} \left\{ F_i(\theta^{\mathrm{B}}_{\mathrm{m},i}) \left[\sum_{j=1}^{m} V^{\mathrm{P}}_{i,j} - \theta^{\mathrm{B}}_{\mathrm{v},ij} \right] \right\} - \frac{\eta}{H(\eta)} \quad (5.28)$$

▷ Total Platform Profit

$$V^{\mathrm{P}}_{\mathrm{i}}\left(\eta\right) = (\theta^{\mathrm{B}}_{\mathrm{v,i}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}\left(\eta\right) + (\theta^{\mathrm{B}}_{\mathrm{v,i}})^{\alpha_{\mathrm{G}}} \cdot \eta \cdot \pi\left(\eta\right) \quad (5.29)$$

▷ Utility of Buyers and Suppliers

$$V_{\mathrm{i}}^{\prime\mathrm{P}}(\eta) = \eta \cdot \left(\left(\gamma_{\eta,\mathrm{i}} \cdot \gamma_{\mathrm{v,i}} \right)^3 \cdot \left(\theta_{\mathrm{v,i}}^{\mathrm{B}} \right)^{\alpha_{\mathrm{G}}} \right) + \left(\frac{2 \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}}{\left(\gamma_{\eta,\mathrm{i}} - \gamma_{\mathrm{v,i}} \right)} \right) \tag{5.30}$$

▷ First Derivation of Gross Profit of Buyers and Suppliers

$$\begin{aligned} \eta_{\mathrm{equ.}} = \sum_{i=1}^{\infty} \cdot V_{\mathrm{i}}^{\prime\mathrm{P}}(\eta) \cdot \frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta)}{\left(\left(1 + \frac{1}{\epsilon_{\mathrm{F,i}}} \right) \cdot \theta_{\mathrm{h,i}}^{\mathrm{B}} \right)^{\epsilon_{\mathrm{F,i}} \cdot m^{\mathrm{B}}}} \\ - \eta^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot m^{\mathrm{S}\,\frac{-1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}} \cdot \left(\frac{1 + \epsilon_{\mathrm{H}}}{\epsilon_{\mathrm{H}}} \right) \end{aligned} \tag{5.31}$$

▷ Equilibrium Number of Suppliers

$$\theta_{\mathrm{m,i}}^{\mathrm{B}} = \frac{V_{\mathrm{i}}^{\mathrm{P}}(\eta)}{\frac{1}{\epsilon_{\mathrm{F,i}}}} \tag{5.32}$$

▷ Equilibrium Number of Marginal Buyer

$$B_{\mathrm{i}} = \left(\frac{\theta_{\mathrm{m,i}}^{\mathrm{B}}}{\theta_{\mathrm{H,i}}^{\mathrm{B}}} \right)^{\epsilon_{\mathrm{F,i}} \cdot m_{\mathrm{i}}^{\mathrm{B}}} \tag{5.33}$$

▷ Equilibrium Number of a Buyer Group

$$B_{\mathrm{total}} = \sum_{i=1}^{\mathrm{n}} B_{\mathrm{i}} \tag{5.34}$$

▷ Equilibrium Number Sum of all Buyer Groups

$$p_{\mathrm{i}}^{\mathrm{B}} = \frac{\left(\theta_{\mathrm{v,i}}^{\mathrm{B}}\right)^{\alpha_{\mathrm{G}}} \cdot u_{\mathrm{i}}^{\mathrm{B}}\left(\eta\right) - \theta_{\mathrm{m,i}}^{\mathrm{B}}}{\eta \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}}} \tag{5.35}$$

▷ Equilibrium Transaction-based Fees Buyers

$$p^{\mathrm{S}} = \pi\left(\eta\right) - \frac{\left(\frac{\eta}{m^{\mathrm{B}}}\right)^{\frac{1}{\epsilon_{\mathrm{H}}}} \cdot \theta_{\mathrm{h}}^{\mathrm{S}}}{\sum_{i=1}^{\mathrm{n}} \theta_{\mathrm{v,i}}^{\mathrm{B}} \cdot B_{\mathrm{i}}} \tag{5.36}$$

▷ Equilibrium Transaction-based Fees Suppliers

$$\Pi^{\mathrm{P}} = \sum_{i=1}^{\mathrm{n}} p_{\mathrm{i}}^{\mathrm{B}} \cdot B_{\mathrm{i}} \cdot \eta \cdot \theta_{\mathrm{v,i}}^{\mathrm{B}} + p^{\mathrm{S}} \cdot \eta \cdot \sum_{i=1}^{\mathrm{n}} \theta_{\mathrm{v,i}}^{\mathrm{B}} \cdot B_{\mathrm{i}} \tag{5.37}$$

▷ Equilibrium Total Profit Platform

5.5 Summary

Summarised, this chapter presents the developed CMfg pricing model:

- The two-sided pricing model of Hagiu (2009) is the basis to develop a pricing model including the specificity of the CMfg platform.
- The requirements of the CMfg pricing model contain a monopoly market situation, transaction-based fees for both market sides, intra-platform competition on the supplier market side, product variety and differentiation, separation into market groups on the buyer market side, horizontally differentiated suppliers and horizontal, vertically differentiated buyers.
- Based on the requirements, a static CMfg pricing model is developed, including the defined determining factors into the basic pricing model.
- For calculating the output value numbers of both market side customers, their transaction-based fees and the total platform profit, a calculation algorithm is developed.
- The calculation algorithm includes eight steps to transform the input functions into output values.
- For a deeper analysis of the relationship between the input and output values, an analytical and numerical analysis is conducted.

6 Analytical and Numerical Analysis

The developed CMfg pricing model of Chapter 5 is analytically and numerically analysed to answer research question number three. Methods of differential calculus and statistical experimental design are used to analyse the relationship between the input and the output parameters.

The variation of the input parameters of the CMfg affects the total platform profit, which is elementary to establish an economically viable, functioning platform. The analysis focuses on examining the effects of the different input parameters to gain insights into the complexity of the CMfg pricing models. Due to the two market sides of the model, the analysis of the parameters scrutinises the impact of the network effects onto the model.

The analysis of the effects of the input parameters aims to understand the CMfg pricing model in detail. A central aspect of the CMfg pricing model is to determine those input parameters that lead to an increasing profitability of the platform. The different input parameters of the two-sided market CMfg pricing model are displayed by Table 6.1. First, the parameters are analysed analytically by the following section.

Table 6.1: Input Parameters of the CMfg Pricing Model

Input Parameters	**Description of Input Parameters**
$\gamma_{\mathrm{v}} \in [0,1]$	Product variety
$\gamma_{\eta} \in [0,1]$	Product differentiation
$\epsilon_F \in [0,1]$	Elasticity of the buyer market side
$\theta_{\mathrm{v}}^{\mathrm{B}} \in [0,1]$	Vertical differentiation costumer
$a_{\mathrm{G}} \in [0,1]$	Value product bundle

6.1 Analytical Analysis

The input parameters of the CMfg pricing model are analysed analytically, beginning with the product variety γ_{v} and the product differentiation γ_{η}. Both parameters are $\in [0,1]$. They have a direct impact on the utility function of the buyer market side and the profit function of the supplier market side, which both influence the progression of the total platform profit function. The utility function of the buyers u^{B} is set equal to zero and derived into $u^{\mathrm{B}'}$.

$$u^{\mathrm{B}}(\eta) = (1 - \gamma_{\mathrm{v}} \cdot \gamma_{\eta}) \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_{\eta})} \tag{6.1}$$

$$0 \stackrel{!}{=} (1 - \gamma_{\mathrm{v}} \cdot \gamma_{\eta}) \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_{\eta})} \tag{6.2}$$

$$u^{\mathrm{B}'}(\eta) = \frac{(1 - \gamma_{\mathrm{v}} \cdot \gamma_{\eta}) \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_{\eta})} \cdot \gamma_{\eta}^2 \cdot \gamma_{\mathrm{v}}^2}{\eta^2} - \frac{(1 - \gamma_{\mathrm{v}} \cdot \gamma_{\eta}) \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_{\eta})} \cdot \gamma_{\eta} \cdot \gamma_{\mathrm{v}}}{\eta^2} \tag{6.3}$$

The first derivation of u^{B} has a defined extreme point for η if γ_{v} and γ_{η} are ≥ 0 as shown by Figure 6.1. If γ_{v} and γ_{η} both are equal to zero, no products are offered on the CMfg platform and no utility is created for the buyers to join the platform.

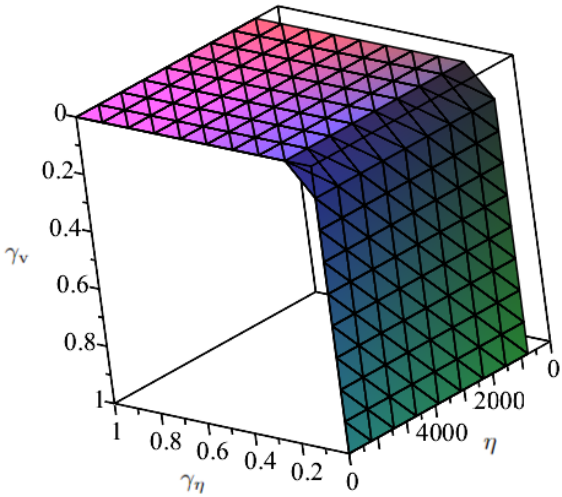

Figure 6.1: γ_{v} and γ_η on $u^{\mathrm{B}'}$

In addition, the effects of the parameters γ_{v} and γ_η on the profit function π of the suppliers are analysed. They have a direct impact on the profit function of the supplier market side and the utility function of the supplier market side. The profit function of the supplier π is set equal to zero and derived into π'.

$$\pi(\eta) = \gamma_{\mathrm{v}} \cdot \gamma_\eta \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta)-1} \tag{6.4}$$

$$0 \overset{!}{=} \gamma_{\mathrm{v}} \cdot \gamma_\eta \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta)-1} \tag{6.5}$$

$$\pi'(\eta) = \frac{\gamma_{\mathrm{v}} \cdot \gamma_\eta \cdot \eta^{(\gamma_{\mathrm{v}} \cdot \gamma_\eta)-1} \cdot (\gamma_{\mathrm{v}} \cdot \gamma_\eta) - 1}{\eta} \tag{6.6}$$

The first derivation of π has a defined extreme point for η if γ_{v} and γ_{η} are $\in [0, 1]$. If γ_{v} and γ_{η} both are equal to zero, no products are offered on the CMfg platform and no profit is created for the suppliers to join the platform.

To summarise, the parameters γ_{v} and γ_{η} are clearly defined within the first derivation of the utility and profit function of the CMfg pricing model for the value η as shown in Figure 6.2.

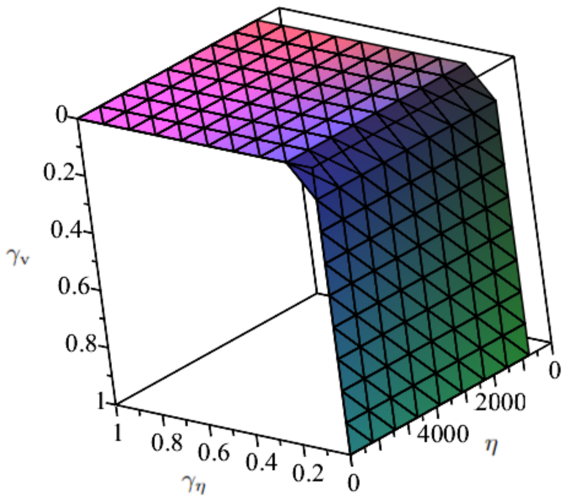

Figure 6.2: γ_{v} and γ_{η} on π'

Moreover, the parameters γ_{v} and γ_{η} have an impact on the progression of the utility and profit function of the CMfg platform. The utility function of the buyer market side is modelled as monotonously increasing and concave. The closer the parameters γ_{v} and γ_{η} to 1 the steeper the rise of the function as displayed by Figure 6.3.

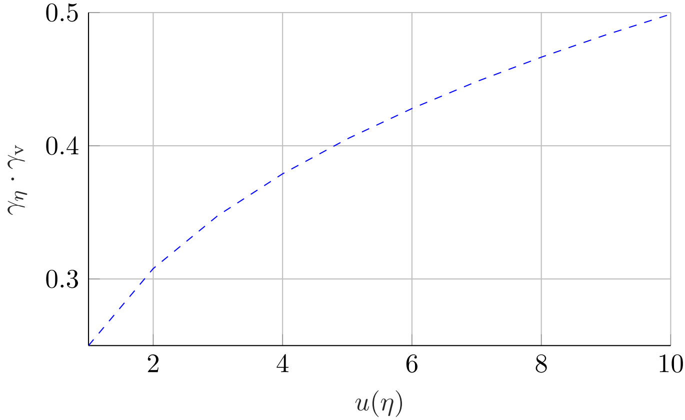

Figure 6.3: Variation of $\gamma_\eta \cdot \gamma_v$ on $u(\eta)$

Regarding the profit function of the supplier market side, the parameters γ_v and γ_η also have an impact on the progression of this function. The profit function of the supplier market side is modelled as monotonously decreasing and convex. The closer the parameters γ_v and γ_η to one, the steeper the fall of the function, as displayed by Figure 6.4.

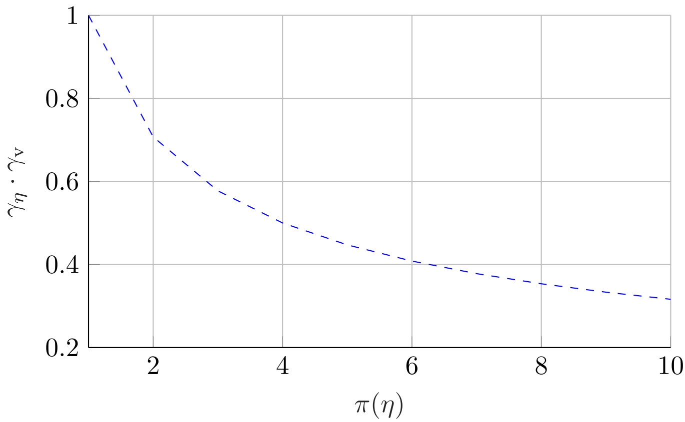

Figure 6.4: Variation of $\gamma_\eta \cdot \gamma_v$ on $\pi(\eta)$

In conclusion, the closer the values of γ_{v} and γ_{η} to one, the higher is the benefit of both market sides to join the CMfg platform, which also increase the total platform profit.

The next input parameter to be analysed is ϵ_F. This parameter is defined as the elasticity of the buyer market side and influences the participation of the buyers on the CMfg platform so that the cumulative distribution function of buyers $F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)$ is calculated.

$$F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right) = \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right)^{\epsilon_{\mathrm{F}}} \tag{6.7}$$

The number of the marginal buyer $\theta_{\mathrm{m}}^{\mathrm{B}}$ is divided by the number of the upper limit of buyers $\theta_{\mathrm{H}}^{\mathrm{B}}$. Both parameters are defined as $\in [0; 1]$ so that the results of the calculation are within the defined number range.

$$0 < \left(\frac{\theta_{\mathrm{m}}^{\mathrm{B}}}{\theta_{\mathrm{H}}^{\mathrm{B}}}\right) \leq 1 \tag{6.8}$$

The denominator is the upper limit of the buyers so that this value is modelled to be greater than or equal to the number of the numerator, which is the number of the marginal buyer. The closer the number of the marginal buyer is towards the upper limit of buyers, the higher is the number of buyers on the CMfg platform.

The result of the division of $\theta_{\mathrm{m}}^{\mathrm{B}}$ and $\theta_{\mathrm{H}}^{\mathrm{B}}$ is multiplied by the power of ϵ_F to calculate $F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)$. The parameter ϵ_F is distributed $\in [0, 1]$ and directly affects the progression of $F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)$. As a result, the closer ϵ_F is to zero, the higher is the number of buyers participating on the CMfg platform, which positively affects the total platform profit as, displayed in Figure 6.5.

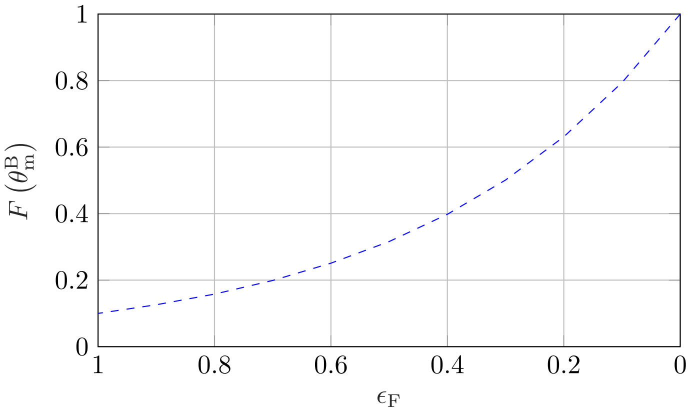

Figure 6.5: Variation of ϵ_{F} on $F\left(\theta_{\mathrm{m}}^{\mathrm{B}}\right)$

Next, the input parameters $\theta_{\mathrm{v}}^{\mathrm{B}}$ and a_{G} are analysed. The total profit of the customers participating on the CMfg platform is depended on the utility function of both market sides multiplied by the vertical differentiation of the buyers $\theta_{\mathrm{v}}^{\mathrm{B}}$ and the value of the product bundle a_{G}, which directly influences the total platform profit.

$$V^{\mathrm{P}}(\eta) = (\theta_{\mathrm{v}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot u^{\mathrm{B}}(\eta) + (\theta_{\mathrm{v}}^{\mathrm{B}})^{\alpha_{\mathrm{G}}} \cdot \eta \cdot \pi(\eta) \tag{6.9}$$

The value range for $\theta_{\mathrm{v}}^{\mathrm{B}}$ and a_{G} is defined as $\in [0;1]$. These parameters influence the progression of the utility function. The closer the value of $\theta_{\mathrm{v}}^{\mathrm{B}}$ is towards one, the more valuable is the utility and profit functions of both market sides, modelled by $V^{\mathrm{P}}(\eta)$, to join the CMfg. The reason is that the utility function is not weakened by a value below one, which leads, by multiplying with the utility function, to a smaller benefit of the customers joining the platform. The influences of $\theta_{\mathrm{v}}^{\mathrm{B}}$ on the total profit of both market sides of the platform is shown in Figure 6.6.

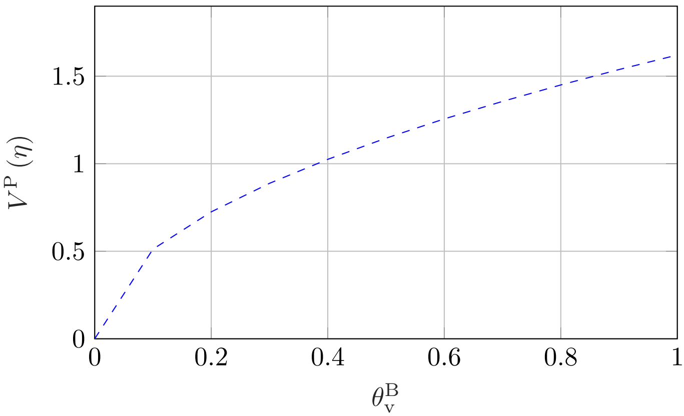

Figure 6.6: Variation of $\theta_{\mathrm{v}}^{\mathrm{B}}$ on $V^{\mathrm{P}}(\eta)$

The vertical differentiation of the buyers $\theta_{\mathrm{v}}^{\mathrm{B}}$ is directly affected by a_{G}. The closer the value of a_{G} is towards zero, the higher the value of $\theta_{\mathrm{v}}^{\mathrm{B}}$ and V^{P} and the more valuable the platform is for both market sides to participate on, as shown by Figure 6.7.

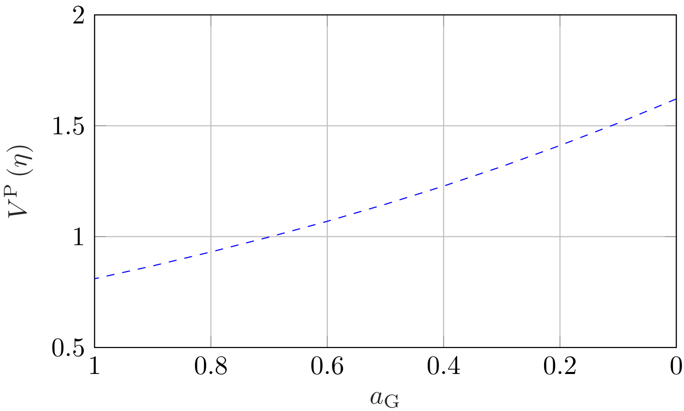

Figure 6.7: Variation of a_{G} on $V^{\mathrm{P}}(\eta)$

Table 6.2: Experimental Design of Input Parameters

Experiments	γ_{v}	γ_η	ϵ_F	$\theta_{\text{v}}^{\text{B}}$	a_{G}
Number 1	$\in [0,1]$	-	-	-	-
Number 2	-	$\in [0,1]$	-	-	-
Number 3	-	-	$\in [0,1]$	-	-
Number 4	-	-	-	$\in [0,1]$	-
Number 5	-	-	-	-	$\in [0,1]$

In summary, if the value of the input parameters γ_{v} and γ_η are closer to one, the utility of both market sides is higher to participate on the CMfg platform. If the input parameter ϵ_F is closer to zero, a higher number of buyers participate on the platform. If the value of $\theta_{\text{v}}^{\text{B}}$ is closer to one and the value of a_{G} is closer to zero, the total utility V^{P} for both market sides to join the platform is higher.

Based on the results of the input parameters γ_{v}, γ_η, ϵ_F, $\theta_{\text{v}}^{\text{B}}$ and a_{G} of the analytical analysis, a numerical analysis is conducted to validate these results in the following section.

6.2 Numerical Analysis

The numerical analysis aims to validate the results of the analytical analysis to further examine the effects of the input parameters on the CMfg pricing model. Especially, the effects of the required values of the input parameters on the total platform profit will be analysed.

In accordance with Siebertz et al. (2017), the statistical experimental design and boundaries are defined, on which the numerical analysis is based. Each of the parameters will be numerical analysed within the defined value range $\in [0,1]$, while the remaining other four input parameters will be unchanged so that in total five experiments are conducted as shown by Table 6.2.

The numerical calculation is based on the developed CMfg calculation algorithm presented in Section 5.3. The calculation algorithm includes eight steps including the algorithm 3, 5, 4 and 6. Based on the calculated values of these algorithms, the values for the number of buyers, the transaction-based fees of both market sides and the total platform profit are calculated.

The first experiment examines the effect of γ_{v} on Π^{P}, which is measured by monetary units (MU). The input parameter γ_{v} is changed to $\in [0,1]$, while the remaining four parameters γ_{η}, ϵ_F, $\theta^{\mathrm{B}}_{\mathrm{v}}$ and a_{G} stay unchanged. Each value $\in [0,1]$ of γ_{v} runs through the eight steps of the calculation algorithm. The experiment is conducted as shown by Figure 6.8.

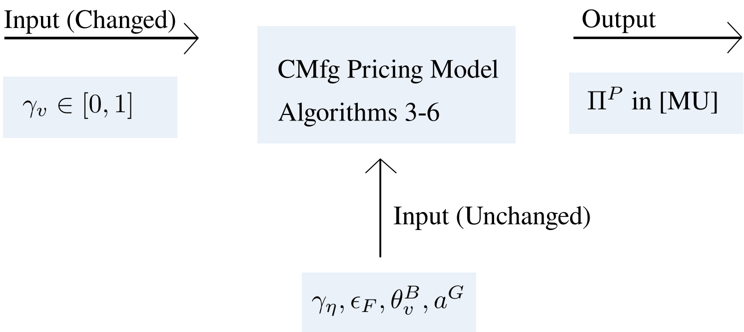

Figure 6.8: Experiment Number 1: γ_{v} on Π^{P}

The results of the experiment are displayed by Figure 6.9. These results validate the analytical results. The platform profit of the CMfg platform is higher, if the value of the input parameters γ_{v} is closer to one.

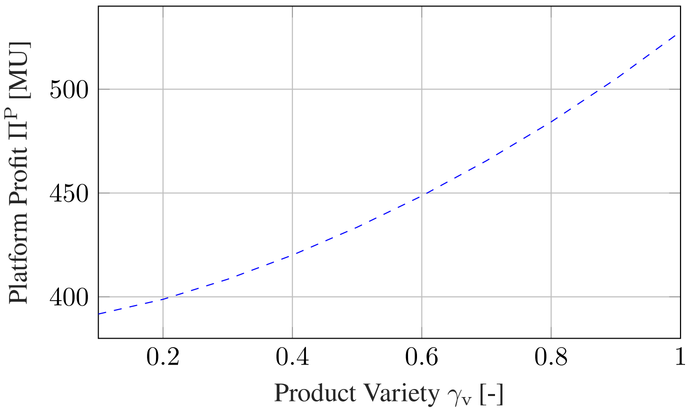

Figure 6.9: Results of Experiment 1: Variation of γ_{v} on Π^{P}

The second experiment shows the effect of γ_η on Π^{P}. The input parameter γ_η is changed to $\in [0, 1]$, while the remaining four parameters γ_{v}, ϵ_F, $\theta^{\mathrm{B}}_{\mathrm{v}}$ and a_{G} stay unchanged. Each value $\in [0, 1]$ of γ_η runs through the eight steps of the calculation algorithm. The experiment is conducted as shown by Figure 6.10.

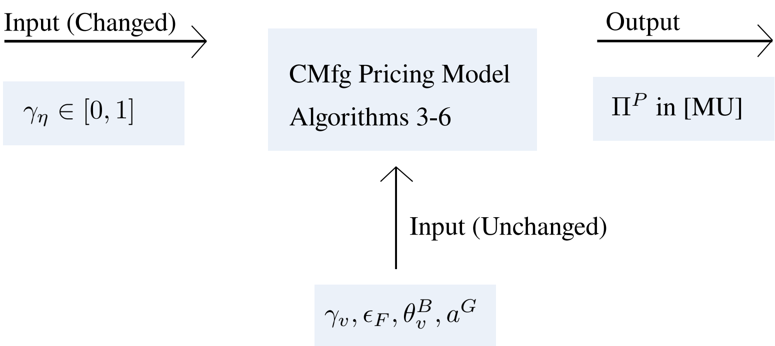

Figure 6.10: Experiment Number 2: γ_η on Π^{P}

The results of the experiment are presented by Figure 6.11. These results validate the analytical results. The platform profit of the CMfg platform is higher, if the value of the input parameters γ_η is closer to one.

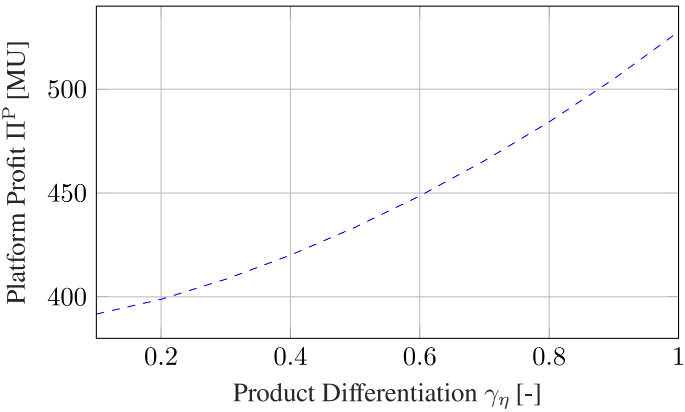

Figure 6.11: Results of Experiment 2: Variation of γ_η on Π^{P}

The third experiment analyses the effect of ϵ_F on Π^{P}. The input parameter ϵ_F is changed to $\in [0, 1]$, while the remaining four parameters γ_{v}, γ_η, $\theta_{\text{v}}^{\text{B}}$ and a_{G} stay unchanged. Each value $\in [0, 1]$ of ϵ_F runs through the eight steps of the calculation algorithm. The experiment is conducted as displayed by Figure 6.12.

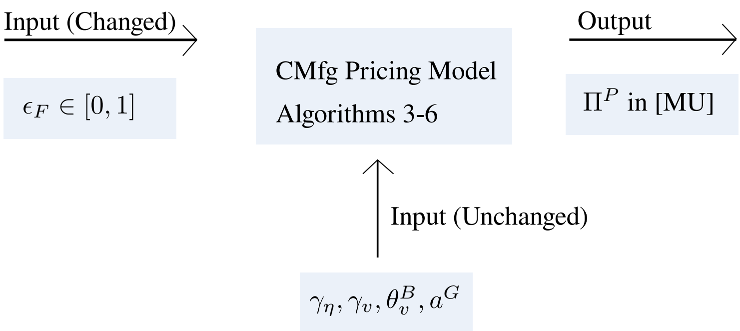

Figure 6.12: Experiment Number 3: ϵ_{F} on Π^{P}

The results of the experiment are shown by Figure 6.13. These results validate the analytical results. The platform profit of the CMfg platform is higher, if the input parameter ϵ_F is closer to zero.

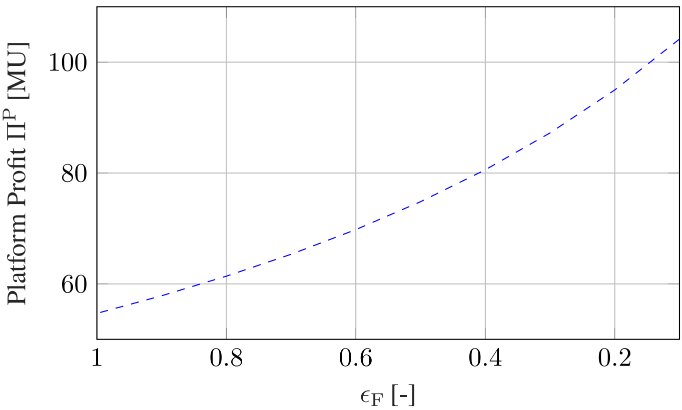

Figure 6.13: Results of Experiment 3: Variation of ϵ_F on Π^{P}

The fourth experiment examines the effect of $\theta_{\mathrm{v}}^{\mathrm{B}}$ on Π^{P}. The input parameter $\theta_{\mathrm{v}}^{\mathrm{B}}$ is changed to $\in [0, 1]$, while the remaining four parameters γ_{v}, γ_{η}, ϵ_F and a_{G} stay unchanged. Each value $\in [0, 1]$ of $\theta_{\mathrm{v}}^{\mathrm{B}}$ runs through the eight steps of the calculation algorithm. The experiment is conducted as displayed by Figure 6.14.

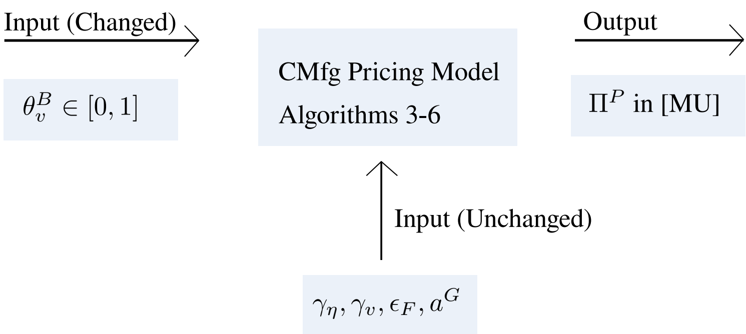

Figure 6.14: Experiment Number 4: $\theta_{\mathrm{v}}^{\mathrm{B}}$ on Π^{P}

The results of the experiment are displayed by Figure 6.15. These results validate the analytical results. The platform profit of the CMfg platform is higher, if the value of $\theta_{\mathrm{v}}^{\mathrm{B}}$ is closer to one.

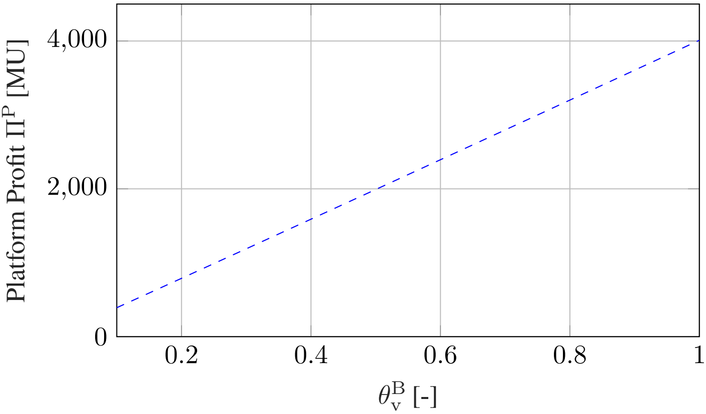

Figure 6.15: Results of Experiment 4: Variation of $\theta_{\mathrm{v}}^{\mathrm{B}}$ on Π^{P}

The fifth experiment analyses the effect of a_{G} on Π^{P}. The input parameter a_{G} is changed to $\in [0, 1]$, which the remaining four parameters γ_{v}, γ_{η}, ϵ_F and $\theta_{\mathrm{v}}^{\mathrm{B}}$ stay unchanged. Each value $\in [0, 1]$ of a_{G} runs through the eight steps of the calculation algorithm. The experiment is conducted as displayed by Figure 6.16.

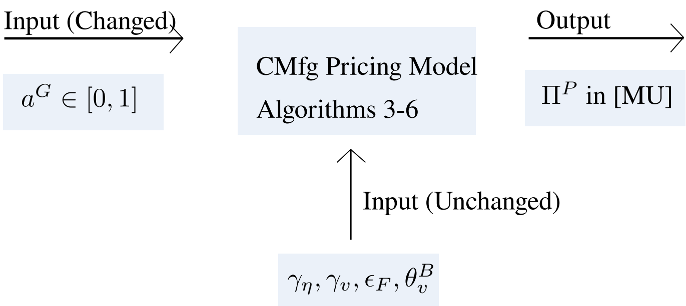

Figure 6.16: Experiment Number 5: a^{G} on Π^{P}

The results of the experiment are shown by Figure 6.17. These results validate the analytical results. The platform profit of the CMfg platform is higher, if the value of a_{G} is closer to zero.

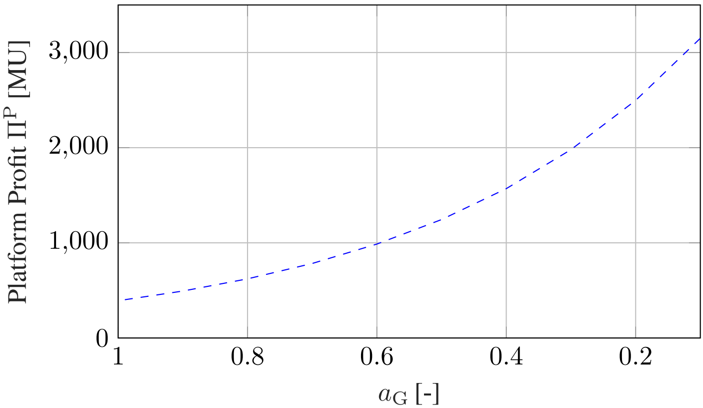

Figure 6.17: Results of Experiment 5: Variation of a_{G} on Π^{P}

In summary, the five numerical experiments validate the results of the analytical analysis so that the required values of input parameters are also confirmed by the numerical analysis.

6.3 Overview of Results

In Section 6.1 an analytical analysis and in Section 6.2 a numerical analysis of the input parameters is conducted. As a result, the effects of the input parameters on the total platform profit of the developed static CMfg pricing model is investigated. Table 6.3 summarises the required values of the input parameters, which affect the participation on the CMfg platform positively, leading to more traffic on the CMfg platform and to a higher total platform profit.

Table 6.3: Required Values of Input Parameters

Parameters	γ_v	γ_η	ϵ_F	$\theta_\mathrm{v}^\mathrm{B}$	a_G
Required Values	1	1	0	1	0

In conclusion, the developed static CMfg pricing approach enables the CMfg platform to determine the required values of the input parameters, which leads to a stable total profit growth of the platform. The analysis examines the influences of the underlying network effects between the CMfg platform and both market sides. Nevertheless, further analysis of the input and output parameters of the CMfg pricing model is required to completely understand the complexity of the two-sided market CMfg pricing model. The next extension of the CMfg pricing model is to include dynamic effects into the CMfg pricing approach to gain a deeper understanding of dynamic effects of the CMfg pricing model.

6.4 Summary

After the analytical and numerical analysis of the CMfg pricing model, a consolidated view of the full results is presented:

- The CMfg pricing model contains five input parameters, which affect the number of both market side participants, their transaction-based fees and the total platform profit.
- The effects of the input parameters on the output parameters are analysed analytically by utilising methods of differential calculus.
- The effects of the input parameters on the output parameters are analysed numerically by utilising statistical experimental design.
- The results of the analytical analysis are validated by the numerical analysis.
- The analysis identifies the required values of the input parameters, as shown by Table 6.3, which affect the number of participants on the CMfg platform positively.
- The required values of the input parameters increase the total platform profit positively.
- Next, dynamic effects of the CMfg pricing model are analysed to understand the underlying dependencies of the two market sides.

7 Outlook Dynamic Pricing Model

Based on the results of the static CMfg pricing model, an outlook for a dynamic CMfg pricing model is presented in this chapter by introducing dynamic effects into the developed static pricing structure. This chapter gives a first impression on how dynamic effects are integrated into the CMfg pricing model. The analysis of the dynamic effects is based on an example by expanding the CMfg pricing model through the aspect of time. Therefore, the model requirements, the model development and the calculation algorithm of the static CMfg pricing model is expanded.

7.1 Model Requirements

The elementary requirement for a CMfg platform to succeed is that the minimum participation of buyers and suppliers reaches a critical mass. Veisdal (2020) analyses that it is the central aspect for the CMfg platform to motivate the first participants of both market sides to enter the platform. Srinivasan and Lakshmipathy (2017) describe the necessity for participants to join a CMfg in order for the platform to grow. These fundamental aspects are influenced by a dynamic pricing model so that it is required to develop a pricing approach including the complexity of price discrimination. Since the CMfg platform model increases the profit of the platform by an equilibrium number of both side market participants, price discrimination of the platform is based on the number of participants.

Additionally, the analysis of a dynamic CMfg pricing model is based on the complexity generated by network effects between the different market sides of the platform. Zhou et al. (2020) analyse various strategies of value creation due to network effects within a platform network by incorporating time aspects into their model. Their model analyses the effects of market shocks. In contrast to their model, a more general approach is needed since dynamic aspects are not only required at a specific time due to market shocks. Wright (2004) analyses that it is not easily possible to transfer a one-sided market mechanism into a two-sided market pricing model so that a special two-sided market approach for price discrimination needs to be developed.

The dynamic effects of the CMfg pricing model are analysed by introducing time periods to examine the discounting strategies. This integration of dynamic effects is a first outlook to consider dynamic influences on the CMfg pricing model. During the analysis, the dynamic effects are analysed on the buyer market side, since there is no intra-platform competition modelled on this market side. If the number of buyers increases, participants of the supplier market side also join the CMfg platform due to the underlying network effects. The analysis of the dynamic effects are based on the equilibrium number of both side participants so that a specific development of a dynamic model for the CMfg is required.

7.2 Model Development

Based on the developed static CMfg pricing model, the first considerations of including dynamic effects into the CMfg pricing model are made. One consideration is to add time, modelled by time of each period ($time$), into the static pricing model. Due to the effects of the aspect time, the CMfg pricing model includes differentiated pricing strategies for each period, which change over a defined number of periods.

The effects of the time periods are developed based on the elasticity of Hagiu (2009), which is the foundation to establish a discrimination strategy within the pricing approach of a CMfg platform to increase its total profit. For each time period, the effects of price discrimination are measured by the ratio of the market position of the suppliers λ over the buyers and the elasticity of the buyer market side ϵ_F. The two parameters λ and ϵ_F affect the number of participants on both market sides and therefore the equilibrium of the developed CMfg pricing model. The CMfg platform subsidises the supplier market side, as modelled by:

$$\lambda \leq \frac{\epsilon_{\mathrm{H}}}{1+\epsilon_{\mathrm{H}}} \tag{7.1}$$

The elasticities are chosen so that the equilibrium calculation in one time period considers the ratios of Equation 7.1, which consider the number of platform participants and their network effects. The CMfg platform subsidises the buyer market side, as modelled by:

$$\lambda \geq \frac{1}{\epsilon_{\mathrm{V}}\left(1+\epsilon_{\mathrm{F}}\right)} \tag{7.2}$$

The CMfg platform will subsidise the buyer market side to analyse the dynamic effects on the CMfg pricing model. The network effects between both market sides are used so that more suppliers will participate if the number of buyers increases. Next, a calculation algorithm needs to be developed, which includes the factor time in the static CMfg pricing approach to calculate the number of customers, the transaction-based fees and the platform profit.

7.3 Calculation Algorithm

The calculation algorithm of the CMfg pricing model aims to determine the total profit of the platform. The calculation algorithm of the static CMfg pricing model is enhanced by Algorithm 7. The ten calculation steps of the dynamic pricing approach are presented by Figure 7.1.

These ten calculation steps are processed within defined time periods. Due to the complexity of the dynamic pricing model, the analysis considers only one

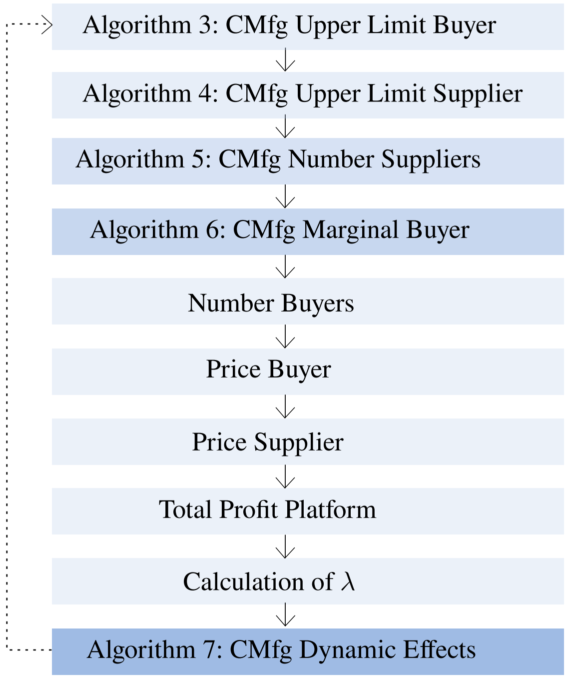

Figure 7.1: Calculation Algorithm of the Dynamic Two-Sided Market CMfg Pricing Model

buyer market group. The CMfg pricing model includes dynamic effects by the adjustment of the demand of the buyer market side, since due to network effects the supplier market side enters the CMfg platform if the number of buyers participating leads to benefit, modelled by the profit function of the suppliers.

The demand of the buyers is modelled by their elasticity defined by ϵ_F, which is modelled to be in the value range of $\in [0, 1]$. The elasticity of the net utility of the customers ϵ_F affects the fixed cost distribution of the buyers in the interval [0,$\theta_{\mathrm{H}}^{\mathrm{B}}$].

$$\epsilon_{\mathrm{F}}(\theta_{\mathrm{h}}^{\mathrm{B}}) = \frac{\theta_{\mathrm{h}}^{\mathrm{B}} \cdot f(\theta_{\mathrm{h}}^{\mathrm{B}})}{F(\theta_{\mathrm{h}}^{\mathrm{B}})}. \tag{7.3}$$

If ϵ_F increases towards one, the cost structure shifts towards the upper limit $\theta_{\mathrm{H}}^{\mathrm{B}}$ leading to an increasing $\theta_{\mathrm{h}}^{\mathrm{B}}$ and lower demand on the buyer market side. Consequently, the buyer demand to participate on the CMfg platform increases if the value of ϵ_F decreases. A high elasticity value close to one decreases the demand of the buyers to participate on the CMfg platform so that the value of the elasticity needs to be close to zero.

In addition to that, Equation 7.2 contains the ratio of subsidising the buyer market side. In accordance with the determined ratios and the information of the required value ranges of the elasticity, modifications of Equation 7.2 are conducted. As the highest possible value for the elasticity of the buyers is defined at the value one, ϵ_F is set to one, so that ϵ_V^{P} multiplied with one is ϵ_V^{P}, which defines the upper limit of the equation.

$$\frac{1}{\epsilon_{\mathrm{V}}^{\mathrm{P}}\left(1+\epsilon_{\mathrm{F}}\right)} \stackrel{!}{=} \frac{1}{\epsilon_{\mathrm{V}}^{\mathrm{P}}+\epsilon_{\mathrm{V}}^{\mathrm{P}}} \tag{7.4}$$

The CMfg platform subsidises the demand of the buyers for the CMfg platform, which can be increased if the elasticity of the buyer market side is decreased:

$$\epsilon_{\mathrm{F}} \leq \frac{1}{\epsilon_{\mathrm{V}}^{\mathrm{P}}+1} \tag{7.5}$$

Next, Algorithm 7 is developed to include the dynamic effects modelled by $time$ into the calculation. An iterative algorithm is reducing ϵ_F by a price discrimination (p^{D}) to model the increase in the demand of the buyers to participate on the CMfg platform. Each decrease of ϵ_F is leading to ${\epsilon_F}^{time+1}$. Since ${\epsilon_F}^{time}$ is replaced by ${\epsilon_F}^{time+1}$, Algorithm 3, 4, 5 and 6 have to be processed for each time period, since the value of ${\epsilon_F}^{time}$ is adjusted in each period to ${\epsilon_F}^{time+1}$. The decrease of ${\epsilon_F}^{time}$ to ${\epsilon_F}^{time+1}$ leads to a higher demand of the buyer market side to participate on the CMfg platform, which affects the CMfg pricing model due to network effects so that it is assumed that the participation for the two market sides is more beneficial.

Algorithm 7 CMfg Pricing Model Calculation Algorithm Dynamic Effects

Require: $\gamma_\eta \in [0,1]$; $\gamma_{\mathrm{v}} \in [0,1]$; $\epsilon_{\mathrm{H}} \in [0,1]$; $m^{\mathrm{S}} \in \mathbb{N}$; $m^{\mathrm{B}} \in \mathbb{N}$;

$\eta_{\min} = 1$; $\eta_{\max} = m^{\mathrm{B,S}}$; $\theta_{\mathrm{H}}^{\mathrm{B}} \in [0,1]$; $\theta_{\mathrm{H}}^{\mathrm{S}} \in [0,1]$; $a_{\mathrm{G}} \in [0,1]$;

$\theta_{\mathrm{v}}^{\mathrm{B}} \in [0,1]$; $\theta_{\mathrm{v}}^{\mathrm{S}} \in [0,1]$; $\eta_{\mathrm{equ.}} \in \mathbb{N}$; $\theta_{\mathrm{m}}^{\mathrm{B}} \in [0,1]$;

$[time,\ time+1,\ \ldots,\ time+n] \in [0,n]$; $p^{\mathrm{D}} \in [0,1]$

Ensure: $\epsilon_{\mathrm{F}}^{\mathrm{time}} \in [0,1]$; $\epsilon_{\mathrm{F}}^{\mathrm{time+1}} \in [0,1]$,

if $\epsilon_{\mathrm{F}} > \frac{1}{\epsilon_{\mathrm{V}}+1}$ **then**

$\epsilon_{\mathrm{F}} = \frac{1}{\epsilon_{\mathrm{V}}+1}$

else

if $\epsilon_{\mathrm{F}} \leq \frac{1}{\epsilon_{\mathrm{V}}+1}$ **then**

$\epsilon_{\mathrm{F}}^{\mathrm{time}} = \epsilon_{\mathrm{F}}^{\mathrm{time+1}}$ - p^{D}

end if

end if

In summary, Algorithm 7 gives a first impression, how a two-sided market pricing model of a CMfg platform can include dynamic effects of $time$ to develop a price discrimination p^{D} strategy. The analysis of the dynamic effects is assumed to increase the total platform profit if the platform manages to decrease the elasticity of the buyer market side. Nevertheless, further analysis will be required to fully examine the influences of dynamic effects on the CMfg pricing model. Chapter 8 discusses the results and transfers them into practical insights and critically analyses them to identify further research areas to improve the dynamic CMfg pricing model.

7.4 Summary

Summarised, this chapter presents the outlook on a dynamic CMfg pricing model:

- Based on the static CMfg pricing model, a first outlook on the development of a dynamic pricing model is presented.
- The dynamic pricing model considers time periods to include dynamic effects into the model.
- The dynamic model development is based on the ratio of λ and the elasticities ϵ_H, ϵ_F and ϵ_V^{P}.
- An algorithm of the dynamic CMfg pricing model is developed to calculate a price discrimination strategy based on the output values.
- Dynamic effects of the CMfg pricing model can support the CMfg to understand the underlying dependencies of the two market sides and how to use them.
- Since the dynamic effect is only based on the introduction of time and the consideration of an increasing demand of buyers, further research is required.

8 Discussion of Central Drivers

The specifics of the CMfg pricing model are defined by Chapter 2 and Chapter 3 by analysing the enormous growth potential of CMfg platforms, which is foreseen in the next years. The central drivers for CMfg platform businesses are the network effects between the different market sides. Chapter 4 until Chapter 7 develop the CMfg pricing model, which is analysed in detail by an analytical and numerical analysis. The relationship between the input parameters of the CMfg pricing model is examined to gain a deeper understanding of the influence which the network effects have on the two market sides participating on the CMfg platform towards the total platform profit.

As the developed CMfg pricing model includes the specific requirements of a CMfg platform, it supports the CMfg platform to adapt its pricing strategies to the current market situation. The results of the analysis of the parameter study of the static and dynamic CMfg pricing model are essential to support the CMfg platforms to make beneficial decisions and for being economically sustainable. These results are discussed in the following, including a first indication of general applicability of the approach, to an example in practice, outside of CMfg.

8.1 Central Drivers of the Analysis

The discussion of the central results of the static CMfg pricing model is based on the results of the analytical and numerical analysis. The underlying network effects between the two market sides are analysed to understand the dependencies, which are included in the CMfg pricing model. The analysis focuses on the effects of the five input parameters on their output values such as the number of participants of both market groups, their transaction-based fees and the total platform profit.

The input parameter combination leading to a higher platform profit includes a high variety and differentiation of the offered products, which are highly individual so that a high demand on both market sides towards the CMfg platform is reached. A central result of the analysis is, that if the vertical differentiation and variety of the product increase, the total platform profit increases based on an increase of the number of both side participants.

In conclusion, the analysis of the static CMfg pricing model shows once again the complexity within the two-sided market pricing model due to its network effects. There is still potential to further expand the approach by, for example, including the cost for the development and operations of the CMfg platform.

Based on the static CMfg pricing model, a first impression on a dynamic pricing model is developed. The analysis of the dynamic effects is based on an example by expanding the CMfg pricing model with the aspect time. Due to the integration of the aspect time, evaluations of dynamic effects are obtained. The assumption of the dynamic pricing model is that the CMfg platform can increase the demand on the buyer market side so that the remaining output values of the pricing structures have to be adapted accordingly.

Therefore, the possibilities of the CMfg platform to increase the demand of the buyer market side have to be analysed. The number of buyers can be affected by subsidising the buyers by setting the entrance prices for one or both market sides accordingly. The analysis of the dynamic pricing model shows that the subsidising of one market side can be based on the individual costs of this market side, rather than adjusting their transaction-based costs to participate on the CMfg platform. By the decrease of the elasticity, the transaction-based prices are adjusted accordingly to contain the number of participants in equilibrium.

The possibility to increase the demand of the buyer market side allows the CMfg platform to steer the dynamic effects to reach a higher platform profit. A central result of the analysis is that a decrease in the elasticity of the buyer market leads to an increase in the demand of the buyer market side, which is assumed to increase the satisfaction of the buyers. One practical possibility to increase their demand is that the CMfg platform offers a full services package to their participants. The CMfg platform is the contracting party for the participants and takes care of all organisational issues, such as payment or insurance. Anonymous ordering and multi-sourcing from different suppliers are also a possibility to further increase the utility of the buyer market side. Buyers can directly access the resources of the suppliers without having to rely on services from third parties. Thus, the platform targets a larger potential user group than established systems, as the barriers to entry are relatively low for both suppliers and buyers. Compared with companies outside the platform, a competitive advantage is achieved due to better access to the market over the CMfg platform. The orders of the buyers on the CMfg platform are processed faster and more securely, lowering costs and prices through better utilisation of production capacities and simultaneously improving the data security of the production orders (Wiesner et al. 2020).

Moreover, the CMfg platform includes a rating service. After a customer order is completed, the customers of both markets rate their satisfaction with the CMfg platform services. Besides the direct rating of the customers, a calculation of an indirect rating based on the generated process data is conducted. The customer feedback collected within the different process steps of the execution contains valuable information, which can be linked to the specific product. Production accuracy of the suppliers and production issues are identified and assigned directly, which increases the satisfaction of the buyers and therefore their demand for the CMfg platform. Through the alignment of product and the rating service, an advantage for the capacity supplier arises, since they can optimise their production, adapt their quality metrics precisely to their manufacturing procedure (Wiesner et al. 2020).

The buyer and supplier market side proceed with an on-boarding process for participating on the CMfg platform. Through the collection of data during the onboarding process, the CMfg platform introduces a standardised agreement of the terms and conditions so that the buyers participating do not have to negotiate terms every time they request products of a supplier, which leads to a decrease of their internal costs by utilising the CMfg platform (Möller et al. 2017).

Additionally, the information of historical customer orders is utilised to predict future customer behaviour. Historical order and transaction data are analysed so that order patterns or customer preferences are included to forecast the customer demand based on previous customer orders (Murray et al. 2018). The forecast supports the planning of the required production capacity so that the platform can examine if the current capacity availability is balanced to the expected demand of the buyer market side (Ren et al. 2015). The information of the identified patterns is used to optimise the forecast of the behaviour of the buyers (Cheung and Zhang 1999).

Next to the increase of the demand of the buyer market side, the demand of the supplier market side should also be taken into consideration. The CMfg platform identifies, collects and categorises data of every customer order, which is examined to extract patterns, knowledge and relevant information of the cloud manufacturing processes. Higher utilisation of the machines, through data analysis to identify suitable production demands, leads to cost benefits for the capacity suppliers of the CMfg platform and could increase the demand of suppliers to participate on the platform (Kaufmann 2015).

In addition, there are several possibilities for the CMfg platform to affect the demand of the buyer and supplier market side to participate on the CMfg platform. The results of the analysis of the CMfg pricing model is elementary to handle the complexity of the CMfg market and can ascertain practical insights to support management decisions. The CMfg platform regulates the number of participants in equilibrium, which substantially improves the number of transactions on the platform. Due to the results of the analysis of the CMfg pricing model, visualisation and controlling tools can be introduced to improve the performance of the CMfg platform. Examples for these tools are utilising applications such as reporting, online analytical processing, dash-boarding, planning and simulation, smart data discovery, data mining and machine learning (Gröger 2018).

In conclusion, the CMfg pricing model analyses the complexity within the two-sided market to determine the influences of the network effects of the CMfg pricing structure, which responds to research question three. Since the dynamic effects are only introduced over the implementation of the aspect time, more research is needed to fully understand the relevance of these effects. For example, the demand of the supplier market side can be modelled to increase so that the influence of the network effects on the buyer market side can be analysed. Furthermore, the shortage of one market side due to changes in the availability of the machine capacities can also have an effect on the CMfg pricing model. Therefore, the developed CMfg pricing model is the foundation for further research into two-sided market pricing approaches, including the complexity of CMfg platforms.

8.2 Central Drivers for CMfg platforms

For the establishment of a CMfg platform, it is relevant to analyse the market situation by examining the existing concepts in theory and in practice to get a general understanding of the market. Based on the first impressions of the market, a framework including platform specific requirements can be constructed. The identified characteristics are the foundation to develop the business model of the platform. The value the platform generates for both market sides is the focus of the establishment of a CMfg platform. Only if the participants have a higher value by joining the platform than not joining the platform, the platform will succeed. This is the basis of the developed pricing model, since the calculation algorithm is based on the utility functions of both markets sides, which is directly linked to the total platform profit.

Consequently, the two-sided market CMfg platform aims to reach the critical mass of participants so that the buyers benefit from the offered products of the suppliers and the suppliers are matched to buyers, which require their products. The generated value of the CMfg platform has to be higher than not participating so that buyers and suppliers join the platform. The more participants join, the higher the value of the platform, if the participants are balanced on both market sides. An unbalanced platform leads to a churn of platform participants, which has to be avoided. A constant and steady growth of both market sides is required so that the CMfg platform generates value for the participants on both market sides. Through the calculation of the required balanced amount of both market side participants, the platform has the possibility to steer the amount of participants to find a balance of participants through the differentiation of the entrance fees of both market sides.

In addition, the offered product of the suppliers can contain a certain differentiation and variation based on the results of the analysis of the CMfg pricing model. Only if the buyer market side benefits from the product portfolio of the platform, the suppliers will be able to sell to them. Every single supplier is less exchangeable, if they specialise on the buyers requirements. In practice, the balance of participants should be evaluated to ensure a constant growth of the CMfg platform, which will lead to more value and benefit for the platform participants and to a higher total platform profit. Since CMfg platform business models are just beginning to establish and traditional manufacturing business is still manifested in different business segments, research in theory and practice will be necessary to further understand the complexity of these two-sided market business models and their pricing mechanisms.

8.3 Central Drivers in Practice

One of the objectives of researching platform business models is to gain insights into the central drivers required to establish and operate profitable platform businesses in practice. The previous chapters examine the necessary steps for developing a CMfg platform business model, by using methods such as empirical research and business concepts. Applying these methods to a two-sided market platform business case, can be the foundation to develop a platform business in practice. Although further research is necessary to determine implementation approaches in practice, a first indication of applicability is NeoCargo (2024), a B2B platform in the logistics industry.

The value proposition of the NeoCargo platform is providing transparency within the freight forwarder market, which is achieved through digital cross-company collaboration. Like CMfg platform businesses, NeoCargo facilitates interactions between suppliers and buyers. The output of the NeoCargo platform is a better market overview and transparency of supply and demand, which lead to improved reaction times, a higher service execution quality, and an increased capacity availability for the freight forwarders. NeoCargo currently offers five different products to drive digitalisation within the freight forwarding industry, such as load and truck matching and auction, GPS-tracking, digital processing of load consignments between freight forwarders, and a digital interface for load carriers.

NeoCargo represents a practical application of theoretical concepts in creating a two-sided market platform. As a start-up, NeoCargo has a simplified pricing model, which can be enhanced by introducing the findings of the research of the CMfg platform pricing model. To successfully implement the pricing model, driving factors for suppliers and buyers to participate on the platform need to be examined. The following considerations can be a starting point for this examination: In the highly competitive landscape of logistics, intra-platform competition is common on both market sides due to slim profit margins and limited availability of load consignments. The heterogeneity of market participants is relevant for the pricing model of the freight forwarders, due to the differentiation in the requirements to execute transports, such as special loads. The homing strategy underscores the relevance of achieving a critical mass of participants on the NeoCargo platform, to avoid churn and multi-homing of customers. The positive impact of these factors on both market sides is essential to ensure the platform profitability. The examination of these determining factors influence platform dynamics, such as pricing strategies, the growth of network effects, and the interaction between suppliers and buyers. The net profit of the platform is linked to the net profit of both suppliers and buyers, highlighting the interdependency of market dynamics within the two-sided pricing model.

A two-sided market model represents a transformative approach to the freight forwarder business. By considering the perspectives of both suppliers and buyers, examining network effects, and platform dynamics, NeoCargo develops a sustainable and economically viable model for the future of freight forwarding. Further research into the interactions and evolving dynamics of two-sided markets in logistics will be needed to further enhance pricing strategies for the NeoCargo platform.

8.4 Summary

Summarised, this chapter presents the discussion of the central results of the static and dynamic CMfg pricing model:

- The results of the analytical and numerical analysis of the pricing model are essential to support CMfg platforms to make beneficial decisions and to be economically sustainable.
- The analysis of the CMfg pricing model shows the complexity within the two-sided market pricing model due to its network effects.
- The input parameter combination of the CMfg pricing model leading to a higher platform profit includes a high variety and differentiation of the offered products.
- The differentiation of the two buyer groups is required for modelling group-specific behaviours of participants on the CMfg platform.
- The dynamic pricing model includes units of time periods, which is the first outlook on how to consider dynamic effects in the CMfg pricing approach.
- A balanced number of the two market sides participating on the CMfg platform is essential to steadily grow the value of the platform.
- NeoCargo, a B2B platform in the logistics industry, exemplifies a first indication of general applicability of the developed CMfg approach, to an example in practice, outside of CMfg.
- The developed CMfg pricing model is the foundation for further research into two-sided market pricing approaches, including the complexity of CMfg platforms.

9 Conclusion

In this chapter, the results of the research of the thesis are summarised. In Section 9.1 a summary of the thesis is presented considering the three research questions introduced in Chapter 1. Further research areas to continue the analysis of the CMfg pricing model are identified by Section 9.2.

9.1 Summary

The research objective of this thesis is to develop a pricing model for a two-sided market CMfg platform. Chapter 1 defines three research questions to examine the research objective.

The first research question examines the identification of the determining factors of two-sided market pricing models to conclude which determining factors are essential for a CMfg platform. Chapter 2 introduces the theoretical and practical concepts, the framework and the business model of CMfg platforms. Empirical research is conducted to gain insights into the current market situation with the transition of traditional business models to CMfg platform business models. Based on the identified characteristics of the CMfg platform, the requirements towards a CMfg pricing approach are determined. Based on the determined requirements of Chapter 2, Chapter 3 conducts a literature analysis according to the methodology of the morphological toolbox to examine the state of the art of two-sided market literature. The pricing approaches included in the morphological toolbox are categorised by the identified determining factors of two-sided market pricing models and are divided into six clusters.

The determining factors include the market situation, the homing strategy, the type of participation fee, the consideration of intra-platform competition within one market group, the variety of products, the separation into groups and the heterogeneity and homogeneity of the buyer and supplier market side. As a result, the determining factors of a two-sided market pricing model for a CMfg platform are identified and thus, research question one is answered.

Additionally, the second research question focuses on the development of a two-sided market pricing structure for the CMfg platform. Chapter 4 selects a basic two-sided market model for the development of a CMfg platform pricing model. The required input and output functions of the pricing model are defined. Based on the model of Hagiu (2009), advancements are made to modify the pricing model to calculate the required output values based on the developed algorithms. Due to the results of Chapter 4 and the identified requirements of research question one, Chapter 5 develops a CMfg platform pricing model to answer research question two. The developed CMfg pricing model is based on algorithms to transfer the input parameters of the model into the relevant output functions of the CMfg pricing models, which includes the transaction-based fees for both market sides, the number of both market side participants and the total platform profit. An overview of the developed CMfg pricing model is presented by Section 5.4 so that the second research question is answered.

Finally, research question three through an analysis of the developed CMfg pricing model. Chapter 6 conducts an analytical and numerical analysis for the static CMfg pricing model. The analysis focuses on the effects of the input parameter combinations, which influences the total CMfg platform profit. The input parameter combination of the CMfg pricing model, which leads to a higher platform profit, are identified. Chapter 7 adds an outlook on dynamic effects on the results of the static pricing model to gain further insights into the complexity of a CMfg two-sided market pricing model. Chapter 8 discusses the results to answer research question three and to gain insights from the calculation of the developed CMfg pricing model. The chapter also derives recommendations for the practical implementation of a CMfg platform, including a first indication of general applicability outside of CMfg. The developed CMfg pricing model is the foundation for further research into two-sided market pricing approaches.

9.2 Further Research Areas

Further research areas are identified by the analysis of the CMfg pricing model. First, the developed CMfg pricing model can be expanded by additional utility and profit functions. In the literature there exists a wide variety of functions, such as exponential functions, which are also applicable to the CMfg pricing model under the made modelling assumptions. Second, the input parameters of the CMfg pricing model can also be further examined. Due to the results of the numerical analysis, the parameters can be modelled according to their distributions and effects to introduce more specific customer behaviour on both market sides instead of being chosen within a defined value range.

Furthermore, a future CMfg pricing model can include the separation into supplier groups or vertical differentiation on the supplier market side. This assumption adds to the complexity of the CMfg pricing model and can weaken the observability of intra-platform competition so that an extension has to be considered carefully. Another major extension of the developed CMfg pricing approach can be to enhance the market situation to a duopoly, in order to also include network effects of the participants entering a different CMfg platform. The influences of the cross-platform network effects on the network effects of the first CMfg platform will provide deeper insights into the complexity of the two-sided market pricing mechanism within a duopoly market situation.

Moreover, further investigation into the concept of production capacities can enhance the findings of the developed pricing model. Currently, production capacities are represented simplistically by the number of suppliers and buyers. A more detailed analysis can enable one to accurately define, measure, and understand these capacities. This in-depth examination provides insights into how production capacities affect platform operations and influence the strategic decisions of both suppliers and buyers.

Another aspect, which needs to be analysed further, is the inclusion of dynamic effects in the CMfg pricing model as shown by Chapter 7. The first implementation of dynamic effects is only based on the introduction of the factor time. The demand on the buyer market side is assumed to increase due to a decrease of their individual costs to participate on the CMfg platform so that the network effects of the dynamic CMfg pricing model are determined. The individual costs of the buyers can be a mathematical model to gain a deeper understanding of the relationship of the individual costs and how the CMfg platform can exactly influence these costs. Additionally, the costs of the supplier market side can also be examined to understand the influences of the network effects while their demand to participate changes.

At the moment, there is still a lack of empirical data to validate the theoretical functions. If it is possible to gain access to the required data sets, the introduced assumptions and functions can be validated. To establish a platform that operates economically successfully without having an entire database, empirical data sets can be the foundation to validate the theoretical insights for the practical utilisation of CMfg platforms. Section 2.4 gives a first impression into empirical research on the customer behaviour of both market sides for their participation on the CMfg platform. The empirical studies can be extended to gain further insights into the specialities of CMfg platforms. In conclusion, CMfg platform businesses will further change traditional business models of manufacturing companies, since

> „*Change is the only constant.*“
> — Heraclitus, Greek Philosopher

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