1 Introduction

Software platforms have emerged as a prominent phenomenon amidst the accelerating digitalization impacting and even profoundly transforming societal, organizational, and individual domains, a trend notably accelerated by the recent COVID pandemic (van der Aalst et al. 2019; LaBerge et al. 2020; Colback 2023; Hasselwander 2024). Along this, the competitive landscape for companies from all sectors has intensified with the advent of business models associated to digital platforms. These digital platform businesses have been successful in capturing approximately 17% of the market share from traditional business models and have caused a reduction of around 30% in the revenue growth of these traditional business structures (Bughin and van Zeebroeck 2017). Furthermore, companies with digital platform as their dominant business model have excelled with their annual EBIT growth rates surpassing those of traditional firms by a factor of four (Bughin et al. 2019). The performance increase between traditional business models and the rising digital platform business models can be attributed to differences in market approach and underlying market characteristics. While traditional business models adhere to linear value creation by the firm itself, digital platforms operate within multi-sided market ecosystems (Rochet, Tirole 2004a; Parker et al. 2016). Such ecosystems foster the collaboration between third parties to co-generate value among market participants utilizing a platform as a technological foundation. The distinguishing factor and underlying rationale for the success of digital platforms lie in their capacity to integrate individual offerings from multiple agents into a comprehensive service or offering and expand their customer and complementor base. Given these favorable economic dynamics, it's not unexpected that digital platform business models outperform traditional firms in terms of market capitalization, despite operating at a fraction of the operational resources, like number of personal or overall operational budget (Jacobides et al. 2019; Accenture 2016).

With the surge of such multi-sided or platform business models dominating contemporary economies, the scholarly exploration of these

markets has intensified especially since the 2000s. The prevailing body of literature initially focused on assessing relative market shares under diverse settings and scrutinizing the factors influencing platform market shares, offering insights into strategies conducive to market share expansion (Rochet and Tirole 2003, 2004a; Rochet and Tirole 2006; Armstrong 2006; Hagiu 2004; Zhu and Iansiti 2012). Contrary to the conventional market understanding, where earnings are the primary indicator of success, in the platform business often market shares are prioritized. It was however realized that the conventional success metric of market share is insufficient. Building on this, subsequent research expanded to investigate the effects of the earnings of the platform. Therein studies found that adopting a pricing strategy characterized by asymmetrical fee structures proportionate to the benefits accrued by each side of the market is considered optimal (Hagiu 2014; Rochet and Tirole 2006; Bakos and Katsamakas 2008; Eisenmann et al. 2006; Parker and van Alstyne 2005). Analogous to monopoly theory (Pigou 1920, pp. 240 - 255), it was also shown for platform businesses that implementing price discrimination proves to be a profit-maximizing strategy for the proprietor of the platform (Kim and Pal 2021). In light of the contemporary antitrust discourse concerning quasi-monopolistic platforms Giardino-Karlinger and Valetti (2020) formulated a model aiming to establish a threshold indicating the potential for entry deterrence by an incumbent platform towards new competing platforms.

Nevertheless, existing research has not looked in detail at the interplay between market characteristics and platform choices in view of both, enhanced platform profitability and long-term market equilibria. This study seeks to address this research gap by analysing platform equilibria in the long term and providing managerial guidance on optimal platform settings for profit maximization.

To achieve these outcomes, it is imperative to grasp the inherent characteristics of the market. In multi-sided markets, network effects introduce dynamics that favour platforms with larger participant bases, thereby catalysing either further growth or hastening decline. (Rochet and Tirole 2003, 2004b; Armstrong 2006; Evans and Schmalensee 2010; Wulfert and Dennhardt 2023). As an initial step, this necessitates an understanding of market characteristics, particularly whether the market naturally tends towards a monopoly structure or weather the market is subject to the potential presence of an oligopoly. The settings where the

presence of an oligopoly is stable may be limited due to the self-reinforcing nature of indirect network effects. Subsequently, optimal pricing strategies can be formulated, tailored to either succeed in an oligopoly market arrangement or in a scenario where one platform dominates in the long run. While extensive research has explored strategies for growth and market share acquisition in the latter scenario (Evans and Schmalensee 2016; Parker et al. 2016; Parker and van Alstyne 2014; Wanner et al. 2019; Reillier and Reillier 2017a; Markovich 2008; Evans 2009; Ojanperä and Vuori 2021; Eisenmann et al. 2009), the former remains relatively underexplored, with no direct literature available to our knowledge.

Given the continuing emergence of new platforms and the growing significance of software platforms in contemporary business landscapes, along with the necessity of positioning one's platform advantageously (Cusumano 2010), it is noteworthy that the existing literature has thoroughly examined growth strategies and pricing based on marginal cost discussions. However, to the best of our knowledge, current research lacks concrete recommendations for pricing strategies and their optimal application in an oligopoly market in the presence of indirect network effects. Therefore, this thesis aims to address the following intertwined research questions:

1. Which market characteristics of two-sided platforms with indirect network effects are conducive to the establishment of an enduring oligopoly?
2. What are profit-optimizing pricing strategies in such markets encompassing variable transaction fees and fixed royalties? Under which conditions do they lead to a long-term oligopolistic market equilibrium?

The findings shall be validated by an application to a real-world example of software platform ecosystems. The strategies are thereby analyzed out of the perspective of the platform owners, who are assumed to be the key decision makers in the ecosystem – put bluntly: without platform owners there will be no platform. Unless the platform owners are non-profit-organizations, they will yet try to increase their own profit through the fee structure in consideration of the pricing implications on the consumer and complementor participation rates.

The methodology and model formulation correspondingly integrate game theory, discrete choice modelling, and multi- or two-sided platform market characteristics. Game theory, notably through the concept of Nash equilibria (Nash 1951), establishes conditions for stable equilibria by determining optimal responses to other platforms' strategies in the platform competition game. Yet this first-stage game has to be complemented on a second stage by discrete choice modelling to cope with the choices of complementors and consumers while accommodating for variations in tastes and heterogeneities among them. These will drive market equilibria at the second stage of the platform competition game which has to reflect unique features of multi-sided markets, such as indirect network effects and their impacts on participation choices of complementors and consumers.

The remainder of this thesis is structured as follows: First in *Chapter 2*, the key aspects of the three theoretical frameworks on which this thesis is built are introduced based on relevant literature. This includes game theory with a focus on Nash equilibria, choice modelling with a focus on discrete choice models and the economics of multi-sided markets. Subsequently in *Chapter 3*, key strategies for platform owners on multi-sided markets are discussed, covering platform growth, pricing and competition strategies. In *Chapter 4*, the own scientific methodology and modeling approach is developed. The research methodology is grounded in an approach of Evans and Schmalensee (2010), yet this is expanded into a game with two stages which enables analytical, numerical and empirical insights. At the second stage, the model determines the long-term participation rates of both sides of the market given a set of market characteristics and specified platform choices made by the platform owner. At the first stage, platform owners decide their respective platform settings. The considered market characteristics encompass agent heterogeneity, perceived costs and utility of all agents, as well as the total number of agents. The platform owners themselves stipulate both variable fees, like transactions commissions, and fixed fees, like royalties. The agents cover multi-homing complementors and single-homing consumers of software applications. In *Chapter 5*, this model is applied for a generic numerical parameter study on two-sided platform markets and in *Chapter 6* it is used to investigate a real-world example: the market for mobile phone applications on the example of the Android and iOS platforms. The findings are concluded in a summary in *Chapter 7*.

This study aims to serve as a valuable framework for enhancing the comprehension of multi-sided markets and software platforms in particular. Through the utilization of this framework, valuable insights can be garnered into the intricate market dynamics and strategic decision-making processes within these ecosystems. It is envisioned that the implementation of the managerial recommendations derived from this analysis will streamline the decision-making process and help assess both the potential and the limitations of platform approaches across different application domains.

2 Theoretical background

This chapter is devoted to a comprehensive exploration of the three fundamental pillars in the realm of this economic analysis: game theory, choice modeling, and the distinctive economic features characterizing two- or multi-sided markets.

Game theory enables the analysis of strategic interactions among rational decision-makers, providing a theoretical framework to understand the decision-making in various economic scenarios. Thereby a particular focus is set on the derivation of equilibrium conditions for non-cooperative games known as Nash Equilibria.

The theory of choice modeling, as represented by the Hotelling and Discrete Choice models, offers insights into decision-making and the effects of heterogeneity when certain aspects of the decision context or the decision-maker are unknown or unobservable. It offers insights into individual and market behavior under realistic conditions of imperfect information.

Turning our attention to multi-sided markets, we identify the distinctive traits that differentiate these markets from traditional market places. With an emphasis on general platforms that facilitate interactions between distinct user groups, but equally diving into specific characteristics of software platforms with complementors and consumers as key agents, we examine the complex dynamics arising from the interdependencies between these sides.

This exploration sets the stage for an integrated analysis where characteristics of multi-sided markets are combined with game theory and choice modeling to derive models enabling the analysis of both market equilibria and optimal strategies

For the sake of readability and harmonization within this chapter, the terminology and the nomenclature of parameters and constants across the literature is harmonized to reflect a common body of terminology emerging from the field which can then serve as basis for the own methodological developments. Following this, indices are reduced to

cases where they are needed for distinguishing between different variations, like for different agents. As a result, discrepancies to common terminology of adjacent fields may occur and key terminology changes are noted in footnotes. As the focus of this analysis will be on software-based platforms, this concrete subset will be highlighted in particular.

The structure of this chapter is organized around the three beforementioned fundamental pillars, which are introduced consecutively. The first section addresses the essential concepts of game theory, as it constitutes the theoretical foundation of the used methodology and sees some direct applications in the subsequent characterization of multi-sided platforms. The second section introduces the adjacent field of choice modelling, which is applied to model heterogeneity and imperfect information. The third section provides an introduction to two- and multi-sided platforms, thereby preparing the ground for the subsequent integration of game-theoretical principles with discrete choice modelling.

2.1 Game theory

Game theory, a multifaceted discipline rooted in mathematics and economics, provides a comprehensive framework for studying and analyzing strategic interactions among rational decision-makers. At its essence, game theory explores settings where the choices made by each participant intricately shape the outcomes experienced collectively. The field is underpinned by the fundamental notion of rational decision-makers, individuals or entities deemed to act in their self-interest while diligently evaluating available information (Myerson 1991, pp. 1-8). This assumption of rationality forms the bedrock for understanding and predicting the behavior of agents engaged in interactive decision-making processes.

The purpose of game theory extends beyond mere observation, delving into the intricate dynamics of strategic decision-making. It seeks to unravel the complexities of settings where the actions of one participant have repercussions on others, creating a web of interdependence. By modeling these strategic interactions, game theory aids in identifying optimal strategies for each participant, considering the responses and counter-responses of others in the process. It aims to answer fundamental questions related to decision-making, such as how individuals or firms

navigate competitive environments, cooperate in collective efforts, or negotiate in situations of conflict (Osborne 2004, pp. 1-2).

The utilization of game theory is extensive across diverse disciplines. In the realm of economics, game theory provides insights into the dynamics of oligopolies, competitive scenarios, and auction mechanisms (Shapley and Shubik 1971, p. 2; Fudenberg and Tirole 1991, pp. XVIII-XXII; Osborne 2004, pp. 1-2). Particularly relevant to formulating managerial recommendations for two- or multisided platforms, game theory serves as the foundation for constructing models that capture the intricacies of such markets. By leveraging these models and incorporating specific assumptions about the participants in these markets, explicit recommendations can be deduced contingent on varying input conditions.

This chapter seeks to establish a foundational understanding of game theory by delving into its fundamental principles and examining more closely the concept of Nash equilibria.

2.1.1 Concept of game theory

In the context of so-called normal form games, three fundamental components emerged:

- a finite and discrete set of agents[1], which are rational decision makers;
- a set of decision alternatives – also referred to as strategies in literature, a term also used subsequently here - assigned to each agent, which may take on discrete or continuous values; and
- a payoff function, determining the specific payoff for each agent based on their chosen strategy and the strategies selected by others.

These critical elements constitute the key ingredients for formulating strategic interactions and solving the corresponding mathematical problems associated with the model. Game theory has traditionally been used as a mathematical tool to find solutions to such modeled problems, providing clear strategies and outcomes based on the interactions of rational decision-makers. The first applications originated in the fields of economic theory, political sciences and psychology, where models where

[1] Within the framework of game theory, the term "player" designates the here named “agent”, denoting an entity that engages in a game. To streamline roles for the sake of simplicity, the terminology was adapted to “agent” here.

set up to predict the behaviour of humans to certain experimental game situations (Osborne 2004, p. 3). From there, game theory made entry to wider fields of economics with its capability to simplify a prediction of a behavior. Encompassing such a predictive mechanism with scenario formulation capabilities made game theory a tool to derive managerial recommendations. Thereby the modeling process notably entails assessing chosen strategies in relation to the selected strategies of other agents (Osborne 2004, p. 4).

The agents: rational decision makers

Rational decision-makers, a cornerstone concept in game theory, are assumed to act with a clear understanding of their own preferences and an awareness of the potential actions and reactions of others (Osborne 2004, p. 4). This assumption allows for the creation of mathematical models that capture the strategic interactions between rational entities.

For rational decision makers, the underlying assumption is that the decision-makers possess the ability to express clear preferences among any pair of actions, either favoring one over the other or indicating indifference. The consistency of preferences is a paramount consideration, necessitating that if the decision-maker prefers strategy α to β and strategy β to β', then a preference for α over β' must also exist. The framework accommodates altruistic preferences, wherein an individual's liking for a particular outcome may be contingent upon another person's welfare. The overarching goal of theories employing rational choice models is to derive implications that transcend specific qualitative characteristics of preferences (Osborne 2004, pp. 4-5).

The description of decision-makers' preferences can take the form of specifying the preferred one among each pair of strategies, or alternatively, it can be achieved through the utilization of a payoff function. Such a payoff function is often referred to as a utility function in economic theory. This concept will be described in further detail below.

The strategy: rational choice

In game theory each agent is faced with a set $\mathbb{W}$ of potential strategies or actions to decide upon. In case of the strategies mentioned before, the set can be $\{\alpha, \beta, \beta'\}$ or any larger set containing these three elements. The theory of rational choice posits that, in any given scenario, decision-makers select the strategy from the available set that aligns best with their