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Conference Paper

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23rd Biennial Conference of the International Telecommunications Society (ITS): "Digital societies and industrial transformations: Policies, markets, and technologies in a post-Covid world", Online Conference / Gothenburg, Sweden, 21st-23rd June, 2021

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Aslan, Fatma; Haouel, Chourouk; Nemeslaki, Andras; Somogyi, Robert (2021) : Direct network externalities and dynamics of two-sided platforms, 23rd Biennial Conference of the International Telecommunications Society (ITS): "Digital societies and industrial transformations: Policies, markets, and technologies in a post-Covid world", Online Conference / Gothenburg, Sweden, 21st-23rd June, 2021, International Telecommunications Society (ITS), Calgary

This Version is available at:

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Direct network externalities and dynamics of two-sided platforms ^{*}

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June, 2021

Abstract

We investigate the effect of direct network externalities on the long-run dynamics of two-sided platforms. Two-sided platforms have been widespread in the economy, acting as intermediaries connecting two distinct groups of agents. A defining characteristic of the two-sidedness is the existence of indirect network externalities between the two sides. However, direct externalities can also be important in one or both sides of the market. For instance, direct externalities include review systems where buyers on the platform benefit from other buyers' ratings and comments. We find that considering direct externalities changes the dynamics qualitatively. For example, instead of saddle path dynamics, they can lead to unstable node dynamics and the collapse of a platform.

1 Introduction

In this paper, we investigate the effect of direct network externalities on the long-run dynamics of two-sided platforms. We build a theoretical model that extends previous research to include direct network effects, with the aim of understanding their managerial implications.

Although a lot of assumptions remain uncertain about the post-covid world, the prevailing and growing dominance of platform based business models seem to be a solid anchor for post-pandemic strategies. The steady growth of electronic commerce, sharing economy innovations or the gaming industry indicates that

^{*}The research reported in this paper has been supported by the National Research, Development and Innovation Fund (TUDFO/51757/2019-ITM, Thematic Excellence Program).

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understanding and managing platforms will be critical during the upcoming years for more and more businesses.

Platforms, or two-sided markets, as they call them in microeconomics, have become essential business models in digital transformation. Following the seminal contributions of Caillaud and Jullien (2001), Rochet and Tirole (2006) and Armstrong (2006), models of two-sided platforms have become widely used as building blocks in the microeconomic theory literature. Note that this literature uses the terms two-sided market/ two-sided platform/ multi-sided market and multi-sided platform interchangeably to describe the same type of markets. Various extensions of these models are used to investigate intermediary platforms that connect two distinct sets of agents where the number of agents on the one side effects the utility of agents on the other side (for the most recent survey, see Schuett, 2010).

A defining characteristic of the two-sidedness is the existence of indirect (a.k.a. cross-group) network externalities between the two sides. Indirect network externalities arise when two distinct sets of players interact on an intermediary platform, and users' utility on the one side depends on the number of users on the other side (either positively or negatively). However, direct (a.k.a. within-group) externalities can also be present in one or both sides of the market (see Belleflamme and Toulemonde, 2009). Within-group externalities arise when each user's utility is a function of the number of other users who are using the same service or product.

Our paper aims to investigate the effect of such direct externalities (both positive or negative) on the long-run dynamics of platforms. Examples of positive direct externalities include review systems where buyers on the platform benefit from other buyers' ratings and comments. On the other hand, buyers of a unique item competing against other buyers (e.g., during an eBay auction) constitutes a negative direct externality.

In fact, the literature had discovered the importance of direct externalities even before it discovered the importance of indirect ones. Starting from the 1980s, (direct) network externalities were seen as a new source of potential market power in the digital markets (Katz and Shapiro, 1985).

One of the few papers that study platforms in a system dynamic approach is Sun and Tse (2009), which we will use as a benchmark. Their main contribution is documenting that the customer base can be viewed as a critical factor in the case of two-sided markets. More precisely, the article argues that the size of the two markets a platform connects (e.g. the number of buyers and sellers in online marketplaces) constitutes resource heterogeneity. Resource heterogeneity, in turn, acts as an isolating mechanism for platforms. Identifying isolating mechanisms is key in the resource-based view of competitive advantage and the literature had not discovered the installed customer base on the two sides as an isolating mechanism before. Therefore, the main goal of Sun and Tse (2009) is to build a model that demonstrates that the size of its customer base can lead to lasting competitive advantage for a firm. However, Sun and Tse (2009) only consider indirect network effects in their model. We enrich their analysis by adding direct network externalities.

Our work is also closely related to the very small literature that considers both direct and indirect externalities on two-sided markets. However, papers in this literature (Belleflamme and Toulemonde, 2009; Belleflamme and Li, 2021) focus on the pricing aspect and use static settings. In contrast, we take prices as exogenous while focusing on the dynamics of the platform and the two sides.

Our findings suggest that considering direct externalities changes the dynamics qualitatively. For example, instead of the standard saddle path dynamics, they can lead to unstable node dynamics and the collapse of a network. From a managerial perspective, this means that neglecting the direct effects can lead to dramatic mistakes. For instance, not taking into account negative direct externalities among buyers can leave to a false sense of security for the platform owners who believe that the platform will keep growing as long as the initial size of the user base is large enough. Nevertheless, the platform can even collapse due to this neglected aspect of the strategic situation.

There is some anecdotal evidence about such failures of platform businesses. According to Accenture, for instance, the total value of the platform market is around \$4,3 trillion ¹. Regardless of this attractive market size, most of the current platform businesses or two-sided markets have a high probability to fail. Indeed, in the last 20 years, around 209 publicly listed American platform companies listed in Forbes Global 2000 failed (Yoffie et al, 2019).

The paper is organized as follows. Section 2 presents the model set-up. Section 3 contains the results of the model, i.e. the different long-run equilibria and equilibrium dynamics. Finally, Section 4 discusses avenues of further research we are planning.

2 Model set-up

In the Section, we develop a model of two-sided platform dynamics to study the effect of within-group externalities on platform growth. As much of the economics literature on two-sided platforms, we follow the modeling approach of Rochet and Tirole (2003, 2006) and Armstrong (2006). We incorporate within-group externalities and dynamics into the standard models of two-sided markets. In other words, we extend the dynamic model in Sun and Tse (2009) to include within-group externalities.

2.1 Valuations of buyers and sellers of a platform

There are three types of agents in the two-sided market we model: an intermediary platform, buyers and sellers. We focus our analysis on the case of a monopoly platform.² As it is common in the literature, we assume an infinite

¹https://www.accenture.com/us-en/_acnmedia/pdf-29/accenture-five-ways-to-win-\protect\@normalcr\relaxwith-digital-platforms-full-report.pdf Accessed 2 February 2021.

²Given the results of Sun and Tse (2009), we believe a monopolistic set-up already captures the main trade-offs in these markets.

number of potential buyers and sellers. Throughout the paper, we will denote variables related to the buyers and sellers with subscript B and S , respectively. We assume that agents must pay lump-sum membership fees (M_B and M_S) in order to join the platform, independently of the number of transactions they undertake. In addition, they also pay per-transaction fees (z_B and z_S).³ Following Sun and Tse (2009), we assume that M_B , M_S , z_B and z_S are exogenously given and constant over time.⁴

Let n_B and n_S denote the number of buyers and sellers that decide to join the platform. We assume that buyers are identical, thus the valuation of all buyers is given by

$$V_B = n_S(u - z_B) - M_B + w_B n_B,$$

where u denotes the per-transaction utility of a buyer. Importantly, we assume $u > z_B$ so that the valuation of a buyer is increasing in the number of sellers on the platform, capturing the positive cross-group externalities.

Our main contribution is captured by the last term in the valuation, $w_B n_B$. We assume that the valuation of a buyer also depends on the total number of buyers on the platform. Thus $w_B > 0$ captures positive within-group externalities, i.e. buyers benefiting from the presence of other buyers. Conversely, $w_B < 0$ translates to negative within-group externalities, i.e. buyers suffering from the presence of other buyers.

Analogously, the valuation of all identical sellers is defined by

$$V_S = n_B(\pi - z_S) - M_S + w_S n_S,$$

where π denotes the per-transaction profit of a seller. We assume $\pi > z_S$ to have positive cross-group externalities. For this reason, in the following we will refer to π and u as the strengths of the cross-group externalities. We also assume the existence of within-group externalities among sellers. Its strength is captured by the parameter w_S which can be either positive or negative or zero.

2.2 Platform dynamics

The decision of agents whether to join the platform is based on a free-entry condition. In particular, if the valuation of a buyer at a given t , denoted by $V_B(t)$ is positive, then some buyers will join the platform. Conversely, some buyers leave the platform when $V_B(t)$ is negative. Let $\dot{n}_B(t)$ denote the change in the number of buyers at time t . Then we have

³This is the most general setting. In addition, in practice Amazon charges a mixture of both royalties and monthly membership fees to sellers.

⁴Sun and Tse (2007) endogenized the choice of these variables which made the analysis considerably more complex without changing the main qualitative insights. The simpler model allows us to better highlight the effects of within-group externalities.

$$\dot{n}_B(t) = \alpha_B V_B(t) = \alpha_B [n_S(t)(u - z_B) - M_B + w_B n_B(t)]. \quad (1)$$

The constant diffusion speed α_B controls how many new buyers join or leave for a given level valuation. In turn, for a given diffusion speed, the higher the valuation of buyers, the more of them will join the platform.

Moreover, let $\dot{n}_S(t)$ denote the change in the number of sellers at time t .

$$\dot{n}_S(t) = \alpha_S V_S(t) = \alpha_S [n_B(t)(\pi - z_S) - M_S + w_S n_S(t)] \quad (2)$$

Analogously to the case of buyers, α_S denotes the exogenous diffusion speed of sellers. Clearly, the higher the valuation of sellers at time t , the more of them will join the platform.

3 Results

Equations (1) and (2) describe the dynamic behavior of buyers and sellers joining the platform, i.e., the two equations constitute a two variable linear dynamic system. In this Section, we first calculate the long-run equilibria of the system depending on the different parameter settings, i.e., different levels of cross-group and within-group externalities. Second, we plot phase diagrams to illustrate the three distinct types of dynamics of the system that are qualitatively different.

3.1 Long-run equilibria

If the system is in equilibrium at time t then there is no inflow or outflow of neither buyers nor sellers, i.e., $\dot{n}_B(t) = \dot{n}_S(t) = 0$ must hold, hence

$$\overline{n}_S(u - z_B) - M_B + w_B \overline{n}_B = 0 \quad \text{and} \quad \overline{n}_B(\pi - z_S) - M_S + w_S \overline{n}_S = 0,$$

where \overline{n}_B and \overline{n}_S denote the equilibrium number of buyers and sellers, respectively. Therefore, the system has a unique long-run equilibrium for each combination of parameters, given by

$$\overline{n}_S = \frac{w_B M_S - (\pi - z_S) M_B}{w_B w_S - (\pi - z_S)(u - z_B)} \quad \text{and} \quad \overline{n}_B = \frac{w_S M_B - (u - z_B) M_S}{w_B w_S - (\pi - z_S)(u - z_B)}. \quad (3)$$

Note that assuming no within-group externalities, i.e., $w_S = 0$ and $w_B = 0$, the long-run equilibrium numbers of buyers and sellers in (3) simplify to

$$\overline{n}_S = n_S^* = \frac{M_B}{u - z_B} \quad \text{and} \quad \overline{n}_B = n_B^* = \frac{M_S}{\pi - z_S}, \quad (4)$$

where n_S^* and n_B^* stand for the equilibrium points in Sun and Tse (2009), in the model without within-group externalities. We will use them as benchmark

in the following analysis. Note that this finding demonstrates that our model is a proper extension of the monopoly model in Sun and Tse (2009).

Notice that the long-run equilibrium numbers as computed in (3) could in principle be negative. To avoid dealing with negative buyer and seller numbers, in the following, we will assume $n_B(t) \geq 0$ and $n_S(t) \geq 0$ for all t .

3.2 Equilibrium dynamics

Next, we will characterize the equilibrium dynamics of the system defined by equations (1) and (2). First, we express the eigenvalues of the system as a function of the parameters of our model. Second, based on the eigenvalues, we discuss the long-run equilibrium dynamics of our model for each possible combination of parameters.

It is straightforward to derive the following eigenvalues:

$$\lambda_1 = \frac{1}{2} \left(w_B + w_S + \sqrt{(w_B + w_S)^2 - 4w_Bw_S + 4(u - z_B)(\pi - z_S)} \right)$$

$$\lambda_2 = \frac{1}{2} \left(w_B + w_S - \sqrt{(w_B + w_S)^2 - 4w_Bw_S + 4(u - z_B)(\pi - z_S)} \right)$$

Before we can derive the dynamics of the system for any parameter values, we make two observations. First, $\lambda_1 > \lambda_2$ always holds. Second, both eigenvalues are real numbers. To see this, one can rearrange the expression under the square root as $(w_B - w_S)^2 + 4(u - z_B)(\pi - z_S)$. Since $u - z_B$ and $\pi - z_S$ are positive by assumption, the entire sum is positive as well.

Given the first observation, we can distinguish three cases: (i) $\lambda_1 > 0 > \lambda_2$ (ii) both eigenvalues are negative, and (iii) both eigenvalues are positive. These three cases will lead to three qualitatively different types of equilibrium dynamics.

- (i) **Saddle Path Dynamics** ($\lambda_1 > 0 > \lambda_2$): The system follows a saddle path dynamics if and only if $w_Bw_S < (u - z_B)(\pi - z_S)$. For an intuition of when such a case arises, we provide two sufficient conditions. First, this is the case when within-group externalities (w_B and w_S) are small in absolute value relative to the cross-group externalities (π and u). Second, the condition also holds whenever the within-group externalities have different signs. As $(u - z_B)(\pi - z_S)$ is assumed to be positive, note that this condition always holds in Sun and Tse (2009) where $w_B = w_S = 0$. In other words, this is the only dynamics that exists in the absence of within-group externalities.

Figure 1 presents⁵ an example of a phase diagram of the system exhibiting saddle path dynamics. Similarly to Sun and Tse (2009), the system grows towards infinity when it starts above the saddle path, and it eventually dies out otherwise.

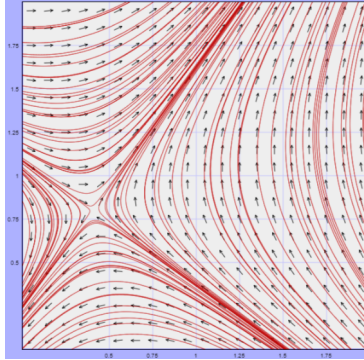


Figure 1: Saddle Path with $w_B = -1$, $w_S = 1$, $u - z_B = \pi - z_S = 3$, $M_B = M_S = 2$

- (ii) **Stable Node Dynamics** ($0 > \lambda_1 > \lambda_2$). The system converges to a stable node if and only if $w_B w_S > (u - z_B)(\pi - z_S)$ and $w_B + w_S < 0$. In addition, it is easy to show that given these conditions, the equilibrium point will be $(0,0)$, i.e., the platform collapses independently of its initial size.⁶ Intuitively, this can only happen when both within-group externalities are strong and negative. Given such a market, the total collapse of the platform should not come as a surprise. Indeed, agents dislike other agents of the same type so much that it overwhelms their utility from interacting with the other side, no matter how large the platform initially is.

Figure 2 presents is an example of a phase diagram of the system exhibiting stable node dynamics. Clearly, the system collapses and converges to $(0,0)$, independently of the initial number of buyers and sellers, due to the strong negative within-group externalities.

- (iii) **Unstable Node Dynamics** ($\lambda_1 > \lambda_2 > 0$): if and only if $w_B w_S > (u - z_B)(\pi - z_S)$ and $w_B + w_S > 0$. These two conditions are jointly satisfied if and only if both within-group externalities ($w_B > 0$ and $w_S > 0$) are positive, and large compared to cross-group externalities. For intuition, first consider the extreme case of zero membership fees. From (3) it is clear that the unstable node will be located at $(0,0)$, which in turn

⁵All phase diagrams were plotted using the <https://aeb019.hosted.uark.edu/pplane.html> website.

⁶To see this, first notice that the two conditions jointly imply that $w_B < 0$ and $w_S < 0$. However, by (3) this implies $\bar{n}_S < 0$ and $\bar{n}_B < 0$, which we have interpreted as zero buyers and sellers.

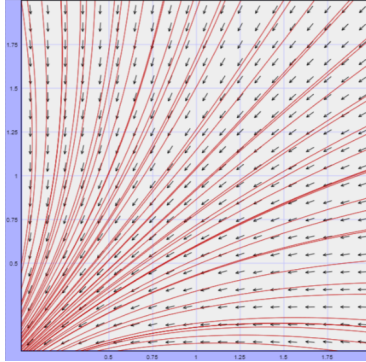


Figure 2: Stable node with $w_B = w_S = -3$, $u - z_B = \pi - z_S = 1$, $M_B = M_S = 1$

implies that the system explodes from any positive initial number of sellers and buyers. This is to be expected given that both within-group and cross-group externalities are positive. More generally, with positive membership fees, the system still explodes under most initial conditions. The only cases when the system collapses is when the initial number of buyers and sellers are so low that two types of externalities cannot compensate the membership fees.

Figure 3 presents an example for the phase diagram of the unstable node dynamics for the parameter values $w_B = w_S = 3$, $u - z_B = \pi - z_S = 1$, $M_B = M_S = 2$. From (3), the unstable node's coordinates are $(0.5, 0.5)$, as also shown in the Figure 3. Clearly, the system collapses if there are very few initial buyers and sellers, and it explodes in all other cases.

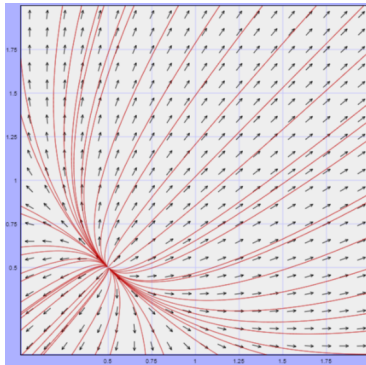


Figure 3: Unstable node with $w_B = w_S = 3$, $u - z_B = \pi - z_S = 1$, $M_B = M_S = 2$

4 Further research

We aim to complement the theoretical model in the present paper with system dynamics simulations. In particular, we plan to test the complex within- and cross-group externalities by system dynamics simulations using VENSIM, similarly to Casey and Töyli (2012). Systems dynamics, as a modelling tool, demonstrates the stability and instability of complex network effects, but also enables to draw conclusion on managerial aspects of systems' behavior. By doing so, it will enable us to draw practical platform strategies from the theoretical results.

Moreover, executing simulations would allow us to incorporate some more realistic assumptions about the markets we model. So far we have assumed that the utility of one user group grows proportionally to the number of users on the other side of the market. In reality, platforms do have a saturation point, e.g. due to capacity constraints or simply because there is a finite number of people on Earth. One of the advantages of the simulations will be to uncover market settings that realistically capture the saturation of platforms.

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