Vertically Disintegrated Platforms *

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Abstract

Understanding the implications of digital platform strategies on user welfare has become a crucial issue for policy makers and economists alike. In payments, distributed ledger technologies such as the blockchain have introduced new models of platform governance in the form of vertically disintegrated platforms (VDP). In this paper, we develop a framework to study the implications of vertical disintegration on user welfare. A VDP mediates between users and processors that enable interactions between users. The VDP controls the price structure but the price level is set in a competitive equilibrium between processors; proceeds from operating the platform service are split between processors and the VDP. We find that the welfare ordering between traditional (integrated) and disintegrated platforms crucially depends on the platform cost structure and the regulatory conditions in the market for processors. When the cost of integrating processors depends on the transaction volume, the VDP can produce higher welfare. In contrast, when this cost is fixed, an unregulated VDP is less desirable than the integrated platform. However, regulatory limits on the VDP power over processors can make user welfare under a VDP dominate. Within our framework, we analyze recent applications in the payment industry, including central bank digital currencies, and show how different design choices affect user welfare.

Keywords: digital economy, multi-sided platform, payment system, distributed ledger technology, blockchain, central bank digital currency.

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1 Introduction

> *More and more physical products and services become largely digital in nature. While the payment systems used by platforms may face challenges, and platforms themselves may change in nature, they seem likely to remain crucial to our ability to interact within the digital economy.*

Frédéric Jenny,
Chairman, OECD Competition Committee. [1]

Multi-sided platforms such as payment systems have taken a prominent role in the organisation of our digital economy. While they create value by enabling interactions between different groups of users, the large network effects associated with these platforms tend to generate excessive concentration of market power, calling for the attention of government authorities. However, traditional economic tools are often found inadequate to support policies addressing the pricing dynamics of digital platforms (OECD, 2018).[2] Recently, the emergence of distributed ledger technologies (DLT), such as the blockchain, has enabled groups of agents to interact and coordinate in the absence of intermediaries, thereby raising the prospect of a technological solution to the issue of market power and network welfare in platforms.[3]

In this paper, we study how new forms of platform governance, made possible by DLT, affect user welfare and market power in digital platform economies. In particular, we consider the effects of vertically disintegrating a payment platform; that is outsourcing key elements of the platform service to a market of competing agents that can coordinate on a common state via DLT or similar technologies. Extending the platform model of Rochet and Tirole (2006), we identify conditions under which a vertically disintegrated platform leads to increased consumer welfare in comparison to traditional platform models. We find that the cost structure of a platform and the conditions in the market for processing transactions determine the desirability of a vertical disintegration. We show that our results are relevant to both current industrial research on the pricing of disintegrated services by platforms as well as the design of public utility platforms such as central bank digital currencies.

Payment systems act both as a classic example of multi-sided platforms and a major domain of implementation for DLT applications (Mills et al., 2016). In a multi-sided payment set-

[1] Foreword to the OECD report on *Antitrust Tools for Multi-Sided Platforms* after the OECD Competition Committee Hearing held a in June 2017. See OECD (2018)

[2] In particular, the asymmetric nature of platforms with multi-sided-demand renders the uniform consumer conditions on welfare ill suited. See Evans and Schmalensee (2014) for an overview of the literature on antitrust issues related to this problem. See also Wright (2004); Tirole (2015) for further theoretical comments.

[3] As Catalini and Tucker (2018) put it: "In theory, blockchain technology can be used to overcome the coordination challenges that otherwise lead network effects to be a source of market power". Catalini and Gans (2016) also provide a discussion on the reduction of networking costs through the adoption DLT.

ting, a platform typically enables money transfers between customers and retailers. By virtue of this intermediary position, the platform can internalize cross-side network effects and impose different charges on each side to optimize the total interaction volume.[4] In order to limit abuses on both customers and retailers, several governments have taken action to monitor the price structure imposed by payment card companies.[5] However, given the multi-sided nature of these business models, which type of pricing strategy regulators should support remains an open question.[6]

In contrast with traditional systems operated by a single platform that processes transactions and sets the fees, a DLT based payment system relies on a decentralized group of agents, so-called miners in the case of Bitcoin, that process transactions, write to a shared database and coordinate on a common state via a consensus protocol.[7] As a result, fees are determined in a competitive market involving user demand and miners' supply. As such, one can view decentralized systems like Bitcoin as vertically disintegrated platforms enabling value transfers between buyers (customers) and sellers (retailers) through a market-based infrastructure.

Much of the enthusiasm around DLT - from major central banks to large industrial conglomerates - originates from the prospect of improved security, speed of settlement and reduced operational costs.[8] Less attention has been put on the economics of platform disinte-

[4]Payment systems have traditionally been dominated by companies such as VISA, MasterCard and American Express which charge the retailer more than the customer through the so-called *interchange fees*. A large body of research starting in 2000 has analyzed the effect of price structure in MSP, including the seminal works Rochet and Tirole (2003); Caillaud and Jullien (2003); Armstrong (2006). See Rysman (2009) for a literature review of the early models.

[5]Government concerns include consumer welfare, lack of innovation and financial inclusion. For instance, Li et al. (2019) show that the market power and rent of electronic payment networks plays a important role in explaining the slow adoption of payment alternatives to cash. Government authorities have taken several actions to promote welfare in payment platforms. For example, the Reserve Bank of Australia introduced pricing standards for VISA in 2006; the European Union has imposed a cap on debit and credit fees since 2015; in the United States, the Durbin Amendment in the Dodd-Frank Act of 2010 limits transaction fees imposed upon merchant by debit card companies. See Bradford and Hayashi (2008) for a longer list of regulatory initiatives on payment fees.

[6]When multiple groups of customers are involved, cases where one group benefits at the expense of the other groups are ambiguous under standard regulatory frameworks. In fact, antitrust regulation traditionally focus on aggregate consumer welfare. For example, in the *Ohio vs. American Express Co.* 138 S.Ct. 2274 (2018) Supreme Court case, the Court's analysis assumed that costs on one side of a two-sided platform are offset by gains on the other side and therefore ruled out alleged antitrust behavior. See Hovenkamp (2019) for a critique of the decision.

[7]For the purpose of this work, we abstract away from the medium of payment (currency or token). Therefore, when referring to cryptocurrencies, we focus on the payment dimension and leave aside monetary discussions regarding their token dimension such as price volatiliy. The value of this approach becomes all the more relevant with the advent of *stable coins*, i.e., tokens whose price is pegged to other stable assets. We also focus on the long-term equilibrium model of these platforms, therefore we neglect the bootstrapping role played by mechanisms such as block-rewards. This approach is similar to Huberman et al. (2017, 2019). For more detailed information about blockchain technology and cryptocurrencies, see Narayanan et al. (2016)

[8]While Bitcoin merely stands as an example of such platform design - and an extreme one (e.g., zero revenue for the platform, unregulated transaction fee market, etc.) - a number of noteworthy projects have been undertaken by both large industry actors and public institutions to take advantage of distributed ledgers technologies. Several central banks have experimented with distributed ledger technologies. For instance, the joint research project

gration.[9] In particular, competition in the market for transaction processing should affect the market power of a vertically disintegrated platform compared to traditional platforms. Under which conditions would a vertically disintegrated platform produce more welfare than traditional platforms? And more broadly, how should vertically disintegrated platforms be designed to maximize user welfare? While highly relevant to the ongoing positive and normative debates on platform regulation, these questions have so far received limited analytical treatment.[10] This paper seeks to fill the gap.

We develop, to the best of our knowledge, the first model that specifically focuses on the vertically disintegrated nature of platforms such as Bitcoin and derive the implications of this disintegration on user welfare. We define a vertically disintegrated platform (VDP) as a platform that mediates between platform users, for example customers and retailers, and a group of agents – the processors – that handle the interaction between users.[11] Total usage fees are set in a competitive equilibrium between processors and users while the price structure – the split of the usage fee among the various user sides of the market – is determined by the platform. In our analysis, we contrast such vertically disintegrated platforms with traditional platform solutions which we refer to as vertically integrated platforms (VIP). While the VDP outsources the treatment of transaction, the VIP processes transactions in-house and can thus be thought of as "owning" the processors. Figure 1 provides an illustration of the organizational discrepancy between VIP and VDP.

Overview of the model and results The VDP and VIP differ in three key respects. First, a VDP cannot, in general, control the total fee charged to the user sides of the market, thus limiting its market power when compared to a VIP which has full control in setting fees. Second, the two platform models face, in general, different cost structures. Since the VIP "owns" the processors, it faces an *integration cost*, which may depend on the total volume of interactions between users of the platform. In contrast, the VDP does not face the same costs as it can source the processing capacity directly from the market. Third, processor ownership is assumed to confer an *informational advantage* to the VIP, whose impact is detailed below.

Stella between the European Central Bank and the Bank of Japan concluded that "DLT-based solutions could meet the performance needs of a Real-Time Gross Settlement (RTGS) payment system and DLT solutions have the potential to strengthen resilience and reliability" (European Central Bank, 2017). Fabric and Corda are two major DLT projects led by industry leaders such as Microsoft, IBM, Goldman Sachs, JP Morgan.

[9] For an overview of the current states of research in the economics of distributed ledger technology and cryptocurrencies, see Halaburda et al. (2020).

[10] Catalini and Tucker (2018) provide a first conceptual discussion about the opportunities and challenges of blockchain technologies on market power concerns in digital platforms.

[11] Note that, while many DLT applications can be thought of as VDPs, our definition is independent of the technology that enables it. Our framework also accommodates VDPs that differ substantially from what is currently observed in the Bitcoin/blockchain universe. We discuss these points in Section 7.

(a) Vertically integrated platform

(b) Vertically disintegrated platform

Figure 1: Stylized illustration of the vertical organisation of two monopolistic multi-sided platforms: (a) the vertically integrated platform owns the infrastructure to process interactions between buyers and sellers; (b) the vertically disintegrated platform outsources the infrastructure to a marker of competing agents to process interactions between buyers ans sellers.

Our model is based on the platform model of Rochet and Tirole (2006) but introduces a number of modifications to incorporate the features of vertically disintegrated platforms. In the VDP model there are three types of agents: users that derive utility from interaction but cannot interact outside of a platform, processors that treat user interactions in a competitive market and the platform that determines the price structure. Processors have private heterogeneous costs. The split of platform revenues between processors and the platform is determined by a tax parameter set by the platform. This tax can be set exogenously, for example by a regulator, or endogenized as the outcome of the platform's profit maximization problem. In Bitcoin, for example, this tax parameter is set to zero. We discuss the effect of such design choice in Section 7. We nest the VIP setup in our model by allowing the platform to set total usage fees and to take control of the processors. In taking control, we assume that the VIP can observe each processor's cost type and can thereby impose a zero profit condition on the processors.

Vertical disintegration creates a new market segment: the market for processors. In our analysis we open the "black box" of the platform infrastructure. First, we study the labor relations between the platform and the processors. Second, we analyze the effect of the integration cost faced by the VIP. The integrated platform owns processors with different cost types and can perfectly observe each processor's type. Therefore, in effect, the VIP can perfectly price discriminate between processors and thus captures the entire processor surplus. Absent any variable integration cost, the only distortion is the VIP's monopoly power on the two-sided market, because the transaction price p is set so as to equate the marginal cost of processing transactions with the marginal revenue of increasing activity on the two-sided market, rather than with the (higher) sum of marginal utilities. Instead, the VDP potentially avoids the market friction since p results from equating processors' supply of capacity with the aggregate demand for interaction by users. On the other hand, the VDP generates profit by collecting ad-valorem taxes on processors at a rate t. Taxes introduce a new distortion because of linear pricing. We can relate this effect to the 'double marginalization' discussed in the literature on vertical integration (see e.g. Tirole (1988)) : when integration transforms 'two monopolies in a row' which each price linearly into a single one, profits and welfare improve because one of the two price-cost margins disappears. Here, the platform faces two types of users but also obtains services from processors. While it is monopolistic with respect to users, it is monopsonistic with respect to processors. Integrating processors allows the VIP to eliminate the linear pricing distorsion. On the other hand, an alternative to integration could be to restrict the pricing discretion of the VDP, by regulating how much it can charge its processors, in a way which is similar to minimum wage regulation for monopsonists.

A result which simplifies the analysis is the fact that both platform setups split the burden of usage fee p in the same way between the two types of users (buyers and sellers). This means that welfare dominance between the two platforms is determined by a lower p. From this perspective, the VIP can be thought as choosing the profit-maximizing p while the VDP chooses the profit-maximizing t. In fact, we show that there exists a tax level t_I which replicates the VIP solution. This means that the VDP outperforms the VIP if and only if t is lower than t_I.

If the VDP can freely choose t and integration costs are the same for both platforms, its choice for t will be higher than t_I, because the VDP will choose t so as to equate the marginal revenue of increasing market activity with the marginal wage bill, which is higher than the marginal cost of labor: the VDP is a monopsonist limited to linear pricing, therefore attracting more processors means lowering t not only on the marginal processor but all the infra-marginal ones too. On the other hand, one could regulate t. If the regulator imposes a cap on t lower than t_I, it will induce higher activity, and thus higher welfare, than the monopoly VIP. Of course, this requires that at t_I the VDP earns strictly positive profits despite conceding rents to processors and therefore earning less than the VIP. Setting an upper limit on the tax t is akin to setting a minimum wage in a monopsony labor market.

When the integration cost faced by the VIP is large, the VIP faces a higher cost to access the information on processors cost types. A trade-off exists between the level of infrastructure investment (i.e., fixed cost of owning and managing processors) and the ability to price discriminate. In fact, when integration costs increase rapidly with the total transaction volume, it becomes optimal for the VIP to suppress transaction volume by choosing a higher usage fee p. Since the VDP does not face these costs, its optimal tax regime t will yield a usage fee below the VIP regime. Welfare under the VDP can therefore dominate in this context without regulatory intervention.

Lastly, we consider the case when the platform operator can choose between implementing a VIP or VDP. While user welfare is determined by the rate of change of integration costs with demand, platform preferences over the VIP and VDP are determined by the level of integration costs. As a result, there exist different regimes under which user welfare and platform preferences can either be aligned or misaligned. Depending on the shape of the integration cost function, a regime could, for example, exist under which both users and the platform prefer the VIP solution over the VDP solution. When preferences are aligned, no regulatory intervention would be required since presumably the platform would voluntarily implement the integration level that maximizes user welfare. However, other regimes under which user and platform preferences are misaligned are also possible. In such a scenario regulatory intervention would be warranted from the perspective of user welfare. In a numerical example we illustrate the existence of the different regimes of user and platform preferences and their dependence on the shape of the integration cost function.

Given the recent emergence of VDP solutions in payments, the number of real-world case-studies remains limited. The framework introduced in this paper is general enough so that it allows for the analyses of current design choices, such as in the case of Bitcoin, as well as an exploration of other designs which might not have reached mainstream applications yet but which could produce higher welfare. Our results suggest that VDP design such as Bitcoin and Ethereum lead to high user welfare through zero taxes and thus high processor supply. However, the price structure rule which makes the buyer bear the entire transaction fee is likely to reduce welfare in case of multi-sided demand. In fact, the design of Bitcoin and Ethereum inadequately addresses the multi-sidedness of markets such as retail payments. This shortcoming could constitute a key barrier to the economic expansion of these platforms irrespective of other, previously raised concerns. Finally, our framework also allows us to consider a series of other settings relevant to current debates on the public implementation of digital payment infrastructures. In particular, a VDP that combines both price structure adjustment mechanisms and low taxes (e.g. due to regulatory limits) could provide substantial welfare improvement, according to our results. Such solution could exist in the form of a public utility such as a Central Bank Digital Payment infrastructure or a Central Bank Digital Currency.

Related work Our proposal to study new forms of platform economies follows the long list of contributions in the field of multi-sided platforms including seminal papers by Gans and King (2003); Rochet and Tirole (2003); Caillaud and Jullien (2003); Parker and Van Alstyne (2005); Rochet and Tirole (2006); Armstrong (2006) which pioneered studies of price structures, platform competition, multi-homing and information intermediation whenever two or more sides of a platform display heterogeneous valuations of cross-side interaction. Rysman (2009) provides a literature review of those early models. Weyl (2010) shows that through insulated tariffs, an MSP can achieve any desired allocation across all sides. Our analysis extends those studies by explicitly imposing a market clearing mechanism to determine the customer price level. Separating between customers and processors also distinguishes between two choices: price structure and transaction taxes.

In payment systems, much of the debate revolves around the right way to address potential abuses by the platform. Rochet and Tirole (2011) have proposed the "tourist test" to identify cases of surcharges. This test assesses a retailer's avoided cost in case of a non-repeat sale with alternative payment options. The test was employed in several antitrust cases.[12] Using the same model, Wright (2012) shows that even when there is no possibility of price discrimination, surcharges can be biased towards merchants because of double counting of the merchant internalization: first when a customer decides to adopt the platform and second when she decides to make a transaction. In contrast, the results of this paper focus on the effects that regulating the market for processors can have on prices for users when platforms are vertically disintegrated. Setting tax limits can be considered as complementary solutions to the tourist test and may be particularly suitable when information collection by authorities is both costly and sensitive.

To date, the effect of the vertical integration of platforms has been studied in few non-digital industries, mainly focusing on product differentiation and entry barriers. Hagiu and Wright (2014) studies the choice of a platform to vertically integrate a service in the context of commodities. They show that the decision between being a marketplace or a reseller relies on the capacity of the platform to access information relevant to the optimal tailoring of each specific product. Hagiu and Wright (2015) look at vertical integration choice in the context of services and show a trade-off between the need to coordinate decisions that generate spillovers across professionals (best achieved by a vertical integrated firm) and the need to both motivate unobservable effort by professionals and ensure professionals adapt their decisions to their private information (best achieved by a MSP). Lee (2013) empirically studies the effect of vertical integration and exclusivity between platforms in the video game industry. Somewhat counter-intuitively, the author finds that vertical integration and exclusivity favors the entrant at the expense of the incumbents. Our paper examines a larger set of platforms that can now be vertically disintegrated due to the advent of DLT in fully digitized platforms. Further, we add to this literature by showing that even under a static setting with a homogeneous product, market dynamics resulting from vertical disintegration have an ambiguous effects on price and user demand.

Finally, our paper also relates to work on the economics of blockchain-based systems. Gans and Halaburda (2015) make the link between the emergence of digital private currencies and

[12]See for example Regulation (EU) 2015/751 of the European Parliament on interchange fees for card-based payment transactions.

the rise to prominence of platforms. In particular, the authors show the capacity for platforms to generate credit through such instruments. Catalini and Gans (2016) argue that blockchain technology has the potential to drive innovation in digital platforms because of its capacity to reduce both the costs of verification and networking. Much in line with our approach, Catalini and Tucker (2018) argue that the decentralized nature of blockchain technology allows for network effects to emerge without assigning market power to a platform operator. The authors also discuss the challenges related to antitrust initiatives in the absence of a central entity (e.g. it may be impossible to establish "intent" in the context of a decentralized platforms with multiple anonymous participants). Cong and He (2019) show that decentralized platforms may also pose a threat to welfare because of an expansion of the information environment. Distributed ledgers, by sharing information more efficiently, may also promote collusion. Closer to this paper is the work by Huberman et al. (2017) which studies the dynamics of the Bitcoin platform as a two-sided platform between users and miners. The authors identify a trade-off between delay costs and the dead-weight loss that a monopoly profit-seeking platform would impose. Our approach departs from previous papers by allowing for a more general model of DLT based platforms which includes multi-sided demands from the users and a market clearing mechanism for processors. Doing so, we study the role played by market power, the price structure on users and the tax parameter on processors in fostering demand for the platform when user groups are heterogeneous and service is homogeneous (e.g. no delay cost).

2 Model

2.1 Vertically disintegrated platform

There is a unit mass each of two types of users that derive utility from interacting with the opposite type, call them buyers B and sellers S for brevity. Buyers and sellers cannot interact directly. Instead, their interaction is mediated by a single platform and a unit mass of processors. In addition to deriving utility from the interaction with the opposite side, users may also obtain a fixed benefit from joining the platform. As will be outlined below, the platform takes on a purely coordinating role while processors treat the interaction between users. In the context of a blockchain application, processors would correspond to the miners while the platform would correspond to the designer of the protocols governing the application.

Users choose whether to join the platform and interact with the opposite side. For each interaction that occurs on the platform, users must pay a type specific fee. The total usage fee, that is the sum of the fee paid by the buyer and the seller, is set in a competitive equilibrium. Each processor chooses whether to provide a fixed quantity of platform services based on this total usage fee. Then, in equilibrium the supply of platform services provided by the processors and the demand for those services by the users is balanced. The price structure, that is the split of the total usage fee among buyers and sellers, is determined by the platform. The revenue from the platform service is split between the processors and the platform. This split can be determined either by the platform, collective bargaining between processors and the platform or a regulator.

The utility of user i of type $\mu \in \{S, B\}$ from joining the platform is given by

$$u_i^\mu = (b_i^\mu - a^\mu)N^{-\mu} + B_i^\mu - A^\mu, \tag{1}$$

where b_i^μ is the per interaction benefit of user of type μ interacting with a user of the opposite type $-\mu$. The volume of interactions for a user of type μ is proportional to the number of users of type $-\mu$ that have joined the platform $N^{-\mu}$. The user may also derive a fixed benefit B_i^μ from joining the platform. The user benefits are private information and drawn from a known joint distribution $(b_i^\mu, B_i^\mu) \sim F^\mu$. The platform charges a usage fee a^μ and a fixed joining fee A^μ to users of type μ. The utility from not joining the platform is normalized to zero. Both the users' utility function and the notation are standard and follow Rochet and Tirole (2006). We depart from Rochet and Tirole (2006) by introducing an additional set of agents – the processors. There is a unit mass of processors. If a processor decides to provide platform services, she provides a fixed quantity γ. The processor's utility from providing services to the platform is then given by

$$u_i^W = r_\gamma(p, t) - c_i, \tag{2}$$

where $r_\gamma(p, t)$ denotes the processor's revenue while c_i represents the processor's private cost of service provision. The utility from not providing services is normalized to zero. The cost is drawn from a known distribution $c_i \sim H$. We assume that the distribution function H is continuous and strictly monotonically increasing. The processor's revenue $r_\gamma(p, t)$ depends on the total usage fee $p = a^S + a^B$, a tax parameter t and the quantity of services a processor can provide γ. The platform retains a fraction of the total usage fees paid by the users through an ad-valorem tax.[13] That is the processor's revenue is

$$r_{\gamma,M}(p, t) = p\gamma(1 - t).$$

Let $N^W \in [0, 1]$ denote the mass of processors that choose to join the platform. Then, in equilibrium, the total usage fee p is such that $N^W \gamma = N^S N^B$, where $N^S N^B$ is the total volume of

[13]The results from the paper do not depend on the functional form of taxation. Replacing the ad-valorem tax with other traditional taxation forms such as a unit tax yields the same outcomes.

interactions generated by the two sides. For brevity we denote $D = N^S N^B$.

The platform takes the total usage fee as given (i.e., determined through market clearing) but determines the price structure by choosing z such that $a^S = p/2 - z$ and $a^B = p/2 + z$. The platform then collects the remainder of the income that is not paid to processors. The platform profit is given by

$$\pi_D = tp\gamma N^W + A^S + A^B - C_D. \tag{3}$$

Notice that we assume that VDP costs C_D do not depend on the total interaction volume. This is reasonable since, as coordinator of processors and users, the VDP does not require any substantial infrastructure investment. Instead, the VDP can access (computing) resources held by the processors. This feature also distinguishes the VDP from some forms of vertically integrated platforms that we discuss next.

2.2 Vertically integrated platform

Throughout this paper we will contrast the vertically disintegrated platform (VDP) with a vertically integrated platform (VIP). The setup of the VIP follows closely the setup in Rochet and Tirole (2006). That is, while a vertically disintegrated platform outsources the processing of user interactions to a set of competitive agents, the VIP acts as an integrated monopoly that processes interactions in-house. This has two implications. First, the VIP incurs an additional cost as it needs to invest in the necessary infrastructure to run the interaction processing (e.g., computing ressources). The VDP does not face this cost as it can utilize resources held by the processors. Second, the total usage fee p is no longer set in a competitive equilibrium between processors and users. Instead, the VIP can now control both the total usage fee p as well as the price structure parameter z. For the VDP and the VIP settings to be comparable, they need to rely on the same processing technology. To achieve this, we assume the VIP takes control of (owns) the processors outlined above.

In general, the VIP profit function is given by

$$\begin{aligned}\pi_I &= pD - \int_0^{c^*} c\,dH + A^S + A^B - C_I(D),\\ &= pD - c_W(D) + A^S + A^B - C_I(D).\end{aligned} \tag{4}$$

where $c^* = H^{-1}(D/\gamma)$. The cost c^* is the cost of the last processor that has to be integrated by the VIP to satisfy the transaction volume D and can thus be thought of as the platform's marginal cost. This expression is equivalent to Rochet and Tirole (2006) with the exception that Rochet and Tirole (2006) assume that $c_W(D)$ is linear in D while in our case the functional form of $c_W(D)$ is determined by the processor cost distribution H. In addition to the operating cost

c, the VIP incurs an integration cost $C_I(D)$, which corresponds to the cost of investment in the infrastructure necessary to process user interactions (i.e., owning the processors). This cost may be increasing in the total interaction volume D, as more processors are required to process these interactions. Importantly, we assume that, by integrating processors, the platform can perfectly observe each processor's cost type c , which is not the case for the VDP, and that the VIP can perfectly price discriminate and extract the full surplus from processors. One could argue that this assumption 'unfairly' favors the VIP: in reality, we should expect imperfect price discrimination. As is well-known however, the imperfect price discrimination allowed here by integration will still favor the linear pricing that the VDP will have to resort to due to having to rely on a market for processors (Bolton et al., 2005). The advantage thereby conferred to the VIP is therefore robust to the introduction of the unobservability of c by a VIP that engages in optimal nonlinear pricing.

Given that the VIP integrates processors, we can also express the profit of the VIP using a processor specific *implicit* tax t such that $u^w = 0$. Depending on the processor remuneration structure, the VIP profit function is then

$$\pi_I = p\gamma \int_0^{c^*} t\,dH + A^S + A^B - C_I(D), \text{ where } t = 1 - \frac{c}{p\gamma} \tag{5}$$

2.3 Discussion

In the following we will briefly motivate our setup and how it relates to recent developments in payments systems — our leading application.

The key distinguishing feature between the VDP and VIP is that the VDP does not, in general, have control over the total usage fee p while the VIP has full control over both the total usage fee p and the price structure z. Traditional models of payment platform, such as VISA, Master Card and American Express, clearly fit the VIP setup, primarily because of the absence of vertical competitive constrains in setting prices.[14] Yet, as mentioned above, some blockchain based platforms, such as the Bitcoin payment system do not fit the VIP setup. In Bitcoin, transaction fees are set through a competitive process involving user demand and miner supply. However, the price structure – the fact that the transaction initiator pays the entire transaction fee – has been "arbitrarily" set by the designer of Bitcoin. Our model of the VDP allows to precisely study the effects of the interaction between a platform's pricing power and the competition among processors. It is general enough so that it allows to (1) analyse leading examples such as Bitcoin and to (2) consider other designs which might guide current debates by both

[14] VISA and Master Card were originally set up as not-for-profit cooperatives between banks. However, since 2007 and 2006, respectively, both companies have become for-profit public companies. We discuss the implications of these different settings and others in Section 7

private and public stakeholders in order to improve consumer welfare.

In addition, to pricing powers, the VDP and VIP can also differ in their cost structure. Because the VDP relies on a market of processors supplying the infrastructure to service users, it does not face the VIP's upfront costs, which arise from the need to acquire and implement the infrastructure (i.e., integrate the processors) from scratch. This integration cost may take different forms and levels as a function of the technology at hand as well as the organizational choices of the platform. Observed differences in the organizational structure of two dominant payment systems, VISA and American Express, offer a suitable micro-foundation for the level of this cost. VISA runs an *open-loop* system (see Benson et al. (2017)) where banks intermediate between the end-users, therefore moving most of the upfront infrastructure cost off of the platform on to the banks. In contrast, the American Express model is based on a *closed-loop* solution: American Express handles the full infrastructure and bears all the associated costs. Such a configuration is therefore heavier in capital (see Section 7 for more details). By allowing for these different cost structures, our model of the VIP allows to assess the extent to which different integration costs may affect our welfare comparison between VIP and VDP.

We have deliberately chosen to keep our VDP model as close as possible to the established platform model developed in Rochet and Tirole (2006). This close relation allows us to focus on the effect of vertically disintegrating a monopoly platform which is the main contribution of this paper. Note that, if not stated otherwise, the resulting platform remains a monopoly. This allows us to single out the welfare analysis of vertical disintegration while keeping consumer welfare from network effects optimal, because all users can reach each other on the same single platform. The VDP merely has less control over the market dynamics in general. Naturally this comes at the cost of neglecting several other aspects of disintegrated platforms. In particular, by modeling the market for the processing of user interactions through competitive market clearing, we abstract from the bargaining process between users and processors that may occur in many DLT platforms. However, such alternative market mechanisms should not, in principle, lead to qualitatively different comparative statics provided that the market mechanism is sufficiently competitive. Also note that we model the platform and the processors as separate entities. This will not be accurate when processors are also the owners of the platform. This is more likely to occur in a permissioned system, such as Ripple, than in an open system such as Bitcoin. Our model can be extended to address this issue.

Finally we would like to emphasize that, while for the sake of concreteness one can think of our model of VDPs as a model for blockchain payments platforms, it is more general. Indeed, any platform setup that combines a competitive market for interaction processing with a platform that sets the price structure is captured by our model. Such setups need not rely on blockchain technologies. To date, Bitcoin and Ethereum are the most prominent examples of

VDPs, but given industry efforts to develop alternative systems such as Libra and Corda, others are likely to follow. We elaborate on this in Section 7.

3 Equilibirum price

In the following we will consider the case when there is either a single VIP or a single VDP. Our objective is to study user welfare in the VDP and VIP regimes. We proxy user welfare by the total equilibrium interaction volume D. To ensure clarity of exposure, we proceed in an incremental order. We start with the assumption that costs are the same for both platforms (i.e., $C_I = C_D =$ const.) and analyze equilibrium prices. We first derive the users' demand and processors' supply functions. We then show that choosing an optimal price structure z is equivalent to determining the price structure that maximizes user demand for any given price. This applies both for the VDP and VIP, meaning that the problems of choosing an optimal total usage fee p and price structure z are separable. In the next section, we rely on these results to establish a welfare analysis between the VDP and the VIP under several scenarios including endogenous taxation, regulatory intervention and positive integration costs. Finally, we analyse the private incentives of a platform to disintegrate and compare platform and user preferences.

Let us focus on the case where fixed user benefits and costs from joining the platform are zero, i.e. $B_i^\mu = A^\mu = 0$. This reflects current conditions for most payment platforms, allowing for fair and realistic comparative grounds. Once we have developed the theory for the special case of $C_I = C_D$, we extend it to the case of $\frac{\partial C_I}{\partial D} > 0$.

In the absence of fixed user benefits and costs the mass of users that join the platform is given by

$$N^\mu(p,z) = \mathbb{P}(b_i^\mu \geq p/2 + s^\mu z) = 1 - F^\mu(p/2 + s^\mu z), \tag{6}$$

where $s^S = -1$ and $s^B = 1$. As mentioned above, the total transaction volume is the product of the mass of buyers and sellers that have joined the platform: $D(p,z) = N^S(p,z)N^B(p,z)$. We will also refer to the transaction volume as the demand and $D(p,z)$ as the demand function. We will assume throughout that $D(p,z)$ is well behaved, in particular that $\partial D/\partial p < 0$. We will further make the technical assumption that $\partial^2 D/\partial z^2 < 0$ and that $\partial D/\partial z = 0$ for some z, i.e. that D has a unique interior maximum in z. The amount of services provided to the platform (in the VDP setting) by the processors is given by

$$S(p,t) = \gamma N^W = \gamma \mathbb{P}(c_i \leq c^*) = \gamma H(c^*), \tag{7}$$

where $c^* = p\gamma(1-t)$. We will refer to $S(p,t)$ as the supply function. We will assume throughout that the supply function is well behaved, in particular that $\partial S/\partial p > 0$. In the VDP setting the equilibrium price structure and usage fee are given by

$$\begin{aligned} z_D^* &= \text{argmax}_z \, \pi_D(p,z) \\ &\quad \text{subject to } p = p_D^* \text{ such that } D(p_D^*,z) = S(p_D^*,t). \end{aligned} \tag{8}$$

By contrast, in the VIP setting the equilibrium price structure and usage fee are determined entirely by the platform's optimization problem; that is

$$z_I^*, p_I^* = \text{argmax}_{(z,p)} \, \pi_I(p,z). \tag{9}$$

What determines the equilibrium price structure? To study this question let us first define the price structure that maximizes interaction volume for a given total usage fee p

$$z_V^*(p) = \text{argmax}_z D(p,z).$$

By assumption, this $z_V^*(p)$ always exists. The function $D(p, z_V^*(p))$ describes the maximally attainable interaction volume at any given usage fee p. All demand curves for some fixed $z \neq z_V^*(p)$ must lie below $D(p, z_V^*(p))$. Given this definition we can formulate the following proposition that summarizes our results on the choice of the price structure.

Proposition 1. *The equilibrium price structure in the VDP and VIP setting maximizes total interaction volume at the equilibrium usage fee. That is:* $z_D^* = z_V^*(p_D^*)$ *and* $z_I^* = z_V^*(p_I^*)$. *For a given* p *we then have that:* $z_D^*(p) = z_I^*(p) = z_V^*(p)$.

Proof. See Appendix A □

This proposition makes two important points. First, maximizing platform profit with respect to the price structure is equivalent to maximizing total interaction volume for a given total usage fee. Second, as a result the VDP and VIP will choose the same price structure for any given price and differences in price structure are exclusively due to different equilibrium prices. The intuition for this result is simple. The supply curve for the VDP is independent of the price structure z. The platform can therefore always increase its profits by raising the level of demand at any given usage fee, i.e. an upward shift in the demand curve. The same argument applies for the VIP.

For completeness, we state the following result on dependence of the price structure on the user demand functions N^S and N^B.

Proposition 2. *At a given usage fee* p*, the optimal price structure will provide a discount to user of type* S $(z > 0)$ *if at* $z = 0$

$$\frac{\partial N^S}{\partial z}\frac{1}{N^S} > -\frac{\partial N^B}{\partial z}\frac{1}{N^B}.$$

In the opposite case the user of type B will receive a discount ($z < 0$). In the case of equality, $z = 0$ will be optimal.

Proof. See Appendix A □

This proposition states that if the magnitude of the rate of change of the demand of user S, scaled by the demand of user S exceeds that of user B, user S will receive a discount. For the sake of illustration, suppose that for a particular usage fee p, both users have the same rates of change of demand with respect to the price structure when both face the same usage cost ($z = 0$). Then total usage will increase if the user with the smaller demand receives a discount. Conversely, if both users also have the same demand $z = 0$ will be optimal. This result recovers a major insight from Rochet and Tirole (2006): if buyers and sellers have different elasticities, failing to achieve the optimal price structure imposes a deadweight loss on the platform. It is important to realize that the optimal price structure here depends on the level of the usage fee p. As the usage fee changes, the price structure may flip sign such that a user that previously received a discount may end up paying a premium.

4 Welfare analysis

The VDP and VIP models represent two alternative platform setups. The VIP is the standard platform operating model, while VDPs are emerging in various forms in the DLT ecosystem. Given the concern around the monopoly power of many traditional (VIP) platforms, it is important to study whether alternative setups, such as the VDP, can improve economic outcomes. Here, we focus on user welfare as proxied by the total interaction volume. We start with a simple scenario of exogenous tax parameter and no integration costs. We then progress by endogenizing the tax parameter and allowing for positive integration costs. This agenda allows us to tractably map out the conditions under which one platform model dominates over the other as a function of the market conditions for processors and the cost structure.

4.1 Exogenous tax

It is reasonable to suspect that the VDP can lead to better outcomes since total usage fees are set in a competitive market, while VIPs can take advantage of their higher pricing power. At the same time, fixing the tax parameter t, as we have done so far and will continue to do in this section, risks introducing inefficiencies. For example, t could be set too high such that processors' incentives to join the platform are diminished and supply of platform services is halted. In the following, we will formally explore these trade-offs. We will consider two scenarios. In the first scenario we assume that we find ourselves in the VIP monopoly equilibrium and ask under which conditions welfare will improve if we move to a VDP monopoly equilibrium. The second scenario considers the opposite: we find ourselves in a VDP equilibrium and ask under which conditions a move to a VIP equilibrium will decrease welfare.

We start with the following result on the tax parameter t.

Lemma 1. There exists a $t(p)$ such that

$$S(p, t(p)) = D(p, z)$$

for any given z and $p \in [\underline{p}(z), \overline{p}(z)[$, where $\underline{p}$ is given by $S(\underline{p}, 0) = D(\underline{p}, z)$ and $\overline{p}(z)$ is the choke price given by $\inf_p D(p, z) = 0$.

To see this consider the case when $t = 1$. In this case, no processors will supply platform services at any p such that $S(p, 1) = 0$. But for any $t < 1$ the supply curve will always intersect the demand curve in the interval $[\underline{p}(z), \overline{p}(z)]$. Varying t will then smoothly vary p. We write $t(p)$ to denote the t that achieves $S(p, t) = D(p, z)$. This then implies that there will always exist a t_I such that the VDP achieves the VIP profit maximizing outcome. Armed with these formalities we can formulate the following proposition:

Proposition 3. *For some VDP tax parameter t, in equilibrium the following hold:*

1. *VIP equilibrium starting point: VDP demand will exceed VIP demand if $t < t_I = t(p_I^*, z_I^*)$.*

2. *VDP equilibrium starting point:*

$$\frac{1}{D(p_D^*, z_D^*)} \left.\frac{\partial D}{\partial p}\right|_{(p_D^*, z_D^*)} > -\frac{1}{t p_D^*}.$$

Proof. See Appendix A □

Let us consider the statements in the proposition in turn. First, if the tax parameter is chosen sufficiently small the VDP will dominate the VIP. To see this note that as $t \to 0$ the supply curve shifts up. Indeed at $t = 0$, the supply reaches its maximum at any given usage fee. However, demand is unaffected by changes in t. Therefore if $t < t_I$, in the VDP equilibrium total usage fees must be lower and demand higher. So why not set $t = 0$ by default? If the platform incurs fixed initial costs, such as software development costs, setting $t = 0$ would not be feasible under a non-negative platform profit constraint. In Section 7, we discuss the implication of setting $t = 0$ as in the case of Bitcoin. Proposition 3 further shows that the elasticities of demand in the VDP equilibrium determine whether or not welfare under the VDP will exceed VIP welfare. In particular, for a given tax parameter t and usage fee p_D^*, if the elasticity of demand of the users is sufficiently large in magnitude, the VIP will dominate the VDP. To see this, suppose for example that the demand curve is very steep at the VDP equilibrium. Then it will be profitable for the VIP to reduce the usage fee by a small amount and thereby increase demand, i.e. total interaction volume, by a large amount. The converse of this scenario is of course when the demand curve is very flat at the VDP equilibrium. Then the VIP will find it profitable to increase prices and incur a small decrease in demand.

In sum, in this section we have shown that no strict welfare dominance relationship between the two platform models exists when t is exogenous. For t sufficiently small, the VDP will dominate the VIP. However, if t is chosen too large the VIP will dominate the VDP.

4.2 Endogenous tax

So far we have assumed that the tax parameter t was fixed exogenously. For example, t could be set by a regulator or it could be determined via an unmodeled bargaining process between the platform and a processor collective. In this section, we will endogenize t by letting the VDP maximize its profit with respect to t. In the above section we have shown that an arbitrary t has ambiguous effects: for sufficiently small values, the welfare under the VDP dominates welfare under the VIP; for sufficiently large values, the opposite is true. In the following, we show that when the VDP optimizes over t, the resulting welfare is strictly lower than in the VIP case.

Formally, when the VDP is profit maximizing with respect to the price structure and the tax parameter, the new VDP equilibrium becomes

$$\begin{aligned} z_D^*, t^* = \text{argmax}_{(z,t)}\, &\pi_D(p,z) \\ &\text{subject to } p = p_D^* \text{ such that } D(p_D^*, z) = S(p_D^*, t). \end{aligned} \tag{10}$$

Notice that equivalently we can let the VDP optimize over p and use $t = t(p,z)$ to ensure market clearing since by virtue of Lemma 2 there exists a one to one relationship between t and the market clearing price. This will be the view we take for the remainder of this section. To build intuition, it is useful to relate the profit of the VIP to the profit of the VDP and the processor surplus. We summarize this relationship in the following lemma.

Lemma 2. For any given usage fee p, price structure z and tax parameter $t = t(p,z)$, the profit of the VIP equals the sum of the VDP profit and the processor surplus,

$$\pi_I(p,z) = \pi_D(p,z,t) + \pi_W(p,z,t),$$

where π_I and π_D are as defined above and the processor surplus is

$$\pi_W(p,z,t) = \int_0^{c^*} h(c_i)(c^* - c_i)dc_i$$

where $h(c) = dH/dc$ and $c^* = H^{-1}(D(p,z)/\gamma)$.

Proof. See Appendix A □

This lemma clarifies that the VIP captures the entire surplus that the processors earn in the VDP case. Equivalently, the VDP faces an extra cost π_W relative to the VIP. This insight leads us to the following proposition.

Proposition 4. *In equilibrium, when the VDP chooses t to maximize its profit, usage costs p_D^* are higher and user welfare is lower in the VDP case compared with the VIP case.*

Proof. See Appendix A □

The intuition for this result is simple. In Lemma 1 we have shown that the VDP has full control over the equilibrium price by picking an appropriate tax parameter t. Thus, the VDP can effectively act as a monopoly and choose the price that maximizes its profit. This price will differ from the profit maximizing price of the VIP however, since both platforms face different cost functions as is apparent from Lemma 2. As we show in the appendix, the incremental cost of the VDP is increasing in the total demand and thus decreasing in the total usage fee p. The VDP will therefore set a higher equilibrium price (via an appropriate choice of t) than the VIP. Note that the profit maximizing choice by the VDP is inefficient. Both VDP and processors could gain if they chose the VIP equilibrium and redistributed the additional surplus among themselves.

We conclude this section with a corollary that follows from Propositions 3 and 4.

Corollary 1. *If the tax parameter is constrained such that for some $\underline{t}$ we have that $t < \underline{t} \leq t_I$, the user welfare under the VDP will dominate user welfare under the VIP.*

In other words, if the the VDP has to choose a tax parameter that has to be smaller than the tax parameter which yields the VIP equilibrium, the VDP will dominate the VIP. This follows immediately from Proposition 3 and the fact that the VDP will pick $t^* = \underline{t}$ to maximize its profits.

4.3 Integration costs

We close this section on user welfare by considering the case when $\partial C_I / \partial D > 0$. Recall that $C_I(D)$ represents the cost that the VIP incurs for integrating processors into the platform. For example, $C_I(D)$ could correspond to the hardware and software computing infrastructure that the VIP needs to acquire in order to operate and process transactions. The VDP does not face this cost as it outsources the transaction treatment to processors. Recall further that, the VIP can observe processor cost types, precisely because it has integrated processors. It can therefore fully capture the processor surplus. This ability to capture the processor surplus, together with the assumption that $\partial C_I/\partial D = 0$, led to our result in Proposition 4. Demand dependent integration costs change this picture. Indeed, these costs can reverse the outcome of Proposition 4. We summarize this insight in the following proposition.

Proposition 5. *In equilibrium, when the VDP chooses t to maximize its profit and the VIP faces integration costs $C_I(D)$, user welfare under the VDP dominates the VIP if the rate of change of integration costs $\partial C_I(D)/\partial D$ at the VIP optimal price p_I^* is sufficiently large.*

Proof. See Appendix A □

This result states that if integration costs faced by the VIP increase by a large amount when total demand (and therefore the "quantity" of processors that need to be integrated) increases slightly, a VDP will choose a tax parameter t that lies below t_I. If this is the case, total supply of transaction processing shifts up relative to its level at t_I, leading to lower usage fees and larger user welfare in equilibrium. The intuition behind this result is simple. When integration costs increase rapidly with the total transaction volume, it is optimal for the VIP to suppress transaction volume by choosing a higher usage fee p_I^*. Since the VDP relies on the market for processors to supply its service, it does not face these integration costs. As a result, its optimal usage fee (implied by t^*) will lie below p_I^*.

5 Platform incentives

So far, we have compared VIP and VDP configurations from the perspective of user welfare. In doing so, we have implicitly assumed that the platform, or the founder wishing to set up a new platform, cannot choose to be integrated or disintegrated. Building on the results developed in the previous sections, we now turn to the determinants of a platform's preferences between integrated and disintegrated configurations. Furthermore, we contrast the platform's preferences (based on profits) to the users' preferences (based on usage fees). For the remainder of this section we assume that the VDP endogenously chooses the tax parameter.

Two forces shape the platform's preferences: on the one hand, the ability to internalize the processors' profits and, on the other hand, the exposure to integration costs. To build an intuition, let us first consider the case when integration costs are negligible. That is we assume that

$C_I = C_D =$ const.. In the VDP configuration, processors always make positive profits in aggregate ($\pi_W > 0$). Therefore, at the usage fee p_D^* implied by the VDP optimal tax rate, profits made by the VDP are less than the VIP: $\pi_D(p_D^*) < \pi_I(p_D^*)$. Since $\pi_I(p_D^*) \le \pi_I(p_I^*)$, the VDP profits are always less than the VIP profits in equilibrium. Thus, in the absence of differences in costs, a platform would always prefer to integrate. This result mirrors the conditions in the previous section under which the VIP turned out to be preferable from the users' welfare perspective. Hence, platform and user preferences are aligned when differences in costs are negligible between the two models of platforms. However, this is not the case in general.

When integration costs are present, no clear preference ordering exists. That is platform and user preferences depend on the precise form of the integration costs. To see this consider the case of fixed integration costs, i.e. $C_I = C_D + \alpha$. The parameter α can be interpreted as an additional upfront investment cost specific to the VIP (or as a subsidy that the VIP receives if $\alpha < 0$). Fixed integration costs do not affect any of the VIPs choices such that user welfare remain unchanged. However, if α is sufficiently large we have that $\pi_I < \pi_D$ and the platform prefers the VDP solution. When C_I actually depends on the volume of transactions, platform profits no-longer move independently from user welfare.

For the sake of concreteness, suppose that integration costs take a linear form $C_I(D) = C_D + \alpha + \beta D$. Further suppose that processor costs are exponentially distributed with parameter λ and that the joint demand function is given by $D(p) = 1 - \Gamma(p, s, l, c)$, where $\Gamma(\cdot)$ is gamma CDF with shape, location and scale parameters (s, l, c) respectively. To illustrate the range of possible preferences over the VIP and VDP, we compute platform profits as well as user welfare for different values of the intercept $\alpha \in [-5, 5]$ and the slope $\beta \in [0, 10]$ of the integration cost function. The results of this numerical example are presented in Fig. 2. The figure features four distinct regimes of disintegration preferences between the platform and the users. Areas under DD (resp. II) indicate that both the platform and the user prefer the disintegrated solution (resp. integrated solution). Areas under ID (resp. DI) indicate that the platform prefers the integrated solution (resp. disintegrated solution) while the users prefer the disintegrated solution (resp. integrated solution). From the figure it is therefore clear that, when integration costs matter, neither the integrated nor the disintegrated solutions are guaranteed to dominate. When both intercept and slope are large or small, platform and user preferences are aligned. When the slope is large but the intercept is small, users prefer the VDP while the platform prefers the VIP. Similarly, when the slope is small but the intercept is large, users prefer the VIP while the platform prefers the VDP. From a regulators perspective, the case when user and platform preferences are not aligned is most relevant as in such cases intervention may be necessary to support user welfare.

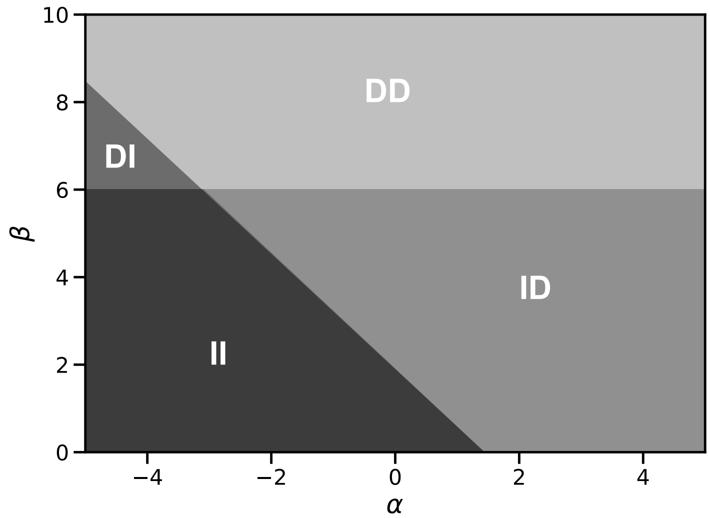


Figure 2: Preferences over VIP and VDP for users and platform for linear integration costs $C_I(D) = C_D + \alpha + \beta D$. For users, the preference is determined by the equilibrium price p^*. For the platform, the preference is determined by the equilibrium profit π^*. The demand function parameters are $s = 3, l = 20, c = 10$. We set $\gamma = 1$. The cost distribution parameter is $\gamma = 0.5$. Four distinct regimes are identified: II corresponds to cases where user and the platform prefer VIP; ID corresponds to cases where user prefers VIP while the platform prefers VDP; DI corresponds to cases where user prefers VDP while the platform prefers VIP; DD corresponds to cases where user and the platform prefer VDP.

6 Policy implications

Our results shed light on an emerging platform model in which a platform outsources the processing of interactions on the platform to a market of competing agents. In our view, two insights from our analysis are particularly important for policy makers.

First, if the market for processors is appropriately regulated, a vertically disintegrated platform can lead to higher user welfare than a vertically integrated platform. For example, if a VDP chooses the tax parameter to maximize its profits, but faces a regulatory constraint that bounds the tax parameter from above, then for a sufficiently low constraint, VDP user welfare will exceed VIP user welfare. Such a regulatory constraint is akin to setting minimum wages in a labor market with a monopsony firm. Second, if the market for processors is left unregulated, a monopsony VDP will lead to lower user welfare relative to the VIP benchmark. This occurs for two reasons. In absence of regulation, a VDP can freely choose the tax parameter to maximize its profits. As we show, this is equivalent to the VDP choosing total usage fees which gives the unregulated VDP monopoly power over the users. However, due to informational frictions in the market for processors, the VDP cannot observe the processors costs and therefore faces higher production costs than the VIP. As a result its profit maximizing price will be higher and corresponding user welfare will be lower.

Second, there is an important practical difference between VIPs and VDPs. In the VIP setting, the platform has to process the interactions in-house and therefore may need both expertise on how to provide these services and large investment capacities (i.e., integration costs). The VDP does not require the same amount of capital investment that the VIP requires because it outsources the platform services to a market of experts – the processors. We have shown that this difference can further exacerbate the welfare gap between a VIP and a VDP solution as well as the alignment of preferences between user welfare and platform profits. As such, cases where user welfare improves under VDP but profits are higher under the VIP may justify a public intervention. In such conditions, it is indeed conceivable that a welfare improving VDP could be set up with a relatively limited amount of public funds and operated as a public utility. However, this utility would take on a purely coordinating role (by determining the price structure) and would not be required to perform the platform services. Furthermore, in a not-for-profit setting, the tax parameter would then be set to recover the initial investments and fund replacement investments. Retail payments system may be good candidate for such implementation as showcased in Section 7. As our results suggest, the potential benefits for user welfare from a move to a VDP model – when orchestrated appropriately – can be substantial.

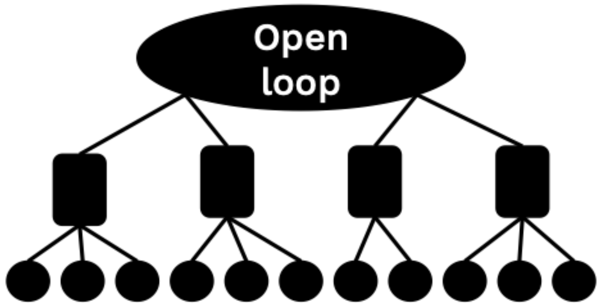
7 Application to payment systems

The framework introduced in this paper allows for a range of different design choices. In this section, we discuss real-world applications in the context of the payment industry and relate them to our benchmark settings. We first discuss organizational aspects of classic payment models. We then consider one main governance implementation observed in emerging payment platforms: the zero-tax VDP. Leveraging the results of the previous sections, we review advantages and disadvantages of each implementation in terms of user welfare and link the results with current discussions on the design of central bank digital payments.

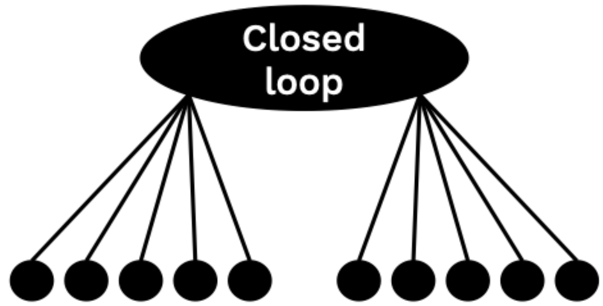
7.1 A note on payment platforms

According to our definition, dominant payment platforms including VISA, MasterCard and American Express constitute examples of VIP settings, primarily because of the absence of vertical competition in the production of their service. In the following, we use the organizational setting exhibited by these major platforms to further support this claim. In addition, we exploit these organizational differences to qualitatively motivate differences in integration costs.

In general, traditional payment systems can be classified into two organizational models: open and closed loop systems. Open-loop systems rely on a network of intermediaries to al-



(a) Open-loop payment platform
(example: VISA)



(b) Closed-loop payment platform
(example: American Express)

Figure 3: Stylized illustration of the two organisation modes in payment systems: (a) open-loop setting where intermediaries (black rectangle) - banks in general - stand between the end-users (black nodes) (e.g., customers and merchants) and the payment platform; (b) closed-loop setting where the platform provides the full infrastructure and directly interacts with end-users (black nodes) (e.g., customers and merchants).

low transfers between end-users. They are capital light; their primary role is to enable message passing between intermediaries to verify accounts and validate transfers. VISA and MasterCard belong to this category. Initially set up as cooperatives of banks acting as intermediaries, both companies have become for-profit public organizations in 2007 and 2006, respectively. In contrast, closed-loop systems provide a fully owned end-to-end service to customers. As they do not rely on intermediaries, these business models require additional layers of services compared to the open-loop systems including customer accounts, implementation and maintenance of a centralized transaction ledger, etc. As a result, these systems are more capital intensive. American Express stands as prime example of a closed-loop system.[15] Figure 3 illustrates the two type of organization.

These two forms of payment system organization shed light on the relative importance of pricing power and integration costs. First, note that, as long as we consider profit-maximizing settings — as is currently the case for the major payment systems — both settings allow the platform to act as a monopoly and extract all the consumer surplus. This is straightforward for the closed-loop setting. In the case of open-loop systems, what we observe from the implementation of Visa and MasterCard is an absence of direct competition between intermediaries to provide the service of the platform. On the one hand, transactions fees are set by the platform. On the other hand, the revenue model of intermediaries does not rely on their activity in the payment platform in spite of the related operational cost.[16] Evidently, there is an indirect com-

[15]See Benson et al. (2017) for an extensive overview of the payment system industry.

[16]Notice that, in order to have a competitive market, intermediaries would in principle need to have access to the entire ledger. In the observed models, intermediaries have only access to the accounts of their own clients.

petition effect at play between intermediaries to attract customers, but it exists outside of the platform. In light of these observations, we conclude that, within our framework, both models can be associated with the VIP.

Second, open- and closed-loop systems have different implications in terms of cost structure. This difference provides us with a micro-foundation for the functional form of the integration cost. In the case of open-loop systems, the costs associated with the size of the customer market is mainly born by the intermediaries. The platform's integration costs can be seen as insulated from the level of user-demand. For a closed-loop system, the platform handles the full infrastructure. In this case, the integration costs depend on the total size of the market. We can therefore use these settings as benchmarks when comparing welfare outcomes with a VDP model by qualitatively associating the results from Proposition 4 to open-loop settings and Proposition 5 to closed-loop settings.

7.2 Emerging payment platforms

To this day, disintegrated platforms with zero tax constitute the main form of disintegrated platforms (e.g., Bitcoin and Ethereum). In this corner case, the platform consists of a software protocol which allows processors to coordinate. The platform virtually bears zero cost and all the revenue from transaction fees is transferred to the processors. However, limiting costs of running the platform also implies an absence of effective monitoring, maintenance and adjustment mechanisms.

In the general case where the demand elasticities for buyers and sellers is different (i.e., multi-sided platform) as in the case of retail payments, the ability to adequately adjust the price structure is crucial but also costly. It requires empirical estimation of elasticities of demand and dynamic re-adjustments of the price structure as these elasticities evolve. In view of its cost bearing limitations, a zero-tax platform typically needs to fix a constant price-structure ex-ante. However, a sub-optimal price structure creates a deadweight loss: prices are not adjusted to each side's elasticity, thus limiting the overall welfare of the users. In fact, by virtue of the Proposition 1, we know that the adapted Lerner formula (Rochet and Tirole (2006)) applies also to disintegrated platforms.

At the same time, when costs are negligible, the platform can sustain a tax parameter at zero. Our results on the effect of taxes in a VDP suggest that, compared to other possible designs, low or zero taxes increase welfare. We therefore observe two opposite forces for welfare in the zero-tax VDP setting: inefficient price structure and low (zero) taxes.

Bitcoin and Ethereum Historically, Bitcoin and Ethereum have been the major community-led solutions in the market for distributed ledger technologies. Bitcoin was the first solution to the issue of decentralized transfers of value. While the focus of Bitcoin is on enabling payments, the Ethereum design has the capacity to handle complex conditional payment scenarios, i.e., smart contracts.[17] Ethereum has been growing rapidly over the years.[18]

From the economic perspective of our model, both platforms have a similar design. Incentives for processors to join the platform and provide services to administer and maintain the ledger are driven by rewards in the form of coins native to the platform. We will here focus on the transaction-based rewards.[19] For each transaction, the buyer arbitrarily sets a fee on top of the transaction value. This fee will be collected by the processor who ultimately registers the transaction to the ledger. The platform does not generate any profit from transaction fees. In our framework, this design translates into the following conditions: $t = 0$, $z = p/2$, where p is determined by the market for processors.

Assuming that buyers and sellers do not negotiate away the transaction fee, the whole transaction cost is born by the buyer, $z = p/2$. Such a choice can be optimal under two possible scenarios: First, this occurs in the corner case when the sellers' demand elasticity is sufficiently large such that buyers stand ready to subsidise the full usage cost to the sellers willing to join the platform. This is unlikely to be the case for Bitcoin. However, $z = p/2$ can also be optimal if there is a single type of user who can be a buyer or a seller with equal probability. In this one-sided setting, the expected value of z equals zero which is optimal by virtue of Proposition 2. In contrast, if the pool of platform users cannot be considered one-sided, the design choice on the price-structure $z = p/2$ lowers welfare and a share of users will not participate.

Given the novelty of VDP in payments, the number of case studies is limited at this stage. However, several ongoing projects can benefit from our analysis to model pricing capacities and welfare implications.

Fabric Fabric is an open-source blockchain solution introduced by Hyperledger, a project initiated under the auspices of the Linux Foundation with the participation of technology firms such as Microsoft, IBM, Intel and financial firms including the Depository Trust & Clearing Corporation, SWIFT, ABN Amro, and others. Fabric is designed to allow for generic transfers of

[17] The contract-oriented programming language of Ethereum, Solidity, is said to be *Turing complete*

[18] As of May 9, 2019, the market capitalization of Bitcoin and Ethereum were of \$108,162,278,591 USD and \$17,821,589,031 USD respectively.

[19] Another important reward is the so-called block-reward. It consists of a number of native coins transferred to the processor who successfully adds valid transactions to the ledger. In Bitcoin, the block rewards decrease over time. In the long run, transactions fees are expected to be the main incentive for processors. Note that we also abstract from the token strategy of both Bitcoin and Ethereum. While implementing a native token on a platform affects participation incentives, we chose to keep our discussion general and applicable to any medium of value transfer.

value among participants, i.e. smart contracts.[20] Fabric itself does not contain any specific economic design. Rather it allows each organization to implement economic incentives on top of its architecture. For example, several cloud services including IBM, Microsoft and Amazon have implemented a Fabric-based service. They offer groups of institutions the possibility to create a distributed ledger solution in order to establish a safe and neutral environment to execute transfers.[21]

Corda Corda is also an open-source blockchain solution for business. It is developed by the R3 consortium composed of around two hundreds financial institutions including among others JP Morgan, Godlman Sachs and BNP Paribas.[22] While Fabric was designed for generic industrial applications, Corda is more tailored towards financial services. Notwithstanding different architectural choices, the overall purpose of Fabric and Corda is similar: provide an environment for institutions to exchange values under customized conditions.[23]

Libra Libra is a private digital currency project originally initiated by Facebook. It was introduced as a solution to facilitate global financial inclusion through drastic cuts in transaction processing fees to customers, in particular in the context of cross-boarder payments and remittances. The consortium of partners consists a conglomerate of for-profit and not-profit, private and public institutions.[24] Reportedly, its long term purpose is to deploy a permissionless blockchain, that is, a free entry market for processors.

All these initiatives remain at an early stage. Details of the business implementations are either unknown publicly or subject to changes. Our results on such platforms' capacity of full pricing powers, positive implicit taxes, integration costs and conditions in the market for processors could help guide welfare improving solutions in each cases.

7.3 Central bank digital currency

The rise of digital private currencies such as Bitcoin and the general decline of cash in retail payments have prompted central banks in a wide variety of countries including Australia, Canada,

[20] For a listing of the latest projects using Fabric visit https://www.hyperledger.org/projects/fabric

[21] See for example, IBM Fabric pricing table: https://cloud.ibm.com/docs/services/blockchain/howto?topic=blockchain-ibp-pricing

[22] The consortium was initially composed of nine companies: Barclays, BBVA, Commonwealth Bank of Australia, Credit Suisse, Goldman Sachs, J.P. Morgan, Royal Bank of Scotland, State Street, and UBS

[23] Projects using Corda involve collaboration with Master Card, SWIFT, Amazon, etc. An updated list can be found at https://www.r3.com/success-stories/

[24] Members of the projects include Uber, Spotify and Woman's World Banking. An updated list can be found at https://libra.org/en-US/

Sweden, China and Uruguay to seriously consider the development of a central bank digital currency (CBDC) or central bank digital retail payments (Mancini Griffoli et al., 2018; Bank of Canada, 2019). At the core, a CBDC can be thought of as a digital alternative to cash (Bech and Garratt, 2017). Research to date has focused on the potential implications of the introduction of a CBDC on monetary policy and financial stability (Bordo and Levin, 2017; Engert et al., 2017), and has largely abstracted from the challenges of implementing and successfully operating the underlying platform infrastructure of a CBDC. In this section, we explore these challenges and, based on the theoretical results obtained above, argue that a central bank controlled, not-for-profit VDP solution is a strong candidate to overcome these challenges.

While in principle a CBDC could be made available only to wholesale clients, most proposals consider giving retail clients access to the CBDC. In addition, CBDCs that are restricted to wholesale clients bear substantial similarity to existing interbank payment systems. It is therefore not clear how the economic principles of such a CBDC would differ from these existing systems. Consequently, for the purposes of this section, we will focus on CBDCs that would also be accessible to retail clients. A central bank wishing to implement such a CBDC faces a number of technological and economic challenges. We discuss each challenge in turn.

Fee structure: Developing, maintaining and running a CBDC payment system is costly. Unless a CBDC is fully funded by tax payers such that CBDC usage is free of charge (which could amount to a substantial cost, see below), the operating costs of the CBDC will have to be born, in part at least, by its users. Note that public interbank payment systems such as TARGET2 do include usage fees to their users. Adoption of the CBDC as a means of payment is therefore not a given, in particular if alternative payments systems coexist. To ensure adoption of the CBDC, it is important that an appropriate fee structure for the CBDC payment platform is designed. A failure to do so can result in low adoption of the CBDC, as happened in earlier experiments with digital money.[25]

Integration decision: A competitive retail payment system must be capable of processing a large volume of transactions. Visa for example processes thousands of transactions per second. This exceeds by many orders of magnitude the processing rate of central bank operated interbank payments systems such as TARGET2, see European Central Bank (2018). This suggests that, as of today, central banks do not have the expertise nor the technology to operate a competitive retail payment system. While central banks could invest in this expertise to run the payment system in-house, this is likely to be very costly. These costs will be precisely the integration costs that the VIP faces in the model introduced in the earlier sections. In addition,

[25]See for example the case e-money introduced by the Finish central bank in the 1990s, see Aleksi Grym (2017).

uncertainty over the rate and scale of adoption of the CBDC would make investment into a large scale CBDC a risky endeavor. Together, the large integration costs and uncertainty of ultimate demand for transaction processing are likely to make outsourcing of the payment system operation an attractive option for the central bank. Indeed, most central banks currently considering the introduction of a CBDC would outsource the operation of the CBDC, see Mancini Griffoli et al. (2018). Clearly, if possible, outsourcing to a competitive market (such as the processors in the case of the VDP), will be preferable from the central bank's perspective than outsourcing to a single provider.

In sum, for a CBDC to have a chance of success, an appropriate fee structure should be chosen and the transaction processing should be outsourced. According to our results, a not-for-profit vertically disintegrated platform is therefore a strong candidate for a CBDC payment system. Under this scenario, the central bank would maintain control over the fee structure of the payments system, allowing it to address concerns over fair access, financial inclusion and adoption, while outsourcing the processing of transactions to a competitive market specialised agents. As a result, the central bank could run a CBDC without having to acquire the infrastructure nor technological expertise to process large volumes of transactions thus yielding lower costs for the users.

8 Conclusion

Platforms such as payment systems have taken a prominent role in the digital economy. As a result, understanding the welfare implications of novel platform designs and strategies has become paramount.

In this paper, we propose an extension of traditional platform models that incorporates a specific innovation emerging from the payment industry, i.e., distributed ledger technology. For example, systems like Bitcoin act as digital platforms while not owning the infrastructure to process interactions and with limited (or zero) pricing power. Referring to platforms where prices are (partially) determined by a side market of competing processors as vertically disintegrated platforms, we have studied how such a platform governance model compares with traditional platform designs. In particular, focusing the analysis on regulatory conditions in the market for processors - a feature specific to disintegrated platforms - as well as differential integration costs, we find that regulating appropriately the tax charged by the platform on the processors could drive user welfare above levels exhibited by traditional platforms. Absent any regulation, vertical disintegration appears to lower user welfare except for cases when integration costs are very sensitive to user interaction volumes.

While we deliberately narrowed our focus to the comparison of integrated vs. disintegrated platforms, further analysis would benefit from product differentiation, in line with the delay costs studied by Huberman et al. (2017); extended platform competition, considering cases of competition between VDPs and VIPs and comparing outcomes with the traditional models of Armstrong (2006) and Lee (2013); integrating variable cost functions depending on the level of integration and considering other strategic dimensions including legal, technological, informational, and other instruments to implement desired outcomes as discussed by Boudreau and Hagiu (2009).

Overall, the growth of digital and financial inclusion increases the need for economically efficient and welfare preserving platforms - particularly in payments systems.[26] Concerns regarding the industrial organisation, the technological efficiency and the adequate regulation of such evolving markets need to be considered jointly to ensure sustainability of the future economy.

[26]See for example the report by OECD (2018)

A Proofs

Proof. Proposition 1: To prove the proposition we need to show that profit is always increasing in the level of demand at a given usage fee. Let $z_V^*(p) = \text{argmax}_z\, D(p,z)$ denote the price structure that maximizes interaction volume. By assumption for every p we have that $\partial^2 D/\partial z^2 < 0$ and $\partial D/\partial z = 0$ for some z. Therefore $z_V^*(p)$ exists and is uniquely defined. First consider the VDP case. For a given supply function $S(p,t)$, the equilibrium usage fee p_D^* is increasing in the level of the demand function and hence maximized when $z_D^* = z_V^*(p)$. When the usage fee is maximized and the demand at any given usage fee is maximized, VDP profit must be maximized. This proves the result for the VDP. Now consider the VIP. Here again an upward shift in the demand curve can only increase profits. If the level of demand shifts ups, the VIP can always increase the usage fee sufficiently to recover the pre-shift demand and hence the pre-shift cost. Demand and costs will be the same but the usage fee will be larger. Hence profit has increased. Thus, when demand is maximized with respect to z VIP profit is maximized. □

Proof. Proposition 2: Recall that $z_D^*(p) = z_I^*(p) = z_V^*(p)$. The derivative of the demand with respect to z is

$$\frac{\partial D}{\partial z} = \frac{\partial N^S}{\partial z} N^B + \frac{\partial N^B}{\partial z} N^S.$$

Recall that D has a unique maximum in z. Thus, if at $z = 0$, the derivative $\partial D/\partial z > 0$ we must have that $z_D^*(p) > 0$. Rearranging the above expression yields the result in the proposition. □

Proof. Proposition 3: We prove the first part of the proposition first. As discussed in the main text, the VDP can always recover the VIP equilibrium by setting $t = t_I$. If the VDP chooses a tax parameter $t < t_I$, the supply curve must shift upwards while demand remains unaffected. As a result $p_D^* < p_I^*$ and $D(p_D^*, z_D^*) > D(p_I^*, z_I^*)$. The second part of the proposition is proved by considering the derivative of the VIP profit at the VDP equilibrium

$$\frac{\partial \pi_I}{\partial p} = \left(p - \frac{\partial c_W}{\partial D}\right)\frac{\partial D}{\partial p} + D.$$

Recall that

$$c_W(D) = \int_0^{c^*} cH(c)\,dc,$$

where $c^* = H^{-1}(D/\gamma)$. Then

$$\frac{\partial c_W}{\partial D} = \frac{\partial c_W}{\partial c^*}\frac{\partial c^*}{\partial D} = c^*/\gamma,$$

where the last equality follows from $\partial c_i/\partial c^* = c^* H(c^*)$ and $\partial c^*/\partial D = 1/(\partial D/\partial c^*) = 1/(H(c^*)\gamma)$. Notice that in the VDP equilibrium, $S(t, p_D^*) = H(p_D^*(1-t)\gamma) = D(p_D^*, z_D^*)/\gamma$ and thus $c^* = p_D^*(1-$

$t)\gamma$. Hence we obtain

$$\left.\frac{\partial \pi_I}{\partial p}\right|_{z_D^*, p_D^*} = p_D^* t \left.\frac{\partial D}{\partial p}\right|_{z_D^*, p_D^*} + D(p_D^*, z_D^*).$$

If in the VDP equilibrium $\partial \pi_I / \partial p > 0$, in the VIP equilibrium usage fees will be larger and demand in turn smaller. □

Proof. Lemma 2:

Consider the VIP profit:

$$\pi_I = pD(p,z) - \int_0^{c^*} cH(c)dc - C_D,$$

where we used the assumption that $C_I = C_D$. Adding and subtracting tpD we obtain

$$\begin{aligned}
\pi_I &= ptD(p,z) + (1-t)pD(p,z) - \int_0^{c^*} cH(c)dc - C_D, \\
&= ptD(p,z) + (1-t)p\gamma \int_0^{c^*} H(c)dc - \int_0^{c^*} cH(c)dc - C_D, \\
&= \underbrace{ptD(p,z) - C_D}_{\pi_D} + \underbrace{\int_0^{c^*} H(c)(p\gamma(1-t) - c)dc}_{\pi_W}.
\end{aligned}$$

Recall that we defined $c^* = p(1-t)\gamma$, the marginal cost of the last processor that is willing to be active at price p and tax parameter t in the case of the VDP or the marginal cost of the last processor that needs to be activated by the VIP to satisfy demand $D(p,z)$. Thus we have

$$\pi_w = \int_0^{c^*} H(c)(c^* - c)dc.$$

□

Proof. Proposition 4: Recall that $\pi_D = \pi_I - \pi_W$ and hence at the VIP profit maximizing price p_I^* we have that

$$\left.\frac{\partial \pi_D}{\partial p}\right|_{p_I^*} = -\left.\frac{\partial \pi_W}{\partial p}\right|_{p_I^*},$$

where

$$\frac{\partial \pi_W}{\partial p} = \frac{\partial \pi_W}{\partial c^*}\frac{\partial c^*}{\partial D}\frac{\partial D}{\partial p} < 0.$$

This is because $\partial \pi_W / \partial c^* > 0$ since increasing c^* increases both the integrand which is always positive and the range of integration. Also, $\partial c^* / \partial D > 0$ since H^{-1} is an increasing function.

Finally $\partial D/\partial p$ is clearly decreasing. Thus

$$\left.\frac{\partial \pi_D}{\partial p}\right|_{p_I^*} > 0,$$

and hence the VDP profit maximizing price $p_D^* > p_I^*$. As a result total demand at p_D^* will be lower than at p_I^* and hence user welfare will also be lower at that point. □

Proof. Proposition 5: For $C(D) > 0$, we have that

$$\pi_I = \pi_D + \pi_W - C_I(D).$$

At the VIP profit maximizing price p_I^* we have that

$$\left.\frac{\partial \pi_D}{\partial p}\right|_{p_I^*} = -\left.\frac{\partial \pi_W}{\partial p}\right|_{p_I^*} + \left.\frac{\partial C_I}{\partial p}\right|_{p_I^*},$$

In the proof of Proposition 4 we showed that

$$\left.\frac{\partial \pi_W}{\partial p}\right|_{p_I^*} < 0.$$

By assumption we have that $\partial C_I/\partial D > 0$ and hence

$$\left.\frac{\partial C_I}{\partial p}\right|_{p_I^*} = \left.\frac{\partial C_I}{\partial D}\frac{\partial D}{\partial p}\right|_{p_I^*} < 0.$$

Thus for sufficiently large $\partial C_I/\partial D$, we have

$$\left.\frac{\partial \pi_D}{\partial p}\right|_{p_I^*} < 0,$$

If that is the case the VDP profit maximizing price $p_D^* < p_I^*$. As a result total demand at p_D^* will be higher than at p_I^* and hence user welfare will also be higher at that point. □

References

ALEKSI GRYM, PAIVI HEIKKINEN, K. K. K. T. (2017): "Central bank digital currency," Tech. rep., Bank of Finland Economics Review.

ARMSTRONG, M. (2006): "Competition in two-sided markets," *The RAND Journal of Economics*, 37, 668–691.

BANK OF CANADA (2019): "Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies," .

BECH, M. L. AND R. GARRATT (2017): "Central bank cryptocurrencies," *BIS Quarterly Review September*.

BENSON, C. C., S. LOFTESNESS, AND R. JONES (2017): *Payments Systems in the U.S. - Third Edition: A Guide for the Payments Professional*, Glenbrook Partners.

BOLTON, P., M. DEWATRIPONT, ET AL. (2005): *Contract theory*, MIT press.

BORDO, M. D. AND A. T. LEVIN (2017): "Central bank digital currency and the future of monetary policy," Tech. rep., National Bureau of Economic Research.

BOUDREAU, K. J. AND A. HAGIU (2009): "Platform rules: Multi-sided platforms as regulators," *Platforms, markets and innovation*, 1, 163–191.

BRADFORD, T. AND F. HAYASHI (2008): "Developments in interchange fees in the United States and abroad," *Payments System Research Briefing*.

CAILLAUD, B. AND B. JULLIEN (2003): "Chicken & egg: Competition among intermediation service providers," *RAND journal of Economics*, 309–328.

CATALINI, C. AND J. S. GANS (2016): "Some simple economics of the blockchain," Tech. rep., National Bureau of Economic Research.

CATALINI, C. AND C. E. TUCKER (2018): "Antitrust and Costless Verification: An Optimistic and a Pessimistic View of the Implications of Blockchain Technology," .

CONG, L. W. AND Z. HE (2019): "Blockchain disruption and smart contracts," *The Review of Financial Studies*, 32, 1754–1797.

ENGERT, W., B. S. FUNG, ET AL. (2017): *Central bank digital currency: Motivations and implications*, Bank of Canada.

EUROPEAN CENTRAL BANK (2017): "Payment systems: liquidity saving mechanisms in a distributed ledger environment," .

——— (2018): "TARGET Annual Report 2018," .

EVANS, D. AND R. SCHMALENSEE (2014): "The Antitrust Analysis of Multisided Platform Businesses," *The Oxford Handbook of International Antitrust Economics*, 1, 404.

GANS, J. S. AND H. HALABURDA (2015): "Some economics of private digital currency," in *Economic Analysis of the Digital Economy*, University of Chicago Press, 257–276.

GANS, J. S. AND S. P. KING (2003): "The neutrality of interchange fees in payment systems," *Topics in Economic Analysis & Policy*, 3.

HAGIU, A. AND J. WRIGHT (2014): "Marketplace or reseller?" *Management Science*, 61, 184–203.

——— (2015): "Multi-sided platforms," *International Journal of Industrial Organization*, 43, 162–174.

HALABURDA, H., G. HAERINGER, J. S. GANS, AND N. GANDAL (2020): "The Microeconomics of Cryptocurrencies," Tech. rep., National Bureau of Economic Research.

HOVENKAMP, H. (2019): "Platforms and the Rule of Reason: The American Express Case," *Columbia Business Law Review, Forthcoming*, 19–10.

HUBERMAN, G., J. D. LESHNO, AND C. MOALLEMI (2019): "An Economist's Perspective on the Bitcoin Payment System," in *AEA Papers and Proceedings*, vol. 109, 93–96.

HUBERMAN, G., J. D. LESHNO, AND C. C. MOALLEMI (2017): "Monopoly without a monopolist: An economic analysis of the bitcoin payment system," .

LEE, R. S. (2013): "Vertical integration and exclusivity in platform and two-sided markets," *American Economic Review*, 103, 2960–3000.

LI, B. G., J. MCANDREWS, AND Z. WANG (2019): "Two-sided market, R&D, and payments system evolution," *Journal of Monetary Economics*.

MANCINI GRIFFOLI, T., M. S. MARTINEZ PERIA, I. AGUR, A. ARI, J. KIFF, A. POPESCU, AND C. ROCHON (2018): "Casting Light on Central Bank Digital Currencies," Tech. rep., International Monetary Fund.

MILLS, D. C., K. WANG, B. MALONE, A. RAVI, J. C. MARQUARDT, C. CHEN, A. BADEV, T. BREZINSKI, L. FAHY, K. LIAO, ET AL. (2016): "Distributed Ledger Technology in Payments, Clearing, and Settlement," Tech. rep., Board of Governors of the Federal Reserve System (US).

NARAYANAN, A., J. BONNEAU, E. FELTEN, A. MILLER, AND S. GOLDFEDER (2016): *Bitcoin and cryptocurrency technologies: a comprehensive introduction*, Princeton University Press.

OECD (2018): "Rethinking Antitrust Tools for Multi-Sided Platforms," .

PARKER, G. G. AND M. W. VAN ALSTYNE (2005): "Two-sided network effects: A theory of information product design," *Management science*, 51, 1494–1504.

ROCHET, J.-C. AND J. TIROLE (2003): "Platform Competition in Two-Sided Markets," *Journal of the European Economic Association*, 1, 990–1029.

——— (2006): "Two-sided markets: a progress report," *The RAND Journal of Economics*, 37, 645–667.

——— (2011): "Must-take cards: Merchant discounts and avoided costs," *Journal of the European Economic Association*, 9, 462–495.

RYSMAN, M. (2009): "The economics of two-sided markets," *Journal of economic perspectives*, 23, 125–43.

TIROLE, J. (1988): *The theory of industrial organization.*

——— (2015): "Market failures and public policy," *American Economic Review*, 105, 1665–82.

WEYL, E. G. (2010): "A Price Theory of Multi-Sided Platforms," *American Economic Review*, 100, 1642–1672.

WRIGHT, J. (2004): "One-sided logic in two-sided markets," *Review of Network Economics*, 3.

——— (2012): "Why payment card fees are biased against retailers," *The RAND Journal of Economics*, 43, 761–780.