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In the modern environment characterized by the competition not only among individual companies but among business networks as well, inter-organizational information systems (IOSs) play an important role as building blocks of the network information infrastructure. Despite many technological advancements of last decades many enterprises still face difficulties with IOS adoption. The need for co-opetition, simultaneous competition and cooperation, among community members and uneven distribution of benefits among them have been often named as barriers for IOS adoption. In this paper we develop an analytical model of fair sharing for IOS users based on Shapley value principle to address these issues. The use of Shapley value ensures that rational interests of individual members get aligned with the interests of the community as a whole. We demonstrate that such a fair sharing scheme can create additional incentives for co-opetition between competitors by estimating the value gain for a data provider that comes from participation of another data provider. The size of positive externalities between providers depends on the network structure which in its turn determines the importance of coordination between competitors for IOS adoption. In the high density networks the benefits from coordination are higher than in the low density networks.

Key words: inter-organizational information system, IOS, technology adoption, fair sharing, Shapley value, network structure

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1. Introduction

Inter-organizational communication means have gained in importance in the modern business environment which is characterized by the competition not only among individual companies but among large business networks as well (Riggins et al. 1994, Markus and Loebbecke 2013). Inter-organizational information systems (IOS) provide a way for a fast and high quality information exchange which is superior in many aspects to other communication technologies like e-mail, telephone or fax (Bakos 1991, Premkumar et al. 1994). Consequently, we can observe a lot of business network-wide initiatives to introduce IOS as the standard for communication between organizations in the context of extended supply chains (Steinfield et al. 2011), industries (King and Konsynski 1995, Markus et al. 2006, Damsgaard and Lyytinen 2001), or clusters of economic activity (Rodon and Ramis-Pujol 2006, Van Baalen et al. 2009). Such initiatives are usually aimed at reducing the costs of communication and improving the quality of information exchange network-wide (Damsgaard and Lyytinen 2001, Markus et al. 2006, Markus and Loebbecke 2013) and through this boosting the competitiveness of adopting community vis-à-vis other business networks (Riggins et al. 1994, Ba et al. 2001).

However, there have been many reports on the difficulties such projects face at different stages, from the IOS development to its adoption and use (Damsgaard and Lyytinen 2001, Beck and Weitzel 2005, Markus et al. 2006). Inter-organizational knowledge sharing in the business community context entails co-opetition when companies need to simultaneously compete and cooperate (Levy et al. 2003). The fine balance between the benefits that information receiver can gain from independent use of shared information use and the synergetic value that is created influences the firm's decision to cooperate or not (Levy et al. 2003). Benefits heterogeneity and uneven distribution of benefits inside an adopting community have been often named among culprits that stand in the way of a successful network-wide IOS introduction (Fulk et al. 1996, Steinfield et al. 2011, Van Baalen et al. 2009). Collective action is required in order to produce an IOS (Kumar and Van Dissel 1996, Monge et al. 1998, Markus et al. 2006) but when not all actors receive enough benefits from using the system, additional instruments are called for to ensure their participation (Fulk et al. 1996, Monge et al. 1998). Large companies can use subsidizing or penalizing strategies to persuade their partners to adopt an IOS (Riggins et al. 1994, Barua and Lee 1997, Beck and Weitzel 2005). But such incentivising instruments are difficult to scale when the targeted adopting community is quite broad like in the case of extended supply chains, industries, or clusters and different kind of organizational incentives might be called for (Ba et al. 2001). Moreover, IOS benefits might be distributed unevenly among different business network roles due to the nature of the technology. For instance, it has been often argued that in many e-markets buyers benefited from the use of the system to a larger extent than suppliers (Wise and Morrison 2000, Wang and Benaroch 2004). In view of these issues many researchers have called for the design of an efficient mechanism that would distribute the surplus generated by an IOS with the use of game theoretical modelling (Clemons and Kleindorfer 1992, Riggins et al. 1994, Ba et al. 2001). Wang and Benaroch (2004) demonstrate that if the buyer could share a certain part of his or her profit with the supplier, the e-market will not break down. Other researchers have suggested that the use of fair sharing models can improve IOS adoption rates (Steinfield et al. 2011) because it will make sure that the benefits from IOS use are distributed in a more even fashion. However, in practice there have not been a lot of reported cases in which such advanced surplus sharing models have actually been implemented. Steinfield, Markus, and Wigand (2011) mention that in their study fair sharing approach has been successful but they do not provide any specifics on the scheme that was used. To the best of our knowledge, there have not been any analytical studies that investigate the application of fair sharing schemes to the case of IOSs. In this paper we intend to fill this gap through the application of game theoretical principles, specifically Shapley value allocation mechanism.

Over the years, a lot of different factors have been found that affect organization's decision to adopt an IOS: external environment, organizational readiness, perceived benefits, transaction characteristics etc (Robey et al. 2008). Initially, economic models mainly focused on EDI networks that supported buying-selling transactions. Such systems were typically initiated by the strong buyer who on occasion had to exert certain influence on its suppliers to make them adopt the system. Riggins et al. (1994) demonstrated that the buyer may experience initial supplier adoption of the network followed by a "stalling" problem due to negative externalities. The researchers showed that the buyer may find it optimal to subsidize some suppliers' costs to join the network in the second stage. Barua and Lee (1997) compared subsidizing and penalizing strategies in the form of buying more or less products for fostering IOS adoption in a vertical market involving one manufacturer and two suppliers. They showed that, regardless of the cost structure, IOS adoption can become an unfortunate strategic necessity for a smaller supplier. Nault (1997) investigated the possibility of subsidy provided by the IOS supplier to the IOS adopter in the contexts of monopoly and duopoly. He showed that the possibility of such a subsidy increases when the added value after the adoption is indispensable and when IOS adopters do not decrease their transactions volume in comparison with before IOS state.

Empirical studies of IOS adoption added other dimensions which are difficult to investigate with the help of economic modeling. Chwelos et al. (2001) showed that organizational readiness, perceived benefits, and external pressure were determinants of EDI adoption, with external pressure and readiness being more important factors in comparison with benefits. Teo et al. (2003) showed that institutional environment in the form of normative, mimetic and coercive pressures also influences the organization's intention to adopt EDI. The potential for strategic information exploitation by the IOS provider can serve as a barrier for IOS adoption. In such a case, multiparty ownership can be a way of mitigating this risk (Han et al. 2004). Nicolaou and McKnight (2006) demonstrated the role of perceived information quality in the decision to use an IOS. Zhu et al. (2006) investigated the influence of network effect and adoption costs on the organization's decision to switch from a proprietary EDI-based IOS to an open standard Internet-based IOS. They found that EDI users are much more sensitive to the costs of switching to the new standard. Venkatesh and Bala (2012) demonstrated that expected benefits and relational trust had significant effect on the adoption of inter-organizational business process standards which is a precondition for successfully functioning IOS. Furthermore, the authors showed that factors pertaining not only to the focal firm but also to its trading partners play a role, namely partner's process compatibility, standards uncertainty, and technology readiness.

A separate stream of research has been dedicated to the issue of IOS adoption by small and medium companies (Iacovou et al. 1995, Chen and Williams 1998, Chau and Hui 2001, Beck and Weitzel 2005). It is easier for large companies to benefit from the IOS implementation due to the large number of messages that can be exchanged electronically (Mukhopadhyay et al. 1995, Beck and Weitzel 2005). The low volume of potentially electronically exchangeable orders and invoices makes it much more difficult to cover the fixed costs of IOS implementation for small and medium companies (Iacovou et al. 1995, Beck and Weitzel 2005). In order to overcome these barriers, Iacovou et al. (1995) advise to EDI initiators "to pursue promotional efforts to improve partners' perceptions of EDI benefits, provide financial and technological assistance to partners with low organizational readiness" (Iacovou et al. 1995, p. 465). Beck and Weitzel (2005), on the other hand, argue that EDI and WebEDI solutions are economically dominated by the use of faxes for inter-organizational communication for small and medium firms because of the differences between their organizational processes and those of large firms which usually develop solutions and standards. Small companies rarely use advanced internal information systems, which is one of the preconditions for realizing full EDI benefits. The authors suggest an alternative to traditional EDI solution, which is more attractive for small firms due to the lower size of the initial investment required (Beck and Weitzel 2005).

The majority of empirical IOS adoption studies had a firm or a dyad as a unit of their analysis. The environment was analyzed as perceived by focal companies. Some of the economic studies considered two-tier networks with buyers as their central nodes and multiple suppliers in a second tier (Riggins et al. 1994, Barua and Lee 1997). However, nowadays many IOS initiatives have a much wider targeted adopting community. Steinfield et al. (2011) describe the AIAG effort to develop data standards and technical architecture, which would enable coordination in the extended supply chains. This project was targeting multiple automotive manufacturers and their multiple suppliers. Rodon and Ramis-Pujol (2006) report on the development of a port community system in a Spanish port, which was targeting the whole port cluster, encompassing such diverse port business network roles as freight forwarders, customs, inland terminals, haulage contractors, banks and others. In order to be successful, such network-wide IOS initiatives have to be able to accommodate the interests of companies that are performing different business roles and have different sizes. The use of penalizing and subsidizing strategies suggested by earlier researchers was a good fit for the earlier IOS which were centred around a single buyer. These instruments are difficult to scale to the wider network with a larger number of companies without a single powerful dominating firm. Following the suggestions of earlier researchers (Clemons and Kleindorfer 1992, Riggins et al. 1994, Ba et al. 2001), we decided to investigate the field of cooperative game theory to look for instruments that would facilitate the development of easy to scale incentive mechanisms. We focus our analysis on the Shapley value principle in this paper because of a number of unique properties that it possesses which are discussed later in detail. The most important of these properties is that Shapley value aligns the interests of individual companies in getting positive participation return with the interests of the community as a whole to maximize the benefit to the network from IOS introduction.

We construct a Shapley value based fair sharing scheme for the distribution of IOS benefits for the case of information links. Bakos (1991) distinguished between two IOS types in the vertical markets: information links and electronic markets. The main difference between these IOS types is that information links support already existing business relationships while electronic markets help with establishing new ones. Hence, the benefits that the users can realize from implementation of these IOS types differ significantly. The goal of the fair sharing scheme is to ensure that not only IOS initiators benefit from IOS but that the gains of the adopting community as a whole are maximized. Information links are based on inter-organizational business processes, which are usually developed within consortia such as RosettaNet standards in the semiconductor and electronic components industry, or MISMO standards in the US mortgage industry (Markus et al. 2006, Bala and Venkatesh 2007). Such IOSs are implemented in order to automate, integrate, and facilitate value chain activities such as supply chain management, scheduling, collaborative forecasting, and inventory management (Bala and Venkatesh 2007). We distinguish among two roles that users take in such systems: data providers and consumers of an IT service. Consumers get benefits from using an IOS in terms of efficiency gains in their processes while data providers have to be reimbursed for their participation. We acknowledge that in most cases, the information exchange goes both ways and companies play both roles in one IOS. Our model can be extended to incorporate this property. It has been often noted that benefits from IOS adoption depend on the position in the business network that the firm occupies (Van Baalen et al. 2009, Rodón and Sesé 2010, Steinfield et al. 2011). Rodón and Sesé (2010) describe that in the case of PortIC IOS in the port of Barcelona freight forwarders who only used the IOS to submit B2B messages gained less than shipping agents who used B2B to receive messages. Distinguishing between consumers and data providers allows us to account for uneven distribution of costs and benefits among different business network roles participating in an IOS.

We show that if the IOS consumption has a strong network effect, which is true for the majority of the IOS, the Shapley value based fair reward creates positive externalities not only between data consumers and data providers groups but also within the data providers group. The reward for one data provider grows in size if the other provider is joining the system. Thus, the Shapley value based reward can serve as an additional incentivising instrument in the co-opetition environment. The size of these positive externalities depends on the network density. In the low density networks the positive externalities between providers disappear which lowers the importance of coordination between data providers in such networks. Over the years, there have been many initiatives to make the use of specific IOS or data exchange schemes a standard for certain industries (King and

Konsynski 1995, Damsgaard and Lyytinen 2001, Markus et al. 2006, Rodon and Ramis-Pujol 2006). However, the spread of the same technology goes differently in different industries (Damsgaard and Lyytinen 2001). Our analysis of the connection between the network structure and IOS adoption sheds light on one of the possible reasons. It is easier for companies in business networks with low density to achieve the full benefits from IOS use. They do not require coordination in order to do this. The business networks with high density, on the other hand, will benefit from the coordination which usually requires additional efforts from the community members. Thus, in certain industries the adoption process might go much smoother because the communication network structure makes it easier to reach the full benefits of the new technology without coordination with the competitors present in the network. In addition, we demonstrate that under Shapley value based fair sharing conditions the reward of a data provider is dependent on his or her transactions volume. Therefore, even under fair conditions, the participation of small actors might not be valuable enough to reimburse their participation costs. Thus, 100% adoption which is often the goal of the network-wide initiatives can be actually suboptimal not only from the viewpoint of individual companies but from the community perspective as well.

The rest of our paper is organized as follows. In the next section, we introduce our model and main assumptions behind it. In section three, we analyse factors that influence the size of the reward to a data provider under Shapley value based fair sharing conditions. In section four, we consider the interdependence between the network structure, coordination, and adoption. We conclude our paper with the discussion of the main insights of our paper and their relevance for both theory and practice, and we suggest a number of future research avenues and possible model extensions.

2. Model

An inter-organizational information system as a product of digital technology has a layered architecture that consists of four layers: contents (i.e. data), service (i.e. software), network, and device (Yoo et al. 2010). In the case of IOS, usually different companies provide these four layers. Often, one company develops software and IOS-specific infrastructure like in the cases of ePortSys (Rodon and Ramis-Pujol 2006) or MOSS project (Steinfield et al. 2011), while the business network members (i.e. IOS users) are providing data to the system and pay for devices required to connect to the system and use it. IOS consumers are usually companies from the same business network. They use IOS services for multiple reasons: to reduce transaction costs, improve information quality and customer service, etc. (Iacovou et al. 1995). The success of an IOS is very dependent on the adoption of the system by both data providers and service consumers. In many cases, the companies that provide data to an IOS are simultaneously the consumers of the very same system. For instance, in the MOSS project that developed a shared standards based collaboration hub to improve communication efficiency in the automotive supply chains, the automotive manufacturer was supposed to share data with the system in the form of order requests and receive data from the system in the form of order acceptances from suppliers (Steinfield et al. 2011). This made automotive manufacturer simultaneously data provider and service consumer for the same IOS.

In order to construct the fair sharing model for an inter-organizational information service we utilize concepts from cooperative game theory which have been successfully applied for this purpose in logistics and supply chain management (Bartholdi III and Kemahlioğlu-Ziya 2005, Krajewska et al. 2008, Leng and Parlar 2009). The cooperative branch of game theory is concerned primarily with coalitions — groups of players — who coordinate their actions and pool their winnings (Branzei et al. 2008). One of the most prominent problems that is being studied in cooperative game theory is how to divide the extra earnings (or cost savings) among the members of the formed coalition. In the case of IOS, we suggest to treat the decision of providers to participate in the information service as a decision to join the coalition of providers. The use of information service creates savings for the consumers. We assume that consumers are willing to sacrifice part of obtained savings in the form of fees for using the system. The pool of these fees which consumers are willing to pay can be treated as the value that can be realized by a providers' coalition and should be shared fairly among them.

2.1. IOS value and costs

A cooperative game consists of a set of players (in our case providers) $\mathbf{P}$ and a characteristic function $\nu(\mathbf{K})$ that specifies the maximum value that can be realized by a coalition $\mathbf{K} \subseteq \mathbf{P}$. For each set of players it should be possible to estimate the best-case scenario of costs reduction i.e. maximum value of the coalition. The characteristic function in the case of IOS reflects how the total willingness-to-pay of IOS users is changing depending on the participation of different data providers. We exclude from our coalition analysis the company that develops software for IOS and supports infrastructure and treat those as development costs. The reason for this is that in the reported cases, the difficulties with IOS adoption tend to be at the users' side (i.e. data providers). We are not aware of cases when it was difficult to find a company to write the software or to run the infrastructure once the financing was available. Meanwhile, securing the participation of the business network members and the use of IOS by them can be a big challenge.

The maximum potential coalition profit can be found as the difference between the willingness to pay of consumers for using the service and the costs of providing the service. In reality, it can be difficult to extract the actual willingness to pay of consumers in the form of fees, because it is in their interest not to reveal it (Lahiri et al. 2013). However, in this paper our focus is on the fair sharing mechanism and its influence on the adoption decisions. Therefore, we believe that it is acceptable to assume that each IOS consumer will be paying the maximum as specified by their willingness to pay for the service, which provides an upper bound of the potential coalition profit. In future, the model can be extended by relaxing this assumption.

In order to describe how the willingness to pay of the consumers depends on the participation of different providers, we make a number of additional assumptions. First, we assume that the willingness to pay of a consumer C_j ($C_j \in \mathbf{C}$, $\mathbf{C}$ — set of all consumers) is proportional to projected savings from using the service and can be expressed as $w_j(s_j) = \alpha \cdot s_j$ where α ($\alpha \in (0, 1)$) is the parameter describing which share of projected savings a consumer is willing to pay in the form of fees. We assume that parameter α is the same for all consumers. Second, we focus in our analysis on inter-organizational information services which facilitate information exchange along the value chain among the companies with already established business relationships. The savings of consumers from using such IOSs are proportional to the number of messages that they receive through the system or to consumer's transactional volume. The messages that are being exchanged through the information links IOSs are orders, invoices, arrival notifications etc (Bakos 1991). The number of these messages are usually proportional to the transactional volume of the company. This assumption is consistent with the work of Barua and Lee (1997). Let us denote n_{ij} as the number of messages received by data consumer C_j from data provider P_i. Then the dependency of the savings of the data consumer j on the data providers' participation (structure of the providers' coalition $\mathbf{K}$) can be expressed as $s_j(\mathbf{K}) = \bar{s} \cdot \sum_{i\in\mathbf{K}} n_{ij}$ where $\bar{s}$ represents the average savings per message which can be an order, an invoice, a pre-arrival notification or anything else.

Furthermore, we analyse cases in which network effect influences the size of the per message benefit as well, namely the average size of savings per message is growing with the increase in the number of data providers. IOS traditionally have been studied as network goods because the value of the system for data consumers grows with the number of data providers in the system (Bakos 1991, Clemons and Kleindorfer 1992). Our previous assumption that benefits are proportional to the number of messages exchanged via the system incorporates this fact. The more of the company's partners are using the system, the more messages are going through it. However, the average benefit per message can also grow with the data providers' adoption rate. If all companies' partners adopt IOS it means that it does not have to support alternative means of communication any longer. While the adoption of IOS is anything less than 100% from the side of the data consumer's business partners the data consumer will have to support alternative business practices like receiving e-mails with this information and manually inputting it into the system. It means that for each data consumer C_j the size of savings per message depends on the share of providers that adopted the system out of all data providers that the data consumer is dealing with what we denote by $\bar{s}_j(\mathbf{K}) = f_j\left(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\right)$. Finally, we assume that function $f(\cdot)$ has the same shape for all data consumers: $f(\cdot)$ is monotonically non-decreasing and reaches its maximum with full adoption $\bar{s}_{max} = f(1)$.

We assume that the costs of developing the software and information infrastructure are born by the coalition of data providers. The development costs of providers (DC^P) are independent of the number of providers participating in the coalition. In addition to this, there are fixed costs (FC^P) of providing access to the system for each data provider and the costs of running information infrastructure (VC^P), which are proportional to the number of messages going through the system. Fixed or setup costs are born by each company individually. They include new hardware and software acquisition or development by companies themselves needed for accessing the IOS or integrating it with the internal system, changes in internal business processes in order to interface with the system and provide the required data elements etc (Barua and Lee 1997, Lee et al. 1999). Variable costs incorporate the infrastructure running costs that are proportional to the number of messages, the costs of generating and inputting data per message etc. Variable costs or costs per message for IOS are usually very low in comparison with fixed costs like for all products of digital technology (Bakos 1991). The costs of developing the standard for messages and exchange structure and the costs of developing the software supporting the exchange are independent of the number of companies providing data to the system and they form the last group — development costs. IOS consumers also have to bear fixed costs (FC^C) and variable costs (VC^C) to be able to use the system. In their structure consumer fixed costs are very similar to the costs of data providers as similar infrastructure is required to receive messages through IOS. The consumer variable costs are fees that the consumers are willing to pay to data providers in order to use an IOS.

Under these assumptions, the characteristic function of our cooperative game for a given set of prospective consumers $\mathbf{C}$ can be formulated as follows:

$$v(\mathbf{K}) = \sum_{j\in\mathbf{C}} w_j - DC^P - FC^P \cdot |\mathbf{K}| - VC^P \cdot \sum_{j\in\mathbf{C}} \sum_{i\in\mathbf{K}} n_{ij} \tag{1}$$

where w_j — willingness to pay for the service of consumer j.

$$w_j = \alpha \cdot f\left(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\right) \cdot \sum_{i\in\mathbf{K}} n_{ij} \tag{2}$$

IOS can also suffer from the negative externalities, for instance the use of the system by competitors can negatively affect the benefits for a consumer if the latter wanted to gain the competitive advantage via IOS adoption (Bakos 1991, Clemons and Kleindorfer 1992). However, we limit our current analysis to positive externalities only. In future the model can be extended to incorporate negative externalities by redefining the willingness to pay function and introducing a term to penalize the participation of competitors in the system.

2.2. Individual provider and consumer participation profits

Using game theoretical principles, we can estimate the fair reward to each data provider based on the defined characteristic function. In game theory, an allocation φ is a vector in which φ_i is the payoff to player P_i. Over time, a number of fair allocation principles have been developed such as core (Gillies 1959), nucleolus (Schmeidler 1969), Shapley value (Shapley 1953), which possess different desirable properties. We decided to use the Shapley value allocation principle in our case because it uniquely satisfies the combination of the following important conditions: additivity, anonymity, efficiency, and dummy player property (Shapley 1953). Efficiency property means that the total gain is being distributed among the contributors. Anonymity property requires that players with identical contributions get identical rewards. The dummy player property means that the player with a zero contribution to the coalition does not get any reward. Finally, the additivity property ensures that if the game can be represented as a sum of two games then the Shapley value for a player in this game can be represented as a sum of two Shapley values in the smaller games. These properties are meaningful and practical in terms of our problem. Efficiency ensures that all the revenue collected by the providers is being redistributed among them. Anonymity and dummy player properties correspond to generally accepted notions of "fairness". The additivity property ensures that Shapley value allocations are not dependent on the time of bargaining between the players. We assume that all parties know how the Shapley value allocation principle works and find this division of the revenue as mutually acceptable and it is reached without any additional bargaining costs. Moreover, the use of Shapley value as an allocation principle allows maximizing the overall profit for the community as will become clear from our further discussion.

A player's Shapley value can be found as expressed in formula (3) and it can be interpreted as expected incremental contribution to the value of the coalition. There are $n!$ joining sequences through which a coalition of n players can be formed. The incremental value of a player to a coalition may be dependent on when the player joins the coalition. Accordingly, the expected incremental contribution made by a player is determined by combining the incremental contribution made by a player for a given joining sequence and the probability $p(\mathbf{K} \cup \{P_i\})$ of that sequence occurring. As the Shapley value reflects the added value of the player to the grand coalition, by including only the players with positive Shapley values into the coalition we can ensure that the total profit for the community is maximized because the inclusion of any player with negative Shapley value effectively reduces the expected profit of the coalition. Consequently, by rewarding each data provider with corresponding Shapley value, we align the individual interests of providers of getting a positive reward for the participation with the interests of the community in maximizing the total profit for the business network. It is important to acknowledge, however, that the Shapley value distribution principle is not aligned with the individual interests of maximizing the participation reward because certain providers could be better off under other distribution schemes which account for their power position in the network, for instance, as described by Clemons and Kleindorfer (Clemons and Kleindorfer 1992). The Shapley value can be written as:

$$\varphi_i(v) = \sum_{\mathbf{K} \subseteq \mathbf{P} \setminus \{P_i\}} p(\mathbf{K} \cup \{P_i\}) \cdot \Big(v(\mathbf{K} \cup \{P_i\}) - v(\mathbf{K}) \Big) \tag{3}$$

We should note that the development costs of producing the IOS are independent from the number of data providers contributing to the system. Therefore, the development costs will not be distributed automatically by the Shapley value principle. In order to incorporate these costs as well, we have to adjust the reward received by data provider P_i in the following way:

$$r_i = \varphi_i(v) - \frac{\varphi_i(v)}{v(\mathbf{P}) + DC^P} \cdot DC^P = \varphi_i(v) \cdot \frac{v(\mathbf{P})}{v(\mathbf{P}) + DC^P} \tag{4}$$

We consider the situations where the profit realized by the grand coalition of data providers is positive, i.e. $v(\mathbf{P}) > 0$, which means that the providers' reward will be positive as long as the

Shapley value is positive. By distributing the development costs in such a way, we are making sure that necessary condition for individual participation (i.e. positive rewards) is aligned with the communal incentive of maximizing the network-wide profit.

We assume that consumers and providers are rational and they adopt the service and participate in the service provision if they get positive profit from this. The profits of providers are equal to rewards allocated to them according to the Shapley value principle (vector r, see formula (4)). The provider P_i will join the coalition of service providers or "adopt" the service if $r_i > 0$ which is equivalent to $\varphi_i > 0$ (see formula (4)). The Shapley value of the provider reflects the value of provider's participation for the user community. Thus, it can be the case that the increase in the revenue that the provider brings to the system is not high enough to justify the costs of joining the system. In the third section we analyze in detail what the size of the Shapley value that the provider is entitled to depends on.

The revenues of consumers are equal to savings that they obtain from using the service (vector s). We assume that consumers also have to incur fixed costs (FC^C) and variable costs (VC^C) if they want to use the information service. Like data providers they have to buy new hardware and software for accessing the IOS or integrating it with the internal system, they also have to change their internal business processes in order to interface with the system and make use of provided data elements etc (Barua and Lee 1997, Lee et al. 1999). The variable costs of consumers are their fees towards the system or their willingness to pay level as specified in formula (2).

The total costs of using the service for consumer C_j can be expressed as the sum of fixed and variable costs. The consumer C_j will adopt the service if savings from using the service are greater than adoption costs: $s_j > FC^C + \alpha \cdot f\left(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\right) \cdot \sum_{i\in\mathbf{K}} n_{ij}$ or, taking into account the earlier formulation of dependence of savings on the number of messages, $(1-\alpha) \cdot f\left(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\right) \cdot \sum_{i\in\mathbf{K}} n_{ij} > FC^C$. The left side of the inequality grows with the number of messages that consumer receives through the system. Thus, the higher the business volume of the consumer, the higher the probability that the consumer will adopt the service. This is consistent with the common observation in the IOS literature that smaller companies are often struggling with IOS adoption because of the high initial investment costs required which are not always offset by the savings realized from using the service (Beck and Weitzel 2005). We assume that parameter α is independent of the size of savings received, i.e. the consumer is willing to sacrifice a fixed share of the savings. In reality it is fair to expect that α is actually changing depending on the size of savings realized by the user. We believe that it can be a fruitful future extension of the model but in the current analysis we stick to the assumption of a fixed α in order not to "overload" the initial model.

2.3. Adoption dynamics

We assume that the system adoption dynamics is happening in the following way. Each provider estimates the participation profit for different combinations of adopting consumers. Each consumer is doing the same for different combination of providers. Each side has complete information regarding the preferences of the other side and providers make the decision to provide the service or not before the consumers decide whether they adopt the service. If we assume that initially each data provider makes the decision to join the service or not independently of other data providers then the service will be created only if at least for one provider P_i there is at least one combination of consumers $\mathbf{L}_i$ ($\mathbf{L}_i \subseteq \mathbf{C}$) which makes it profitable for the provider to participate ($\varphi_i > 0$) and such that for each consumer in this combination it is profitable to adopt the service even if the consumers gets data from this single provider P_i only (for $\forall C_j \in \mathbf{L}_i : \ (1-\alpha) \cdot f\big(\frac{n_{ij}}{\sum_{i \in P} n_{ij}}\big) \cdot n_{ij} > FC^C$). This provider-consumers combination ($\mathbf{A} = \{P_i\} \times \mathbf{L}_i$) will form the adopting community. If there is more than one provider satisfying this condition then the adopting community will be the union of such provider-consumers combinations.

If we assume that data providers can coordinate their decisions to provide the service or not (i.e. provider can have 100% confidence that another provider will provide the service if they agree upon it) then the service will be created if at least for one combination of providers $\mathbf{K}$ ($\mathbf{K} \subseteq \mathbf{P}$) there is at least one combination of consumers $\mathbf{L}_K$ ($\mathbf{L}_K \subseteq \mathbf{C}$) which makes it profitable for all providers in $\mathbf{K}$ to participate (for $\forall P_i \in \mathbf{K} : \ \varphi_i > 0$) and such that for each consumer in this combination it is profitable to adopt the service even if the consumers gets data from this combination of providers only (for $\forall C_j \in \mathbf{L}_K :\ (1-\alpha)\cdot f\big(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\big)\cdot \sum_{i\in\mathbf{K}} n_{ij} > FC^C$). This providers-consumers combination ($\mathbf{A} = \mathbf{K}\times\mathbf{L}_K$) will form the adopting community. If there is more than one combination of providers satisfying this condition then the adopting community will be the union of such provider-consumers combinations.

We consider the cases only where the value of the service provided by the total community is greater than the development costs. We assume that the variable costs of the service provision are negligible (Bakos 1991). Thus, in our model the adoption of the service is mainly dependent on the relationship between the savings obtained by individual consumers and the fixed acquisition costs. The consumer C_j will never adopt the service if $\sum_{i\in\mathbf{P}} n_{ij} < \frac{FC^C}{(1-\alpha)\cdot f(1)}$. The savings are proportional to the business volume of the company, thus the higher is the number of big companies among the consumers, the higher is the adoption rate among the consumers. As for the data providers, their adoption depends on the relationship between their contribution to the system and their costs. In the next subsection, we analyze what provider characteristics influence the size of the reward and subsequently the adoption decision of the providers.

The suggested fair sharing model can be easily extended to the case when data providers to an IOS are also the consumers of its services. In our earlier example of the MOSS project an automobile manufacturer provided order requests via the system and received order confirmations from suppliers in return. This IOS service can be seen as a combination of two one-way data flows: from manufacturer to supplier and reverse. For each sub-service it is possible to conduct the estimation of consumer savings, corresponding fees, and provider rewards. Then for each player which was a consumer in one sub-service and a provider in another one the consumer savings should be combined with provider rewards and deducted by corresponding fees, fixed costs, and provider variable costs. If the resulting participation profit is positive, then it is rational for the player to adopt an IOS. In the rest of the paper we consider the case where each company performs one role only: data provider or service consumer. However, as we have just demonstrated this model can be used as a building block for a more complicated scenario when a company performs both roles.

3. Network effect, network structure, and fair reward size

We start our model analysis with considering a basic scenario when consumers' savings are dependent on the number of messages exchanged via an IOS in a linear way. Consumers' savings per message are fixed and equal to b ($f(x) = b$). We assume that all sequences of coalition formations have the same probability. Then the Shapley value of data provider P_i can be found as (see Appendix B for details):

$$\varphi_i(\upsilon) = \sum_{k=0}^{|\mathbf{P}|-1} \binom{|\mathbf{P}|-1}{k} \frac{(k)!(|\mathbf{P}|-k-1)!}{|\mathbf{P}|!} \cdot \Big((\alpha \cdot b - VC^P) \cdot \sum_{j \in \mathbf{C}} n_{ij} - FC^P \Big) \tag{5}$$

Taking into account that α, b, VC^P are all fixed parameters, the inspection of formula (5) allows us to formulate our first proposition.

Proposition 1. When consumers' savings per message are constant ($f(x) = b$), the Shapley value of a data provider P_i is dependent on the transactions volume of this provider ($\sum_{j \in \boldsymbol{C}} n_{ij}$) in a linear way.

Throughout this paper we assume that variable costs of producing the service are negligible, i.e. consumers' willingness to pay per message is higher than variable costs of producing that message ($\alpha \cdot b - VC^P > 0$). It means that when consumers' savings are linear in the number of messages exchanged through IOS the higher the total transactional volume of a provider, the higher the fair reward to a provider for the participation in the IOS. The participation of larger companies is more valuable from the business network point of view because it brings larger total consumer savings. Furthermore, in this scenario two suppliers with similar total transactional volumes receive the same reward irrespective of how their transactions are distributed among consumers within the network.

We discussed earlier that a more realistic assumption regarding consumers' per message savings, however, would be that they are also growing with the adoption rate. Thus, the second scenario we consider is the one with the network effect in the consumers' savings function ($\bar{s}_j(\mathbf{K}) = f\big(\frac{\sum_{i \in \mathbf{K}} n_{ij}}{\sum_{i \in \mathbf{P}} n_{ij}}\big)$).

Once we have adjusted the characteristic function of the game, the Shapley value for the data provider P_i can be found as (see Appendix C for details):

$$\varphi_i(v) = \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{(|\mathbf{K}|)!(|\mathbf{P}|-|\mathbf{K}|-1)!}{|\mathbf{P}|!} \cdot \left[\sum_{j\in\mathbf{C}} \left(\left[\alpha \cdot f\left(\frac{\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\right) - VC^P\right] \cdot n_{ij} + \right.\right.$$
$$\left.\left. + \left[\alpha \cdot f\left(\frac{\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\right) - \alpha \cdot f\left(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\right)\right] \cdot \sum_{p\in\mathbf{K}} n_{pj} \right) - FC^P \right] \tag{6}$$

We see that the relationship between the business volume of the provider and the Shapley value becomes more complex. Now the Shapley value is not simply proportional to the total transactional volume of a provider but depends on the distribution of this volume among different consumers and the transactional volumes of these consumers with other providers. In this scenario a provider is being rewarded for increasing the savings per message for the messages received by its customers from other providers. Thus, in the presence of the network effect in the average saving per message the provider's reward depends not only on the provider's transactional volume but also on the transactional volumes of their customers with other providers. This implies that in the same network we can have two providers with identical total transactional volumes but with different Shapley values because of the differences in their customer bases which is not the case when savings per message are constant. We refer you to Appendix C for detailed explanations of how we come to these conclusions.

Proposition 2. When consumer savings per message are growing with providers' adoption rate ($f'(x) > 0$), the total business volume of each consumer is fixed (for $\forall j : \sum_{p\in\boldsymbol{P}} n_{pj}$ — constant) and the variable costs are negligible ($\alpha \cdot f(x) > VC^P$ for $x > 0$), the Shapley value of a data provider P_i is positively related to the business volume of the data provider with each customer (n_{ij}) and depends on the network structure (i.e. the transactions volumes of provider's consumers with the other data providers).

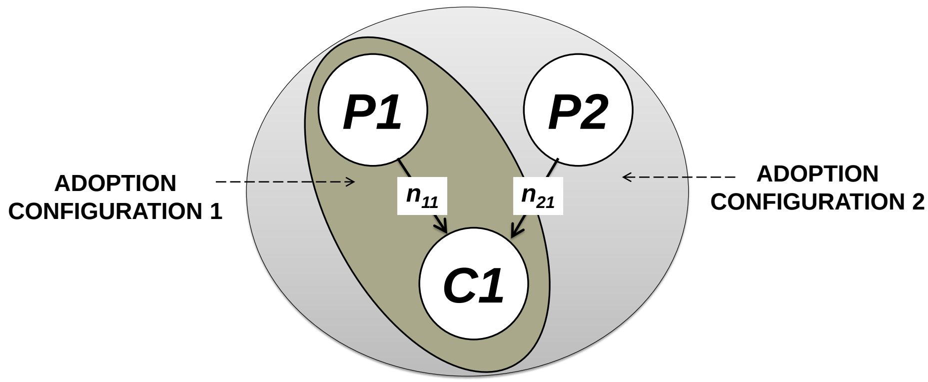
In order to understand the influence of the network structure on the reward size, let us consider an example of a small business network that consists of one consumer and two data providers. The business volume between provider P_1 and consumer C_1 requires exchange of n_{11} number of messages; the business volume between provider P_2 and consumer C_1 requires exchange of n_{21} number of messages. From the perspective of data provider P_1 we can consider two options: the provider provides the service alone or together with provider P_2 (see Figure 1). In the first case the Shapley value of provider P_1 can be found as: $\varphi_1^1 = \alpha \cdot f(\frac{n_{11}}{n_{11}+n_{21}}) \cdot n_{11} - VC^P \cdot n_{11} - FC^P$. In the second case: $\varphi_1^2 = \frac{1}{2} \cdot \alpha \cdot n_{11} \cdot \left(f(\frac{n_{11}}{n_{11}+n_{21}}) + f(1) \right) + \frac{1}{2} \cdot \alpha \cdot n_{21} \cdot \left(f(1) - f(\frac{n_{21}}{n_{11}+n_{21}}) \right) - VC^P \cdot n_{11} - FC^P$. The difference in the Shapley values for data provider P_1 between the two adoption configurations is:

$$\varphi_1^2 - \varphi_1^1 = \frac{1}{2} \cdot \alpha \Big(\big(f(1) - f(\frac{n_{11}}{n_{11}+n_{21}}) \big) \cdot n_{11} + \big(f(1) - f(\frac{n_{21}}{n_{11}+n_{21}}) \big) \cdot n_{21} \Big) \tag{7}$$

As we consider positive network effect between consumers and number of providers ($f'(x) > 0$), the Shapley value for the second adoption configuration is higher: $\varphi_1^2 - \varphi_1^1 > 0$. It means that the participation of data provider P_2 in the information system increases the Shapley value of data provider P_1 even though the number of messages provided by the data provider P_1, fixed and variable costs remain the same. This happens because without the participation of provider P_2 the consumer does not realize full potential savings per message exchanged with provider P_1. Consumer gets only $f(\frac{n_{11}}{n_{11}+n_{21}})$ in savings per message exchanged with provider P_1 if this is the only provider adopting the service. When both providers adopt the service, the consumer can get $f(1)$ of savings per message exchanged with both providers. The growth in consumer savings results in higher Shapley value realized by provider P_1 when the other provider is involved in the service provision. Thus, in our example the presence of the positive network effect between consumer gains and providers' participation brings about the positive network effect between the providers gains and other providers' participation.

We can generalize our observation to the networks of larger size by examining formula (6). We refer you to Appendix D for the detailed discussion of this matter. There are two main mechanisms through which the participation of other providers influences the Shapley value of provider P_i. First, it affects the savings per messages realized by consumers on the messages exchanged between them and provider P_i because the average savings size is dependent on the adoption rate of other

Figure 1 **Two adoption configurations**



providers. Second, the adoption of the service by other providers increases the Shapley value of provider P_i due to the influence that the participation of this provider has on the consumer savings realized for the messages exchanged between consumers and those other providers. It is important to note that this provider–provider positive network effect appears only when providers share a common consumer. The higher the number of consumers that providers have in common with each other, the stronger the influence of providers' adoption on the gains realized by other providers.

Proposition 3. When consumers' savings per message are growing with the providers' adoption rate ($f'(x) > 0$), the Shapley value of a data provider is positively related to the participation of another data provider if those providers have consumers in common.

This proposition can be easily related to the business network level characteristic of network density which can be used to describe the existence of common customers between providers. Network density is defined as a ratio of the number of links in the network to the number of possible edges (Seidman 1983). We define that a link between data provider P_i and consumer C_j exists if $n_{ij} > 0$. The maximum number of links that are possible in a network with n providers and c consumers is $n \times c$, taking into account that there can be no links between consumers, there can be no links between providers, and the edges are one-way directed (from provider to consumer). The minimum number of links that are possible is equal to c. In this case, each customer is connected to at least one provider. Thus, the network density lies in the interval $[\frac{1}{n}, 1]$. We refer to a network with the minimum number of links as a low density network (density ratio is $\frac{1}{n}$) and a network with the maximum number of links as a high density network (density ratio is 1).

The positive network effect between providers appears only if they serve the same customer. Providers do not have common consumers in a low density network. Consequently, the Shapley value received by a provider in such a network is not affected by the adoption of service by other providers. In a network with high density, each provider's Shapley value is affected by the service adoption by every other provider because they all have common consumers. In a network with density in between two extreme points, there can be both type of providers: the gains of which are affected by the adoption of the service by other providers and which are indifferent to it. The higher is the density level of the network, the higher is the number of the providers affected by the provider–provider network effect. Accordingly, even if two business networks have the same number of providers, the same number of consumers, and the same transactions volume per consumer and per provider, it does not necessarily mean that the Shapley values of providers in these networks will be the same across all adoption configurations. The network density can play a role in how the total value created by IOS is distributed among the providers depending on their network position: the number of ties that they have with consumers and the number of ties that their consumers have with other providers. Hence, proposition 3 can be reformulated for the business network level in the following way.

Proposition 4. When consumers' savings per message are growing with providers' adoption rate ($f'(x) > 0$) and the network has high density (density ratio is 1), the Shapley value of each provider is dependent on the service adoption by every other provider. When consumers' savings per message are growing with providers' adoption rate ($f'(x) > 0$) and the network has low density (density ratio is $\frac{1}{n}$), Shapley values of providers are indifferent to the service adoption by other providers. When the network has medium density ratio (density ratio lies in the interval $[\frac{1}{n}, 1]$), then there can be two types of providers: the Shapley values of which are affected and unaffected by the participation of other providers. The providers the Shapley values of which are unaffected by others can exist only if there are providers who do not have any customer in common with other providers.

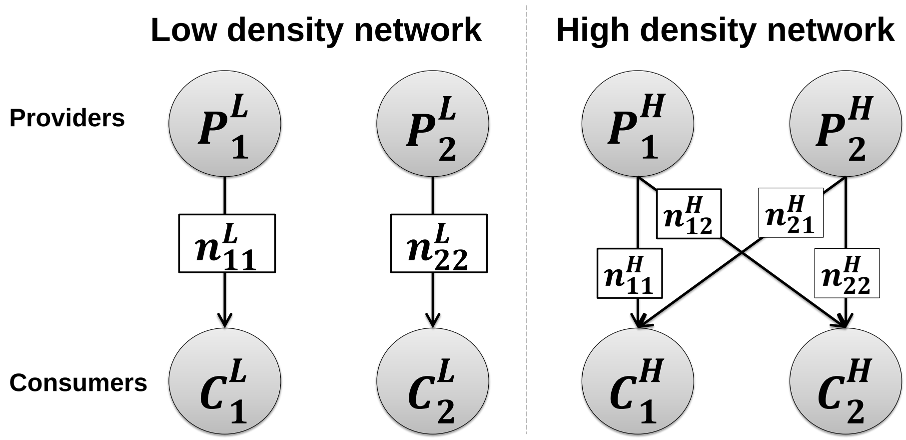
4. Network structure, coordination, and adoption

The presence of the network effect between consumers and providers brings about the positive network effect between providers and providers in terms of higher Shapley values but only for certain network structures. This difference in its turn can influence how the adoption of the same information service goes in the business networks that are the same in size and business volume but differ in their density. In this section, we analyse the implications of different network structures and coordination scenarios for an inter-organizational service adoption under fair-sharing. We distinguish between low and high density networks which differ in the number of connections among providers and consumer (see illustration for 2×2 networks depicted in Figure 2). In order to facilitate the comparison between two network structures we assume that consumers and providers in the high density network have the same business volume as consumers and providers in the low density network ($\sum_{j \in \mathbf{C}} n_{ij}^H = \sum_{j \in \mathbf{C}} n_{ij}^L$, $\sum_{i \in \mathbf{P}} n_{ij}^H = \sum_{i \in \mathbf{P}} n_{ij}^L$). Furthermore, we consider two coordination scenarios: (1) when data providers do not coordinate their decision to adopt the service and assume that they cannot count on the participation of the others and (2) when data providers make their decision to adopt the service jointly. In practice the scenario with coordination could be represented by the formation of a consortium among providers with the goal to promote the use of a certain IOS like in the case of MERS (the Mortgage Electronic Registry System) which had community members as co-owners of the system (Markus and Bui 2012). On the other hand, when an IOS is offered by an independent system provider then each data provider can be making decision to adopt the system or not separately. This is an example of uncoordinated adoption like in the case of terminal gate appointment system e-Modal which is being used in the ports of Los Angeles and Long Beach. The system is offered by an independent software provider and each terminal operator took decision to adopt the system or not independently from another (Van Baalen et al. 2009).

4.1. Uncoordinated adoption

Providers and consumers make their adoption decisions by comparing their rewards and savings to the costs respectively. The provider's reward can be calculated as in formula (4). We already

Figure 2 **Messages flows in low and high density 2×2 networks**



mentioned that usually the variable costs of the IOS provision are negligible. Therefore, we assume that they are always low enough to be covered by the per message willingness to pay of the customers. The fixed costs, however, are often an issue in IOS adoption. Therefore, we define the barrier costs as the size of the fixed costs above which the provider or the customer will not adopt the service. The barrier fixed costs for the data provider P_i under the condition that only customer C_j adopts the service are denoted as $B(P_i|C_j)$. The barrier fixed costs can be found by estimating the value that provider or consumer gets from using the system depending on the different adopter configurations.

In the case of uncoordinated adoption, we assume that providers do not know anything about the actions of the other providers. Hence, provider P_i estimates the value of the system for all possible adopter combinations which can include any number of consumers but only one provider P_i. The fair sharing reward for providers and willingness to pay of consumers both depend on the volume of the transactions that go through the system. In order to understand whether the full adoption is possible it is sufficient to investigate only the smallest provider and the smallest consumer in the network (smallest in the sense of the number of transactions going through the IOS). If the size of the barrier fixed costs is high enough for the smallest provider to adopt the system, then the other providers will adopt it as well. The same is true for the consumers' side.

To investigate how the network structure affects the chances of an IOS being adopted by the whole community, we need to investigate how it affects the barrier fixed costs of its smallest members. In case of a low density network where each provider is connected to only one consumer we have a pair provider–consumer which is the smallest in terms of the number of messages exchanged. Their barrier costs are the following: $B(P_s^L|\mathbf{C}^L) = n_{ss}^L \cdot (\alpha \cdot f(1) - VC^P)$ and $B(C_s^L|P_s^L) = (1-\alpha) \cdot f(1) \cdot n_{ss}^L$ where n_{ss}^L is the number of messages exchanged between them. In case of a high density network the barrier costs of the smallest provider can be found as $B(P_s^H|\mathbf{C}^H) = \sum_{i\in\mathbf{C}}(\alpha \cdot f(\frac{n_{si}^H}{\sum_{j\in\mathbf{P}}^H n_{ji}}) - VC^P) \cdot n_{si}^H$ and the barrier costs of the smallest consumer assuming the service adoption of its main corresponding provider as $B(C_s^H|P_d^H) = (1-\alpha) \cdot f(\frac{n_{ds}^H}{\sum_{j\in\mathbf{P}} n_{js}^H}) \cdot n_{js}^H$. It is easy to demonstrate that if the smallest consumers and the smallest providers have the same transactions volumes in high and low density networks (i.e. $n_{ss}^L = \sum_{j\in\mathbf{C}} n_{sj}^H = \sum_{i\in\mathbf{P}} n_{is}^H$) and $f'(x) > 0$) then $B(P_s^L|\mathbf{C}^L) > B(P_s^H|\mathbf{C}^H)$ and $B(C_s^L|P_s^L) > B(C_s^H|P_d^H)$ (see Appendix E for details).

The barrier fixed costs for the smallest provider and consumer are higher in the case of the low density network. This means that the low density network is more likely to adopt the expensive technology than the high density network if the actions of providers are uncoordinated because it has higher tolerance to the size of the fixed costs. The main reason for this is that for the low density network it is easier to reap the full benefits of the technology implementation because they are independent of the actions of the other providers in the network. For the same reason each actor in the low density network can tolerate much higher adoption costs than its counterpart in the high density network.

Proposition 5. When the saving per message of the consumer from using an IOS service is growing with the providers' adoption rate ($f'(x) > 0$) and data providers make the participation decision independently of each other under fair sharing scheme, the acceptable fixed costs adoption region is larger for the low density network than for the high density network.

4.2. Coordinated adoption

Providers can coordinate their decisions regarding the adoption of an IOS. In such a case the number of prospective IOS adoption configurations that they can consider grows in number. Now they include the possibility of participation of different providers as well. To understand how the coordination between providers influences the chances of an IOS to be adopted we need to consider the differences in the fixed barrier costs for the smallest provider and the smallest consumer. For the general case of $n \times c$ high density network the full adoption region has at least two limits when there is coordination between providers: barrier costs of the smallest data provider under the assumption that all provider's consumers use the service and at least one of other providers coordinate $B(P_s^H|P_d^H, \mathbf{C}^H)$ and barrier costs of the smallest consumer under the assumption that the largest provider of this consumer adopts the service together with one other provider $B(C_s^H|P_d^H, P_z^H)$. $B(C_s^H|P_d^H, P_z^H) = (1-\alpha) \cdot f\left(\frac{n_{ds}+n_{zs}}{\sum_{i \in \mathbf{P}} n_{is}}\right) \cdot (n_{ds} + n_{zs})$; $B(C_s^H|P_d^H) = (1-\alpha) \cdot f\left(\frac{n_{ds}}{\sum_{i \in \mathbf{P}} n_{is}}\right) \cdot n_{ds}$. It is easy to demonstrate that in the high density network in the case of coordination between providers the fixed barrier costs of smallest provider and consumer are higher (see Appendix F). In the high density network if providers coordinate their adoption decision they expect to create more value for consumers together and accordingly to receive higher rewards from service provision in return. Such joint actions increase the network tolerance towards the size of the fixed costs of the service adoption.

Proposition 6. When the saving per message of the consumer is growing with the providers' adoption rate ($f'(x) > 0$) and the network structure has high density, the acceptable fixed costs adoption region for 100% adoption is larger when providers coordinate their participation decisions rather than make them independently.

In the case of the low density network, however, the barrier costs for the customers remain the same as in the uncoordinated adoption case because they are only sensitive to the participation of their counter agent in the service ($B(C_s^L|P_s^L) = (1-\alpha) \cdot f(1) \cdot n_{ss}^L$). The Shapley values of the data providers will also be identical to the ones that they would receive under the uncoordinated scenario when they do not consider the participation of other providers because their customers only interact with them and the participation of other providers does not influence their savings ($B(P_s^L|\mathbf{C}^L) = n_{ss}^L \cdot (\alpha \cdot f(1) - VC^P)$). This is the direct consequence of the Proposition 3 which states that the Shapley values of providers are positively related if those providers have consumers in common which is not the case for low density networks. Thus, in low density networks the acceptable adoption regions are indifferent to whether providers coordinate their participation decision or make them independently from each other.

Proposition 7. When the saving per message of the consumer is growing with the providers' adoption rate ($f'(x) > 0$) and the network structure has low density, the acceptable fixed costs adoption regions are indifferent to whether providers coordinate their participation decisions or make them independently from each other (i.e. $B(P_s^L|P_d^L, \boldsymbol{C}^L) = B(P_s^L|\boldsymbol{C}^L)$ and $B(C_s^L|P_d^L, P_z^L) = B(C_s^L|P_d^L)$).

When we compare uncoordinated and coordinated adoption it is important to remember our assumption regarding development costs. We assumed that $\upsilon(P_1^H) > 0$, $\upsilon(P_2^H) > 0$, $\upsilon(P_1^L) > 0$, and $\upsilon(P_2^L) > 0$. If we relax this assumption and imagine that the value produced by smaller providers is not high enough to justify the development costs ($\upsilon(P_2^H) < 0$ and $\upsilon(P_2^L) < 0$), it can be the case that the value created jointly is high enough to cross this barrier $\upsilon(P_1^H \cup P_2^H) > 0$ and $\upsilon(P_1^L \cup P_2^L) > 0$. Then the coordination of the decision between providers can make it possible for the smaller provider to adopt the service as well because the development costs can be shared with the larger provider proportionally to the Shapley values. Thus, even though the acceptable fixed costs are indifferent to whether providers coordinate their participation decisions or make them independently from each other for the case of low network density, the acceptable development costs are not. The acceptable development costs for coordinated adoption will be higher because they can be shared with other providers.

5. Discussion

5.1. Study contributions and limitations

In this paper we develop a Shapley value based fair sharing mechanism for the case of information links IOS which aligns the interests of individual organization with the interests of the business network as a whole. The use of Shapley value for the calculation of fair reward ensures that the network-wide profit from IOS adoption can be maximized. The costs of the system development among the providers are shared proportionally to their Shapley values. This ensures that if the company is valuable for the community then it will adopt the IOS. The main benefit of the designed approach is that it creates positive externalities for the IOS data providers from the participation of other data providers (Proposition 3). It has been reported that community-wide IOS initiatives struggle with bringing together competitors in order to cooperate on the system development (Levy et al. 2003). Shapley value based rewards provide additional incentives for coopetition in this case.

The size of the positive externalities between providers depends on the network density (Proposition 4). In the low density network the provider's reward depends only on its own transactions volume. In this case each consumer is only served by one provider. Thus, the consumers can realize full potential savings from IOS once the corresponding provider has adopted the system. But in the high density network some or all consumers are served by multiple providers. For such a consumer to realize the full potential savings from IOS adoption the participation of all of the providers with which the consumer is dealing is required. Accordingly, the fair reward to such providers connected by common consumer depends on the participation of the other providers serving the same consumer. In the presence of the network effect the higher the number of other providers in the IOS serving the same consumer(s), the higher the realized savings and the higher is the size of the fair reward to the provider (Propositions 3 and 4).

The network effect and network density affect the community's tolerance towards the high fixed per company costs of adoption. When data providers make the decision to join IOS or not independently from each other (i.e. uncoordinated adoption) then the acceptable size of fixed costs is higher for the network with low density in comparison with the network with high density (Proposition 5). In the low density network providers know that once they adopt the system then their consumers can fully realize their savings. Meanwhile in the high density network if the providers assume that other providers do not participate then their consumers cannot realize full potential savings due to the presence of the network effect. Thus, the reward to the provider will be higher in the low density network (assuming both providers have the same business volume size). As the reward is higher so is higher the provider's tolerance to the rising of the fixed per company costs of IOS adoption. Even though the fair sharing mechanisms are rarely implemented in practice, we believe that this observation might add to our understanding of the differences in the spread of the same IOS technologies in the different business networks as evidenced by Damsgaard and Lyytinen (2001). Certain industry structures make it easier to realize benefits from IOS introduction and consequently the spread of the technology there goes much quicker.

Under fair sharing conditions the networks with high density can benefit from coordination between providers: the region of acceptable fixed costs for providers and consumers becomes larger if providers coordinate their adoption decisions rather than make them independently (Proposition 6). It happens because when providers coordinate they expect that consumers will receive higher savings from an IOS and accordingly providers will receive higher reward. In the low density network, however, the acceptable region of providers' fixed costs is indifferent to the coordination (Proposition 7). Their consumers will not benefit from providers' cooperation as savings that they receive from an IOS do not depend on the participation of other providers. The development costs, on the other side, are independent of the number of IOS providers. Thus, in the low density network providers can still benefit from the coordination by sharing the development costs among them. These insights suggest that the success of the implementation of fair sharing model is dependent not only on the business network structure but also on the ability of the competitors within the network to cooperate and coordinate their actions. Previous research has already underlined the importance of collective action for IOS development (Monge et al. 1998, Markus et al. 2006). Our analysis demonstrates additionally that the propensity for cooperation is much more important when the business network has high density because the realization of full benefits by adopters requires the IOS adoption by much larger number of players.

Shapley value based approach allows differentiating between contributions of different companies and promote the participation of the crucial actors (Propositions 1 and 2). Previous research has often reported two types of conflicts with respect to the uneven distribution of benefits in the IOS adopting community: between companies performing different business roles (Rodón and Sesé 2010) and between companies of different sizes (Fulk et al. 1996, Van Baalen et al. 2009, Steinfield et al. 2011). The separation of IOS users into data providers and data consumers makes it possible to analyse the influence of the participation of individual organizations on the savings realized by other community members. This explicit contribution evaluation can solve the conflict of the uneven IOS benefits distribution between different business roles.

We assume that the size of the consumer savings from using the information links IOS is proportional to the transactional volume of the company which is consistent with previous research (Barua and Lee 1997). From this assumption it follows that the fair reward to the providers is proportional to their transactional volumes (Propositions 1 and 2). It means that the community values the participation of larger companies higher in comparison with small ones. The size of the fair reward is negatively related to the size of fixed costs required for a provider to adopt the system (formula 6). Thus, if the per company fixed costs of adopting the system are rather high, it can be the case that the fair reward to a small company will be negative because its participation is actually diminishing the community profit. The savings that are being realized due to the messages that it sends to the consumers might not be high enough to counteract the costs of the connecting the company to the IOS. In such a case, the use of other communication means can be preferred to support information exchange with these small companies from the community perspective. Thus, it is not necessarily that 100 % adoption by the community members ensures the maximum community profit from the use of the technology. Lower adoption levels can be more beneficial in this respect.

Beck and Weitzel (2005) encouraged the use of modified EDI solutions by small companies because those solutions have the lower size of initial investment required. However, those solutions tend to have higher variable costs from provider's side as those technologies allow for lower level of process automation (e.g. human operators are required to input the data into solutions with web-interface (McLaren et al. 2002)). The increase of the variable costs brings about the decrease of the fair reward to the provider which in return manifests in lower barrier fixed costs. Thus, even if the modified solution has lower fixed costs it still might not be adopted by small companies under fair sharing scheme if the variable costs associated with the new solution rise to an unacceptable level. This outcome with less than 100% adoption of even modified solution will be still optimal from the community perspective as the additional benefits from IOS adoption by those companies will not outweigh associated costs for bringing them in.

Our model is the first attempt to evaluate the potential of applying fair sharing approach to the re-distribution of IOS benefits in order to improve IOS adoption. We made a number of limiting assumptions that can be relaxed and explored in future research. We assumed that each IOS consumer will be paying according to their maximum willingness to pay which can be a challenge to realise in the real-world setting. We estimated consumer's willingness to pay as a fixed share of the realized savings when in reality it is fair to expect that this share is changing depending on the size of savings realized by the user. In our model, Shapley value estimation is based on the assumption of equal probability of different coalitions and sequencing of providers' joining. Discriminating in probabilities of different provider coalition formations can be a fruitful direction for further research.

5.2. Practical implications

We believe that our analysis provides some useful for insights for practitioners. Firstly, we suggest a fair sharing approach to the re-distribution of IOS benefits which with certain adjustments could be used in the charging model for IOS services. Admittedly, estimation of Shapley values can be a computational challenge for the networks of large sizes but for certain game types Shapley value formula can be successfully adjusted to be computed in pseudo-polynomial time (Reinhardt and Dada 2005). In the case of high density communication networks, such a reward scheme will provide additional incentive for data providers to cooperate and coordinate their actions. This approach can successfully eliminate the problem of uneven distribution of IOS benefits among users that have different roles in the business network. As for solving the problem of IOS adoption by small companies, this fair sharing model has big potential if the targeted business network has high connection density, i.e. many larger companies have a lot of connections to many smaller companies, and the IOS use is characterized by a strong network effect, i.e. the costs of maintaining communication channels parallel to IOS are very high. Moreover, our analysis highlights the importance of understanding of the communication structure within business network for IOS providers in order to realize the value of fostering cooperation. Networks with low connection density require much fewer cooperation fostering efforts for successful IOS implementation and adoption than networks with high density of connections.

6. Conclusion

IOSs provide a great opportunity to improve information exchange between firms and reap to the full extent the benefits from information digitisation and the ease of information transfer with the use of modern technologies. As competition nowadays happens not only at the level of individual companies but at the level of business networks as well, the successful adoption of IOSs by business network members gains on importance. The necessity of cooperation between competitors, uneven distribution of benefits among IOS users, and high fixed costs of adoption have been often named among the barriers for community wide IOS adoption. A number of researchers have suggested that the use of fair sharing schemes can be beneficial in the IOS context. To the best of our knowledge, in this paper we develop a first analytical model of fair sharing of IOS benefits. We demonstrate that Shapley valued based fair sharing approach can provide additional incentives for cooperation among competitors and has good potential in solving the problem of IOS benefits re-distribution among different network roles and limited application in solving the problem of small firm adoption. Furthermore, we analyse the influence of IOS characteristics, network structure, and coordination potential on the effectiveness of the fair sharing mechanism. Our findings have implications for initiatives that are aiming at improving IOS adoption within the large business network contexts like industries or clusters of economic activity.

Appendix A — Inventory of mathematical notations

Notation	Explanation
$\mathbf{P}$	set of all data providers
$\mathbf{K}$	coalition of data providers
$\nu(\cdot)$	characteristic function of the game
$\mathbf{C}$	set of all data consumers
w_j	willingness to pay of consumer C_j
s_j	savings realized by consumer C_j from using the information service
α	parameter describing which share of projected savings a consumer is willing to pay in form of the fees
n_{ij}	number of messages received by consumer C_j from data provider P_i
$\bar{s}$	average savings per message
$f(\cdot)$	function describing dependency of the average savings per message on the number of messages in the system (i.e. data providers participation)
DC^P	information service development costs
FC^P	provider fixed costs of information service provision
VC^P	provider variable costs of information service provision
FC^C	consumer fixed costs of information service adoption
VC^C	consumer variable costs of information service adoption
VC^C	consumer variable costs of information service adoption
φ_i	Shapley value of data provider P_i
r_i	reward received by data provider for information service provision
$B(P_i \vert C_j)$	barrier fixed costs for the data provider P_i under the condition that only customer C_j adopts the service

Appendix B — Proposition 1. Consumer savings per message are linear in the number of messages exchanged.

We consider the scenario when the average savings per message of the consumer are fixed and equal to b ($f(x) = b$). In this case, the characteristic function of the game has the following shape:

$$\upsilon(\mathbf{K}) = \alpha \cdot b \cdot \sum_{j\in\mathbf{C}}\sum_{i\in\mathbf{K}} n_{ij} - DC^P - FC^P \cdot |\mathbf{K}| - VC^P \cdot \sum_{j\in\mathbf{C}}\sum_{i\in\mathbf{K}} n_{ij} \tag{8}$$

We assume that all sequences of coalition formations have the same probability. Then the general formula for Shapley value calculation (formula (3)) should be adjusted:

$$\varphi_i(\upsilon) = \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{|\mathbf{K}|!(|\mathbf{P}| - |\mathbf{K}| - 1)!}{|\mathbf{P}|!} \cdot \Big(\upsilon(\mathbf{K}\cup\{i\}) - \upsilon(\mathbf{K})\Big) \tag{9}$$

Added value of P_i for a coalition $\mathbf{K}(P_i \notin \mathbf{K})$ in the scenario with linear function:

$$\begin{aligned}\upsilon(\mathbf{K}\cup\{P_i\}) - \upsilon(\mathbf{K}) = {} & \alpha \cdot b \cdot \sum_{j\in\mathbf{C}}\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} - DC^P - FC^P \cdot |\mathbf{K}\cup\{P_i\}| - \\ & -VC^P \cdot \sum_{j\in\mathbf{C}}\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} - \alpha \cdot b \cdot \sum_{j\in\mathbf{C}}\sum_{p\in\mathbf{K}} n_{pj} + DC^P + \\ & +FC^P \cdot |\mathbf{K}| + VC^P \cdot \sum_{j\in\mathbf{C}}\sum_{i\in\mathbf{K}} n_{pj} = \\ & = (\alpha \cdot b - VC^P)\sum_{j\in\mathbf{C}} n_{ij} - FC^P\end{aligned} \tag{10}$$

Now we can substitute the general formula for value added in formula (9) with the case specific one derived in formula (10):

$$\varphi_i(\upsilon) = \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{(|\mathbf{K}|)!(|\mathbf{P}| - |\mathbf{K}| - 1)!}{|\mathbf{P}|!} \cdot \Big((\alpha \cdot b - VC^P)\sum_{j\in\mathbf{C}} n_{ij} - FC^P\Big) \tag{11}$$

The probability coefficient can be reformulated and the final formula for Shapley value of provider P_i has the following shape:

$$\varphi_i(\upsilon) = \sum_{k=0}^{|\mathbf{P}|-1} \binom{|\mathbf{P}|-1}{k} \frac{k!(|\mathbf{P}| - k - 1)!}{|\mathbf{P}|!} \cdot \Big((\alpha \cdot b - VC^P)\sum_{j\in\mathbf{C}} n_{ij} - FC^P\Big) \tag{12}$$

Appendix C — Proposition 2. Consumer savings per message are increasing in the number of messages exchanged.

Once we introduce the network effect in the savings function of the consumers, the characteristic function of the game should be adjusted:

$$\upsilon(\mathbf{K}) = \sum_{j\in\mathbf{C}} \alpha \cdot f\left(\frac{\sum_{i\in\mathbf{K}} n_{ij}}{\sum_{i\in\mathbf{P}} n_{ij}}\right) \cdot \sum_{i\in K} n_{ij} - DC^P - FC^P \cdot |\mathbf{K}| - VC^P \cdot \sum_{j\in\mathbf{C}}\sum_{i\in\mathbf{K}} n_{ij} \tag{13}$$

Added value of P_i for a coalition $\mathbf{K}(P_i \notin \mathbf{K})$ given the new characteristic function:

$$\upsilon(\mathbf{K}\cup\{P_i\}) - \upsilon(\mathbf{K}) = \sum_{j\in\mathbf{C}} \alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)\cdot \sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} - DC^P - FC^P\cdot|\mathbf{K}\cup\{P_i\}| -$$
$$-VC^P\cdot\sum_{j\in\mathbf{C}}\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} - \sum_{j\in\mathbf{C}} \alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)\cdot\sum_{p\in\mathbf{K}} n_{pj} + DC^P + FC^P\cdot|\mathbf{K}| +$$
$$+VC^P\cdot\sum_{j\in\mathbf{C}}\sum_{p\in\mathbf{K}} n_{pj} = \sum_{j\in\mathbf{C}}\Bigg((\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} -$$
$$-(\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot\sum_{p\in\mathbf{K}} n_{pj}\Bigg) - FC^P \tag{14}$$

Accordingly, the Shapley value formula can be adjusted:

$$\varphi_i(\upsilon) = \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{(|\mathbf{K}|)!(|\mathbf{P}|-|\mathbf{K}|-1)!}{|\mathbf{P}|!}\cdot\Bigg(\sum_{j\in\mathbf{C}}\Bigg((\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot\sum_{p\in\mathbf{K}\cup\{P_i\}} n_{pj} -$$
$$-(\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot\sum_{p\in\mathbf{K}} n_{pj}\Bigg) - FC^P\Bigg) =$$
$$= \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{(|\mathbf{K}|)!(|\mathbf{P}|-|\mathbf{K}|-1)!}{|\mathbf{P}|!}\cdot\Bigg(\sum_{j\in\mathbf{C}}\Bigg((\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot(\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}) -$$
$$-(\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot\sum_{p\in\mathbf{K}} n_{pj}\Bigg) - FC^P\Bigg) =$$
$$= \sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}} \frac{(|\mathbf{K}|)!(|\mathbf{P}|-|\mathbf{K}|-1)!}{|\mathbf{P}|!}\cdot\Bigg(\sum_{j\in\mathbf{C}}\Bigg((\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - VC^P)\cdot n_{ij} +$$
$$+\Big(\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj} + n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big) - \alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)\Big)\cdot\sum_{p\in\mathbf{K}} n_{pj}\Bigg) - FC^P\Bigg) \tag{15}$$

Now we see that the relationship between the business volume of the provider and the Shapley value becomes more complex. Taking into account that $f'(x) > 0$, it is obvious from formula (15) that keeping the total business volume of each consumer constant ($\sum_{p\in\mathbf{P}} n_{pj}$) the higher is the business volume of the provider P_i with each individual customer (n_{ij}) the higher is the reward that the provider is being assigned assuming that the variable costs per transaction are negligible ($\alpha\cdot f(x) > VC^P$ for $x > 0$). We cannot predict the influence of the change in the total business volume of the provider ($\sum_{j\in\mathbf{C}} n_{ij}$), however, because the change can be associated with the rise of the business volume with one customer (for instance $n_{i1}\uparrow$) and the fall of the business volume with another customer (for instance $n_{i2}\downarrow$). The total change might be positive but the downward effect of n_{i2} reduction might have a more pronounced effect because of the network structure parameters (e.g. transactional volumes of customers 1 and 2 with other providers — $\sum_{p\in\mathbf{K}} n_{p1}$ and $\sum_{p\in\mathbf{K}} n_{p2}$) that are present in formula (15).

In addition we can see from formula (15) that the provider is being rewarded for increasing the average savings per message for the messages received by its customers from the other providers: the term $\sum_{j\in\mathbf{C}} \Big[\alpha\cdot$

$f\left(\frac{\sum_{p\in\mathbf{K}} n_{pj}+n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\right)-\alpha\cdot f\left(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\right)\Big]\cdot\sum_{p\in\mathbf{K}} n_{pj}$ in formula (15). Thus, in the presence of the network effect in the average savings per message the provider's reward depends not only on the provider's transactional volume but also on the transactional volumes of their customers with other providers ($\sum_{p\in\mathbf{K}} n_{pj}$). This means that in the same network we can have two providers with identical total transactional volumes but with different Shapley values because of the differences in their customer bases which is not the case when the savings per message are constant.

Appendix D — Proposition 3. Role of shared customers.

In the context when savings per message are increasing in the number of messages exchanged the Shapley value of provider P_i can be found as:

$$\varphi_i(v)=\sum_{\mathbf{K}\subseteq\mathbf{P}\setminus\{P_i\}}\frac{(|\mathbf{K}|)!(|\mathbf{P}|-|\mathbf{K}|-1)!}{|\mathbf{P}|!}\cdot\Bigg[\sum_{j\in\mathbf{C}}\Bigg(\Big[\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}+n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)-VC^P\Big]\cdot n_{ij}+ \\ +\Big[\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}+n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)-\alpha\cdot f\Big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\Big)\Big]\cdot\sum_{p\in\mathbf{K}} n_{pj}\Bigg)-FC^P\Bigg] \tag{16}$$

The role of participation of other providers is captured by the term $\sum_{p\in\mathbf{K}} n_{pj}$ which refers to all messages exchanged between consumer C_j and providers in coalition $\mathbf{K}$ which does not contain provider P_i. This term plays two roles in the formula. First, it affects the savings per messages realized by consumer C_j: $f\big(\frac{\sum_{p\in\mathbf{K}} n_{pj}+n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\big)$. As total potential number of messages exchanged between consumer C_j and providers ($\sum_{p\in\mathbf{P}} n_{pj}$) is fixed irrespective of providers' participation, the higher is the number of other providers adopting the service ($\sum_{p\in\mathbf{K}} n_{pj}\uparrow$), the higher is the Shapley value received by provider P_i ($\phi_i\uparrow$). Second, the adoption of the service by other providers increases the Shapley value of provider P_i due to the influence that the participation of this provider has on the consumer savings realized for the messages exchanged between the consumer C_j and those other providers: $\alpha\Big(f\big(\frac{\sum_{p\in\mathbf{K}} n_{pj}+n_{ij}}{\sum_{p\in\mathbf{P}} n_{pj}}\big)-f\big(\frac{\sum_{p\in\mathbf{K}} n_{pj}}{\sum_{p\in\mathbf{P}} n_{pj}}\big)\Big)\cdot\sum_{p\in\mathbf{K}} n_{pj}$. It is important to note that this provider–provider positive network effect appears only when providers share a common consumer. If providers P_e and P_i do not serve the same consumer, then the set of all consumers $\mathbf{C}$ can be divided into two distinct subsets, subset $\mathbf{C}_e$ which contains all consumers communicating with provider P_e and subset $\mathbf{C}_i$ which contains all consumers communicating with provider P_i, such as $\mathbf{C}_e\cap\mathbf{C}_i=\emptyset$. In formula (16) for $j\in\mathbf{C}_e$ $n_{ij}=0$ which means that consumers from those subset will not contribute to Shapley value of provider P_i. For $j\in\mathbf{C}_i$ $n_{ej}=0$ which means that the participation of provider P_e will not contribute to the savings realized by consumers from subset $\mathbf{C}_i$ and in its turn will not influence the Shapley value of provider

P_i. Thus, in a business network there exists a positive effect of provider–provider adoption among providers that have at least one consumer in common. The higher the number of consumers that providers have in common with each other, the stronger will be the influence of providers' adoption on the gains realized by other providers.

Appendix E — Proposition 5. Uncoordinated adoption high density vs low density $n \times c$ network

In the general case of nxc network when data providers make the participation decision independently of each other, the size of the full adoption region has at least two upper limits: the barrier costs of the smallest provider assuming the full adoption from the consumers' side ($B(P_s|\mathbf{C})$) and the barrier costs of the smallest consumer assuming the service adoption of its main corresponding provider ($B(C_s|P_d)$). In case of a low density network where each provider is connected to only one consumer we have a pair provider–consumer which is the smallest in terms of the number of messages exchanged. Their barrier costs are the following: $B(P_s^L|\mathbf{C}^L) = n_{ss}^L \cdot (\alpha \cdot f(1) - VC^P)$ and $B(C_s^L|P_s^L) = (1-\alpha) \cdot f(1) \cdot n_{ss}^L$ where n_{ss}^L is the number of messages exchanged between them. In case of a high density network the barrier costs of the smallest provider can be found as $B(P_s^H|\mathbf{C}^H) = \sum_{i \in \mathbf{C}} (\alpha \cdot f(\frac{n_{si}^H}{\sum_{j \in \mathbf{P}}^H n_{ji}}) - VC^P) \cdot n_{si}^H$ and the barrier costs of the smallest consumer as $B(C_s^H|P_d^H) = (1-\alpha) \cdot f(\frac{n_{ds}^H}{\sum_{j \in \mathbf{P}} n_{js}^H}) \cdot n_{js}^H$. It is easy to demonstrate that if the smallest consumers and the smallest providers have the same transactions volumes in high and low density networks (i.e. $n_{ss}^L = \sum_{j \in \mathbf{C}} n_{sj}^H = \sum_{i \in \mathbf{P}} n_{is}^H$) and $f'(x) > 0$ then $B(P_s^L|\mathbf{C}^L) > B(P_s^H|\mathbf{C}^H)$ and $B(C_s^L|P_s^L) > B(C_s^H|P_d^H)$:

$$B(P_s^L|\mathbf{C}^L) - B(P_s^H|\mathbf{C}) = n_{ss}^L \cdot (\alpha \cdot f(1) - VC^P) - \sum_{j \in \mathbf{C}} (\alpha \cdot f(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}} n_{ij}^H}) - VC^P) \cdot n_{sj}^H = \sum_{j \in \mathbf{C}} n_{sj}^H \cdot (\alpha \cdot f(1) - VC^P) -$$
$$- \sum_{j \in \mathbf{C}} (\alpha \cdot f(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}} n_{ij}^H}) - VC^P) \cdot n_{sj}^H = \alpha \sum_{j \in \mathbf{C}} \Big(f(1) - f(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}}^H n_{ij}}) \Big) \cdot n_{sj}^H$$

$$f'(x) > 0 \Longrightarrow f(1) > f(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}}^H n_{ij}}) \Longrightarrow B(P_s^L|\mathbf{C}^L) > B(P_s^H|\mathbf{C}^H)$$

$$B(C_s^L|P_s^L) - B(C_s^H|P_d^H) = (1-\alpha) \cdot f(1) \cdot n_{ss}^L - (1-\alpha) \cdot f(\frac{n_{ds}^H}{\sum_{i \in \mathbf{P}} n_{is}^H}) \cdot n_{is}^H$$

$$f'(x) > 0 \Longrightarrow f(1) > f(\frac{n_{ds}^H}{\sum_{i \in \mathbf{P}} n_{is}^H})$$

$$n_{ss}^L = \sum_{i \in P} n_{is}^H \Longrightarrow n_{ss}^L \geq n_{is}^H$$

Hence, $B(C_s^L|P_s^L) > B(C_s^H|P_d^H)$.

Appendix F — Proposition 6. Uncoordinated adoption vs coordinated adoption for high density $n \times c$ network

For the general case of $n \times c$ high density network the full adoption region has at least two upper limits when there are no coordination between providers: barrier costs of the smallest data provider under the assumption that all provider's consumers use the service and at least one of other providers coordinate ($B(P_s^H|P_d^H, \mathbf{C}^H)$ — analogous to $B(P_2^H|P_1^H, C_1^H, C_2^H)$ for 2×2 network) and barrier costs of the smallest consumer under the assumption that the largest provider of this consumer adopts the service together with one other provider ($B(C_s^H|P_d^H, P_z^H)$ — analogous to $B(C_2^H|P_1^H, P_2^H)$ for 2×2 network). The upper limits of the high density network with no coordination scenario have been formulated earlier ($B(P_s^H|\mathbf{C}^H)$ and $B(C_s^H|P_d^H)$). It is easy to demonstrate that if the networks are identical in terms of transactional volumes and network structure then $B(P_s^H|P_d^H, \mathbf{C}^H) > B(P_s^H|\mathbf{C}^H)$ and $B(C_s^H|P_d^H\ P_z^H) > B(C_s^H|P_d^H)$:

$$B(C_s^H|P_d^H, P_z^H) = (1-\alpha) \cdot f\Big(\frac{n_{ds} + n_{zs}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) \cdot (n_{ds} + n_{zs})$$

$$B(C_s^H|P_d^H) = (1-\alpha) \cdot f\Big(\frac{n_{ds}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) \cdot n_{ds}$$

$f'(x) > 0 \Longrightarrow f\Big(\frac{n_{ds}+n_{zs}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) > f\Big(\frac{n_{ds}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) > 0$

$n_{ds} + n_{zs} > n_{ds} \Longrightarrow (1-\alpha) \cdot f\Big(\frac{n_{ds}+n_{zs}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) \cdot (n_{ds} + n_{zs}) > (1-\alpha) \cdot f\Big(\frac{n_{ds}}{\sum_{i \in \mathbf{P}} n_{is}}\Big) \cdot n_{ds}$

$B(C_s^H|P_d^H, P_z^H) > B(C_s^H|P_d^H)$

$$\begin{aligned}
B(P_s^H|P_d^H, \mathbf{C}^H) &= \frac{1}{2} \sum_{j \in \mathbf{C}} \Big[\Big(\alpha \cdot f(\frac{n_{dj} + n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) - VC^P\Big) \cdot n_{sj} + \Big(\alpha \cdot f(\frac{n_{dj} + n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) - \\
&- \alpha \cdot f(\frac{n_{dj}}{\sum_{i \in \mathbf{P}} n_{ij}})\Big) \cdot n_{dj}\Big] + \frac{1}{2} \sum_{j \in \mathbf{C}} \Big((\alpha \cdot f(\frac{n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) - VC^P) \cdot n_{sj}\Big) = \\
&= \alpha \sum_{j \in \mathbf{C}} \Big[\Big(\frac{1}{2} \cdot f(\frac{n_{dj} + n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) + \frac{1}{2} \cdot f(\frac{n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}})\Big) \cdot n_{sj} + \frac{1}{2} \cdot \Big(\alpha \cdot f(\frac{n_{dj} + n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) - \alpha \cdot f(\frac{n_{dj}}{\sum_{i \in \mathbf{P}} n_{ij}})\Big) \cdot n_{dj}\Big] - \\
&- VC^P \sum_{j \in \mathbf{C}} n_{sj}^H
\end{aligned}$$

$$B(P_s^H|\mathbf{C}^H) = \alpha \sum_{j \in \mathbf{C}} f\Big(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}} n_{ij}^H}\Big) \cdot n_{sj}^H - VC^P \sum_{j \in \mathbf{C}} n_{sj}^H$$

$f'(x) > 0 \Longrightarrow f\Big(\frac{n_{dj}+n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}\Big) > f\Big(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}} n_{ij}^H}\Big) \Longrightarrow \frac{1}{2} \cdot f(\frac{n_{dj}+n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) + \frac{1}{2} \cdot f(\frac{n_{sj}}{\sum_{i \in \mathbf{P}} n_{ij}}) > f\Big(\frac{n_{sj}^H}{\sum_{i \in \mathbf{P}} n_{ij}^H}\Big)$

$B(P_s^H|P_d^H, \mathbf{C}^H) > B(P_s^H|\mathbf{C}^H)$

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