

Basaure, Arturo; Suomi, Henna; Hämmäinen, Heikki

Conference Paper

Effects of transaction and switching costs on mobile market performance

20th Biennial Conference of the International Telecommunications Society (ITS): "The Net and the Internet - Emerging Markets and Policies" , Rio de Janeiro, Brazil, 30th-03rd December, 2014

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Basaure, Arturo; Suomi, Henna; Hämmäinen, Heikki (2014) : Effects of transaction and switching costs on mobile market performance, 20th Biennial Conference of the International Telecommunications Society (ITS): "The Net and the Internet - Emerging Markets and Policies" , Rio de Janeiro, Brazil, 30th-03rd December, 2014, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/106830>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Effects of transaction and switching costs on mobile market performance

Arturo Basaure, Henna Suomi and Heikki Hämmäinen

Department of Communications and Networking

School of Electrical Engineering, Aalto University. Espoo, Finland

{arturo.basaure, henna.suomi, heikki.hammainen}@aalto.fi

Abstract

The exponential growth in demand of mobile Internet urges mobile network operators (MNOs) to increase the supply of wireless network capacity at a high pace. From this perspective, operators should not only obtain further network capacity but also make a more efficient use of the existing capacity. Latest developments in load balancing solutions address this challenge through two opposite evolution paths, cooperative and competitive. On the one hand, operator-driven cooperative solutions permit operators to trade spectrum capacity at wholesale level through e.g., Dynamic Spectrum Access (DSA) technologies. On the other hand, user-driven competitive solutions enable users to access and switch between different networks e.g., by adopting user multihoming capability and thereby intensifying retail competition. The deployment of these solutions determines the level of transaction and switching costs and consequently the level of retail competition and wholesale trading of spectrum capacity in a mobile market. This paper analyzes the effects of decreasing these costs in different mobile access scenarios, by employing agent-based modelling. Thus, the performed simulations aim to understand the effect of load balancing technologies on market performance. Finally, the paper suggests policy implications for different markets.

Key words: transaction costs, switching costs, load balancing, dynamic spectrum access, user multihoming, wholesale trading and retail competition

1. Introduction

The mobile Internet market is presently characterized by an exponential growth in demand of capacity due to a high variety of new services. Thus, mobile network operators (MNOs) are pushed to respond to this increase not only by building a new network infrastructure but also by exploring and adopting diverse *load balancing* technologies. Different technologies yield control of load balancing to different actors in the mobile Internet market. Operators could obtain additional access to spectrum by means of Dynamic Spectrum Access (DSA) technologies, such as Cognitive Radio Systems (CRS)¹, which can be developed as operator-driven cooperative solutions. DSA technologies aim to dynamically access the so-called *spectrum holes*, which are unused pieces of

¹ Cognitive Radio (CR) refers to the original concept introduced by Mitola (2000), in which users access dynamically the spectrum. CRS is a general framework defined by ITU, which standardizes technologies aiming to access dynamically the spectrum, which can be both user or operator driven. DSA is the most general term to refer to all those technologies accessing dynamically the spectrum.

spectrum in time or frequency. On the other hand, users could employ *multihoming* capabilities² to switch from an MNO to another and thus the resulting load balancing is developed as user-driven competitive solutions. The ability of all industry actors, including network and handset vendors, mobile operators and users, to choose a certain solution depends on the structure of the mobile market, specifically, on the level of transaction costs between operators and switching costs of users. Low transaction costs facilitate operator-driven, while low switching costs facilitate user-driven solutions. However, the availability of technologies and the adopted regulations in each market affect the level of these costs.

Both developed and developing markets require load balancing technologies to increase their mobile Internet supply. Mobile markets highly differ in terms of the market structure, which can be measured through several variables, such as the number of MNOs, level vertical integration of MNOs, average revenue per user (ARPU), and churn rate. The overall market structure determines the level of transaction and switching costs, and therefore, the capability to adopt operator-driven and user-driven solutions may vary from a market to another.

The economic theory suggests that a scarce resource, such as spectrum or network capacity, is employed efficiently when it maximizes the surplus of consumers and producers (Furubotn and Pejovich, 1972). Low switching costs increase retail competition but at the same time they may disincentivize network investment, because they lower retail prices and reduce operator profits³. MNOs may rather favor lowering transaction costs to decrease their production costs. At the same time, they typically strive to avoid decreasing switching costs. Regulators around the globe have employed different approaches. In many markets, they have pushed switching costs down e.g., by allowing mobile number portability (MNP) or handset unbundling. At the same time, many regulators have assigned the mobile spectrum to few MNOs and push them to trade network capacity at wholesale level by means of infrastructure sharing, roaming agreements, and allowing Mobile Virtual Network Operators (MVNO). Similarly, load balancing technologies may impact the level of retail competition and wholesale trading between MNOs.

The structure of the mobile market is typically identified with its performance. For example, Cricelli, Grimaldi and Ghiron (2011) affirm that the type and structure of operators, in particular the level of vertical integration (at service and network levels) and the existence of MVNOs affects the market performance. In addition, Lundborg, Reichl and Ruhle (2012) analyze how spectrum allocation affects mobile competition, since the type and amount of spectrum clearly present differences in costs for network deployment. Finally, Whalley and Curwen (2012) claim that also some historical issues, such as the role of the incumbents and new entrants, affect the status of competition. In fact, markets in Europe usually possess a strong incumbent with a significant first mover advantage, and new entrants (especially those with 3G license only) have encountered difficulties in challenging these incumbents.

² Multihoming refers in this context to any mechanism, solution or protocol enabling the user to maintain several concurrent and active subscriptions to different MNOs. For a detailed explanation on multihoming mechanisms, see Suomi, H. (2014)

³ According to Schumpeter, there is a positive relationship between monopoly power and technological innovation. This conjecture was firstly criticized by Scherer (1967), who introduced the idea of an inverted U-shape relation between competition and innovation. Aghion et al. (2002) formalized this relation.

The role of wholesale trading and its connection with retail competition has been understudied in the mobile telecommunications industry. In other markets, this issue has been more widely addressed, in particular in the electricity and energy markets. A number of authors emphasize the importance of retail competition and wholesale trading for the performance of this market. For instance, Bohi and Palmer (1996) report that while retail competition achieves lower electricity prices, wholesale trading may encourage better investments. Mirza and Bergland (2012) emphasize the role of user prices as a signal for attaining efficiency in energy allocation, while Goulding, Rufin and Swinand (1999) claim in this same line that a lack of true retail competition results in wholesale prices providing wrong signals. Finally, Polo and Scarpa (2013) suggest that an introduction of a compulsory wholesale market generates retail competition. The conclusions obtained from the energy and electricity markets are relevant for mobile telecommunication market, even though the levels of costs are naturally different.

In the telecommunications field, a number of authors have investigated the relation between retail competition and wholesale trading, but have applied different terminology. Markendahl (2011) analyzes the competition and cooperation mechanisms between MNOs, while Hazlett (2006) studies the dynamic of competing networks with compulsory infrastructure sharing. In general terms, they indicate that even though competition is usually favored by regulators, an excessive competition may lower the level of investments and thus, in some cases, wholesale trading mechanisms between firms result in additional gains for the industry. In practice, a regulator can mandate incumbent operators to provide competitors with access to their facilities or may prefer to encourage facilities-based competition. In any case, legislators should regulate the wholesale trading between operators, to avoid the risk of non-competitive behaviors.

This paper aims to understand the effects of transaction and switching costs on the mobile market performance by comparing the operator-driven load balancing solutions against the user-driven ones as a means to match the increasing mobile demand with the network supply. In concrete, this work responds to the following questions.

- 1) When should a regulator favor the strategy of lowering transaction costs and /or switching costs?
- 2) Are they complementary or substitute strategies?

With this purpose, this paper continues the analysis started by Suomi, Basaure and Hämmäinen (2013), which identifies the future phases for mobile access competition and the technologies lowering the transaction and switching costs. From a methodology perspective, this study employs agent-based simulations to analyze the overall effect of many interacting agents with changing cost conditions.

The paper is structured as follows. Section 2 introduces the evolution of transaction and switching costs in the mobile market and Section 3 describes the chosen method for this analysis. Section 4 performs the simulations and presents the results whereas Section 5 discusses the implications of the findings on concrete country cases and section 6 briefly concludes the study.

2. Background

Transaction and switching costs are the two key cost elements which affect the dynamics and structure of a market. Transaction costs are induced when employing the price mechanism offered by the market for performing an economic transaction. The importance of these costs was firstly introduced by Coase (1939). More recently, Barzel (1982) and Allen (1991) defined transaction costs as those of transferring, capturing and protecting property rights. This last definition is especially suitable when transferring the usage right of natural resources, such as spectrum. The level of transaction costs may explain, for instance, the level of vertical integration of an industry. Regarding these costs, changes in transaction conditions achieve a restructuring of the industry due to increased efficiency (Ulset, 2007). Low transaction costs increase efficiency by diminishing opportunistic behaviors of agents⁴ (Hill, 1990). On the contrary, an increase in transaction costs results in governance deficiency explained by agency costs and a market restructuring characterized by expansion to non-related activities (e.g. vertical integration).

Switching costs, on the other hand, are seen as barriers to new products or service providers to enter a specific market, and are defined as one-time costs that a buyer faces when switching from one provider to another (Porter, 1980). Burnham et al. (2003) characterized switching costs by classifying the types of resulting costs into financial, procedural and relational. For example, if a company considers switching its component supplier, it will incur in monetary and procedural costs. Monetary costs refer to the expenses caused by annulling the present and setting up the new supply contract. Procedural costs are often measured in time and effort required to tender all suppliers.

The transaction and switching costs have also affected the dynamics of telecommunication throughout its history and will continue shaping the future of this market. The emergence of new technologies and changing regulations impact the level of these costs. This chapter describes the evolution of these costs in the mobile telecommunications market. In addition, it introduces the emerging load balancing technologies in different telecommunication layers, which may impact transaction and switching costs in the future.

2.1 *Evolution of transaction costs in the mobile market*

From the liberalization of mobile telecommunication markets at the end of the 80s and the beginning of the 90s, many countries have harmonized their mobile network standards to achieve lower transaction costs due to standard compatibility that facilitates trading between operators. Low transaction costs induce efficiency through reallocation of network resources at different levels, such as spectrum, network capacity, and physical location of infrastructure (Basaure, Marianov and Paredes, 2014). Additionally, regulatory authorities can reduce transaction costs to increase market efficiency and trading between operators, for example, by fixing interconnection prices or demanding operators to separate their network from their service operations to allow network access to multiple service operators at non-discriminatory prices⁵. Furthermore, the regulator has

⁴ this refers to the economic meaning of opportunism, which means a self-interest seeking with guile and not to an engineering perspective, which may imply an increase in efficiency

⁵ This also facilitated the entrance of MVNOs.

enforced infrastructure sharing⁶ to enable all industry actors to enjoy equal opportunities for competition. Nonetheless, it has been historically difficult for regulators to maintain equilibrium between forcing and permitting network capacity trading at wholesale level. For instance, Hazlett (2006) claims that compulsory infrastructure sharing raises the costs of infrastructure if the conditions are favorable for the new entrant, or it can stimulate too little entry, if conditions are favorable for the incumbent. To illustrate the challenges of this balance, Cave (2006) suggests that regulators set an access charge which increases over time, and thus encourages new entrants to climb the *ladder of investment*, providing them with time for investing in not replicable assets. Even though this approach has been well received by some regulators, it has also earned criticism (Bourreau, Doğan & Manant, 2010).

All the above mentioned mechanisms (interconnection, access charging, and separation between network and service operators) promote wholesale trading by diminishing transaction costs between MNOs and have been imposed by the regulator to increase market efficiency. On the other hand, similar mechanisms have been favored by mobile operators, resulting in voluntary wholesale trading. Such mechanisms include roaming agreements at national or international levels, strategic agreement with MVNOs and infrastructure sharing at certain agreed locations to make the service offer more cost efficient⁷. These trading mechanisms have been studied by Markendahl (2011), who concludes that voluntary trading⁸ of network resources between MNOs will continue to be relevant for mobile operators in the future, since it usually implies higher revenues and no negative impact on operators.

Infrastructure sharing is currently better conceived as a cooperative process rather than one imposed by the law. For example, Hazlett (2006) finds that mandatory network sharing regimes may effectively increase competition on a retail level, but at the expense of diminishing investment for infrastructure. In this same line, Kim et al. (2011) show that the mandated provision of mobile access to MVNO results in less infrastructure investment, while voluntary access provisioning has no negative effect on investments.

In this context, DSA technologies decrease transaction costs, allowing operators to share and trade their spectrum to attain higher efficiency by employing the *spectrum holes*. DSA technologies are a means to create a market mechanism, which incentivizes wholesale trading by diminishing transaction costs. An efficient wholesale market can also favor competition by decreasing entry barriers.

However, the costs related to coordination between operators may sometimes exceed the benefits achieved through this coordination. For instance, Kang (2014) performs a techno-economic analysis to evaluate the cost of coordination for different small-cell solutions which employ dynamic

⁶ One such example is the sharing of antenna locations, which allows all operators to enjoy a similar position for locating base stations.

⁷ Voluntary infrastructure sharing between MNOs can have many forms, depending on the agreement. It may happen at location level (share of masts) or at network level (share of base stations). The reasons for sharing are diverse, may be to decrease costs of network implementation or because one of the involved parties lacks e.g. spectrum licenses for deploying one particular network technology.

⁸ The author employs the term cooperation. This paper prefers the term trading, which emphasizes the economical perspective, since resources are traded in exchange for an economical value. In the case of infrastructure, sharing is defined through a legal contract, which also can be understood as a trading.

spectrum access. The author concludes that solutions lacking coordination such as Wi-Fi still have an advantage in many scenarios with respect to solutions providing a more coordinated access.

DSA technologies define a set of protocols and standards, most of them still under development, such as those related to IETF, 3GPP and ETSI organizations. For example, ETSI focuses on the development of sensing technologies, such as the functional topology for software defined radio (SDR) (Mueck et al., 2010). On the other hand, IETF has put effort to DSA standardization. Its most relevant work is the standardization of spectrum database through the protocol for accessing white spaces or IETF PAWS (Manusco, Probasco & Patil, 2013). 3GPP is improving the spectrum usage within one operator network through LTE carrier aggregation (Yuan et al., 2010), or even between LTE and Wi-Fi networks (Alkhansa, Artail & Gutierrez-Estevez, 2014), which allow to transmit the traffic coming from one source through different frequency bands and thus improving the spectrum utilization.

These latest developments of DSA technologies are pushing for two opposite scenarios leveraging spectrum efficiency. An operator-driven scenario is being achieved by technologies which allows operators to mutually balance the traffic load and network resources. On the contrary, a user-driven scenario is being achieved by technologies which allow the user to access the network resources according to his/her needs. DSA technologies (such as spectrum database and sensing technologies) can be deployed for operators as a means to trade their unused spectrum to other operators or may provide the user access to the unused frequencies of the spectrum. In other words, the difference between these two scenarios resides on who is making the decision on spectrum or network utilization rather than on the employed technology.

From this perspective, a user-driven evolution of DSA technologies boosts the level of retail competition, while an operator-driven evolution increases the wholesale trading of network capacity and spectrum resources.

2.2 Evolution of switching costs in the mobile market

There is a common view that a decrease in switching costs intensifies competition, causing prices to drop at a retail level. Thus, the lower the switching costs, the fiercer the price competition, which consequently reduces operator profits (Farrell and Klemperer, 2007). In many occasions, a decrease in switching costs can achieve an increase in social welfare. However, this may not be always the case. Many authors (Aghion et al., 2002; Hazlett, 2006; Markendahl, 2011) have suggested that an excess of competition has a negative impact on investment and therefore may reduce the social welfare. In addition, Bouckaert et al. (2012) claim that even though a *proportional*⁹ decrease in switching costs increases competition and social welfare, a *lump-sum*¹⁰ decrease in switching costs may soften competition and reduce the social welfare. Finally, Chen (2011) affirms that the role of switching costs critically depends on the strength of the network effect and on the quality of the alternative option.

⁹ A proportional decrease arises when consumers with high switching costs enjoy a higher absolute decrease than other consumers.

¹⁰ A lump-sum decrease arises, for example, when enhanced compatibility cuts the adaptation cost by a certain fixed amount, irrespective of the initial level of switching costs.

In practice, regulators have historically reduced user switching costs to drive market competition. Examples of such reduction are the unbundling of a device and a connectivity service as well as the implementation of mobile number portability (MNP). For instance, Tallberg et al. (2007) describe the effect handset bundling (and thus increasing the user switching costs) on the Finnish market. In Finland, handset bundling was allowed since the introduction of 3G services in 2006 and it had a strong positive effect on the introduction of new mobile services. In addition, the introduction of MNP by regulators has stimulated the entrance of new operators, such as MVNOs. However, the impact of MNP on competition depending highly depends on the type of implementation. While Sanchez and Asimakopoulos (2012) claim that the results of MNP have been diverse across Europe, Shin (2006) affirms that US operators have maintain high switching costs despite the MNP implementation. In the case of Japan, operators are highly vertically integrated and therefore a MNP implementation may have limited impact on switching costs (Nakamura, 2010).

In most western countries (including Europe and USA), the dominant model for providing mobile services is the *single-homed*. This means that the user has only one single contract with an operator attached to a specific device. To switch to another operator, a mobile user needs to cease the contract with the current MNO and set up a new one by acquiring a new subscriber identity module (SIM)¹¹. In some emerging markets, however, users are adopting *multihoming* devices, which support several subscriptions with different mobile operators. For example, in India and China users actively use multi-SIM mobile phones and tablets (Sridhar, 2012; Tech2, 2013). The multihoming functionality highly decreases switching costs because the user can instantly switch to a desired operator when the required contracts have been set-up.

Embedded SIM (eSIM) (GSMA, 2014) is another interesting direction of development, which reduces switching costs. The primary purpose of eSIM is to foster the development of machine-to-machine (M2M) communications since the MNO subscription can be updated remotely without the need to change the physical SIM card. The eSIM specification may also allow two active profiles of MNO (i.e. *multihoming*) which could be used interchangeably between the user sessions. eSIM would further decrease the switching costs, consequently intensifying the retail competition.

Furthermore, mobility and multipath protocols make user switching between MNOs even more dynamic. These protocols are being developed in the IETF at different Internet layers, but they are not yet widely deployed (Suomi, 2014). They aim for better utilizing the network resources and thus improving the quality of experience (QoE). One such example is the Multipath Transmission Control Protocol (MPTCP), which is already implemented in Apple's operating system (iOS7) (Bonaventure, 2013). MPTCP is capable of switching the user connection automatically from one operator to another (even in the middle of an online session) or, alternatively, using simultaneously two paths (passing through different access networks). The protocol makes the switching decisions according to a pre-coded algorithm in terms of, for example, performance on each path. This means that any MPTCP-like protocol would reduce switching costs practically until zero.

¹¹ Note that users having a device with Wi-Fi and cellular interfaces are already capable of multihoming if the cellular and Wi-Fi networks are overlapping each other.

3. Method

Behind the research question of this paper resides the problem of balancing retail competition and wholesale trading. While decreasing transaction costs allows operators to trade between them, decreasing switching costs forces operators to compete at a retail level. As stated in the introduction, this paper aims to analyze and compare these two evolution paths. With this purpose, this analysis considers DSA technologies as being operator-driven, while considering multihoming capabilities as being user-driven.

When analyzing transaction and switching costs, the mobile market should be considered as a complex and evolving system (Tsfatsion & Judd, 2006), which usually deviates from the economic equilibrium, in which the demand matches the supply. While classical economics study the equilibrium, other posterior methodologies emphasize the evolving perspective of the entire system. Agent-based Computational Economics (ACE) models the dynamic behavior of an economic system consisting of interacting agent. This economic system is adaptive and complex in nature, meaning that its units (i.e. agents) react according to certain environmental conditions. Other methodologies, such as System Dynamics modelling, study the dynamic behavior of the entire system from a top-down approach. On the contrary, agent-based modelling (ABM) focuses on the behaviors of agents from a bottom-up approach.

This study employs ABM to analyze the interaction of multiple agents in an evolving mobile market, affected by a gradual decrease of transaction and switching costs. ABM is the most suitable methodology given the dynamic behavior of the users and operators, since they constantly react to certain conditions of costs. Moreover, since the most probable path of this evolution is still unknown, ABM simulations provide a feasible means to analyze several future scenarios.

There are a number of studies analyzing transactions costs through an ABM approach. Klos and Nooteboom (2001) study the trading between firms by incorporating trust into a transaction cost analysis and thus evaluating the role of this behavior under different market conditions. Yoon, Hwang and Weiss (2012) compare different mechanisms of secondary spectrum trading by estimating the economic value of spectrum transactions. In other fields, Nguyen, Shortle, Reed and Nguyen (2013) simulates water quality trading considering asymmetry of information and transaction costs, concluding that both bilateral and clearinghouse mechanisms yield to cost saving. Finally, Zhang, Zhang and Bi (2011) study the effect of transaction costs on emission trading markets based on real data, concluding that transaction costs are still high and can block emission trading and decrease market efficiency.

On the other hand, several studies evaluate user switching costs of mobile services at different markets. For example, Grzybowski (2008) estimates the switching costs of mobile market by means of a regression analysis, arguing that these costs are already low in the UK due to an early MNP implementation. Other authors, such as those mentioned in section 2.2, estimates the effect of decreasing switching costs (through MNP) on churn rate and on the overall market performance. There are very few studies employing an agent-based approach to analyze switching costs. One such example is performed by Liu, Zhang, Xu, Andersen and Xu (2014).

This study performs a bottom-up analysis of the behaviors of mobile operators and users, which evaluates the effect of the changing conditions of transaction and switching costs on the mobile market. From a methodology perspective, this study presents a novel approach to incorporate the transaction and switching costs into the study of an evolving market.

4. Analysis of MNO and user interaction to match demand with supply

This section describes the model, its assumptions and the obtained simulation results for a scenario consisting of mobile operators and users, which interact to match the mobile demand with the network supply.

4.1 Simulation model and setup

The simulation considers three mobile network operators (MNO) and sixty users with different traffic characteristics, each user being subscribed to one of the three existing MNOs. In the simulated area defined as 2 km x 2 km (4 km^2), each MNO has four base stations, each base station having a radius of 0.5 km of coverage. Base stations are located depending on the scenario, in an overlapping and non-overlapping fashion. Mobile users move randomly (the direction is determined through a random walk algorithm) at a constant speed (2.5 km/h), and their average traffic requirements changes randomly from 10 to 30 Mbps, depending on the utilized service. The assumptions of the simulation are intended to represent a realistic scenario, which at the same time, are as simple as possible. In this way, the simulations permit to obtain accurate enough results, which are robust to the assumptions. See *Appendix I* for a list consisting of the simulation parameters.

The simulation scenarios are depicted in Figs. 1 and 2. Fig. 1 illustrates the simulation setup for MNOs, the left side for network overlapping case and the right side for network with less overlapping (herein referred as non-overlapping case). Fig. 2 shows the model implementation performed with Repast Symphony 2.0, which is a simulation tool available online.

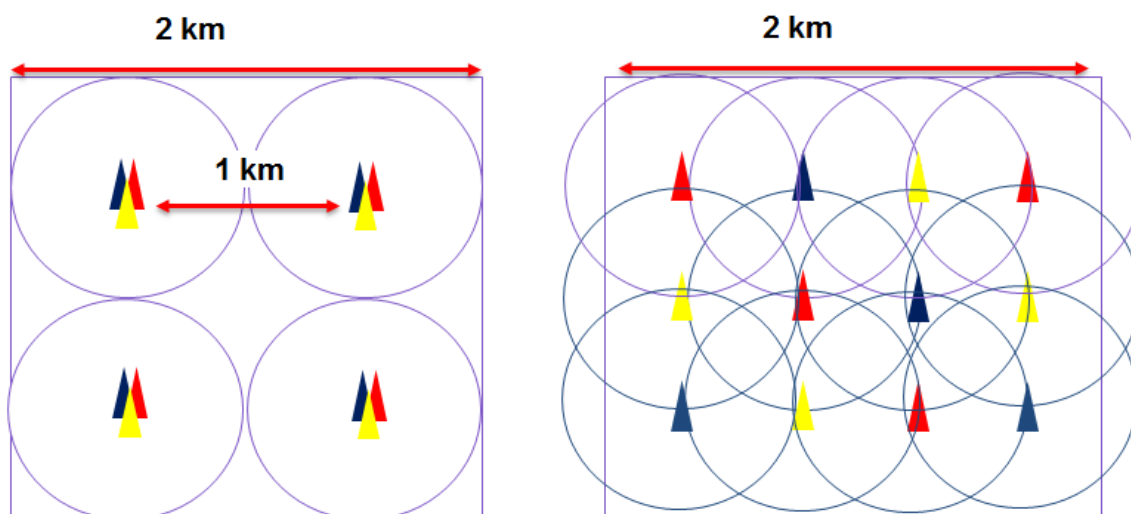


Fig. 1: Simulation setup for the MNO scenario. Each triangle represents a base station, each color indicates a MNO. Circles illustrate the coverage of base stations.

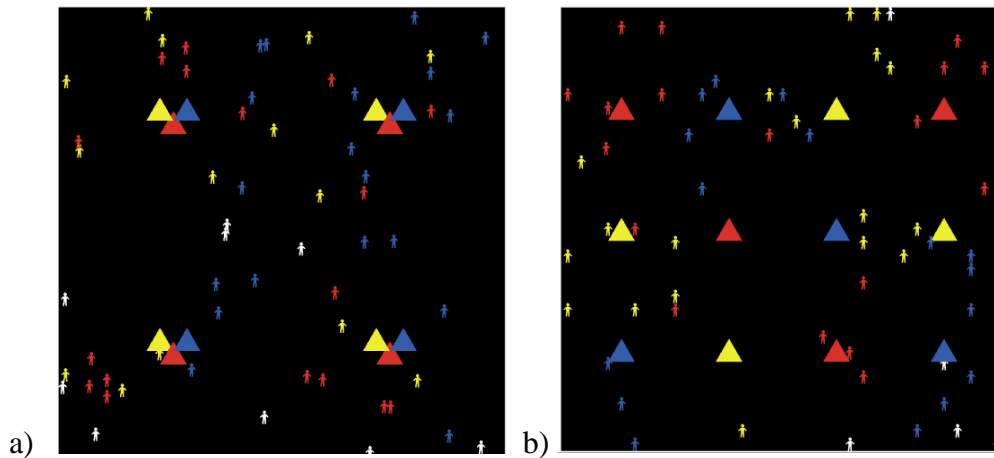


Fig. 2: Implementation of the simulation performed with Repast Symphony 2.0. Each color indicates a particular MNO. When a user is attended, he/she gets the color of the attending MNO. a) Overlapping network topology, b) non-overlapping network topology

4.2 Modelling transaction and switching costs

In each simulation cycle, users can change their operator depending on the experienced quality of service (QoS) and their switching costs. In addition, operators can buy or sell spectrum capacity, depending on their transaction costs and the available demand for that spectrum. Fig. 3 describes one simulation cycle for the agent-based modelling of transaction and switching costs.

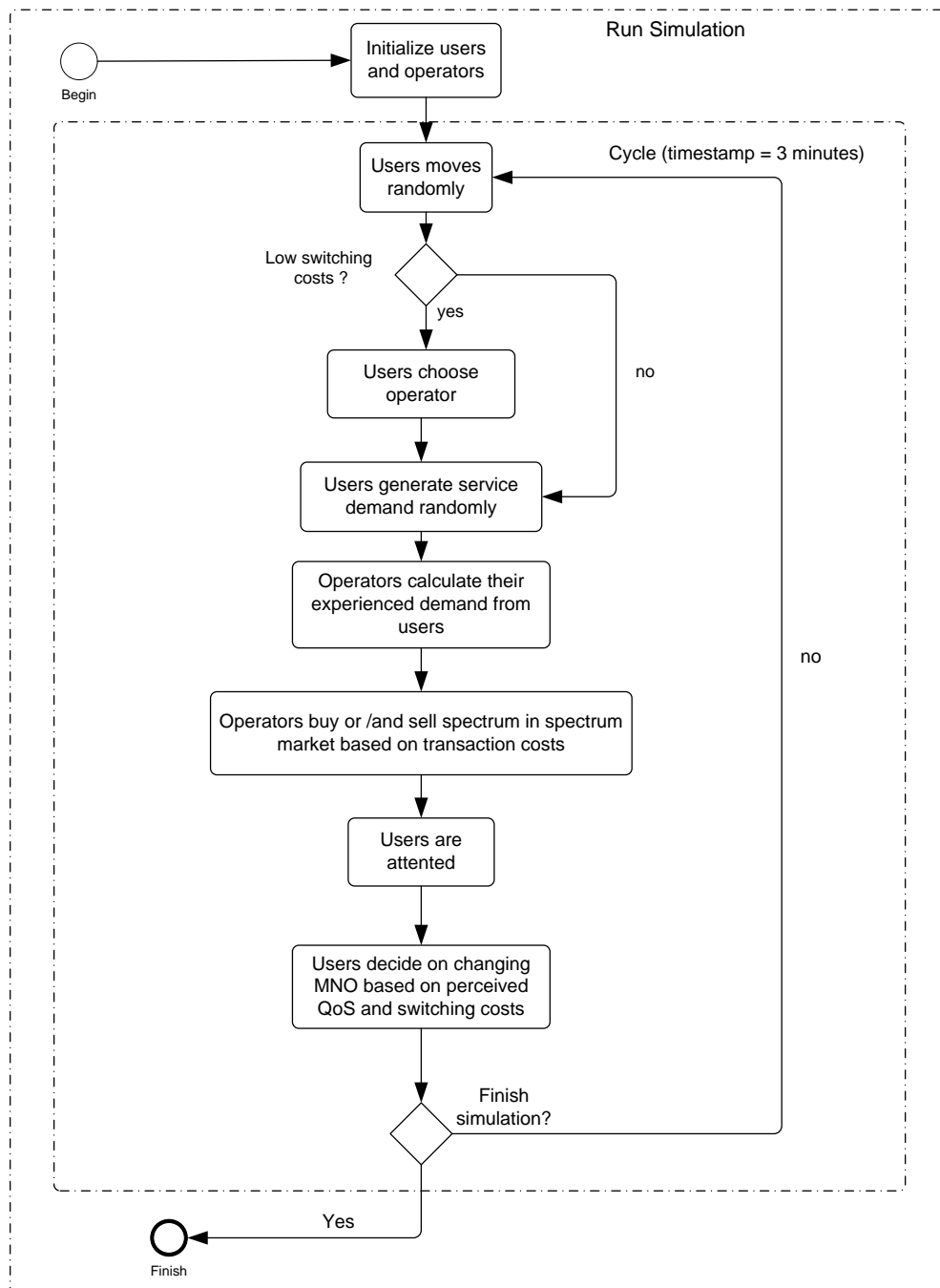


Fig. 3: Agent based modelling representation for one simulation cycle.

Table 1 shows in more detail how this model defines transaction and switching costs for the simulations. Switching costs consist on the easiness of the user to change from one operator to another. A user changes MNO, if the perceived benefits of belonging to that new operator in present value exceed his/her switching costs¹². To evaluate the change, the user bases the decision on (his/her) own experience and on the availability of information. In this model, the user is able to obtain the information on which MNO is offering the best QoS in his/her current location (the base station, which has the highest available capacity). The capability of correctly assessing this

¹² See Courcoubetis and Weber (2003) for a mathematical formulation.

information will depend on the available technology. For instance, information on network quality may be available in online databases, which requires from the user to search that information. However, multihoming capabilities may already offer automated mechanisms to provide users the ability to switch from one network to another, with little or no effort. Switching costs are considered high when the user is ready to experience many failures in the QoS before changing the operator (after 5 failures for this case). When switching costs decrease to a medium level, the user changes the operator after less number of perceived failures in QoS (after one failure in this case). Finally, when switching costs are low, the user is able to choose the base station with the best QoS offering each time he/she is accessing to the network. The best QoS is defined for this case as the base station possessing highest level of available capacity.

Transaction costs are defined herein by the minimum number of user located in the coverage area of other operator required to successfully perform a spectrum transaction. Thus, the total cost level due to spectrum transaction is divided in the number of users involved in the transaction. High transaction costs require a high number of users involved in a beneficial transaction, and consequently the required number of users decreases with the costs. In this model transaction costs are high when a minimum of 5 user are required to perform a spectrum transaction between two base stations belonging to different MNOs. In a similar way, transactions costs are medium when the minimum required number of user is 3. Finally, transaction costs are low, when only one user is enough to perform successfully a spectrum transaction between two MNOs.

Table 1: Definition of switching and transaction costs for the simulations.

	Switching costs		Transaction costs
	Number of experienced failures, after which the user change operator	Choose best base station every time?	Critical number of users to make agreement between MNO's BSs.
Low	NA	Yes	1
Medium	1	NA	3
High	5	NA	5

4.3 Simulation results

This section presents the simulation results for the scenario described in sections 4.1 and 4.2, which shows the effect of load balancing between MNOs with different switching and transaction costs.

Figs. 4 and 5 depict how the demand matches the supply while decreasing transaction and switching costs. In all the cases, the amount of available network capacity and the average service demand is the same. The network topology changes from being overlapped to non-overlapped, as described in Fig. 1. The figures show the average amount of capacity, which has been attended and not attended from the demand, and the unused capacity from the supply. In addition, traded capacity refers to the amount of capacity traded between MNOs, and churn rate describes the average amount of users, in percentage, which switched from one MNO to another, at each simulation cycle.

Fig. 4 shows that lowering transaction and/or switching costs results in higher efficiency in a non-overlapped as compared with the overlapped topology. This evidences that cooperative strategies between MNOs may have a positive impact on the overall achieved efficiency. Note that it could be possible to simulate more extreme case for overlapped and non-overlapped network topology. However, the scenario described in Fig. 1 is enough to show the effect of network topology on the achieved efficiency. Figure 4 also depicts that both types of cost reduction achieve similar efficiency in matching mobile demand with network supply; however, they cause a very different effect at retail and wholesale levels. While diminishing transaction costs increase the level of traded capacity, diminishing switching costs increase the churn rate of users and consequently it decreases the retail prices. In addition, both cost reductions exhibit a similar speed in achieving efficiency in matching demand with supply. Note that, in practice, the speed depends on how a particular technology is deployed (such as defined in Table1). For instance, even though a switching costs reduction demands lower investments and may be technically easier, transaction cost reduction is preferred by operators. For the switching costs case, the amount of information available for the user plays an important role. For instance, if the user changes to the best available operator against what he/she perceives as the best operator. This model includes this level of knowledge already in the medium level of switching costs, which in practice demands a suitable protocol or solution providing high level of automation. For transaction costs, the most demanding effort for MNOs is the initial deployment of DSA technologies. After that, transaction costs should gradually decrease towards zero.

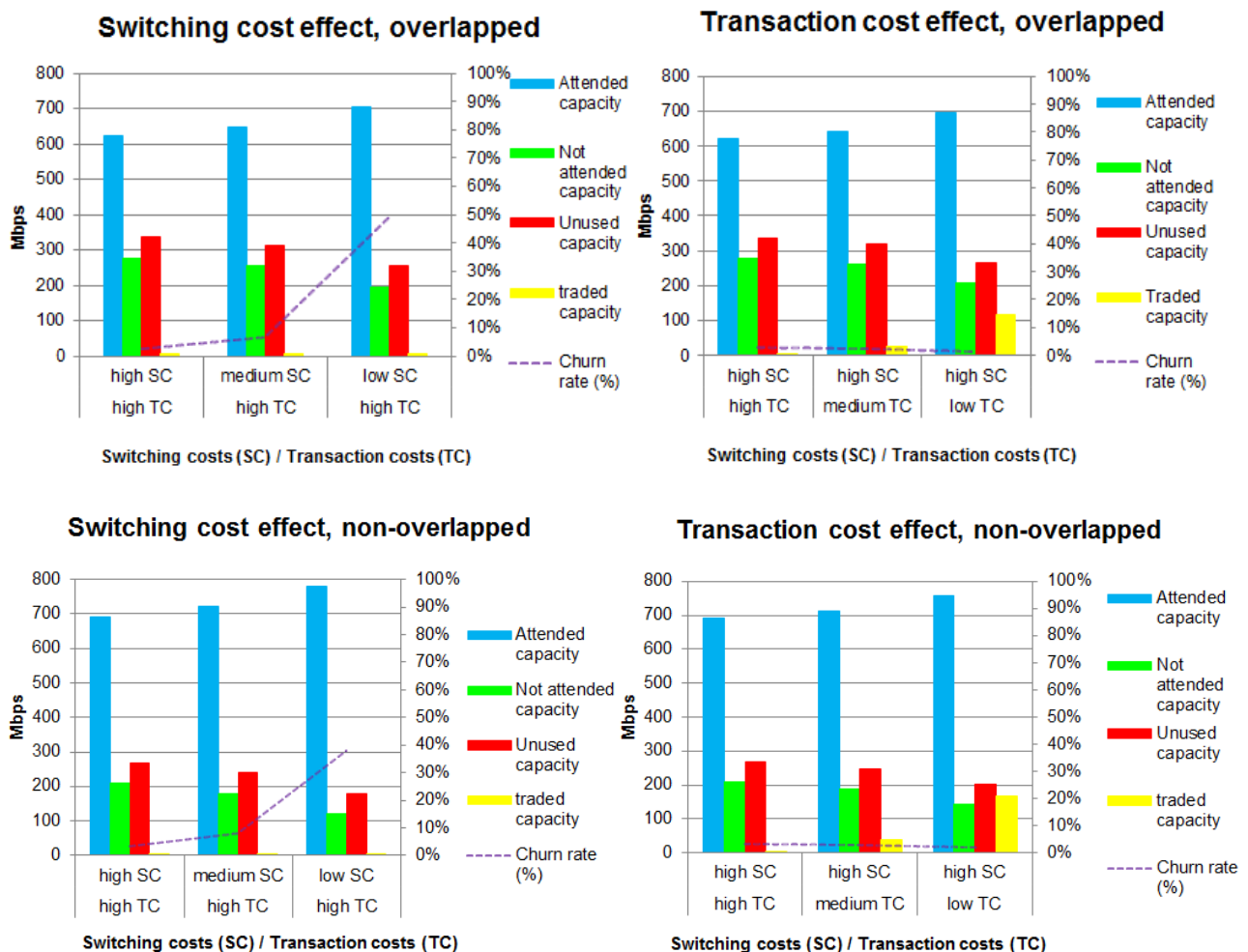


Fig. 4: Separate effect of decreasing transaction costs against switching costs for overlapped and non-overlapped network topologies.

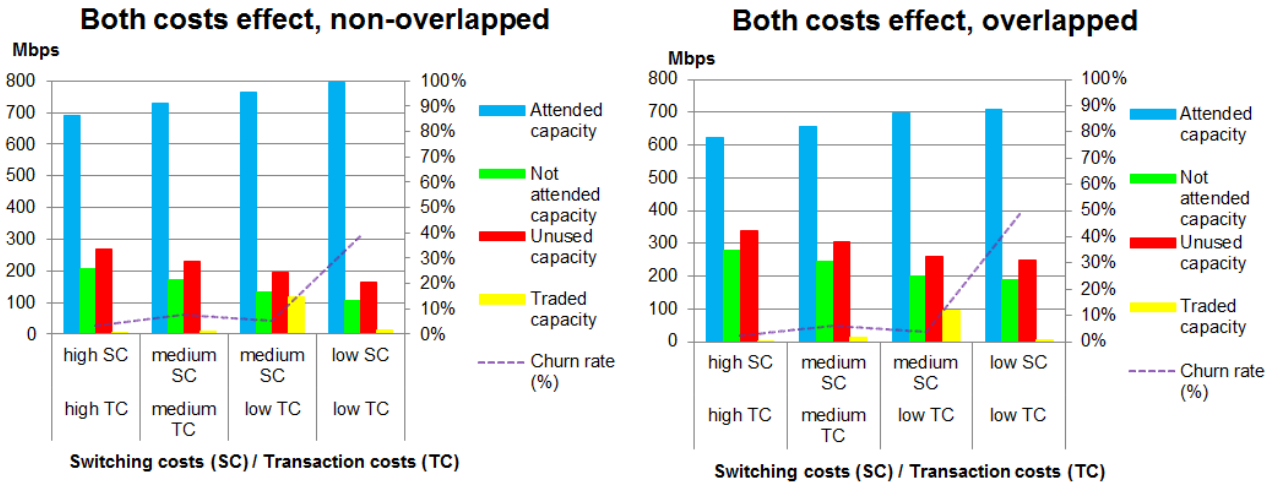


Fig. 5: Effect of decreasing both costs for overlapped and non-overlapped network topologies.

Fig. 5 shows that efficiency is attained more quickly in a case, in which both costs are reduced at the same time. This figure corroborates the non-overlapping topology attains higher efficiency than an overlapped one, when reducing both costs. This fact highlights the importance of infrastructure cooperation for attaining higher levels of efficiency. In addition, this figure evidences the resulting effect on market performance for both cost reductions. In fact, an operator-driven strategy increases the level of traded capacity and investment and a user-driven strategy increases retail competition and decreases prices. Especially interesting are the development of traded capacity and churn rate curves. While traded capacity achieves a high level at medium switching and low transaction costs, churn rate radically increases at low switching and transaction costs at traded capacity expenses. Even though that the magnitude of this change may depend on a particular user-driven or operator-driven technology, this evidences the high impact that one or other technology may have on the market performance by driving a retail competition or a wholesale trading.

Depending on the necessity of a particular market, one path may be more beneficial than the other. In a market with low investment and QoS levels, an operator-driven efficiency is more suitable, while in a market with high prices and low retail competition, user-driven efficiency is more suitable. For this reason, these two paths seem to be compatible rather than substitute solutions, even though cause similar results in matching mobile demand with network supply.

5. Discussion

The simulation results show that mobile networks attain a similar efficiency in matching demand with supply either by decreasing switching or transaction costs. Additionally, decreasing switching costs stimulates retail competition, whereas decreasing transaction costs stimulates wholesale trading. Even though the simulations simplify the reality when defining the cost parameters, the magnitude of the results imply robustness to the assumptions. This model only addresses the impact of decreasing costs on a predefined market structure, without considering the entrance of new

operators and the overall impact of these changes on market concentration, investments and price levels. However, in its simplicity, this simulation exercise achieves interesting results, which can be applied to developing policy implications for mobile markets.

The simulation results evidence that the mobile network topology, and in concrete, the level of overlapping, highly affects the efficiency attained by decreasing transaction and switching costs. From this perspective, a mobile market which presents already a high level of trading between MNOs can benefit with less effort from decreasing these costs. On the other hand, markets with no trading between MNOs, and presumably with a high level of network overlapping, may require more effort to achieve efficiency by decreasing these costs.

The obtained results are relevant given the evolution scenario related to the DSA technologies and the multihoming capabilities, which clearly reduce transaction and switching costs, respectively. Therefore, regulators should carefully consider the level of switching and transaction costs of their mobile market when facilitating the adoption of these technologies.

While increasing competition has historically been the goal for regulators throughout the globe, the optimal level of competition is not always the maximum in industries which are intensive in infrastructure investments. Decreasing switching costs is the most cost-effective means of enhancing efficiency in matching demand and supply, since it is considerably easier than decreasing transaction costs from a technical perspective. However, radically reducing switching costs may negatively impact investment, and therefore a gradual reduction of both costs is the most beneficial combination. From this perspective, a dynamic wholesale trading achieved through decreasing transaction costs may compensate for the negative effects of decreasing switching costs on investments, while reaching the most efficient conditions for matching demand and supply.

In addition, a dynamic wholesale market may attract new entrants, which simultaneously increase the overall investment level required to implement new technologies. On the other hand, lowering switching costs may also attract new entrants since it lowers entry barriers, but it may additionally disincentivize investment if price competition is too high. The overall effect of lowering these costs on a specific market should be studied case by case.

In the following lines, this section briefly analyzes the switching and transaction costs of different mobile markets based on available data. *Appendix II* summarizes the data describing the level of these costs for different mobile markets, including Europe, USA, Canada, Latin America, India, South Korea and Japan.

The first table shows variables describing direct switching costs, such as monthly churn rate, share of prepaid users from total subscription base (prepaid subscriptions usually imply low switching costs), the status of mobile number portability and other variables describing competition such as market concentration (HHI¹³), price index, and the average revenue per user (ARPU). The second table consists of variables describing transaction costs in terms of trading between operators. These variables include the separation between network and service operators, mobile termination rate of interconnection, number of MNOs (a higher number of MNOs implies a higher level of trading but

¹³ HHI stands for Herfindahl-Hirschman Index

also higher coordination requirements), technology neutrality (which indicates the standard harmonization), spectrum reselling rights (which facilitates spectrum transactions), infrastructure sharing (passive and active elements), and the number of MVNO (the higher the number, the higher the trading). These tables depict high diversity in terms of retail competition and wholesale trading across mobile markets.

Nordic countries (specifically Finland, Sweden and Denmark) show high wholesale trading in terms of network infrastructure sharing, standard harmonization in mobile networks¹⁴, low termination rate and reselling rights. However, they also show a low number of MVNOs, probably because of the size of their markets. At the same time, competition seems to be high, since ARPU and price levels are lower than in other European markets, while showing similar levels of investments and market concentration.

The other European countries are also characterized by high trading and high competition levels, though lower than in their Nordic neighbors. Among these European markets, the UK shows an especially low market concentration, low price index and ARPU level, and a pioneer role in infrastructure sharing and spectrum reselling rights, together with an extremely high number of MVNOs. This suggests that UK and the Nordic countries presently balances well between retail competition and wholesale trading and should continue to attain high efficiency through decreasing both switching and transaction costs.

The USA and Canada show a level of trading lower than European markets in terms of infrastructure sharing, standard harmonization, network and service operators separation, however, with very low termination rates, a high number of MVNOs and spectrum reselling rights. They also have high switching costs in terms of low churn rates, a high ARPU, a low prepaid share and a medium level of prices, while reaching almost real-time MNP and low market concentration. In addition, they widely practice mobile service bundling. Given the tendency towards decreasing transaction costs, the USA and Canada can obtain more benefits from exploring a user-driven efficiency.

In Latin America, the situation differs from a country to another. The level of competition may highly vary in terms of market concentration (high in Mexico, average in Chile and low in Brazil) and investment level (relatively high in Chile, while low in Brazil and Mexico). However, a low ARPU, high prepaid subscription share, medium-to-high level of churn rate with a recent deployment of MNP and average level of prices seems to evidence some similarities in terms of lowering switching costs. Wholesale network resource trading between operators is low, as compared with other markets. Brazil, for instance, still has different mobile network standards. However, recent efforts in passive infrastructure sharing and the emergence of MVNOs in several markets signal an increase in wholesale trading in recent years. Thus, these markets can be described as having low switching costs and higher transaction costs. Given this situation, these markets should obtain additional benefits from further decreasing transactions costs. However, they may still acquire further benefits from lowering switching costs through user-driven technologies for cost sensitive customers.

¹⁴ in specific, the GSM memorandum of understanding (MoU)

Korea and Japan demonstrate a stronger lack of network resource trading between operators than western countries in general, with no or little MVNOs, lack of infrastructure sharing and standard harmonization. Japan has a very low churn rate, which indicates high switching costs. However, Korea shows a much higher churn rate than Japan. Both countries have a medium level of market concentration, very high ARPU in Japan and medium in Korea. In addition, Japan stands on a very high investment level and high price index, while Korea presents medium-to-high investment levels and medium price index. Finally, both markets show very low share of prepaid subscription. All these characteristics are associated with high switching and transaction costs especially in Japan, but also in Korea. Given the lack of wholesale trading in the past and the high investment level of the markets, these markets may attain efficiency with less effort by decreasing switching costs; however, a balanced strategy may be more beneficial in the longer run.

In India, switching costs are extremely low, with the highest level of churn rate and the lowest market concentration, ARPU, investment and price indexes of all analyzed markets of Appendix II. At the same time, transaction costs are considerably higher than switching costs. However, it has recently put effort to spectrum reselling rights, infrastructure sharing and low termination rates. This situation indicates a clear tendency towards user-driven efficiency; however, it also evidences the necessity for wholesale trading of network resources to obtain a higher level of QoS. Thus, India may achieve a higher level of investment (and consequently QoS) through incentivizing the interaction between different mobile networks.

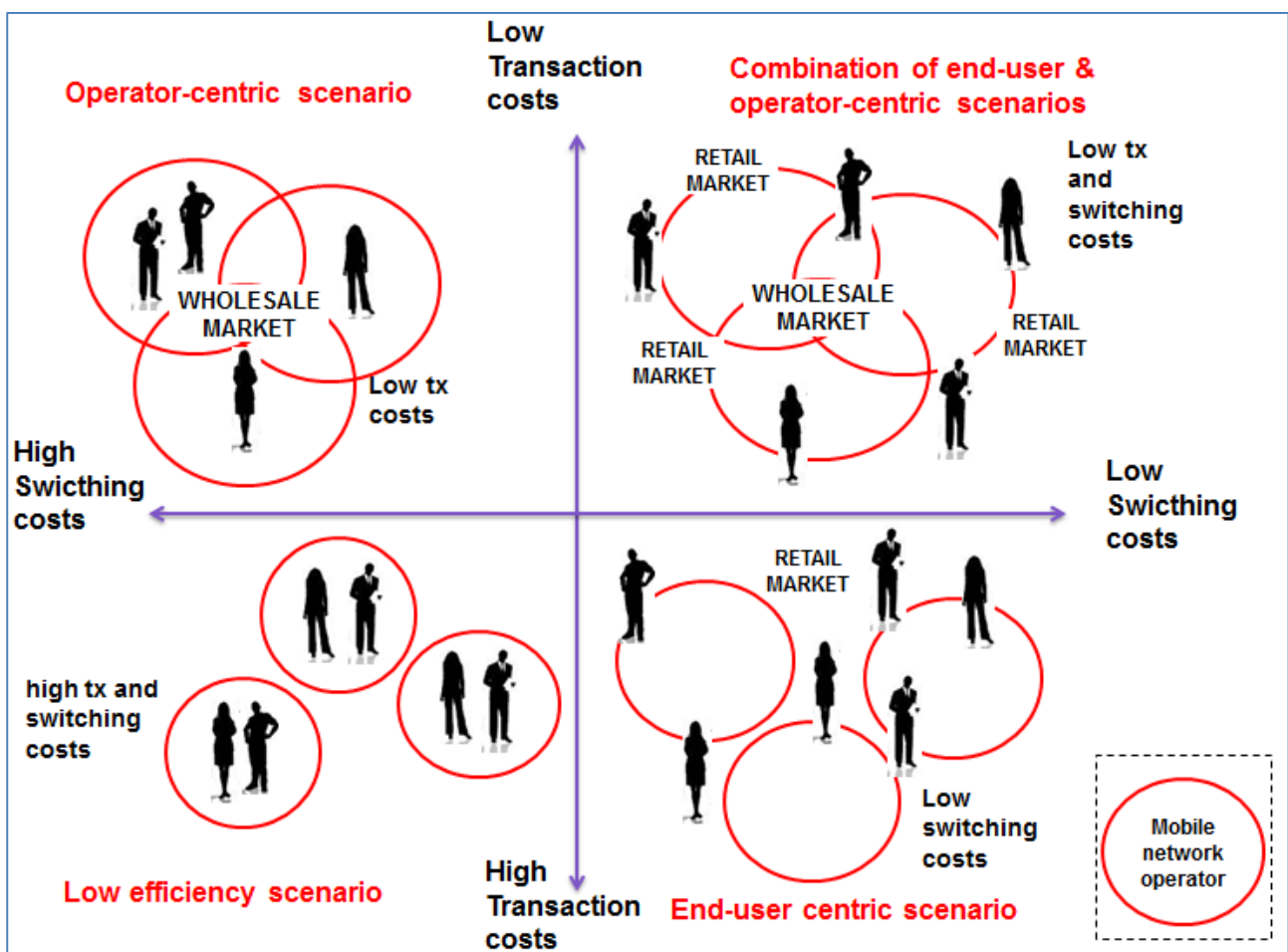


Fig. 6: Possible scenarios for a market with three MNOs at different levels of switching and transaction costs.

Based on the analysis performed in this paper, Fig 6 describes four possible scenarios for mobile markets in terms of switching and transaction costs. This figure complements the results acquired in the previous section, which suggest that the decrease in both transaction costs (operator-driven evolution) and switching costs (user-driven evolution) achieves a similar level of efficiency in matching mobile demand with network supply (scenarios at bottom-right and upper-left sides), resulting in different outcomes at retail and wholesale levels. Therefore, a combined effort of decreasing both costs (scenario at upper-right side) may be the most efficient means of optimizing market performance, since it stimulates market dynamism at both retail and wholesale levels. However, each market should finally decide on its strategy: user-driven against operator-driven evolution.

Even though both wholesale trading and retail competition may produce separately positive results for the industry, the combination of these two effects attains the most beneficial scenario. A dynamic retail market may obtain additional benefits from a dynamic wholesale market and vice-versa. Thus, countries with a very high level of retail competition should stimulate a higher level of wholesale trading, and on the contrary, countries with a high level of wholesale trading should pay attention to their retail competition.

6. Conclusions

This study indicates that a decrease in either transaction or switching costs attains a similar efficiency in matching user demand with network supply. However, they produce different effects in terms of retail competition and wholesale trading. In addition, decreasing transaction costs is considerably more demanding than decreasing switching costs, from technical and regulatory perspectives.

While decreasing switching costs intensify retail competition, decreasing transaction costs stimulate the wholesale trading of network resources. This suggests that mobile markets with a high level of retail prices may benefit the most from decreasing switching costs, and consequently, the markets with a low level of investments may benefit the most by decreasing transaction costs. See in Table 2 a summary of the effects of decreasing transaction and switching costs.

Table 2: Summary of the observations.

	Decrease transaction costs	Decrease switching costs
<i>Facilitated by</i>	DSA operator-driven technologies	Multi-SIM, multihoming, user-driven technologies
<i>Ability to adjust the supply</i>	High	High
<i>Investment required</i>	High	Low
<i>Main impact</i>	Increase wholesale trading	Increase retail competition
<i>Allow new entrants?</i>	Yes	Yes
<i>Willingness of incumbent</i>	Medium	Low

In other words, both DSA technologies and multihoming capabilities play a complementary role in the mobile market, rather than being a substitute to each other, since both retail competition and wholesale trading are needed to attain maximum market performance. From this perspective, these technologies bring regulators two separate tools to affect the level of retail competition and wholesale trading of mobile markets. However, the easiness of introducing a new technology highly depends on the type of market and may turn out to be challenging. In fact, the choice of user-driven against operator-driven technologies is highly affected by path dependence. This means that when a market achieves a certain level of efficiency by means of specific technologies and regulations, the incentives for attaining further efficiency through the other means are reduced.

Finally, regulators should consider the current structure of their mobile markets, in terms of switching and transaction costs, when facilitating the introduction of new DSA technologies and multihoming capabilities. In practice, some European markets show a balanced combination between low switching and transaction costs, and they require less effort to continue stimulating both retail competition and wholesale trading. Some other emerging markets, such as India, with extremely low switching costs, may benefit the most by decreasing transaction costs and exploiting wholesale trading of network resources more dynamically. In this same line, other countries with low switching costs and lack of wholesale trading, such as some Latin American markets, should attain a higher level of efficiency through decreasing transaction costs. Countries with high transaction and switching costs, such as Japan and, at a lower level, USA and Canada, have more freedom to choose their most suitable strategy, but they, however, may experience a longer path towards a higher level of efficiency. In any case, all markets should develop both retail competition and wholesale trading by decreasing both costs.

Acknowledgment

This work has been partially funded by the End-to-End Cognitive Radio testbed project of Aalto University, which is part of the Tekes TRIAL program. Authors additionally want to thank Ricardo Paredes for his valuable comments.

References

- Aghion, P., Bloom, N., Blundell, R., Griffith, R. & Howitt, P. (2002). *Competition and innovation: An inverted U relationship* (No. w9269). National Bureau of Economic Research
- Alkhansa, R.; Artail, H. & Gutierrez-Estevez, D.M. (2014). LTE-WiFi Carrier Aggregation for Future 5G Systems: A Feasibility Study and Research Challenges. *Procedia Computer Science* 34, p 133 – 140
- Allen, D.W. (1991). What Are Transaction Costs? *Research in Law and Economics*, 14, 1-18.
- Alston, L. J., & Gillespie, W. (1989). Resource coordination and transaction costs: A framework for analyzing the firm/market boundary. *Journal of Economic Behavior & Organization*, 11(2), 191-212.

- Barzel, Y. (1982). "Measurement Cost and the Organization of Markets, *Journal of Law and Economics* 25 (1), 27-48.
- Basaure, A., Marianov, V., & Paredes, R. (2014). Implications of dynamic spectrum management for regulation. *Telecommunications Policy*., <http://dx.doi.org/10.1016/j.telpol.2014.07.001>
- Bohi, D. R. & Palmer, K. L. (1996). The efficiency of wholesale vs. retail competition in electricity. *The Electricity Journal*, 9(8), 12-20
- Bonaventure, O. (2013). Apple seems to also believe in Multipath TCP. blog post on Spetember 18, 2013. Available at <https://perso.uclouvain.be/olivier.bonaventure/blog/html/2013/09/18/mptcp.html>, accessed August 22nd, 2014.
- Bouckaert, J.; Degryse, H. & Provoost, T. Enhancing market power by reducing switching costs. *Economics Letters* 114 (2012) 359–361
- Bourreau, M., Doğan, P. & Manant, M. (2010). A critical review of the "ladder of investment" approach. *Telecommunications Policy*, 34(11), 683-696.
- Burnham, T.A.; Frels, J.K. & Mahajan, V. (2003). Consumer switching costs: A typology, Antecedents, and consequences. *Journal of the Academy of Marketing Science*, 31 (2), 109-126.
- Cave, M. (2006). Encouraging infrastructure competition via the ladder of investment. *Telecommunications Policy* 30 (2006), 223–237
- Chen, J. (2011). How do Switching Costs Affect Market Concentration and Prices in Network Industries?. Unpublished manuscript, 7.
- Courcoubetis, C & Weber, R. (2003). Pricing Communication Networks: Economics, Technology and Modelling. Chapter 6: competition models. John Wiley and Sons, Ltd. ISBN: 0-470-85130-9
- Cricelli, L; Grimaldi, M & Ghiron, N.L. (2011). The competition among mobile network operators in the telecommunication supply chain. *Int. J. Production Economics* 131 (2011) 22–29
- Farrell, J. & Klemperer, P.D., 2007. Coordination and lock-in: competition with switching costs and network effects. In: Armstrong, M., Porter, R. (Eds.), *Handbook of Industrial Organization*, 3. Amsterdam, North-Holland.
- Furubotn, E.G. & Pejovich, S; (1972). Property Rights and Economic Theory: A Survey of Recent Literature. *Journal of Economic Literature*, Vol. 10, No. 4, 1137-1162.
- Global Wireless Matrix 2011. Bank of America, Merrill Lynch, Industry Overview, Telecommunications. 28 Sept 2011
- Goulding, A. J., Rufin, C. & Swinand, G. (1999). The role of vibrant retail electricity markets in assuring that wholesale power markets operate effectively. *The Electricity Journal*, 12(10), 61-73
- Grzybowski, L. (2008). Estimating switching costs in mobile telephony in the UK. *Journal of Industry, Competition and Trade*, 8(2), 113-132.

- GSM Association. (2013). GSMA publishes “embedded SIM” specification for machine-to-machine (M2M) services. Available at <http://www.gsma.com/newsroom/gsma-publishes-embedded-sim-m2m-services/>, accessed August 22nd, 2014.
- Hazlett, T. W. (2006). Rivalrous Telecommunications Networks with and without Mandatory Sharing. 58 *Federal Communications Law Journal*, 477-510
- Hill, C. W. L. (1990). Cooperation, Opportunism, and the Invisible Hand: Implications for Transaction Cost Theory. *The Academy of Management Review*, Vol. 15, No. 3 (Jul., 1990), 500-513
- ITU, (2014, a). ICT Regulation Toolkit. Mobile Sharing in the European Union. Retrieved on August 2014 from : <http://www.ictregulationtoolkit.org/en/toolkit/notes/PracticeNote/3258>
- ITU, (2014, b). ICT Regulation Toolkit. Sharing Mobile Network Infrastructure in India. Retrieved on August 2014 from: <http://www.ictregulationtoolkit.org/en/toolkit/notes/PracticeNote/3157>
- ITU-D, (2012). Yearbook of Statistics, Telecommunication / ICT Indicators 2002–2011
- Kang, D. H. (2014). Interference Coordination for Low-cost Indoor Wireless Systems in Shared Spectrum. Doctoral thesis. KTH Royal Institute of Technology. TRITA-ICT-COS, ISSN 1653 - 6347; 1401. Accessed from in July 2014: <http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-144195>
- Kim, J., Kim, Y., Gaston, N., Lestage, R., Kim, Y., & Flacher, D. (2011). Access regulation and infrastructure investment in the mobile telecommunications industry. *Telecommunications policy*, 35(11), 907-919.
- Klos, T. B. & Nooteboom, B. (2001), Agent-based computational transaction cost economics. *Journal of Economic Dynamics and Control* 25 (2001) 503 – 526
- Liu, Y. F., Zhang, W., Xu, C., Vitting Andersen, J., & Xu, H. C. (2014). Impact of information cost and switching of trading strategies in an artificial stock market. *Physica A: Statistical Mechanics and its Applications*, 407, 204-215.
- Lundborg, M., Reichl, W., & Ruhle, E. O. (2012). Spectrum allocation and its relevance for competition. *Telecommunications Policy*, 36(8), 664-675.
- Manusco, A.; Probasco, L. & Patil, B. (2013) “Protocol to Access White Space (PAWS) Database: Use Cases and Requirements”, Internet-draft, 2013.
- Markendahl, J., (2011). Mobile Network Operators and Cooperation - A Tele-Economic Study of Infrastructure Sharing and Mobile Payment Services, Chapter 3, Network sharing and dynamic roaming, PhD Dissertation, Royal Institute of Technology, Stockholm.
- Mirza, F. M. & Bergland, O. (2012). Pass-through of wholesale price to the user retail price in the Norwegian electricity market. *Energy Economics* 34, 2003–2012
- Mitola, J. (2000). Cognitive Radio-An Integrated Agent Architecture for Software Defined Radio.

- Mueck, M., Piipponen, A., Kalliojarvi, K., Dimitrakopoulos, G., Tsagkaris, K., Demestichas, P., ... & Hayar, A. (2010). ETSI reconfigurable radio systems: status and future directions on software defined radio and cognitive radio standards. *Communications Magazine, IEEE*, 48(9), 78-86.
- Nakamura, A. (2010). Estimating switching costs involved in changing mobile phone carriers in Japan: Evaluation of lock-in factors related to Japan's SIM card locks. *Telecommunications Policy* 34 (2010) 736–746
- Nguyen, N.P.; Shortle, J.S, Reed, P.M. & Nguyen, T.T. (2013). Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation. *Resource and Energy Economics* 35, p. 60–90
- OECD (2011), *OECD Communications Outlook 2011*, OECD Publishing. http://dx.doi.org/10.1787/comms_outlook-2011-en
- Polo, M., & Scarpa, C. (2013). Liberalizing the gas industry: Take-or-pay contracts, retail competition and wholesale trade. *International Journal of Industrial Organization*, 31(1), 64-82.
- Coase, R. H. (1937). The nature of the firm. *Economica*, 4(16), 386-405.
- Sanchez, B. U. & Asimakopoulos, G. (2012). Regulation and competition in the European mobile communications industry: An examination of the implementation of mobile number portability. *Telecommunications Policy* 36 (2012) 187–196
- Scherer, F. M. (1967). Market structure and the employment of scientists and engineers. *The American Economic Review*, 524-531.
- Shin, D. H. (2007). A study of mobile number portability effects in the United States. *Telematics and Informatics*, 24(1), 1-14.
- Suomi, H.; Basaure, A. & Hämmäinen, H. (2013). Effects of capacity sharing on mobile access competition. *Capacity Sharing Workshop (CSWS'13)*, October 7, Göttingen, Germany
- Sridhar, V., Casey, T. & Hämmäinen, H. (2012). Flexible spectrum management for mobile broadband services: How does it vary across advanced and emerging markets? *Telecommunications Policy*, 37(2-3), pp. 178-191.
- Suomi, H. (2014). *Techno-economic feasibility analysis of multipath protocols in the Internet*. Doctoral dissertation, Aalto University, Department of Communications and Networking, June 2014.
- Tallberg, M; Hammäinen, H.; Töyli, J.; Kamppari, S. & Kivi, A. (2007). Impacts of handset bundling on mobile data usage: The case of Finland. *Telecommunications Policy* 31 (2007) 648–659
- Tech2 News (2013). iBall launches Slide 3G-7334i tablet for Rs 9,990, available at <http://tech.firstpost.com/news-analysis/iball-launches-slide-3g-7334i-tablet-for-rs-9990-96727.html>, accessed August 22nd, 2014.

Tesfatsion, L. & Judd, K. (2006) Handbook of Computational Economics. Agent based computational economics, Volume 2, pages 829-1660, First Edition. Amsterdam, The Netherlands: North-Holland, Elsevier.

TRAI 2007. Recommendations on Infrastructure Sharing, April 11th, 2007. Retrieved on August 2014 from: www.trai.gov.in/trai/upload/PressReleases/447/recom11apr07.pdf

Ulset, S. (2007). Restructuring diversified telecom operators. Telecommunications Policy 31, 209–229

Whalley, J. & Curwen, P. (2012). Incumbency and market share within European mobile telecommunication networks. Telecommunications Policy 36 (2012) 222–236

Yoon, H.; Hwang, J. & Weiss, M.B.H. (2012). An analytic research on secondary-spectrum trading mechanisms based on technical and market changes. Computer Networks 56, p 3–19

Yuan, G., Zhang, X., Wang, W., & Yang, Y. (2010). Carrier aggregation for LTE-advanced mobile communication systems. Communications Magazine, IEEE, 48(2), 88-93.

Zhang, B., Zhang, Y., & Bi, J. (2011). An adaptive agent-based modeling approach for analyzing the influence of transaction costs on emissions trading markets. Environmental Modelling & Software, 26(4), 482-491.

Appendices

Appendix I

Simulation parameters	
Number of MNOs	3
Number of base stations per MNO	4
Number of users	60
User mean traffic randomly changes with the following values	5, 10, 15, 20, 25 Mbps (Poisson distribution)
Capacity of each base station	80 Mbps
Simulation Area	2 kms x 2 kms
Coverage radius of each base station	0.5 km
User randomly moves at speed	2.5 km/h
Each cycle represents (1 tick equals to)	3 min
Number of cycles per simulation	10000

Appendix II

List of selected countries with variables describing competition and user switching costs. Sources: OECD Communications Outlook 2011, ITU (2012), Wireless Matrix 2011, ITU (2014, a & b) and TRAI (2012).

Countries	Market (HHI ¹⁵)	Mobile monthly ARPU ¹⁶ (USD)	MNP (days)	Churn rate (% monthly)	Cellular investment per capita per year (USD)	Price (USD per minute)	Fraction of prepaid subscriptions (%)
Australia	0,3002	48	1	1,90	47,56	0,19	44
Brazil	0,2452	13	3	3,10	13,32	0,54	82
Canada	0,2916	52	0	1,60	79,97	0,34	21
Chile	0,3311	17	1	2,80	44,27	0,36	73
China	0,4456	10	NA	3,30	28,93	0,16	87
Denmark	0,3074	36	1	3,70	58,60	0,09	15
Finland	0,3320	32	5	1,60	34,33	0,14	10
France	0,3200	36	3	2,00	54,21	0,36	27
Germany	0,2845	23	6	2,20	37,02	0,31	56
India	0,1857	3	7	5,80	6,05	0,04	95
Italy	0,2920	23	3	2,10	67,44	0,29	85
Japan	0,3477	84	NA	0,60	134,49	0,63	1
Korea	0,3868	31	NA	3,10	61,22	0,32	2
Mexico	0,5539	16		2,90	5,93	0,27	88
Netherlands	0,3890	39	3	2,40	56,22	0,36	39
New Zealand	0,5162	21	1	2,40	27,99	0,40	66
Spain	0,3248	33	5	2,30	45,53	0,32	41
Sweden	0,3102	18	5	1,40	32,98	0,17	38
United Kingdom	0,1726	17	1	2,70	44,93	0,20	59
United States	0,2473	47	0	1,80	77,91	0,39	22

¹⁵ HHI index can be calculated as follows: $HHI = s_1^2 + s_2^2 + s_3^2 + \dots + s_n^2$ (where s_n is the market share of the i th firm).

¹⁶ average revenue per user

List of selected countries with variables describing the level of trading between operators and other parameters describing transaction costs.

Countries	Separation of network and service operators	Termination rate (USD)	Number of MNOs	Technology neutrality	Reselling rights	Infra sharing (active elements)	Infra sharing (passive elements)	Number of MVNOs
Australia	No	0,0930	3	No	Yes	Yes	Yes	40
Brazil	No	0,1839	5	Yes	No	No	Yes	2
Canada	No	0,0000	5	Yes	Yes	Yes	Yes	11
Chile	No	0,1650	4	No	No	No	Yes	6
China	No	0,0096	3	Yes	No	No	Yes	11
Denmark	Yes	0,0629	4	Yes	Yes	No	Yes	1
Finland	Yes	0,0625	3	No	No	Yes	Yes	1
France	Yes	0,0426	4	No	Yes	No	Yes	18
Germany	Yes	0,0477	4	No	No	Yes	Yes	2
India	No	0,0044	10	Yes	No	No	Yes	1
Italy	Yes	0,0938	4	No	No	No	Yes	15
Japan	No	0,1126	3	Yes	No	No	No	0
Korea	No	0,0285	3	Yes	No	No	No	0
Mexico	No	0,0327	5	Yes	No	No	Yes	0
Netherlands	Yes	0,0597	5	No	Yes	No	Yes	50
New Zealand	No	0,0570	3	No	Yes	No	Yes	7
Spain	Yes	0,0568	4	No	Yes	Yes	Yes	20
Sweden	Yes	0,0421	4	No	Yes	Yes	Yes	3
United Kingdom	Yes	0,0429	4	No	Yes	Yes	Yes	30
United States	No	0,0007	6	Yes	Yes	No	Yes	43