Analyzing the Economic Effects of Past Mobile Network Sharing Deals for Future Network Deployment

Dongwook Kim, Sungbum Kim, and Hangjung Zo

The increase in data traffic calls for investment in mobile networks; however, the saturating revenue of mobile broadband and increasing capital expenditure are discouraging mobile operators from investing in next-generation mobile networks. Mobile network sharing is a viable solution for operators and regulators to resolve this dilemma. This research uses a difference-in-differences analysis of 33 operators (including 11 control operators) to empirically evaluate the cost reduction effect of mobile network sharing. The results indicate a reduction in overall operating expenditure and short-term capital expenditure by national roaming. This finding implies that future technology and standards development should focus on flexible network operation and maintenance, energy efficiency, and maximizing economies of scale in radio access networks. Furthermore, mobile network sharing will become more viable and relevant in a 5G network deployment as spectrum bands are likely to increase the total cost of ownership of mobile networks and technical enablers will facilitate network sharing.

Keywords: CAPEX, Empirical operator data, Mobile network sharing, Next-generation network, OPEX.

Manuscript received Sept. 13, 2017; revised Jan. 9, 2018; accepted Jan. 25, 2018.

Dongwook Kim (heavenk1@kaist.ac.kr) is with the Graduate School of Innovation and Technology Management, Korea Advanced Institute of Science and Technology, Daejeon, Rep. of Korea.

Sungbum Kim (it89@kumoh.ac.kr) is with the Department of IT Convergence, Kumoh National Institute of Technology, Gumi, Rep. of Korea.

Hangjung Zo (corresponding author, joezo@kaist.edu) is with the School of Business and Technology Management, Korea Advanced Institute of Science and Technology, Daejeon, Rep. of Korea.

I. Introduction

Mobile communications have reshaped society in the 21st century by enabling communication (for example, voice, messaging, and data) that is not restricted to a certain location (unlike fixed communications where the device is fixed and communication is not possible outside of that fixed location). Smartphones would not be as effective without the mobile broadband services that provide mobile connectivity, highlighting the importance of mobile communications.

The popularity of mobile communications would have been impossible without the mobile operators that deploy and operate mobile networks. Mobile operators are not purely altruistic; there is a business case for deploying mobile networks (that is, a return on investment). However, revenues have recently begun to stagnate, while the traffic volumes of mobile broadband services and, consequently, network costs are growing rapidly, and this is likely to discourage mobile operators from investing in mobile networks. Indeed, the once-promising economic feasibility of mobile broadband is no longer valid and its prospects may even be gloomy in extreme cases because mobile communications are switching from voice services with plans proportional to the used traffic to mobile broadband services with bundle pricing [1].

This revenue gap may be addressed by new businesses enabled by future networks. For example, immersive media such as virtual reality and augmented reality and the Internet of things such as smart meters and connected vehicles are providing new revenue opportunities to mobile operators. However, new business development is difficult and operators should always look into viable cost reduction solutions such as mobile network sharing to address the issue of growing costs and stagnating revenue

[2]. Indeed, Mölleryd and others [3] indicate that the cost-to-revenue ratio of operators is increasing.

The revenue gap, along with the decreasing significance of coverage and capacity, is leading operators to consider solutions where they can share the cost burden while still providing an equivalent level of coverage and capacity to that offered today [4]. Meddour and others [5] find that the high sunk costs of network deployment may discourage mobile operators from innovating and migrating to new technologies, thus making mobile services less affordable. It may also cause licensed incumbent operators to obstruct the entry of new operators, which may, in turn, find the barriers to entry to be high because of the significant initial deployment costs.

In this context, mobile network sharing, where a single mobile network is shared and/or deployed among different operators, is an effective way in which to lower the deployment and operation costs of networks. Mobile network sharing has previously been adopted to roll out infrastructure quickly while ensuring economic feasibility and it remains the preferred implementation strategy in sparsely populated areas [6]. Further, mobile network sharing will become more relevant for networks as the deployment and operation costs of new radio access technologies rise.

This research evaluates the effect of mobile network sharing on CAPEX (capital expenditure) and OPEX (operating expenditure) by using real operator data instead of simulating the potential savings. Furthermore, the analysis is conducted for different types of mobile network sharing to determine which type leads to the highest cost reduction.

The rest of this paper is organized as follows. Section II reviews the existing literature to identify gaps and formulate classification schemes for mobile network sharing. Section III describes the data collection and processing as well as the development of the research framework based on a difference-in-differences (DID) methodology selected from various candidates. Consequently, the results of the analysis are described in Section IV, which is followed by the discussion (Section V) and conclusion (Section VI).

II. Literature Review

1. Definition of Mobile Network Sharing

Many studies focus on the definition of mobile network sharing. This section consolidates the technical and business framework provided by the literature into a coherent classification framework for mobile network sharing. The first subsection provides an overview of the high-level architecture of traditional mobile networks to remind readers of the technical criterion, while the second subsection provides the classification framework.

A. High-Level Architecture of Traditional Mobile Networks

Figure 1 shows the high-level architecture of mobile networks and their corresponding entities in the GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunication System), and LTE (Long Term Evolution) networks.

In Fig. 1, passive site elements represent the passive elements of the network such as the masts and pylons, electrical or fiber optic cables, physical space, power supply, air conditioning, alarm installations, and other passive equipment [5]. The radio access network (RAN) includes the base stations and components of the network that interface with the user and deal with radio-related procedures. The core network is where users and the RAN are controlled (for example, call control and mobility management).

It should be noted, however, that because we are looking at both the short term (one year before and after the sharing agreement) and the long term (four years before and after the sharing agreement), most of the sharing agreements analyzed in this article are for GSM and UMTS.

B. Types of Mobile Network Sharing

While Fig. 1 offers a glimpse of what mobile network sharing is and which entities can be shared in a sharing agreement, mobile network sharing can be considered from more perspectives than just technical entities as summarized in Table 1, where the factors of each axis are arranged in ascending order of the degree of collaboration/sharing.

In the business axis, there is unilateral service provisioning where only one operator provides the infrastructure and allows others to use it. Mutual service

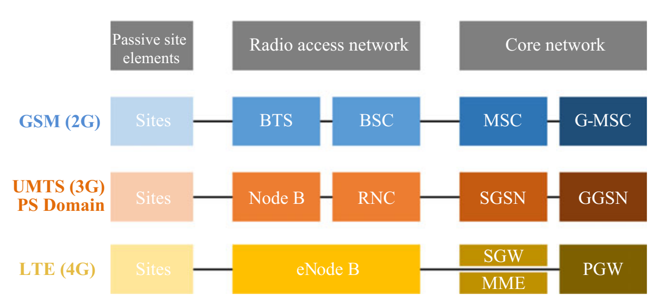

Fig. 1. High-level architecture of the GSM, UMTS, and LTE networks.

https://doi.org/10.4218/etrij.2017-0175

Table 1. Decomposition of mobile network sharing using four axes [5].

Axes	Technology	Business	Geographic	Process
Less sharing ↓ More sharing	Site sharing	Unilateral service provisioning	Full split	Engineering, planning, and network design
	RAN sharing	Mutual service provisioning	Unilateral shared region	Deployment and rollout sharing
	Core network sharing	Joint venture	Common shared region	Maintenance and operations sharing
	National roaming	Third party service provider	Full sharing	

provisioning is where more than one operator involved in the agreement provides the infrastructure for sharing. Joint venture is where the operators form a company that operates and manages the networks of the two operators, making it virtually one network. Under the third party service provider option, the network infrastructure owner leases its network to any party interested in using the infrastructure. This is also known as neutral hosting [7].

Geographically, network sharing can be divided in different ways. In a unilateral shared region, the operators in the agreement maintain their own infrastructures in non-agreed regions but rely on a single operator's infrastructure for the agreed region. The common shared region case is the same as the unilateral shared region case except that the participating operators' networks are shared in agreed regions (there is more than one operator). Finally, full sharing indicates where all partner operators' coverages are shared.

Network sharing can also be broken down into three processes. The first is engineering, planning, and network design where the planning of the network architecture and design is shared. The second is the sharing of actual deployment and rollout, where the investment and rollout activities are shared. The last is the most complex to implement as it involves sharing maintenance and operations, which is a continuous process that does not end with a specific milestone.

Although the three axes are important in the implementation of network sharing, the list of network sharing deals available is mostly classified according to the technology axis and it is most feasible to identify this aspect. This research, therefore, evaluates the quantitative effects of mobile network sharing from the technology perspective: site sharing, RAN sharing, core network sharing[1)], and national roaming. Before defining these four types of network sharing, Fig. 2 visualizes the three examined herein, using UMTS as an example.

Site sharing is the most straightforward way of mobile network sharing and is already a well-established industry in some nations (for example, some companies specialize in establishing and leasing towers) [6]. Site sharing usually involves sharing the costs related to trading, leasing, acquiring property items, contracts and technical facilities, and passive site elements [5].

RAN sharing occurs by splitting the physical RAN entities (for example, Node B, the base stations, RNC, and the centralized controller of base stations) into multiple virtual instances connected to the core networks of the respective operators [4]. The extent of sharing could be limited to only antennas/transceivers or be extended such that even the frequency used by operators is shared. Frequency pooling, however, may result in operators giving up a major proportion of their independent control of traffic quality and capacity; therefore, this has not been as widely adopted as site sharing [4].

Core network sharing refers to sharing servers and core network functionalities such as SGSN (Serving GPRS Support Node) [5]. Although this particular type of mobile network sharing is not covered in this research[2)], it is

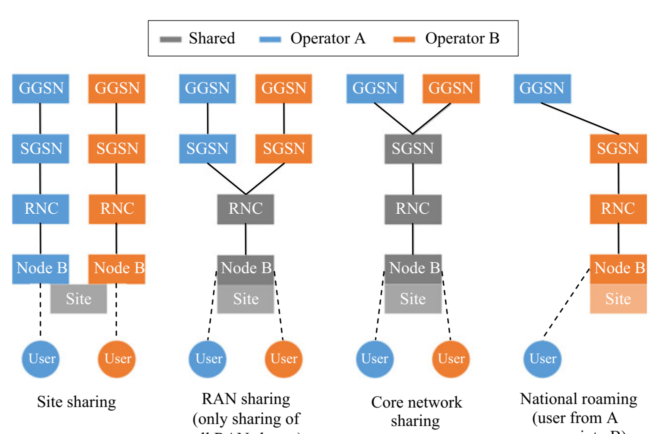

Fig. 2. Different types of network sharing.

1) Core network sharing is excluded as few operators are engaged in this process.

2) Core network sharing lacks samples (only two operators in the dataset).

important to distinguish national roaming from sharing agreements that share core network functionalities.

National roaming is employed in the national context, whereas under international roaming, operators offer mobile communications to subscribers outside of the home country by establishing an agreement with operators in other countries. National roaming likewise allows customers of an operator to still enjoy service when they are in an area not covered by the operator. In Korea, two mobile operators engaged in this type of roaming. For example, LG Telecom (now LGU+) subscribers may roam into KTF (now KT) networks when the coverage of LG Telecom is not available. Similarly, LG Telecom subscribers can access mobile networks even if their subscribed LG Telecom network is not available in the region. While this scheme is typically used to enable a new operator to provide nationwide coverage from the start, it can be adopted to deploy new-generation mobile networks from the perspective of the geographic axis. For example, an operator could serve one region and its partner could serve other regions to form a joint network overall.

2. Mobile Network Sharing and Potential Cost Reduction

Another body of the literature on mobile network sharing investigates potential cost reductions for operators. Frisanco and others [4] investigate the technological, regulatory, and business landscape of sharing network resources. They introduce a model to estimate CAPEX and OPEX savings and provide a “managed services” model for the shared network case to overcome the business and/or regulatory hurdles that may be present in mobile network sharing. They also provide a good taxonomy of infrastructure sharing that highlights the technological, business, and geographic aspects of network sharing, providing a good starting point to classify network sharing.

Pereira and Ferreira [8] compare the extent to which different technology alternatives (both wireline and wireless) profitably serve customers and support future needs. By taking into account all kinds of costs (for example, civil works), the study identifies the importance of infrastructure sharing for both fiber-to-the-home and LTE for new entrants and suggests that LTE is the better solution for rural areas.

Li and Bai [9] explore the value of infrastructure sharing by analyzing the costs and benefits of network sharing. The study compares “self-build” and “sharing” scenarios to identify the threshold value of sharing costs that would benefit participating operators (that is, a lower cost than each three building on its own). The network sharing cases in this research are classified based on technical grounds where site sharing, RAN sharing, and MVNO (Mobile Virtual Network Operator) are discussed as well as on geographical grounds where sharing depends on the geographical region.

Bartlett and Jackson [10] analyze possible OPEX and CAPEX savings by different types of mobile network sharing. They also investigate the business/marketing and engineering complexity aspects of mobile network sharing to deduce the recommended type for three scenarios. The network sharing options are decomposed into site sharing, base station sharing, transmission network sharing, base station controller sharing, core network sharing, national roaming, and MVNO.

Meddour and others [5] provide a technical and economic overview of mobile network sharing and analyze how network sharing could be applied to deploy affordable mobile and broadband services in developing nations. They estimate the CAPEX and OPEX savings in the emerging market context and provide regulatory considerations of mobile network sharing. They also offer the most comprehensive classification of mobile network sharing, as discussed in the previous section.

These studies provide a useful indicator for an operator or a regulatory body that would like to implement/endorse mobile network sharing. However, they focus on estimating/forecasting potential cost reductions and do not evaluate the actual effect of mobile network sharing on the financial performance (that is, OPEX and CAPEX) of mobile operators.

3. Infrastructure Sharing and Welfare Changes

The third type of research estimates the potential welfare changes (that is, economic effect) due to mobile network sharing. Song and others [2] analyze the potential economic effect of mobile network sharing of WiBro (Korean adoption of WiMAX) technology based on the supply and demand model. By considering six types of mobile network sharing, the study concludes that lower service prices and cost reductions bring about a significant economic effect that is equivalent to 3%–4% of the annual revenue of Korean mobile operators. They adopt a technological classification of mobile network sharing where site sharing, mast sharing, RAN sharing, core network sharing, network roaming, and MVNO are discussed.

Foros and others [11] use game theory to analyze roaming policy in the mobile telecommunications market to show how the collusion of firms at the investment level changes firms’ interests. The study provides the point at which the regulator's intervention is necessary to align with the benevolent welfare-maximizing regulator's interests.

Kim and Seol [12] analyze the anticipated economic effects of the introduction of the MVNO system for Korean mobile communications. The results indicate that the consumer surplus increases because of the reduction in the mobile service rate and highlight the importance of discount rates in setting an access charge between MVNO and mobile network operators.

Some researchers also examine broadband network sharing (or investment sharing for deploying new broadband networks). Ribeiro [13] uses economic models with three and four operators to study how the exclusion of outsiders by members of investment sharing agreements affects the competitive nature of the market and justifies regulatory intervention in wholesale access prices to improve social welfare.

Cambini and Silvestri [14] model the competition between an incumbent and another operator in a broadband market to analyze the benefits of investment sharing for next-generation networks on market competition and investments. The results suggest that investment sharing may be beneficial, but that other concerns (such as the exclusion of outsiders) may arise as the number of firms involved increases. However, as is the case for the literature on mobile network sharing, studies of broadband network/ investment sharing estimate the potential welfare effects of sharing given assumptions and do not evaluate the actual effects of mobile network sharing.

Overall, the literature review suggests that this research could bridge a gap in the body of knowledge by evaluating the effects of actual mobile network sharing agreements and providing a comprehensive framework for classifying network sharing agreements based on technological aspects.

III. Data and Methodology

This section describes the data and methodology used to analyze the effects of mobile network sharing on network costs, with mobile network sharing deals classified on a technological basis.

1. Data

A. Data Collection

To analyze the impact of mobile network sharing on network costs, a definition and measurement of cost must be established beforehand. In this study, network costs are decomposed into OPEX and CAPEX costs. However, as network costs are often undisclosed as the data can provide insight into important trade secrets, the study uses proxy variables to measure network OPEX and CAPEX. This research, therefore, uses the total OPEX and total CAPEX disclosed by operators as a proxy. While these do not fully represent the network costs, this is the best proxy that can be adopted considering the data limitations.

The target operators for this analysis were deduced from the network sharing deals included in Ovum's Mobile Network Sharing Deals Analyzer [15]. Of those, only deals with at least one operator that has a full dataset of both CAPEX and OPEX from GSMA Intelligence for 16 quarters before the deal to 16 quarters after the deal were selected. For example, if T-Mobile and Verizon Wireless engaged in a site sharing agreement in the second quarter of 2007 and either/both has/have both CAPEX and OPEX from the second quarter of 2003 to the second quarter of 2011, the deal was included in the analysis. If the deal included an operator without such a complete dataset, the operator was excluded from the analysis. The CAPEX and OPEX data were converted into US dollars by using a spot exchange rate to avoid distorting the expenditure data. For example, having different exchange rates could lead to higher expenditure in the first quarter of 2007 than in the third quarter of 2007 in US dollars but the reverse for the figures in the original currency. This functionality was already implemented in the GSMA Intelligence database.

For each deal, counterparts in the same country that had not implemented mobile network sharing in the past were selected as the control group. There were 22 operators in the treatment group and 11 operators in the control group.

After collecting the CAPEX and OPEX data for 32 quarters (16 quarters before the sharing deal and 16 quarters after) for the treatment group and control group, the data were divided into a full set (32 quarters) and a short-run set (eight quarters: four quarters before and four quarters after) to evaluate the effect of mobile network sharing on CAPEX and OPEX by comparing the trend before and after its implementation.

B. Data Processing

The data were adjusted for inflation by using GDP deflator statistics from the World Bank. Since only yearly GDP deflator statistics were available, the yearly GDP deflator was applied to the data of the corresponding quarters (for example, the GDP deflator for 2007 was applied to data for Q1–Q4 2007), with the GDP deflator of the quarter in which the network sharing agreement was established set as the base (100).

To account for the differences in absolute cost figures, the data were normalized, with 100 being the value of the base quarter (when the sharing deal was established). For the hypothetical T-Mobile and Verizon Wireless example given previously, all the datasets were normalized such that CAPEX and OPEX in the second quarter of 2007 would have a value of 100.

2. Methodology

To evaluate the effects of mobile network sharing agreements, it is essential to compare possible methodologies. Peters and Allouch [16] study 25 novice users of a new mobile communications device for three months and examine how their perceptions of expected use change over time. Interrupted time series (ITS) were used to analyze how their perceptions changed, as this approach allowed the researchers to track the 25 subjects for the short duration of the experiment. However, it is difficult to take account of changes in endogenous variables (for example, overall revenue growth as the market grows and the consequent increase in OPEX and CAPEX) when using ITS. ITS also require "about 100 observations on one unit, during which a treatment is introduced at some known time" [17]. Therefore, ITS were not selected.

Regression discontinuity design (RDD) is another methodology that could be used. RDD "occurs when assignment to treatment depends deterministically on a quantified score on some continuous assignment variable. This score is then used as a covariate in a regression of outcome" [18]. Since the treatment does not depend on a quantified score on some continuous assignment variable (that is, information on which operator implemented mobile network sharing and the time of implementation is available), RDD was not selected.

Unlike ITS and RDD, DID is a useful tool for comparing the effect of a treatment. DID, simply put, evaluates the effect of a treatment by comparing the changes in the control group with those in the treatment group, when the other effects on two groups are similar over time. Hence, DID is more accurate than analyzing the change in the treatment group alone. Ward and Woroch [19] analyze the effect of price subsidies by using a non-parametric estimation of cross-price elasticity and DID analysis "to account for potential bias due to endogeneity of program participation" By using data on consumer expenditure, Hong [20] uses DID analysis to examine the impact of Internet growth and consumer spending on different entertainment goods, with the effects on the treatment and control groups evaluated over time.

DID analysis studies the differential effect of a treatment on a "treatment group" versus a "control group." It calculates the effect of a treatment on an outcome by comparing the average change over time in the outcome variable for the treatment group with the average change over time for the control group. That is, taking the dataset as an example, it calculates the following: (Cost of treated after sharing – Cost of treated before sharing) – (Cost of control after sharing – Cost of control before sharing). The value of this estimator and its statistical significance determine whether the event in question (network sharing) had a statistically significant effect on the cost.

3. Research Framework

The DID analysis, in essence, analyzes the effect of a specific treatment after it has been implemented by comparing the change after the treatment of a treatment group with that of the control group. According to Waldinger [21], the DID estimator can be estimated in a regression framework as follows:

$$C_{ist} = \beta_1 + \beta_2 Treat_s + \beta_3 Time_t + \beta_4 (Treat \times Time)_{st} + \varepsilon$$

where, C_{ist} is the cost variable (OPEX or CAPEX) of operator i, given s and t; *Treat* is the dummy variable for the treatment group; *Time* is the dummy variable for post-treatment; $Treat \times Time$ is the interaction term that derives the DID estimator; and ε is the error term.

The regression framework derives the DID estimator, as: The cost of treatment after sharing would correspond to $\beta_1 + \beta_2 + \beta_3 + \beta_4$; The cost of treatment before sharing would correspond to $\beta_1 + \beta_2$; The cost of control after sharing would correspond to $\beta_1 + \beta_3$, and; The cost of control before sharing would correspond to β_1.

Substituting these values to the DID equation shows that β_4 is the DID estimator: $[(\beta_1 + \beta_2 + \beta_3 + \beta_4) - (\beta_1 + \beta_2)] - [(\beta_1 + \beta_3) - (\beta_1)] = \beta_4$.

Taking the dataset as an example, the CAPEX data of NTT DoCoMo in the control group in the second quarter after would possess the following dummy variables: 0 for *Treat*, 1 for *Time*, and 0 for $Treat \times Time$. The CAPEX data for NTT DoCoMo in the third quarter would possess the same value for the dummy variables.

While the DID analysis conducted in this research is a simple one, the dataset still needs to meet some assumptions [22]. The first assumption is the Stable Unit Treatment Value Assumption (SUTVA), which implies that the treatments are completely represented and that there are no relevant interactions between the members of

https://doi.org/10.4218/etrij.2017-0175

the population. While the ultimate effects of mobile network sharing such as reduced prices due to cost reductions may affect the mobile market, mobile network sharing affects *only* the participating operators in principle and thus this assumption is met. The second assumption is exogeneity, namely that the conditioning variables are not influenced by the treatment. Again, as in the case of the SUTVA, mobile network sharing is expected to influence only network costs (deployment and operation) and it can be assumed that this assumption is met. The next assumption is no effect on the pre-treatment population, that is the treatment did not affect the population in the pre-treatment period. This is trivial because mobile network sharing cannot affect operators unless they participate. The common trend assumption states that the differences in the expected potential non-treatment outcomes over time are unrelated to whether the operator belongs to the treatment group or control group. This may not hold since mobile operators are heterogeneous and may have different corporate cultures and/or competitive advantages. Nevertheless, the mobile industry is regulated to some extent and the common trend assumption would be likely to hold for a group of operators on average. Lastly, the common support assumption states that observations with constant characteristics exist in all four subsamples. This is assumed to hold because we have data for the pre- and post-treatment for both the treatment and the control groups.

IV. Results

The results, including the DID estimator derived from the analysis, are presented in Table 2 for OPEX and Table 3 for CAPEX.

Table 2. Results of the DID analysis on OPEX.

	DID estimator	Std. error	*P*-value	*N*	Adjusted R^2	*F*-test
Long-term OPEX						
Overall	−0.916	4.663	0.844	1,056	0.047	0.000
Site sharing	−6.448	5.146	0.211	480	0.091	0.000
RAN sharing	6.402	8.918	0.473	480	0.095	0.000
National roaming	−19.796	6.085	0.001	320	0.111	0.000
Short-term OPEX						
Overall	−1.806	4.169	0.665	264	0.027	0.018
Site sharing	−4.322	4.964	0.386	120	0.073	0.008
RAN sharing	1.194	7.240	0.869	120	0.069	0.010
National roaming	−14.655	6.668	0.031	80	0.094	0.015

Table 3. Results of the DID analysis on CAPEX.

	DID estimator	Std. error	*P*-value	*N*	Adjusted R^2	*F*-test
Long-term CAPEX						
Overall	5.564	20.100	0.782	1,056	−0.003	0.989
Site sharing	33.850	28.090	0.229	480	−0.003	0.686
RAN sharing	−51.250	36.490	0.161	480	−0.002	0.573
National roaming	−12.949	38.623	0.738	320	0.035	0.003
Short-term CAPEX						
Overall	−6.823	13.565	0.615	264	−0.002	0.458
Site sharing	−20.621	17.126	0.231	120	0.039	0.055
RAN sharing	17.640	26.650	0.509	120	−0.021	0.916
National roaming	−36.080	19.240	0.065	80	0.068	0.040

The results suggest that RAN sharing increased OPEX relatively (the DID estimator is positive), while the other types of sharing decreased it relatively (the DID estimator is negative). However, only national roaming was statistically significant for both the short run and the long run. On average, national roaming yielded a 14% relative reduction in OPEX in the short run (the DID estimator is −14.66) but a 19% relative OPEX reduction in the long run (the DID estimator is −19.80).

Since the models have good *F*-test statistics, it is most likely that the time variable (before/after mobile network sharing) and the treatment variable (that is, indicating merely whether the operator has implemented mobile network sharing or not regardless of the timeframe considered) had a more statistically significant effect on the OPEX reduction than the differential effect of implementing mobile network sharing over time.

For CAPEX, the results suggest that site sharing increased CAPEX relatively (the DID estimator is positive), while the other types of sharing decreased it relatively (the DID estimator is negative). However, national roaming was statistically significant in the short run only. This means that national roaming yielded a 36% relative reduction in CAPEX on average in the short run (the DID estimator is −36.08).

Since five cases have *F*-test statistics over 0.1, this suggests that the DID model itself was statistically insignificant for explaining mobile CAPEX trends. That is, the time variable (before/after mobile network sharing), treatment variable (whether the operator is in the treatment group or the control group), and differential effect of implementing mobile network sharing over time were all not statistically significant. This means that other factors influenced the mobile CAPEX trends of the five cases more strongly than the variables mentioned.

For the other three cases (short-run site sharing, long-run national roaming, and short-run national roaming), it is most likely that the time variable and treatment variable had more statistically significant effects on CAPEX reduction than the differential effect of implementing mobile network sharing over time.

V. Discussion

The results indicate that only national roaming was able to yield a relative CAPEX reduction in the short run as well as a relative OPEX reduction in both the short run and the long run, while the other cases did not yield statistically significant relative OPEX/CAPEX reductions.

For CAPEX in general, the total cost of ownership (TCO) nature of mobile operators should be highlighted, where equipment costs account for approximately 25% [23]. Since sharing agreements do not necessarily reduce the whole 25% but only partially reduce the equipment cost, other factors such as changes in network design and the adoption of new technology may have offset the CAPEX reduction effect of mobile network sharing. In addition, the investment cycles for operators may differ: an operator involved in network sharing may start/have started investment in networks, while its counterpart in the control group may have already finished investment. This means that even if network sharing reduced *total* network investment, this may not be captured in the dataset. Furthermore, the potential cost reduction due to economies of scale may not have been significant.

For OPEX in general, given the TCO nature of mobile operators mentioned above, other factors such as marketing expenses may have constituted a greater proportion of OPEX than network operations. Furthermore, network sharing inevitably involves a degree of complexity in operations as it requires inter-vendor cooperation in addition to inter-operator cooperation. This may have contributed to higher OPEX.

Specifically, the result that RAN sharing did not yield a statistically significant OPEX reduction could be attributed to the operational and technical complexities that offset the OPEX reduction. Firstly, according to Village and others [6], operators can optimize coverage by adjusting the beam tilt of the antenna and many operators use this technique to engineer particular coverage in certain areas. RAN sharing, however, would require participating operators to abide by the same tilt and therefore result in worse coverage for at least one operator than in the no-sharing scenario. Secondly, RAN sharing may require all participating operators to agree on how exception situations would be handled [10]. Furthermore, interoperability between equipment from different manufacturers and possibly interoperability between different RNCs (during handover) would require inter-vendor cooperation and development, which increases the complexity [5].

The statistically significant effect of national roaming can be attributed to its nature, since only one operator of the agreement has coverage in a region rather than two operators consolidating already deployed infrastructure. This simplifies operation compared with other types of network sharing as there is no need to consolidate pre-existing infrastructure. Indeed, Bartlett and Jackson [10] find that national roaming offers the greatest potential cost savings compared with other mobile network sharing types. The statistically significant CAPEX reduction of

https://doi.org/10.4218/etrij.2017-0175

national roaming in the short run may be due to the nature of its implementation in the past. As described in Section II, national roaming has typically been used to enable new entrants to enter the market. Over time, the new entrant would complete nationwide deployment and provide service over its own network. Therefore, the CAPEX saving is for the short term only because, in the long run, the new entrant still needs investment to deploy its own network.

Readers should be aware that the analysis is for 2G and 3G networks and that the feasibility may differ for 4G and 5G. Indeed, for 5G, architectural changes and spectrum bands make network sharing prospective. 5G is likely to be offered on a higher-frequency radio spectrum above 6 GHz and as high as 300 GHz. This means that cell offers a smaller radius of coverage; hence, achieving widespread coverage may be challenging in terms of cost of deployment and operation [24]. While technologies such as Massive MIMO and beamforming can increase coverage, they also incur higher costs. Consisting of more base stations and consequently more sites means that site acquisition and maintenance costs are greater. For example, Meddour and others [5] find that site and passive elements account for 20% of deployment costs. In this context, site sharing could be an attractive solution in the 5G era, as it also comes with less complexity than other types of mobile network sharing because it requires minimal inter-vendor cooperation [10]. In addition, the introduction of Network Function Virtualization and Software Defined Networking in cellular networks could boost the potential of mobile network sharing, as they enable the creation of multiple virtual networks on top of a single physical network.

VI. Conclusions

1. Technology and Standards Development

Only national roaming yields a statistically significant reduction in OPEX and CAPEX according to the results. This means that technologies supporting national roaming are relatively mature and that technology and standards development efforts should focus on reducing the OPEX and CAPEX of network sharing types other than national roaming.

Focusing on OPEX, an analysis by Analysys Mason provides a hint on the directions for future technology research for effective mobile network sharing [25]. For both developed and emerging markets, the top four factors contributing to OPEX are land rent, hardware and software support, power/electricity, and backhaul. While land rent is not significantly affected by technical advances, the other three factors can be reduced by technological development. To reduce hardware and software support, automation and flexible operation and maintenance should be encouraged. The network should also become more energy-efficient to reduce power/electricity consumption. Finally, the backhaul network should be able to accommodate sharing more cost-effectively.

In addition, the TCO breakdown of Meddour et al. [5] provides further guidance. This indicates that the active elements of the RAN account for 60% of the TCO, site and passive elements 20%, and the core network 20%. Since the RAN accounts for almost 80% of the TCO (including both active and passive elements), economies of scale should be maximized by network sharing in RAN development.

2. Network Deployment Implications

National roaming should be endorsed for nations/operators interested in minimizing the network deployment cost to allocate capital to other priorities. However, although national roaming has great cost reduction benefits, it may hinder competition as no other infrastructure operator may be able to compete in an agreement region. For instance, the operator may be the sole operator in the nation providing service, as all operators servicing in the nation are in that single national roaming agreement. Therefore, regulatory bodies must carefully balance the benefits of cost reductions to the mobile ecosystem and the costs of competition hindrance.

3. Limitations and Future Research

A major limitation of this research is that the OPEX and CAPEX data do not fully represent the network OPEX and CAPEX, respectively. Nonetheless, as discussed earlier, these data are the best proxy as no more details are disclosed by mobile operators. Future research may focus on network CAPEX data disclosed by mobile operators, although the scope would have to be limited to network investment only.

Another limitation of this research is that it focuses only on the technological aspects of mobile network sharing. However, business aspects (for example, joint ventures, third party hosting) do also play a major role in the success of mobile network sharing. Therefore, the evaluation of the effects of mobile network sharing from different perspectives (business, geographic, and process) is suggested to identify the *best practice* combination for effective mobile network sharing.

Finally, network sharing effects may be analyzed based on whether the operator is an incumbent. This would be an interesting topic for future study as policy measures to endorse mobile network sharing may need to accommodate an operator's market power.

References

[1] J. Markendahl, "*Mobile Network Operators and Cooperation*," Ph.D. Thesis, Stockholm, Sweden: KTH, 2011.

[2] Y.K. Song, H. Zo, and S. Lee, "Analyzing the Economic Effect of Mobile Network Sharing in Korea," *ETRI J.*, vol. 34, no. 3, June 2012, pp. 308–318.

[3] B.G. Mölleryd, J. Markendahl, J. Werding, and Ö. Mäkitalo, "Decoupling of Revenues and Traffic – Is There a Revenue Gap for Mobile Broadband?" presented at the *9th Conf. Telecomm. Media Internet*, Ghent, Belgium, June 7–9, 2010, pp. 1–7.

[4] T. Frisanco, P. Tafertshofer, P. Lurin, and R. Ang, "Infrastructure Sharing for Mobile Network Operators," presented at the *Int. Conf. Inform. Netw.*, Busan, Rep. of Korea, Mar. 21, 2008, pp. 1–5.

[5] D.E. Meddour, T. Rasheed, and Y. Gourhant, "On the Role of Infrastructure Sharing for Mobile Network Operators in Emerging Markets," *Comput. Netw.*, vol. 55, no. 7, 2011, pp. 1576–1591.

[6] J.A. Village, K.P. Worrall, and D.I. Crawford, "3G Shared Infrastructure," presented at the *Third Int.Conf. 3G Mobile Commun. Technol.*, London, UK, May 8–10, 2002, pp. 10–16.

[7] J. Hultell, K. Johansson, and J. Markendahl, "Business Models and Resource Management for Shared Wireless Networks," presented at the *IEEE 60th Veh. Technol. Conf.*, Los Angeles, CA, USA, Sept. 26–29, 2004, pp. 3393–3397.

[8] J.P. Pereira and P. Ferreira, "Infrastructure Sharing as an Opportunity to Promote Competition in Local Access Networks," *J. Comp. Netw. Commun.*, vol. 2012, 2012, pp. 1–11.

[9] T. Li and L. Bai, "Model of Wireless Telecommunications Network Infrastructure Sharing: Benefit-Cost Analysis," presented at the *Int. Conf. Inform. Manag. Innov. Manag. Ind. Eng.*, Shenzen, China, Nov. 26–27, 2011, pp. 102–105.

[10] A. Bartlett and N.N. Jackson, "Network Planning Considerations for Network Sharing in UMTS," presented at the *3G Mobile Commun. Technol.*, London, UK, May 8–10, 2002, pp. 17–21.

[11] O. Foros, B. Hansen, and J.Y. Sand, "Demand-Side Spillovers and Semi-Collusion in the Mobile Communications Market," *J. Ind. Competition Trade*, vol. 2, no. 3, Sept. 2002, pp. 259–278.

[12] B.W. Kim and S.H. Seol, "Economic Analysis of the Introduction of the MVNO System and Its Major Implications for Optimal Policy Decisions in Korea," *Telecommun. Policy*, vol. 31, no. 5, 2007, pp. 290–304.

[13] V.M. Ribeiro, "Exclusion and Regulatory Intervention in Investment Sharing Agreements," *Telecommun. Policy*, vol. 40, no. 10–11, Oct. 2016, pp. 1032–1051.

[14] C. Cambini and V. Silvestri, "Investment Sharing in Broadband Networks," *Telecommun. Policy*, vol. 37, no. 10, Nov. 2013, pp. 861–878.

[15] E. Obiodu and H. Anisetti, "*Mobile Network Sharing Deals Analyzer: 2h11–1h12 (Ovum)*," OVUM, 2012.

[16] O. Peters and S.B. Allouch, "Always Connected: A Longitudinal Field Study of Mobile Communication," *Telematics Inform.*, vol. 22, no. 3, Aug. 2005, pp. 239–256.

[17] W.R. Shadish and T.D. Cook, "The Renaissance of Field Experimentation in Evaluating Interventions," *Annu. Rev. Psychol.*, vol. 60, Jan. 2009, pp. 607–629.

[18] T.D. Cook, "'Waiting for Life to Arrive': A History of the Regression-Discontinuity Design in Psychology, Statistics and Economics," *J. Econometrics*, vol. 142, no. 2, Feb. 2008, pp. 636–654.

[19] M.R. Ward and G.A. Woroch, "The Effect of Prices on Fixed and Mobile Telephone Penetration: Using Price Subsidies as Natural Experiments," *Inform. Economics Policy*, vol. 22, no. 1, Mar. 2010, pp. 18–32.

[20] S.H. Hong, "The Recent Growth of the Internet and Changes in Household-Level Demand for Entertainment," *Inform. Economics Policy*, vol. 19, no. 3–4, Oct. 2007, pp. 304–318.

[21] F. Waldinger, *Differences-in-Differences*, London, UK: LSE, 2017, pp. 1–55.

[22] M. Lechner, *The Estimation of Causal Effects by Difference-in-Difference Methods*, Breda, the Netherlands: Now Publishers Inc., 2011, pp. 165–224.

[23] Frost & Sullivan, "*Wireless Technology: Breaking the Limits of TCO Reduction in Mobile Networks*," Texas, USA: Frost & Sullivan White Paper, 2011.

[24] GSMA Intelligence, "*Understanding 5G: Perspectives on Future Technological Advancements in Mobile*," London, United Kingdom: GSMA Intelligence, 2014.

[25] Analysis Mason, "*Market Research Report: Emerging Market Opportunities*," London, UK: Analysis Mason, 2010.

Dongwook Kim acquired his MS in Management Science at KAIST, Daejeon, Rep. of Korea, in 2012. After graduating from KAIST, he joined the R&D division of Korea Telecom in Seoul, Rep. of Korea, working in the field of network technology strategy. In the department of technology strategy in the R&D division, he evaluated mobile network sharing, different network technologies for IoT application, and hologram technology for next-generation media services. In 2015, he started working at GSMA as an interconnections technical expert, specializing in interconnections between mobile networks. In 2017, he became a 5G project manager, analyzing interoperability issues in the introduction of 5G networks and technologies to enhance network economics. Since 2016, he has been pursuing a PhD at the Graduate School of Innovation and Technology Management at KAIST.

Sungbum Kim is an assistant professor of IT convergence at the Kumoh National Institute of Technology, Gumi, Rep. of Korea. He acquired his PhD from the Graduate School of Innovation and Technology Management at KAIST, Daejeon, Rep. of Korea in 2013. Before joining KAIST, he worked at LG Electronics as a product planning senior manager of mobile handsets since 2000. His specialty includes business strategy and future forecasting of mobile communications, entrepreneurship, and innovation. He has also collaborated with public research institutes to facilitate the commercialization of intellectual property.

Hangjung Zo is an associate professor of IT management in the School of Business and Technology Management at KAIST, Daejeon, Rep. of Korea. He gained his PhD in IT management from the University of Wisconsin-Milwaukee, USA. His research interests include digital social innovations and the impacts of digital technology on business and society. His papers have appeared in *IEEE Transaction on Systems Man and Cybernetics*, *Decision Support Systems*, *Journal of Business Research*, *Electronic Commerce Research and Applications*, and *Computers and Education*, among others. He is the director of the Research Institute for Social Technology and Innovation at KAIST.