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Efficiency of Mobile Network Operators from a Data Service Perspective

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Abstract

The ubiquity of mobile devices such as smartphones, laptops, tablets, and mobile routers drives unprecedented mobile data traffic every year. However, the actual mobile data usage per subscriber or data volume delivered to the subscriber varies significantly between operators and nations. Understanding the reasons behind these differences is important for the mobile network operator's evolving business and telecom regulation in general. Towards this goal, this study analyzes the efficiency of delivering data services (data usage by subscribers) of 94 mobile operators from 28 countries through the method of data envelopment analysis (DEA). The study also provides a case study of the highly efficient but also very dissimilar data service markets of Finland and India. Overall, the results illustrate that many countries have a single highly efficient MNO due to its effort for market share growth (i.e. a disruptive operator). While in other countries all MNOs displayed good efficiency likely due to country level initiatives. Furthermore, majorly economic disparities between countries highly affect the differences in efficiency scores at the country level. The case study between Finland and India shows the causes for differences in mobile data services from the view of regulation policies, spectrum management, market competition and economic disparities.

Keywords: Data envelopment analysis, efficiency, mobile network operator (MNO), data services

1 Introduction

The first hand-held mobile phone was invented in 1973, subsequently there has been a rapid advancement in mobile phone and communication technologies. The growth of cellular devices has spurred demand for more and more mobile data across the world. Many factors are supporting this demand including rapid commodification and adoption of smartphones along with the explosion of mobile applications, development of IoT and connected smart home devices. Specifically, Ericsson estimates that by 2023 total mobile data traffic will increase seven-fold compared to 15EB/month in 2017 (Ericsson, 2018). However, this data usage is not equally distributed across nations or operators. For instance, in 2017, the average mobile data usage per subscription (sub) per month in OECD countries was 2.94 GB, with the highest usage of 15.45 GB in Finland and lowest usage of 0.72GB in Slovakia (OECD, 2017). Whereas, even within a single country, such as Austria, differences between operators can be substantial. For the main three Austrian operators, the data per sub per month volumes are 15.4 GB, 4.69 GB, and 3.4 GB. Given these differences, performance evaluations of various operators are important.

More generally, efficiency is an illustrative indicator in assessing business performance. Efficiency based on performance is relative to the organization's deployed or utilized resources to achieve that performance. Such metrics can help in finding the best strategies and regulatory policies for the mobile telecom sector. In this context, the DEA method is a frequently used non-parametric approach to assess productive efficiency.

Previous research has studied the telecommunication industry's efficiency by applying DEA to the telecommunications domain. These studies have focused on comparing the efficiencies of operators at the national level (Debnath & Shankar, 2008; Masson et al., 2016), regional level (Salleh et. al, 2012; Hu et al., 2018), economic group level (Liao & González, 2009; Lien & Peng, 2002), or world level (Tsai et al., 2006; Hung & Lu, 2007). All these prior studies used financial parameters as the main operational performance measures for the DEA model. In other words, no prior study has applied DEA for measuring the performance of MNOs in delivering data services with data service parameters.

Given this context, this research estimates the performance of MNOs in delivering such data services using non-financial parameters including the amount of spectrum and number of subscribers. Furthermore, the analysis, in turn, helps to illuminate the reasons for data usage differences at the operator and country level. Furthermore, the research provides an example case study of performance differences between a developed nation (Finland) and a developing nation (India) to give further insights such as variations in business strategies, market behaviors, subscription patterns, technology upgrade patterns and regulation policies.

The remainder of this research paper is organized as follows. Section 2 presents a literature review, which consists of the importance of non-financial parameters in performance assessment and application of DEA in the telecommunication industry. Section 3 describes the DEA method and variables adopted. Section 4 explains the empirical results and comparing the operating strategies of MNOs in the provisioning of data services. Section 5 summarizes the research conclusions. Finally, section 6 outlines future work.

2 Literature review

Previous research studies have studied the efficiency of telecommunication industries by applying DEA method. These studies focused on different areas such as world level, economic group level, regional level, and national level.

At world level, (Tsai et al., 2006) compared the ranking of 39 mobile operators listed in the 2003 Forbes list with their productive efficiency, where authors found that Forbes rankings and productive efficiency rankings of mobile operators are not identical. In addition, (Hung & Lu, 2007) attempted to find the managerial performance of 36 global telecom operators. In which, these operators grouped based on the regions and learned that European telecom operators were performing better than the operators in Asia-pacific and America. In addition, state-owned firms operated better than private telecoms. In another study, (Ruiz et al., 2010) benchmarked 24 Fortune 500 ranked global telecom operator's performance using context-dependent DEA. They grouped operator's efficiency into various levels of efficiency frontier and analyzed the firm's operating performance further.

Some studies focused on economic group levels such as OECD, APEC, and BRICS. (Giokas & Pentzaropoulos, 2008) and (Lien & Peng, 2002) used OECD published telecommunications data and calculated the efficiency of the telecommunications at the country level. In which, (Giokas & Pentzaropoulos, 2008) used 30 member states data and analyzed performance in four different groups. Eight countries found efficient ones and concluded the results with finding requirements

needed to improve the efficiency of low performed states in relation to the policy implications. (Lien & Peng, 2002) used 24 OECD countries data from 1980 to 1995 and found that the competition in the telecommunication industry to be linked with escalated production efficiency. At APEC level, (Hu & Chu, 2008) investigated that efficiency improvement influenced heavily by scale and scope economies, whereas market competition and privatization impact on performance were not at a considerable level. In this study, the authors used 24 telecom firms' data for the period 1999-2004 in APEC member economies. In some other study, (Liao & Lien, 2012) reviewed the performance of 16 major operators in APEC countries. In this study, results show that higher efficiency achieved by the operators with high penetration rate and this efficiency not related to their revenue and policy implications. (Liao & González, 2009) performed DEA analysis on ten major mobile operators in BRIC nations to find operational efficiency. In which, authors observed full operational efficiencies achieved by few operators irrespective of differences in their revenue scales.

At the regional level, specifically in Asia-pacific region, (Hu et al., 2018) appraised the efficiency of 17 major telecom operators, where authors used efficiency scores to explore the performance of mobile operators in relation with country's fixed-line penetration rate. Based on this penetration, they categorized companies into mobile jumping countries and non-mobile jumping countries. The results indicated that companies in the lower fixed-line penetration achieved total asset efficiency than their counterparts. In addition, Salleh et al. considered DEA based efficiency analysis to inspect the impact of corporate mergers and acquisitions (M&A) on the operator's performance in Association of Southeast Asian Nations (ASEAN) countries (Salleh et al., 2012). (Pentzaropoulos & Giokas, 2002) performed the benchmark of operators in the European region, in which 19 public telecommunications organizations considered and explored that operational efficiency can be achieved irrespective to the revenue size.

When it comes to a country level, Masson et al. and Debnath et al. scrutinized the performance of Indian mobile operators (Masson et al., 2016), (Debnath & Shankar, 2008). Masson et al. observed that companies with higher operational efficiency and effective service had achieved greater profitability. Whereas, Debnath et al. used parameters related to the quality of service delivery and reviewed the performance.

More than 90% of the above researches used account-based measures either fully or partially. Account-based measures have been using to assess the performance of a firm for a long time. However, the advent of competitive nature actualities such as quick response to customer expectations, improved customization, flexible to deliverables, quality over price and new manufacturing processes are questioning the adequacy of account-based performance measurement methods (Chow et al., 2006). Several authors highlighted the importance of non-financial elements in the firm's performance (Ittner & Larcker, 1998; Kaplan & Norton, 1992; Chow et al., 2006; Banker et al., 1998). These elements like the quality of the product or service, user satisfaction, and market share have been using by numerous companies to assess and reward managerial performance (Ittner & Larcker, 1998). Besides, rewards connected to future financial performance and this ignited by innovation, quality and customer satisfaction, which are the outcomes of managerial actions (Kaplan & Norton, 1992; Hauser et al., 2008). Additionally, customer satisfaction significantly associated with future financial performance (Banker et al., 1998).

This reflects the importance of performance measurement using non-financial parameters. As the objective of this study is finding the reasons for dissimilarities in data usage with respect to

managerial actions of MNOs and policy implications, the efficiency measured using non-account based measures. There have been studies where DEA has employed for finding the efficiency of a firm exclusively using non-financial parameters. Dénes et al. used DEA with non-financial measures for finding the performance of rehabilitation departments and explored operational shortcomings in these departments (Dénes et al., 2017). The non-financial approach followed in another service industry where the performance of Latin-American airline companies measures (Charnes et al. 1996). Alam et al. used the DEA method to find the relation between operational technical efficiency of the US airline industry and its stock market returns, where they used non-account-based measures (Semenick Alam, 1998). In the telecommunication industry, (Debnath & Shankar, 2008) used non-financial measures related to mobile services quality such as faults, success rate, drop rate, delay, complaints and subscribers for finding the performance in service quality.

3 Methodology and data

3.1 CCR-DEA method

DEA is a non-parametric mathematical method that allows multiple inputs and multiple outputs concurrently to calculate a single inclusive efficiency measure. The basic DEA method was introduced by Charnes, Cooper, and Rhodes (CCR) in 1978 based on the seminal work of Farrell (Charnes et al., 1978). DEA defines the efficiency as a weighted sum of outputs to the weighted sum of inputs for each decision-making unit (DMU) (which means a firm or a production unit under measure). A DMU with an efficiency of one is considered an efficient unit while an efficiency less than one is considered inefficient. A DMU selects its optimal weight that maximizes its efficiency under the condition that the calculated efficiency should not exceed one. The DEA method is widely used in the telecommunication industry, as discussed in section 2. In this section, a brief review of the basic DEA model provided.

The objective of the CCR-DEA model is to maximize the efficiency of a DMU j from among a set of n DMUs by selecting the input and output weights related to the inputs and outputs. The linear programming model is formulated as:

$$\max h_0 = \sum_{r=1}^s u_r \cdot y_{r0}$$

s. t.

$$\begin{aligned} \sum_{i=1}^m v_i \cdot x_{i0} &= 1 \\ \sum_{r=1}^s u_r \cdot y_{rj} - \sum_{i=1}^m v_i \cdot x_{ij} &\leq 0; j = 1, \dots, n \\ u_r, v_i &\geq 0; r = 1, \dots, s; i = 1, \dots, m \end{aligned}$$

Where, x_{ij} and y_{rj} are j^{th} DMU's inputs and outputs and each of n DMUs: DMU_1, \dots, DMU_n with m inputs: x_1, \dots, x_m and s outputs: y_1, \dots, y_s are considered. Additionally, v_i and u_r are the input and output weights (or) multipliers respectively.

The dual model of above formulation is:

$$\min \theta - \epsilon \sum_{i=1}^m S_i^- - \epsilon \sum_{r=1}^s S_r^+$$

s. t.

$$\begin{aligned} \theta \cdot x_{io} - \sum_{j=1}^n \lambda_j \cdot x_{ij} - S_i^- &= 0; i = 1, \dots, m \\ \sum_{j=1}^n \lambda_j \cdot y_{rj} - S_r^+ &= y_{r0}; r = 1, \dots, s \\ \lambda_j, S_r^+, S_i^- &\geq 0; j = 1, \dots, n; i = 1, \dots, m; r = 1, \dots, s \end{aligned}$$

The dual (envelopment form) model in CCR method (Charnes et al., 1978) is typically more appropriate. In DEA, generally, the number of DMUs n is larger than the inputs and outputs sum $m+s$. Thus, the dual form is easier to solve (with $m+s$ constraints) than the primal (with n constraints). Further, solutions obtained from the dual model are easy to interpret than the primal solutions. The results from the dual model also help inefficient units by indicating the improvement options.

In this study, we first adopt the CCR-DEA method to analyze the relative efficiencies at the operator level by using each operator's data. Next, we aggregate the operator-level data to get country-level data and then apply CCR-DEA method at the country level.

3.2 Input and output pointers

In order to measure the efficiency of MNOs using the proposed model, we first select the inputs and outputs associated with data services. Total data volume (transferred over the network) is a primary indicator of the delivery of data services. Furthermore, for customers, data volume is the second most important consideration after the data service price (Arcelus et al., 2014). Thus, the selected output is the total data volume (transferred over the network). This output is produced as a function of the number of connections using the operator's spectrum (the main transfer medium). Accordingly, we used the number of total connections and spectrum associated with each DMU as two inputs in the study. We used the term "number of connections" which referred as all the subscriptions hold by a MNO irrespective of subscriptions category such as SIMs, e-SIMs, prepaid, postpaid, business customers, cellular IoT and any other.

3.3 Data collection and availability

Many MNOs do not publicly publish the total data volumes within their network. This is a key challenge in data collection and restricts the number of MNOs considered, which in turn limits the number of countries for the study. Countries were selected for the study based partly on the availability of input and output data for all the MNOs of that country. All the MNOs selected in a country holds more than 90% of market share cumulatively, which would help us further to examine the differences at the country level. The data available for a limited number of operators in a particular country is not considered in the study, as it would not reflect the performance differences at the country level. Finally, 94 MNOs from 28 different countries data used for the study.

This research employed an external secondary data collection approach to acquire the selected inputs and outputs data for each DMU. Further, the required data is not available in a single database source. Thus, several different sources were used. The main sources used for the collection of each input and output are listed in *Table 1*. The data set used in this study belongs to the year 2017.

Table 1 Summary of sources used for each input and output variables and other variables

Variable	Source
Number of connections (x_1)	Operator reports GSMA intelligence database
Spectrum (x_2)	ECO Frequency Information System (EFIS) for European operators Asia Pacific Telecommunity for Asia-Pacific operators Operator reports Spectrummonitoring.com
Data volume (y)	Operator reports Regulator reports GSMA intelligence database Tefficient analyses Calculations (Missing operator data is calculated by subtracting all other reported operators data from the country's total data)

4 Empirical results and discussions

4.1 Descriptive statistics and correlation coefficient of data

Descriptive statistics of the input and output variables including mean, standard deviation, median, minimum and maximum are detailed in *Table 2*. The maximum values of connections and data usage are from a Chinese operator and maximum spectrum value is from an Austrian operator. Whereas, the minimum number of connections and data usage are from Icelandic operators and minimum spectrum value from an Indian operator.

Table 2 Descriptive statistics of the input and output variables

Variables	Obs.	Mean	Std. Dev.	Median	Min	Max
Connections (x_1) (In millions)	94	45.11	132.86	10.26	0.149	1116
Spectrum (x_2) (in MHz)	94	159.95	57.91	168.8	47.38	322.6
Data volume (y) (in PB)	94	1023	2181	244	4.24	15140

Table 3 illustrates the correlations between the inputs and output variables. Unsurprisingly, connections and data volume are strongly positively correlated. Whereas, spectrum and data volume are very weakly negatively correlated. This suggests that spectrum scarcity might not be a major constraint in increasing data volumes delivered to the customers. 5G literature discusses increasing data volume density by 1000-fold as a key KPI of 5G. However, there is a possibility of

increasing the data volumes of current generation mobile networks by using the available spectrum for most of the MNOs.

Table 3 Correlation statistics between inputs and output variable

Variables	Data Volume (y)
Connections (x_1)	0.744 p=2.2e-16
Spectrum (x_2)	-0.145 p=0.163

4.2 Efficiency analysis at the operator level

4.2.1 Productive efficiency

Regarding operator efficiency, *Figure 1* illustrates the efficiency of mobile data service delivery for the 94 operators ranked by efficiency scores. Two operators, DNA (Finland) and Reliance Jio (India) are fully efficient. A further case study of these two operators and their dissimilar reasons for high efficiency is detailed in section 4.4. Also, notably, CK Hutchinson’s Three brand is very efficient in most of their countries of operation (e.g. Austria, United Kingdom, Denmark and Sweden). Therefore, illustrating that even big telecom groups can be widely efficient. *Figure 2* details efficiency of operators with the addition of a market share curve and ranked first by country of operation and then by descending order of market share. Interestingly, CK Hutchinson’s Three brand also shows low market share in many of their markets. Thus, their efficiency may be driven by their status as upstart operators.

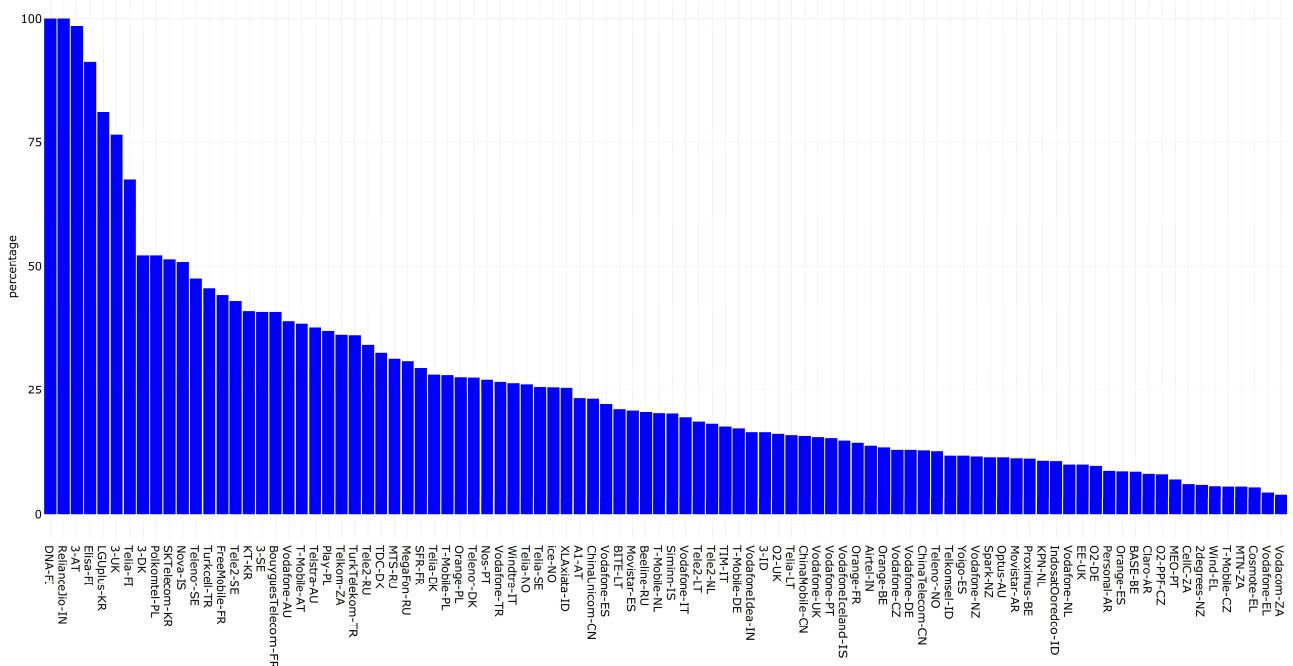


Figure 1 Efficiency scores of MNOs (ranked by value)

Furthermore, in many countries, a single operator dominates in terms of efficiency the other operators in the same country; this phenomenon is discussed further in section 4.2.2. Though, in several cases, the operators of a single country are about equally efficient (e.g. Argentina, Belgium, China, Czech, Greece, Italy, Lithuania, New Zealand, and Russia). We hypothesize that this behavior may be due to strong regulatory policies.

4.2.2 Efficiency vs market share

We observe several cases where one MNO dominates in data service efficiency in comparison to the counterparts from the same country. In order to explain this behavior, we take market share as an alternative performance measure (again see *Figure 2*). In 14 of 28 countries, the highly efficient MNO holds less market share. Furthermore, in nine countries (including Austria, Finland, India, etc.) the highly efficient MNO is at least 10% more efficient than the second-best operator. We hypothesize two reasons for this phenomenon.

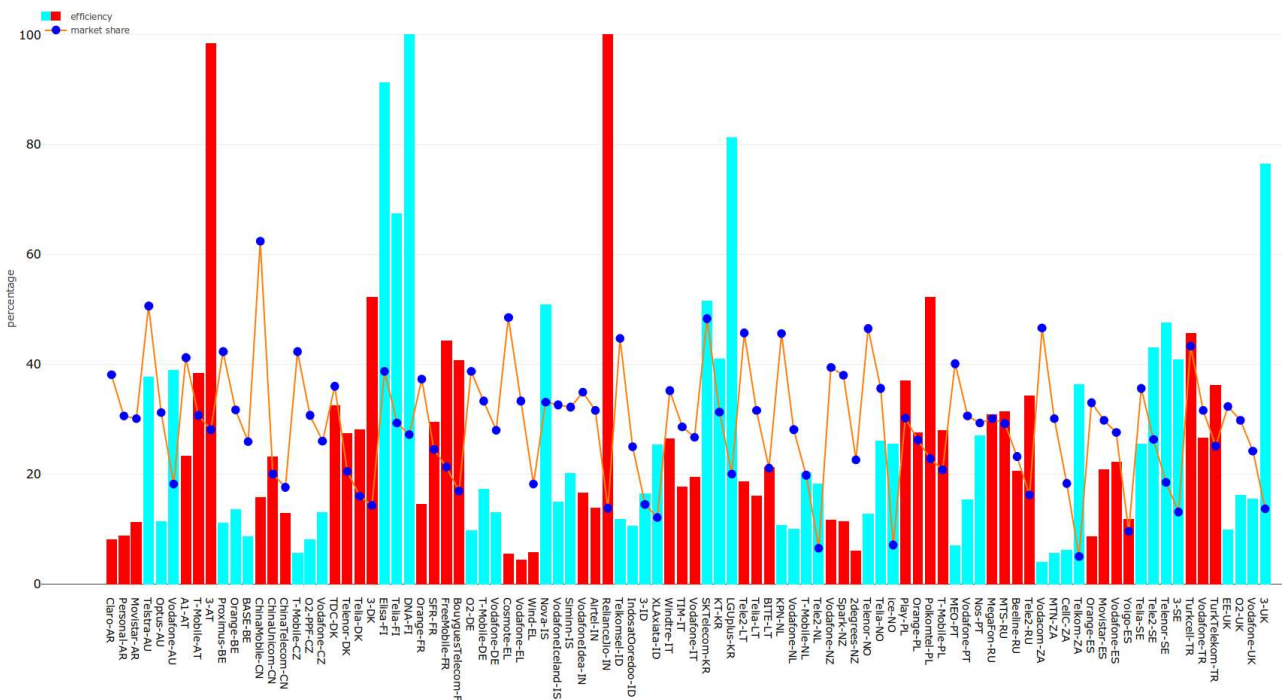


Figure 2 Efficiency scores and market shares of MNOs (ranked by country alphabetically)

Firstly, all these operators are either the newest entrant or second newest entrant in their respective markets. In general, this gives a late-mover advantage as the new entrant can use the newest network technologies (3G and 4G) directly. All the newest mobile technologies are mobile-data driven and significantly more efficient in delivering data services. Thus, the newest entrants benefit. Whereas, established operators must satisfy both older generation mobile technology users and the latest mobile technology users. This scenario is predominant in developing countries such as India and Indonesia. Traditional operators in these countries might try to offer similar data services to users due to severe competition. However, their efficiency scores in data services is not as good as opponents because of their older technology, customer base, and lower penetration of mobile broadband.

Secondly, new entrant MNOs, even in mature telecom markets, look to quickly increase their market share to gain legitimacy. The common approaches towards gaining market share are pricing, data limit, and quality-based strategies. Aggressive strategies with higher data limits (or unlimited) and lower pricing thus attract high data usage users from traditional operators. Synergistically, the combination of high data limits and cheap prices attracts younger customers that are more price sensitive and use more data. This churn both significantly increases usage of the entrant and decreases the usage of the traditional operator.

4.3 Efficiency analysis at country level

4.3.1 Productive efficiency

Figure 3 shows efficiency analysis results at the country level. Finland, India and Korea are fully efficient in mobile data service delivery at the country level. Further investigation suggests that Finland and Korea are efficient for similar reasons, whereas India is efficient for significantly different reasons. Specifically, Finland and Korea are forerunners in the global mobile telecommunications market. The success of countries is likely due to sustained effort towards the development of new mobile technologies.

Finland is a pioneer country in mobile communications with extensive coverage throughout the country. The major factors driving the highly efficiency include cooperative and fast adapting regulatory policies, high competition between MNOs, speed based rather than data volume based pricing, and high mobile over fixed broadband substitution.

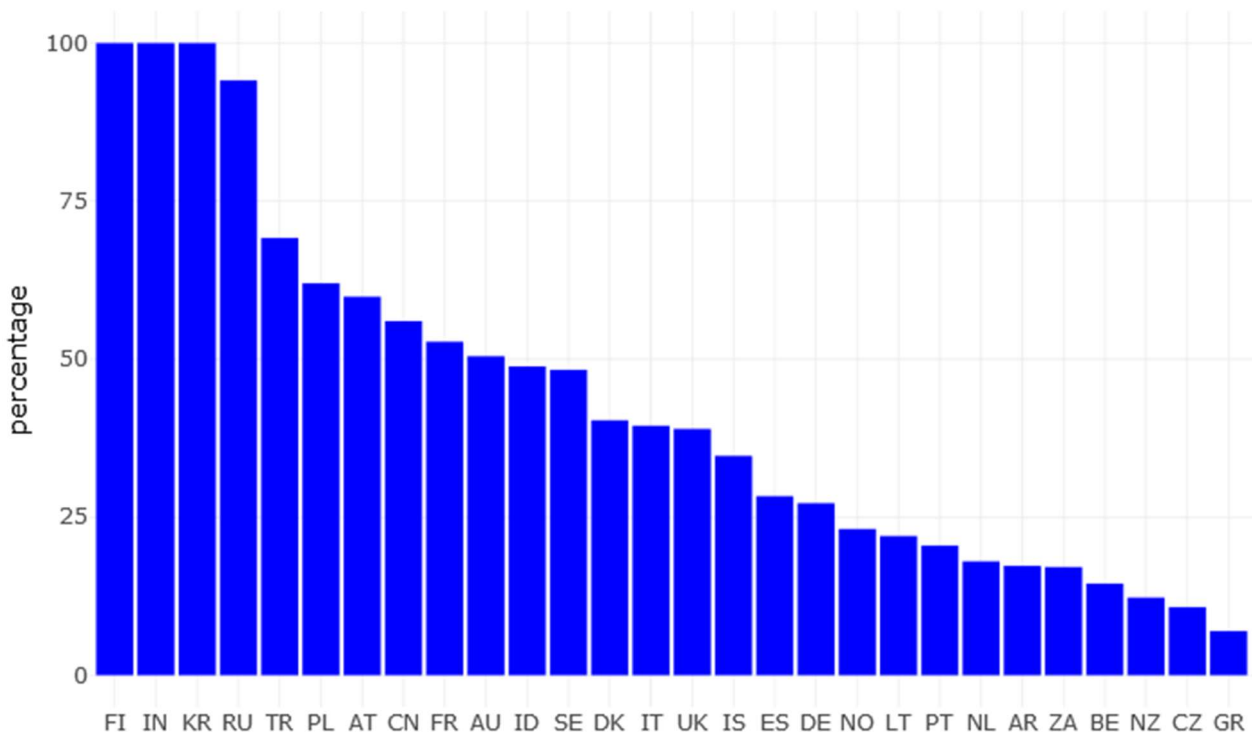


Figure 3 Efficiency scores of countries (ranked by value)

At a broader level, the reasons behind the efficient performance of Korea are the sociocultural environments, citizen participation, the participation of major players (primarily handset manufacturers Samsung and LG; Operators KT, LG U plus and SK; research institute ETRI) in the development, and continuous support initiatives from the government towards mobile revolution and industrial support policies (Jin, 2018). Particularly, the government initiated national infrastructure programs such as Cyber Korea (1999) to focus on providing resources for ICT systems and private investments and Korean Information Infrastructure (2015) to establish high-speed information infrastructure. Further, the government also supported both monetary and regulatory ways to promote broadband, ICT related R&D and standardization. Demographically, the Korean housing structure is densely populated, which made to provide broadband networks to 90% of the population without last mile delivery problem. At the same time, society acceptance also very high towards internet usage. Finally, extreme market competition between MNOs to grab new business opportunities through innovating alternative new products and services towards the rapid diffusion of mobile broadband services (Curran, 2018; Shin & Koh, 2017).

On the other hand, India is efficient due to MNOs using very little spectrum relative to the traffic volumes, the lack of alternative (fixed) infrastructure for internet access, and the very high efficiency of the single operator Reliance Jio. The differences between India and Finland are further discussed in section 4.4.

Despite these countries' efficiency, the effectiveness of the data service should also be quantified by the quality of service. One such quality measure is the average connection speed. As per Open Signal 2017 data, the average 4G data speed was 40.44 Mbps in Korea, 26.62 Mbps in Finland and 6.07 Mbps in India. Therefore, though India is efficient, the quality of that data service is quite a bit lower than Korea and Finland. This lower service quality could be partly explained by the lack of spectrum of Indian operators, specifically 3-fold less than the Korean operators and 4-fold less than the Finnish operators.

4.3.2 Efficiency vs fixed broadband subscriptions

We also examine the country's efficiency scores in relation to traditional fixed-line broadband penetration. *Figure 4* indicates that the efficiency score is weakly (non-significantly) negatively correlated with fixed-line broadband subscriptions per 100 people. Next, we compare and discuss several different countries regarding efficiency scores and fixed-line subscriptions.

For example, both Finland and Korea have high efficiency scores and high fixed-line subscriptions. Whilst Finnish and Korean customers are both large mobile data users, these two countries do have some significant differences. The edge is taken by mobile technology in Finland whereas Korea uses more fixed line networks for data needs. Accordingly, mobile broadband penetration in Finland is 1.4 times higher than Korea and Korea holds more fixed line subscriptions than Finland. Additionally, the price per GB of mobile data is 13 fold higher in Korea than Finland.

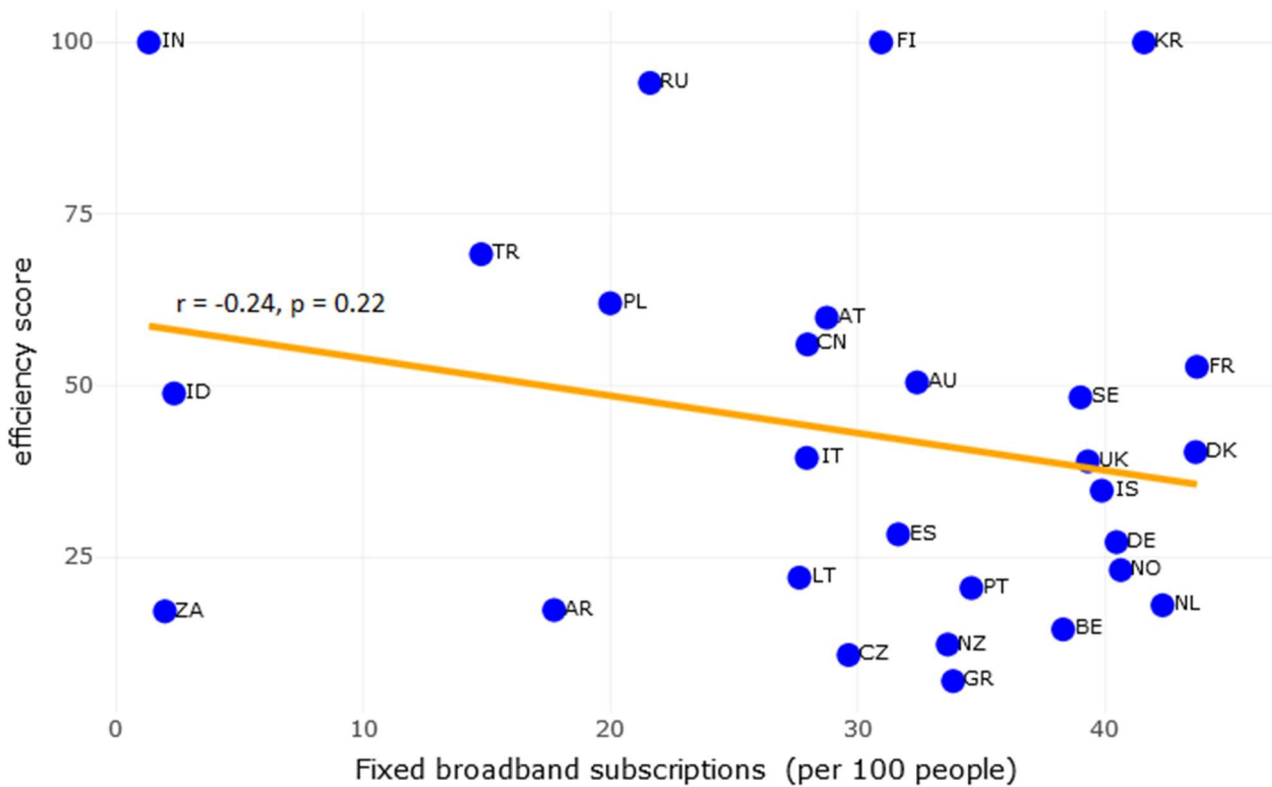


Figure 4 Comparison of country's mobile data efficiency scores with its fixed-line broadband subscriptions per 100 people

Many countries could be considered either mobile efficiency dominant, fixed subscription dominant or roughly central in both. About 23 out of 28 countries could fall under this category. Developing nations such as Russia and India heavily depend on mobile data and perform well due to low spectrum usage. Although, China is also a developing nation it performed similarly to most of the developed nations. The remaining 20 countries are developed OECD countries with a high mean GDP per capita of USD 44K and a high mean urbanization rate of 79% in 2017. These countries enjoy higher fixed broadband subscriptions (per 100 people) with a mean of 34. Specifically, from Figure 4, about 72% of developed economies have low efficiency scores (below 50%) and high fixed line subscriptions (with an average of 35 subscriptions per 100 people). This pattern indicates that customers in developed nations might depend on fixed-line broadband as an alternative to mobile broadband for their data needs. This might be one of the reasons for low performance of majority of OECD countries in mobile data efficiency.

Finally, roughly three countries have both low efficiency scores and low fixed-line subscriptions. These countries are developing nations with the GDP (PPP) per capita ranges from USD 12K to 20K. In these nations, the mobile broadband penetration and smartphone penetrations are above 90% and 76% respectively. These countries are demographically different with 92% urban population in Argentina and above 30% rural population in South Africa and Indonesia. Thus, Argentina could be able to provide more fixed line connections than the other two countries due to densely populated urban areas. Though, the three countries have good penetration of smartphones irrespective of demographic constraints, their mobile data usage per subscription is low. The customers are

restricted to low data usage because of high cost (USD 7.19) per GB in South Africa. Contrastingly in Indonesia users have been increasing their data usage because of low cost (USD 1.21) per GB.

4.4 Case study on efficiencies in Finland and India

The case study countries of Finland and India were chosen because these countries are fully efficient at the country level. Additionally, at the operator level the fully efficient operators of DNA and Reliance Jio operate in Finland and India respectively. In addition, other operators in Finland have achieved relatively good efficiency scores whereas no other operators in India achieved a good efficiency score. Thus, this suggests an interesting contrast.

More specifically, Finland's mean operator efficiency score is 86.25%, while India's mean operator efficiency score is 43.5%. Generally, Finland has strong technological advantages and effective policy implementations. While India has quite ineffective policy implementations. Furthermore, economically, Finland is a developed market and India is an emerging market. Next, we detail the differences between Finland and India with respect to regulatory policies, spectrum management, market situation, and economics.

a) Regulatory policies

Finland was one of the first countries to start deregulation of telecommunications and has been implementing such policies effectively and consistently. Consequently, the telecommunications regulatory reforms are mostly pioneering and favor market openness and free competition. As part of the EU, Finland implements the EU legislation widely. The ministry of transport and telecommunications (LVM) is responsible for regulation drafting, policy-making, guiding and supervising the operations of its agencies. Finnish regulatory body, Finnish Communications Regulatory Authority (FICORA) (now as TRAFICOM) as an agency under LVM is responsible for regulatory framework implementations, radio frequency allocations, and market competitions. The Finnish telecommunications market is transparent and non-biased. Encouraging political decisions, along with technical developments, have also helped Finland to succeed in telecommunications. However, a few major setbacks in policy implementations of late include deregulation of anti-bundling (Hazlett, Oh, & Skorup, 2018) and market-based assignment of the 2600MHz band (Sridhar et al., 2014).

In India, the regulatory body operations and policy implementations have fallen well short of expectations. A major reason is the duplication of regulatory activities between regulatory bodies, including Telecom Regulatory Authority of India (TRAI) and other bodies in Department of Telecommunications (DoT) (Hallur & Sane, 2018). Further, this duplication limits accountability. Even when the TRAI does initiate recommendations, they must pass through many bureaucratic levels and the original recommendations might not be approved as it is or might causes an interruption in the process (Sutherland, 2016). Additionally, political meddling in bureaucracy along with delays in merger & acquisition, spectrum scarcity, and poorly organized auctions also contribute to inhibiting the operator to provide seamless services across the nation (Curwen & Whalley, 2017). These studies illustrating the ineffective regulation policies but the impact of these policies on mobile data efficiency pattern need a further study in India.

b) Spectrum allocations and management

Regulatory policies pertaining to spectrum allocations is one of the fundamental and major differences between both countries. Sridhar et al. analyzed the differences between Indian and Finnish spectrum management policies extensively for mobile broadband services. According to their study, Finland regulator, FICORA has been allocating spectrum to the operators based on beauty contest method with a motive to develop new technologies and being a forerunner in technological evolution. Whereas, TRAI has been adopting an auction method, which is a market-driven mechanism and with a prime objective to increase the revenue from the telecom sector (Sridhar et al., 2014). Further, the spectrum allocation policies followed by India worked well to increase the competition and revenue generation for the government in the past. Nevertheless, eventually an overburden of high initial investments on the spectrum and low revenue generation deterred operators from investing in spectrum holdings and potentially delayed the deployment of new technologies.

Finland is also a forerunner in spectrum refarming efforts compared to India. Spectrum refarming brings greater spectral efficiency by using the spectrum with newer more efficient mobile technologies. Spectrum refarming is a very slow process in India partly because 64.67% (only 11% in Finland) of subscribers still depend on 2G services (GSMA, 2018), slow investments to replace older equipment and excessive spectrum fragmentation (in India spectrum is allocated differently based in 22 geographic circles rather than country wide).

c) Market situation and competition

The telecommunications market situation is entirely different pre and post entry of Reliance Jio in India. There were more than 10 operators before the entry of Jio into the market which then converged to oligopoly situation after Jio's entry with currently four major operators (95% market share) in the market. Jio entered the market by solely adopting the latest LTE technology with a predatory pricing model. Jio offered services to satisfy the needs of both traditional and technologically savvy mobile users. For traditional users, Jio offered unlimited voice calls using VoLTE as most customers in India rely on voice services. However, existing feature phones did not have VoLTE support. Thus, Jio offered low priced handsets with VoLTE support as part of its service packages. Additionally, it also offered 1GB/day mobile service to attract younger savvy customers. All these approaches helped Reliance Jio gain 281 million subscribers within two years of operation (Jio, 2019). Many established MNOs either merged, exited, or were acquired due to the fierce competition. The remaining MNOs were forced to offer similar packages as Jio or deploy entirely new business models. Customers benefitted from this market competition through mobile data services with higher capacities at cheaper prices. Overall, mobile broadband penetration and usage increased. However, the long-term profitability of Jio is uncertain and the operator (and in fact all major Indian operators) are currently lossmaking.

In contrast, Finland's mobile market is quite mature. However, the Finnish mobile market also confronted a similar situation previously. The situation in Finland was driven by Elisa's trailblazing mobile plans post-2010. Specifically, Elisa introduced unlimited mobile data plans with a flat pricing model, then other operators offered similar packages in the market due to the demand for high data volumes. Furthermore, Elisa launched plans based on speed tiers thus changing the axis of competition from data volume to data speed. This combination has driven huge traffic growth in

Finnish mobile networks. Additionally, Finnish MNOs have been forerunners in upgrading existing technologies and deploying new tech. For example, high network automation (auto-optimization) has become a necessity due to the combination of huge traffic growth and slow revenue growth. Other MNO initiatives include testbeds for 5G technology, carrier aggregation to increase the data capacity in LTE, IoT services through NB-IoT, and smart city pilot projects.

d) Economic differences

The mobile data services have the influence of economic differences between Finland and India. According to World Bank data, GDP per capita (PPP) of India was 6.5 times less than Finland for the year 2017. These economic differences are strongly related to mobile broadband penetration with a share of 30.39% in India and 162.86% at the end of 2017 (GSMA, 2018). However, the penetration is about five times less in India than Finland but the average price for 1GB of data is 0.26USD in India and 1.16USD in Finland (Cable, 2018). The low price of mobile data is also quite a significant factor in the efficiency achievement of India.

5 Conclusions

The main objective of this study was finding the reasons for dissimilarities in mobile data service efficiency at the operator level and country level through a performance analysis. The analysis adopted a CCR-DEA model to find the relative efficiency scores of 96 MNOs from 28 countries for 2017. The model used non-financial parameters including the number of connections and spectrum as input variables and data volume as the output variable.

The analysis revealed a flat relationship between an MNO's available spectrum and the data usage of their customers. In other words, only a few MNOs using their available spectrum efficiently while many others are simply holding large reserves of inefficiently used spectrum. These reserves could be effectively used in the future to deliver more data with current generation mobile technologies.

The analysis has also quantified the differences in mobile data efficiencies at the operator level. There are two important patterns that can be extrapolated from the results. In the first, a new entrant pushes to gain the market share and customer base utilizing a late-mover advantage by using new mobile technologies. This case is often found when only one operator in a country has a high efficiency score (e.g., Reliance Jio (India) and 3 (Austria)). In the second, regulation policies encourage innovation and adoption of advanced technologies. This is often found when all operators in a country have relatively good efficiency scores (e.g., in Finland and Korea).

Additionally, at the country level, developed nations (Finland and Korea) and a developing nation (India) are illustrated as efficient countries. Though part of the reason for these efficiencies might diverge between developed and developing countries. For example, some developing nations (e.g. India) are likely more efficient due to a lack of fixed-line networks that drives up mobile usage.

Finally, a case study between India and Finland further elucidated the differing reasons for the efficiency scores of MNOs in those countries. These reasons range from economic situations, market strategies, regulation policies, government initiatives, technology adoption, spectrum usage and alternative infrastructure for data usage.

6 Appendix

The sources referred for the statistics used in section 4 are listed in *Table 4*. These statistics are related to the terms such as market share of MNOs, country-wise GDP per capita (PPP), demographics, fixed-line broadband subscriptions per 100 people and price per GB of mobile data.

Table 4 Summary of sources used for the statistics used in section 4

Term	Source
Market share	GSMA intelligence database
GDP per capita (PPP), demographics and fixed-line broadband subscriptions per 100 people	The World Bank Data
Price per GB of mobile data	www.cable.co.uk (Cable, 2018)

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