Analysis of the role of international network effects on the diffusion of second and third generation mobile communication networks*

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Abstract
Using quarterly data of 58 countries, this paper provides empirical evidence that mobile phone diffusion from 2007 to 2009 is positively influenced by international network effects. Direct and indirect network effects are a result of the international standardization of telecommunication technologies, which allows consumers in a given country to benefit from other countries` networks by using international roaming services or imported handsets. We define international network effects as the installed base of mobile phone subscribers in countries different than the home country which uses the same technology, weighted by various distance metrics (i.e., geographic distance, trade value of mobile handsets and number of personal travelers between the home country and the partner countries.) To measure international network effects, we estimate a series of differentiated-products demand-system models of mobile phones by technology standard with international network effects. To overcome the endogeneity of mobile service price and international network effects, we propose two new instrumental variables (IV). In addition, we test if the impact on mobile phone diffusion differs whether technologies are local or global standards, or whether they are backward/forward-compatible. Based on our findings, we conclude that the large

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network effects of GSM (Global System for Mobile Communications) technology prevent the diffusion of third generation (3G) mobile phones. We show that the high 3G diffusion rates in Japan and Korea are not driven by state-of-the-art technology or high consumer preference, but by the absence of the GSM standard. Finally, to assess the effect of technology choice on welfare in Japan, we conduct a counterfactual analysis and demonstrate that if the GSM technology was introduced in Japan, it would increase Japanese monthly per-consumer surplus from $94.2 to $188.
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JEL Classifications; L15, L96, F10

1. Introduction

Network effects are defined as a situation in which the consumer's utility of adopting or using a product depends on the number of other consumers using the same product. The successful diffusion of new technologies or services in many industries such as telecommunications, video games, music, software or transportation, among others, depends greatly on network effects. According, to previous research by Doganoglu and Grzybowski (2007), network effects had a larger impact than price reductions on the diffusion of second generation (2G) mobile phones in Germany.

In this paper, we focus on the network effects in the 2G and 3G (third generation) mobile communications market. Our objective is to measure the international network effects using a wide sample of countries. The study of international network effects is important in order to understand the interconnection between the diffusion patterns of new technologies in different countries, as well as to confirm the existence of an increased feedback between installed base and quality of service in the current context of growing interdependence between countries. In particular, this topic has important implications for policies concerning international standardization and compatibility between technologies among different countries.

We define the international network effects of mobile telecommunications for each country as the number of subscribers of the same mobile telecommunication technologies in countries different than the home country. Along this paper, the econometric models using the said definition will be called "no weight" models. In addition, we will use the above mentioned installed base of mobile subscribers weighted by the following economic distance metrics: geographical distance, the value of mobile handsets trade and the number of travelers between the home country and the partner countries. Hereafter, we will call the models using the above weighted installed base of mobile users "geographic distance" models, "handset trade" models and "international travel" models respectively.

Previous works focused only on the national-level network effects of few selected countries (Doganoglu and Grzybowski, 2007; Grajek, 2010; Birke and Swann, 2006). However, to the best of our knowledge, no empirical study concerning network effects in telecommunications, between countries with strong commercial ties and geographical proximity, has been done yet.

We use a nested logit model in order to specify the utility function of subscription to different mobile phone technologies for consumers in each country. We follow the differentiated-products demand-system model proposed by Berry (1994), which allows us to calculate the mean utility using inverted market shares.

In addition, we overcome some of the endogeneity problems that, according to Birke (2009), have hampered early empirical work. To control for the endogeneity of price and mobile phone subscribers in other countries, we propose two new instrumental variables (IV) that reflect the pricing behavior of firms and the choice of technology standards. The employed IV for mobile service price for a given standard is the number of firms that provide services using other technologies in the same market and time period, whereas the proposed IV for international network effects is the per-capita income and total population in countries different than the home country. We justify the validity of our proposed instruments first conceptually and then empirically by using the Hansen J test.

The estimation of the nested logit model with instrumental variables was performed using the system GMM (Generalized Method of Moments) by Blundell and Bond (1998). This estimator is appropriate for situations with few time periods and many individuals. The dataset is an unbalanced panel that covers 58 countries from the first quarter of 2007 to the fourth quarter of 2009.

Identifying network effects is challenging in any setting. Diffusion may be correlated with technology innovation or consumer preferences, even if network effects are absent. In order to control for innovation, we use a technology-year dummy, and to control for the unobservable preferences or the service quality, first, we analyze local versus global standards, second we include country fixed effects, as explained hereafter, and third, we conduct a falsification test (Miller and Tucker, 2009) using the technological difference as defined by various international standardization organizations.

Concerning local versus global standards, since the function of international network effects depends on the presence of a standardization organization that guarantees compatibility, we compare the impact of local technologies and the impact of international standards. Similar to analog technologies, which differ in each country, 2G technologies, except for GSM and cdmaOne, i.e., TDMA (Time Division Multiple Access), iDEN (Integrated Digital Enhanced Network) and PDC (Personal Digital Cellular) are local technologies that were not standardized by any international standardization organization. Consequently, the difference between those local technologies and the international standard technologies (i.e., GSM (Global System for Mobile Communications), W-CDMA (Wideband Code Division Multiple Access), cdmaOne and CDMA2000) reflects the international network effects.

In addition to the local/global characteristic, we also analyze the availability of cross-generational compatibility of some 2G and 3G technologies. For instance, GSM and W-CDMA are compatible in their network elements and most W-CDMA handsets enable GSM network connectivity. In the case of CDMA2000, this standard is backward-compatible with its previous 2G cdmaOne. Thus, we estimate the effects of forward-compatibility and backward compatibility of the above mentioned technologies. Concerning country fixed effects, because they represent consumer preferences and service quality, we compare country fixed effects and the diffusion rates of 3G technologies. A high correlation between the technology diffusion and the country fixed effects means that the difference in the 3G diffusion rates are caused by local factors in each country. In contrast, a low correlation indicates importance of the international network effects. We show that the high diffusion rates of the W-CDMA technology in Japan and Korea are not affected by local factors, and moreover that the international network effects are caused by the absence of a GSM operator.

Finally, to assess the impact of the choice of global mobile telephony standards and international network effects on welfare, we additionally conducted a counterfactual analysis of the technology choice, in which we calculated a hypothetical partial equilibrium in the Japanese mobile telephony market where the GSM service is available. After conducting this analysis, we found that if the GSM technology was available in the Japanese market, it would be chosen by almost all consumers during the analyzed period, and the Japanese monthly per-consumer surplus would increase from $94.2 to $188.

Our paper is organized as follows. Section 2 discusses the relevant literature and the contribution of our study to the research concerning the diffusion of network technologies and international standards of network goods. Section 3 discusses the econometric method employed, our model specification and the analyzed panel data. Section 4 studies how international network effects shape the diffusion of 3G technologies and compares the role of local versus global standards of technology. Section 5 concludes the paper.

2. Relevant Literature

Network effects can be classified into direct and indirect. Direct network effects consist in the dependency between consumer value and the installed base of product users. In mobile communications, subscribers can communicate with more people the larger the installed base of subscribers. Therefore, the more subscribers, the more utility for the individual consumer get.

Direct network effects in national mobile phone markets have been found in the literature. Using aggregated market data Okada and Hatta (1999), Doganoglu and Grzybowski (2007) and Grajek (2010) analyzed the direct network effects in mobile phones in the Japanese, German and Polish mobile telephone markets, respectively. Those studies found strong and significant network effects which constitute essential factors determining mobile phones diffusion, even more important than price reduction. Grajek and Kretschmer (2009) analyzes the impact of network effects on usage intensity by using cross country data. Employing more detailed market data, Birke (2009) shows that members of the same household coordinate the choice of mobile phone operator; and Birke and Swann (2006) shows that the correlation of operator choice in different countries is due to tariff-mediated network effects as opposed to other causes.

Network effects in the mobile phone industry may cause a market failure. Katz and Shapiro (1985, 1986) show that markets may fail to achieve optimal compatibility due to network effects. Farrell and Saloner (1985, 1986) show the presence of excess inertia and excess momentum. Excess inertia occurs when in equilibrium all users stay with the old technology although a new technology would yield a higher utility to all users. In contrast, excess momentum occurs when a new technology replaces an old technology, but, compared to the new technology, the old technology yields a higher utility to all users.

In response to market failure, governments could improve efficiency by standardization. According to the related literature, there is a trade-off between network effects and platform competition. Gruber and Verboven (2001) assesses the importance of a single technological standard for analogue technology, but argue that for digital technologies the advantages of a single standard are offset by the benefit of improvements in competing digital systems. However, they conclude that, at the time of their study, it was too early to draw reliable conclusions. Koski and Kretschmer (2005) finds that standardization accelerated 2G entry and diffusion, although within-standards competition triggers less aggressive price competition than between-standards competition.

The above mentioned studies have focused on the role of national network effects on mobile telephony adoption. However, these studies do not analyze the role of international network effects, which are increasingly important as transportation and telecommunications services improve, and countries get more interconnected.

Gandal and Shy (2001) and Barrett and Yang (2001) extend the network effect literature to the field of international economics. They show that governments do not have incentives to set the global optimal standardization. Costinot (2008) compares World Trade Organization (WTO) and European Union (EU) agreements on product standards. They show that standards are imposed for levels of externalities that are too low under WTO and too high under EU. Even if governments can set optimal national standards, market might fail in network goods because of the governments` incentive towards international standardization.

Among the few studies on international network effects, Suarez (2005) investigates 2G technology choice patterns between countries in North, South and Central America (95 operators) from the third quarter of 1992 to the second quarter of 2001. The author finds that technology choice was interrelated in a selected subset of countries with strong ties compared to the worldwide situation. Nevertheless, as Birke (2009) pointed out, the used methodology does not allow to effectively distinguish between network effects and other effects leading to choice correlation, and the distinction between strong ties (the three closest countries) and weak ties (all other countries) is somewhat arbitrary and connections between countries are not directly taken into account, but only as an aggregate.

Indirect network effects, on the other hand, are generated if the utility of adopting a good is influenced by complementary relations between goods. In mobile telecommunications networks, indirect network effects consist of the dependence of consumer utility of mobile phone subscription and complementary goods or services, such as smart phones with multiple functions (digital camera, or games) as well as numerous mobile Internet applications.

Empirical evidence of indirect network effects has been found in various markets such as hardware and software (Gandal, 1994), CD players and CD titles (Gandal et al. 2000), video games consoles and video games (Clements and Ohashi, 2005), Video Cassette Recorders (VCR) and video content (Ohashi, 2003), and banks and ATM network (Saloner and Shepard, 1995;). However, due to the lack of detailed data on handset variety, there are no studies that offer empirical evidence of the indirect network effects in mobile phone markets.

In this study, we measure the international network effects in wireless telecommunications markets from the first quarter of 2007 to the fourth quarter of 2009 in 58 countries by taking into account the number of subscribers of the same mobile telecommunication technologies in other countries, weighted by various economic distance metrics (the geographical distance, the value of mobile handset trade and number of international travelers.)

Our contributions to the network effects literature stem from: first, extending the study of network effects from the national level to the international level; second, proposing new instrumental variables to overcome the endogeneity of mobile service price and international network effects; third, analyzing the role of local versus global technological standards, as well as backward/forward compatible technologies; and fourth, by carrying out a welfare analysis of technology choice and 3G mobile telephony diffusion in the Japanese market.

We show that the presence of international network effects explains why the diffusion of 3G technologies (notably W-CDMA) is slower than expected in Europe and USA at the beginning of 2000 and faster in Japan and Korea. In the next section, we discuss our estimation strategy in order to measure the international network effects.

3. Econometric method, model specification and panel data

3.1. Nested logit model by market shares

Our analysis uses the nested logit model to measure the international network effects, as well as the price effect, on countries mobile phone subscribers. We obtained the estimates of the demand parameters of the nested logit model by converting the market share function, following the differentiated-products demand-system method developed by Berry (1994). This procedure does not need assumptions neither on the parametric distribution of unobservables nor on the actual process that generates prices. The approach by Berry (1994) has been used in many empirical studies on network effects, where, additionally to traditional ways of differentiation, products can be differentiated according to their network size (Rysman, 2003; Ohashi, 2003; Clements and Ohashi and Birke, 2009). In this section we begin by giving a brief explanation of the multinomial logit model for market shares, and then relax one important assumption using the nested logit model.

The multinomial logit model is the most widely used discrete choice model, since the formula for the choice probabilities takes a closed form and is straightforward to interpret. In addition, the logit formula is derived from assumptions about the characteristics of choice probabilities, namely the independence from irrelevant alternatives (IIA) property, explained below, which implies that the model is consistent with utility maximization (Train, 2009).

In the multinomial logit model, the utility U_{imjt} that the consumer i in market m obtain from product j at time t is composed by a mean utility δ_{mjt} and an unobservable consumer heterogeneity part ε_{imjt} treated as random. The logit model is obtained by assuming that each ε_{imjt} is independently and identically distributed (i.i.d) extreme value (Train, 2009). An important assumption of the logit model is that errors are independent. This assumption implies that the error for one alternative provides no information about the error for another alternative. In other words, V_{mjt} is correctly specified and the remaining, unobserved part of utility is white noise (Train, 2009).

Utility is usually specified to be linear in parameters with a random error that reflects any unobservable demand shock that affects the mean utility level: $\delta_{mjt} = \beta' x_{mjt} + \xi_{mjt}$, where x_{mjt} is a vector of observed characteristics of product j in market m at time t. Let the mean utility of the outside good (no mobile phone subscription) be normalized to zero. Then, the market share s_{mjt} of product j in market m at time t is derived by the logit probabilities

$$s_{mjt} = \frac{\exp(\delta_{mjt})}{1 + \sum_k \exp(\delta_{mkt})} \tag{1}$$

In our model, we observe J products in market m at different points in time. The J products are the mobile phone technologies: analog, cdmaOne, GSM, PDC, iDEN, TDMA (D-AMPS), CDMA2000 and WCDMA[1].

Following Berry (1994), the mean utility δ_{mjt} is uniquely identified directly from an algebraic calculation using observed market shares.

$$\ln\left(s_{mjt}\right) - \ln\left(s_{m0t}\right) = \delta_{mjt} \tag{2}$$

Thereafter, we can estimate the logit demand parameters from the following linear parameter regression

$$\ln\left(s_{mjt}\right) - \ln\left(s_{m0t}\right) = \beta' x_{mjt} + \xi_{mjt} \tag{3}$$

As mentioned previously, the multinomial logit formula is derived from assumptions about the characteristics of choice probabilities, namely the independence from irrelevant alternatives (IIA) property. However, since consumer behavior does not always hold the IIA property, we relax the IIA property by using the nested logit model. We assume the consumer choice is made in two stages. In the first stage, the consumer

[1] "analog" is composed by various analog technologies. cdma2000(family) is composed by cdma2000x1 and cdma2000 EV-DO. WCDMA (family) is composed by WCDMA, HSPA and HSPA+.

decides whether to subscribe to mobile telephony or not. In the second stage, the consumer chooses a mobile phone technology. Following Berry (1994), choice probability and the estimation model takes the form below.

$$s_{mjt} = \frac{e^{\delta_{mjt}/(1-\sigma)}}{D_g^{\sigma} \sum_g D_g^{1-\sigma}} \tag{4}$$

where $D_g = \sum_{j \in g} e^{\delta_{mjt}/(1-\sigma)}$, and

$$\ln\left(s_{mjt}\right) - \ln\left(s_{m0t}\right) = \beta' x_{mjt} + \sigma \ln\left(s_{mjt} / (1 - s_{m0t})\right) + \xi_{mjt} \tag{5}$$

In our model, x_{mjt} is a vector of observed characteristics of product j including service charge of technology j and international network effects. To account for the endogeneity of prices and network effects, it is necessary to use instrumental variables correlated with the endogenous variables but uncorrelated with the unobservable demand shocks. Instrumental variables for price used in the literature include proxies for cost factors (Ohashi, 2003; Koski and Kretschmer, 2005; Doganoglu and Grzybowski, 2007), lagged values of price (Grajek, 2010), price of service of the same firm in other market (Hausman, 1996; Goolsbee and Petrin, 2004; Clements and Ohashi, 2005), exogenous characteristics of other products (Berry et al., 1995; Ohashi, 2003). Instrumental variables for network effects used in the literature are the cost and the characteristics of other firms (Gowrisankaran and Stavins, 2005; Miller and Tucker, 2009).

In our study, we must instrument for the international network effects and service charge as well as within share. But, we do not observe exogenous characteristics of technology j. Therefore, we propose two new instruments related to the characteristics of other agents and the firms pricing behavior based on the instrumental variable explanation by Berry et al. (1995).

First, the international network effect of technology j in market m at time t is instrumented by characteristics of countries that did not employ technology j. The used characteristics of other countries that employ technology j determine the international network effect of technology j, but do not affect the mean utility of technology j. Gruber and Verboven (2001) and Liikanen et al. (2004) found a positive relationship of per capita income and mobile phone diffusion. Because of our definition of international network effects, the amount of population should affect the scale of international network effects. Thereafter, we use average per capita income and total population of those counties as instruments.

Second, the service charge of technology j in market m at time t is instrumented by the number of firms that provide other technologies in market m at time t. Because of firm heterogeneity, the number of firms that employ technology j may affect the service quality of technology j. But, the service quality of other technologies does not affect the utility of technology j. On the other hand, the number of firms in a given market affects the service charge by firm pricing behavior (Gagnepain and Pereira, 2007). Thereafter, these two variables can be considered as relevant and valid instruments of international network effects and service charge[2].

The above nested logit model was fitted using the system GMM proposed by Blundell and Bond (1998) designed for situations with small T and large N panels, meaning few time periods (13 quarters from 2007 Q1 to 2010Q1) and many countries. We also use the lagged values of each variable as instruments. Since too many instruments weaken the Hansen over identification test, when the number of instruments exceeds the number of panel, we restrict the use of lagged values.

3.2. Definition of variables and data source

In this study, we employed an unbalanced panel data set from 58 countries and territories with quarterly data from the first quarter of 2007 to the fourth quarter of 2009. We define each country as a regional market, and the population in a market as the total market capacity of mobile phone subscription. The mobile technology subscriber data available to us cover 224 countries. However, since we combine multiple international datasets, not all countries provide all the necessary variables for our analysis.[3]

-Table 1 here-

The specification of the main model is the following:

$$\ln\left(s_{mjt}\right)-\ln\left(s_{m0t}\right)=\beta_{\text{int}}N_{mjt}^{\text{int}}+\alpha_1 p_{mjt}+\alpha_2 p_{mjt}/w_{mt}+\sigma\ln\left(s_{mjt}/(1-s_{m0t})\right)+\gamma_{jt}+\xi_{mjt}$$

[2] Under the free entry condition, the number of firms may depend on the scale of demand. However, mobile telecommunication technologies have to use the limited frequency spectrum. In almost all the countries, the spectrum is allocated by either beauty contests or auctions. Under both mechanisms, governments usually set the number of operators. An exception is the German auction that was designed to allow between four and six winners. We use Hansen J test statistics to show the validity of our instruments.

[3] In particular, the employed trade database reduces our dataset significantly. In addition, we removed from our estimation countries whose number of mobile phone subscribers exceeds the total population.

(6)

where s_{mjt} is the share of the mobile phone subscribers of technology j in country m at time t, s_{m0t} is the share of population without mobile subscription in country i and at time t. Mobile phones subscribers by technology, country and quarter were obtained from the Wireless Intelligence Database and were used to calculate the independent variable of the model. Where α_1 is the price coefficient and σ is represent correlation of unobserved service quality between alternatives. p_{mjt} is the service charge of technology j in country m at time t. Service charge of technology j was calculated from the effective price per minute charged by each operator in dollars, weighted by the market share of the operator. w_{mt} is GDP per capita and α_2 represents shift of price coefficient by income. Operators effective price per minute and market shares were taken from the Wireless Intelligence Database. GDP per capita is taken from the World Develop Indicator. γ_{jt} are a series of year fixed effects by technology. Year fixed effects reflect innovation of technology by year.

N_{mjt}^{Int} indicates the international network effect and β_{int} is parameter of N_{mjt}^{Int}. Mobile phones subscribers by technology, country and quarter were obtained from the Wireless Intelligence Database that covers 224 countries from the first quarter of 2000 to the first quarter of 2010. We calculate international network effects in all countries in this database. The "analog" alternative is composed by various analog technologies as defined in our database, which gives us the chance for the first falsification tests. To perform the first falsification test, we divide β_{int} for the "analog" alternative by the alternatives of other technologies. For the same test, $\beta_{\text{int,analog}}$ represents the demand correlation with various factors, except for the international network effect. If a difference between β_{int} and $\beta_{\text{int,analog}}$ can be shown, it gives us supporting evidence that our estimates reflect the international network effects. The second falsification test uses the presence of an international standardization organization. TDMA, iDEN and PDC are local standards that were not imposed by an international standardization organization. In contrast, GSM, W-CDMA, cdmaOne and CDMA2000 have their corresponding international standardization organization. GSM was standardized by the European Telecommunications Standards Institute (ETSI)[4]. Two 3G technologies, namely W-CDMA and CDMA2000, were standardized by the International Telecommunication Union (ITU) and have their own Organizational Partners. The 3rd Generation Partnership Project (3GPP) gathers groups of telecommunications associations, known as the Organizational Partners and developed the W-CDMA technology standard. The 3rd Generation Partnership Project 2 (3GPP2) is that for the cdmaOne and CDMS2000 standards.

We divide the coefficients of local standards and international standards to identify the international network effects. The difference between those estimates gives us additional supporting evidence.

We try to use various definitions of international network effects. At first, we define N_{mjt}^{Int} as the sum of number of subscribers of technology j in other country.

$$N_{mjt}^{Int} = \sum_{k \neq m} n_{kjt} \quad (7)$$

Where n_{mjt} is the number of subscribers of technology j in country k ($k \neq m$) at time t.

Second, we summed the number of subscribers of technology j in other countries and weighted by various definitions of economic distance between country j and k (d_{mk})

$$N_{mjt}^{Int} = \sum_{k \neq m} d_{mkt} n_{kjt} \quad (8)$$

We use three variables as economic distance. The first measure of economic distance is the geographic distance between country m and k. The distances between countries were obtained from the Distances Database of the "Centre d'Etudes Prospectives et d'Informations Internationales" (CEPII). The second measure of economic distance is export value of mobile handset from country m to country k. The values of trade between countries were obtained from the United Nations (UN) Comtrade Database. The UN Comtrade Database records mobile handset import and export under the code 851712 of the Harmonized System (HS) 2007. The third measure of economic distance is the number of international personal travelers (different from business travelers) between country m and k. The number of international personal travelers was obtained from the UN Service Trade Database. The country characteristics used as instruments, namely income and population, were obtained from the World Development Indicators (WDI).

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[4] The ETSI is officially recognized by the European Union as a European Standards Organization.

To investigate the cross generational international network effects, we add to the utility function the number of mobile phone subscribers in other countries who use backward compatible technology or forward compatible technology. Liikanen et al. (2004) and Koski and Kretschmer (2005) found a positive impact of backward compatibility between the first and second generations.

In our case, two 3G technologies have backward compatibility with 2G technologies. The first 3G technology is W-CDMA, which has backward compatibility with the GSM core network[5]. Since, GSM careers can share the GSM core network with the W-CDMA network, the compatibility of core makes GSM operators tend to introduce the W-CDMA technology and, as a result, many W-CDMA handsets can use the GSM network. This fact causes backward compatibility to W-CDMA and forward compatibility to GSM. The second 3G technology is CDMA2000, whose handsets have backward compatibility with the cdmaOne network. This fact triggered the earlier diffusion of CDMA2000 compared to W-CDMA. In this context, we try to estimate the backward and forward compatibility. We define the forward compatibility variables corresponding to GSM and cdmaOne technology as the international network effect of W-CDMA and CDMA2000, respectively; and the backward compatibility variables corresponding to W-CDMA and CDMA2000 as the international network effect of GSM and cdmaOne, respectively. Those variables are instrumented by the interaction term resulting from multiplying the international network effect times the forward/backward compatible dummy variable.

3.3. Summary statistics

Figure 1 shows the global diffusion of each technology. Table 2 shows the summary statistics of shares by technology. GSM is the most frequently employed technology in our dataset and its average share of subscribers is the largest within all technologies. Two of the 3G technologies (CDMA2000 and W-CDMA) follow GSM. Table 3 shows the summary statistics of price and subscribers by technology in selected countries. GSM is widely used in developed countries and developing countries as well. Japan is the only country in the world that employs the PDC technology. Japan and Korea are the only countries that have not employed the GSM technology. These two countries have a high number of subscribers of 3G technology. This fact implies that GSM network effects cause excess inertia in the majority of countries, e.g. the USA and European nations,

[5] Core network is the component of a mobile telecommunication system that carries out call switching and mobility management functions for mobile phones roaming on the network of base stations.

where consumers stay with the 2G technology although the 3G technology would yield a higher utility to all users, or excess momentum in Japan and Korea

Table 4 shows the summary statistics of international network effects. The relative importance of the GSM international network effects is the largest in every definition employed in this study. However, the definition of economic distance makes a remarkable difference in the relative size of international network effects. Comparing the "no weighted" case with "geographic distance" and "international travel" case, the international network effect shrinks in the latter two definitions in Japan and the United states. In these definitions, the international network effects well reflect the use of international roaming. Comparing the "no weighted" case with the " handset trade" case, the relative importance of international network effects expanded in Germany and Finland.

-Table 2 here-

-Table 3 here-

-Table 4 here-

4. Estimation results: international and national network effects

The benchmark estimation results are presented in Table 5.

-Table 5 here-

Ordinary Least Squares (OLS) and Fixed Effects (FE) coefficients are biased estimates because of the endogeneity of price and the international network effects. That is, in the absence of fixed effects, price and international network effects are not consistent to economic theory. FE model shows a negative significant price coefficient and a positive significant international network effect coefficient, consistent with economic theory. Concerning the GMM estimates, we use IVs to overcome the endogeneity of price and international network effects. Estimates are obtained from the system GMM proposed by Blundell and Bond (1998). Coefficients of price and international network effects are larger in absolute values. It partially reflects a measurement error. Positive international network effects and negative analog diffusion coefficients give us supporting evidence that our estimation strategy can capture international network effects. The "Within share" coefficient is not between 0and 1. It may reflect the fact that our model cannot capture error correlation between alternatives.

The validity of our instruments.is shown by the fact that the over identification hypothesis is not rejected by the Hansen J-statistic. We show the first-stage estimates that regress endogenous variables on IVs in table 5. At least one IV has a significant effect on price, the international network effects and the logarithm of the within share. All F tests reject the null hypothesis. Therefore, our IVs are statistically relevant and valid to deal with our endogenous variables.

We proceed to compare the three economic distance variables. Table 6 shows GMM estimates of benchmark model, estimates without the international network effects and the three economic distance variables. In all the models, the price coefficients are negative significant and have similar values. In contrast, the Price / GDP per capita coefficients are not significant in all models.

In relation to the estimates of international network effects, the "no weight" model and "geographic distance" model show positive significant international network effects. However, the "handset trade" and "international travel" models are not significant. Therefore, the "no weight" and "geographic distance" models are suitable to our investigation. As in the previous results, the "within share" coefficients in all the models are not between 0 and 1.

-Table 6 here-

Table 7 shows the estimates of the model including cross generational international network effects. We add the international network effect of cross generation compatible technologies in the utility function, and an interaction term between the IVs and cross generational compatibility dummy for additional IVs. However, the number of instruments exceeds the number of panels. Since too many instruments weaken the power of the Hansen test, we estimate two models, one for each international network effects definition.

The upper part in table 7 shows the estimates that use all lagged variables as instruments, whereas the lower part in table 7 shows the estimates that use only one lagged variable as instrument. When we restrict a use of lagged variables, the Hansen test shows that our over identification restriction holds. As a result, some parameter values and significance levels differ between the two models. The "no weight" model with all lagged values has significant price and international network effect coefficients. The falsification test using the world analog diffusion shows that our model successfully captures the international network effects. The 95% confidence interval of within share coefficients are [0.425, 0.878] for the "no weight" model and [0.481, 0.918] for the "geographic distance" model. The "no weight" model explains well the consumer behavior that is consistent with the utility maximization behavior. Subsequently, we calculate elasticities and discuss the results based on this model.

-Table 7 here-

For cross generational international network effects, we find positive significant backward compatibility. It means that the diffusion of GSM and cdmaOne technologies has positive effects on the diffusion of W-CDMA and CDMA2000 standards, respectively. On the contrary, the diffusion of W-CDMA and CDMA2000 has negative effects on the spread of GSM and cdmaOne. In other words, once 3G technologies are available, users of 2G technologies migrate to 3G standards. Nevertheless, the large installed base of GSM users prevents consumer migration to 3G mobile networks. The market failure might be caused by excess inertia of GSM-adopting countries.

To understand consumer behavior, we calculate own-elasticities of price and international network effects of the "no weight" model. Following Clements and Ohashi (2005), we calculate the ratio of international network elasticities to price elasticities to compare price and international network effects. We find international network effects have higher elasticities than price in average. In addition, the ratio of elasticities grows along with global mobile phone diffusion. The relative importance of price and international network effects is different among technologies. Particularly, the GSM standard has the highest ratio of elasticity as a consequence of its extensive installed base of users. Similarly, W-CDMA has the highest cross generational elasticity that comes from the large installed base of GSM users as well.

-Table 8 here-

To investigate the impact on the diffusion pattern of immeasurable characteristics, we calculate the unobservable part of utility ξ_{mjt} .which reflects, for instance, unobservable service quality or common preferences in a country. A stronger correlation between the diffusion rate of 3G networks and the unobserved part of utility for the same 3G networks indicates that service quality or country preferences tend to promote the diffusion of 3G services. Noticeably, Japan and Korea, which are countries that lack any GSM operator, are known for their fast diffusion of 3G services. Therefore, we investigate if the high diffusion of 3G technologies in those two countries can be explained by the unobservable part of utility or the absence of a GSM operator. For this purpose, we estimate the utility parameter by using the system GMM model with first-difference equation that do not hold country specific constants. To implement our model, we calculate the residuals based on our data and estimated parameters, and subsequently average it in time. Then, we compare these average residuals with the subscription rate of 3G technologies. Tables 9 and 10 show the rank of average residuals and the diffusion rate of the W-CDMA standard and the CDMA2000 standard, respectively.

-Table 9 here-

-Table 10 here-

According to our results, the CDMA2000 standard has a higher correlation between its diffusion and the unobserved part of utility than the W-CDMA standard. We note that although Japan and Korea have the first and second highest W-CDMA diffusion rate, their unobserved part of utility is ranked 8 and 7, respectively. This means that a high preference or high quality of service in those countries is not the cause of their high 3G diffusion rate, but rather the absence of a GSM operator is the source of their high diffusion rate of 3G services. We conclude that the fast diffusion of 3G services in those countries might be caused by excess momentum in the technology standard adoption.

Finally, to assess the welfare effect of technology choice, we calculate a partial counterfactual equilibrium in the Japanese market. We add a GSM service to the choice set of Japanese consumers while keeping the equilibrium of the rest of the countries. First, we set the hypothetical price and the country and technology specific constants of GSM equal to those of PDC (a Japanese 2G standard). In addition, we use the estimates of the "no weight" model with cross generational compatibility. Then, we calculate the share of technologies by average utility of each analyzed period. Figure 2 shows the partial counterfactual equilibrium in Japan if GSM technology was available.

-Figure 2 here-

In the counterfactual equilibrium, the number of total mobile phone subscribers increases from 104 million (82% of population) to 127 million (100%). The number of GSM subscribers is 126 million and the number of 3G mobile phone subscribers declines from 90.7 million (71% of population) to 0.309 million (0.24% of population). Following McConnell (1995), we calculate the monthly per-consumer surplus in Japan. The monthly per-consumer surplus increases from $94.2 to $188. The welfare gain from the introduction of the GSM technology would be rather large in Japan. Our analysis predicts a large decline of 3G subscribers due to the following reasons. The first reason is that the country and technology specific fixed effect of the 3G technology is not so large relative to the 2G technology fixed effect. The second reason is that the international network effect of GSM is larger than that of 3G technology. From the results of our counterfactual analysis, we argue that the rapid diffusion of 3G mobile phone services in Japan might be due to excess momentum caused by a failure of government technology choice.

To check the robustness of our counterfactual analysis, we perform an additional falsification test. Specifically, we test if there is a difference of international network effects coefficients between technologies that have any international standardization organization and technologies that does not have any. We call the latter local technologies. Table 11 shows the estimation results of the additional falsification tests.

According to the "no weight" and "geographic distance" models, the coefficients of local technologies (TDMA, iDEN and PDC) and of international standard technologies are statistically significantly different. Similar to previous models, our models weighted by other distance metrics fail to capture the international network effects. The price coefficients of the "geographic distance" model are negative and significant, but those of "no weight" model are not significant. As before, the "within share" coefficients are not between 0 and 1. We conclude that the latter models, using distance metrics, fail to capture the full consumer behavior, but in contrast to the former models succeed to capture the international network effects and therefore give us supporting evidence.

-Table 11 here-

5. Conclusions

In this paper, we measured the international network effects in the mobile telephony markets of 58 countries from 2007 to 2009, by using a discrete choice model, implemented under the differentiated-product demand system method with inverted market shares proposed by Berry (1994) and the IV system GMM by Blundell and Bond (1998). Among various models with different economic distance definitions for the international network effects, the "no weight" and "geographic distance" models show significant international network effects, but the other models do not fit as well.

One possible reason for this result is the endogeneity of the distance metrics. It is obvious that geographical distance is not affected by the agent's economic behavior, but the trade of mobile handsets and personal travelers are jointly determined by some exogenous variables. To overcome this endogeneity, we must find other instruments.

Adding cross generational network effects to our "no weight" model results in higher international network effects elasticities than price elasticity in average. Similarly, international cooperation aimed at standards setting is required to overcome old technologies network effects (excess inertia) and thus promote the diffusion of new technological standards. For instance, in the case of 3G mobile phones, the ITU could not establish a single global standard. This may be one reason for the slow diffusion of 3G technologies in the majority of countries, except for Japan and Korea. When the network effect is limited to regional markets, governments can reduce the market failure. However, market failures are likely to persist because international agreement among governments is difficult and governments have no incentive to achieve a global optimal choice. Therefore, we argue that the 3G mobile phone industry is a representative case of failure of international policy coordination. In this context, an important issue in the field of network economics and international economics is how to manage the market failure caused by the international network effects is. In order to evaluate standard-setting policies, future research is required. For instance, a good way to assess global standardization policies is to calculate counterfactual equilibria under different technology choices by using demand functions.

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Table 1: List of countries for the network effects analysis

Albania	Czech Republic	Latvia	Slovenia
Algeria	Ecuador	Macedonia	South Africa
Angola	Egypt	Malaysia	Sri Lanka
Argentina	France	Malta	Syrian Arab Republic
Armenia	Georgia	Mexico	Taiwan, Province of China
Australia	Ghana	Morocco	Tajikistan
Bangladesh	Hungary	Nigeria	Thailand
Belarus	India	Pakistan	Tunisia
Belgium	Indonesia	Peru	Turkey
Brazil	Iran, Islamic Republic of	Philippines	Turkmenistan
Canada	Iraq	Poland	Ukraine
Cape Verde	Japan	Puerto Rico	United States
Chile	Kazakhstan	Romania	Uzbekistan
China	Kenya	Russian Federation	
Colombia	Korea, Republic of	Sao Tome and Principe	

Figure 1: Global mobile phone diffusion by technology

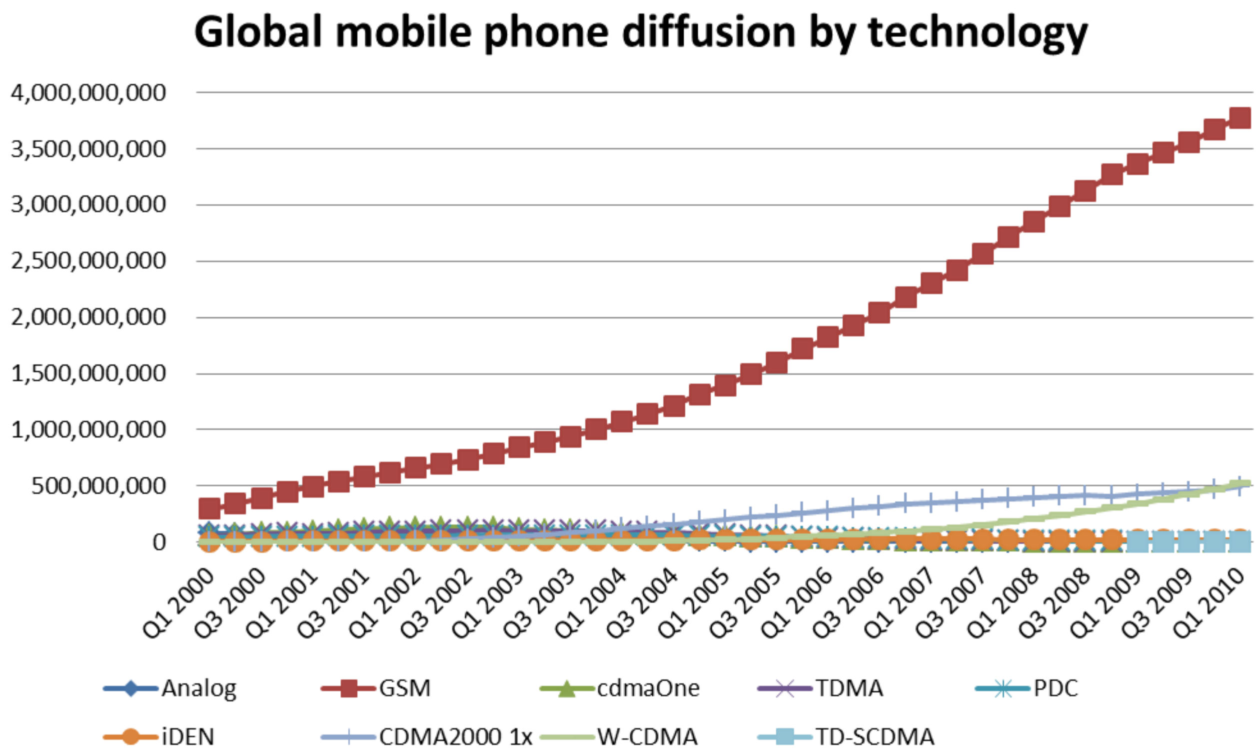

Table 2: Shares by technology

		1G	2G					3G	
	All technology	analog	cdmaone	GSM	iDEN	PDC	TDMA	cdma2000	W-CDMA
No of observations	1,075	44	52	403	21	12	47	151	345
Mean	28.79%	0.35%	1.10%	59.23%	3.39%	10.09%	0.82%	18.30%	11.64%
Std. Dev.	30.31%	0.70%	0.93%	23.88%	1.18%	5.53%	1.13%	20.51%	14.49%
Min	0.00%	0.00%	0.01%	5.51%	2.18%	3.28%	0.00%	0.25%	0.01%
Median	16.94%	0.02%	0.93%	63.22%	2.66%	9.13%	0.37%	7.65%	5.24%
Max	99.60%	2.71%	3.63%	99.60%	5.88%	20.34%	4.79%	82.90%	67.06%

Table3: Share and Price of selected countries by technology

			generation		1G	2G					3G	
			2G	3G	analog	cdmaOne	GSM	iDEN	PDC	TDMA	CDMA2000	W-CDMA
Japan	Subs	2007Q1	26514550	70203350		597200			25917350		26719600	43483750
		2010Q1	3591538	109000000		247300			3344238		31676810	77752839
	Price	2007Q1	0.272296	0.340979		0.3773			0.269882		0.3773	0.318669
		2010Q1	0.376785	0.333004		0.4135			0.374018		0.4135	0.300196
Germany	Subs	2007Q1	82838144	5354857			82838144					5354857
		2010Q1	86764225	21745873			86764225					21745873
	Price	2007Q1	0.162581	0.244898			0.162581					0.244898
		2010Q1	0.215809	0.197848			0.215809					0.197848
USA	Subs	2007Q1	120000000	117000000	1685769	7089363	87899005	21414500		3914074	115000000	1902115
		2010Q1	88194477	202000000		566306	75128171	12500000			156000000	46066487
	Price	2007Q1	0.036285	0.008548	0.046355	0.033261	0.044571			0.054339	0.0032413	0.0665
		2010Q1	0.061843	0.025759			0.063597	0.0541			0.0122753	0.070652
Finland	Subs	2007Q1	5372581	476076			5372581					476076
		2010Q1	4655623	3503344			4655623					3503344
	Price	2007Q1	0.127517	0.123737			0.127517					0.123737
		2010Q1	0.108392	0.109862			0.108392					0.109862
Brazil	Subs	2007Q1	78679073	24388864	53555	1408729	67003883	981400		9285061	24388864	
		2010Q1	164000000	18180778	3078		162000000	2663300		234133	6599653	11702375
	Price	2007Q1	0.131413	0.1789	0.169007	0.1789	0.126401			0.174079	0.1192667	
		2010Q1	0.112805	0.139136	0.143		0.114625			0.143	0.0476667	0.136991
Russia	Subs	2007Q1	146000000	406925			146000000			46364	406925	
		2010Q1	18585670		555429	192000000				18030241		
	Price	2007Q1	0.051007				0.051018			0.007966		
		2010Q1	0.002433				0.002433					
India	Subs	2007Q1	121000000	39788351			121000000				39788351	
		2010Q1	471000000	117000000			471000000				116000000	1298408
	Price	2007Q1	0.009316				0.009316					
		2010Q1	0.007978	0.004788			0.007978				0.0016137	
China	Subs	2007Q1	425000000	37724000			425000000				37724000	
		2010Q1	679000000	77964000			679000000				65450000	4824000
	Price	2007Q1	0.029289	0.0281			0.029289				0.0093667	
		2010Q1	0.021012	0.003486			0.021012					0.0243

Table4: International network effects of selected countries by technologyes (devided by mean)

			2G					3G	
			cdmaOne	GSM	iDEN	PDC	TDMA	CDMA2000	W-CDMA
Japan	no weight	2007Q1	0.0208	3.0331	0.0356	0.0000	0.0245	0.4228	0.0934
		2010Q1	0.0009	4.9808	0.0302	0.0000	0.0004	0.6093	0.5890
	Trade Value	2007Q1	0.0759	1.0095	0.2291	0.0000	0.0418	1.2373	0.0266
		2010Q1	0.0001	0.0396	0.0012	0.0000	0.0000	0.0171	0.0093
	Geographic distance	2007Q1	0.0288	5.9481	0.0402	0.0000	0.0167	1.2023	0.1201
		2010Q1	0.0011	9.8587	0.0275	0.0000	0.0002	1.4725	1.0695
	International Travel	2007Q1	0.0743	10.3636	0.1673	0.0000	0.0339	2.3909	0.0807
		2010Q1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Germany	no weight	2007Q1	0.0216	2.9239	0.0356	0.0341	0.0245	0.4580	0.1436
		2010Q1	0.0012	4.8665	0.0302	0.0044	0.0004	0.6510	0.6628
	Trade Value	2007Q1	0.0170	10.7911	0.0522	0.0004	0.0118	0.3513	0.7753
		2010Q1	0.0007	2.8703	0.0154	0.0000	0.0000	0.2430	1.1582
	Geographic distance	2007Q1	0.0323	16.0872	0.0690	0.0450	0.0345	0.7860	1.1643
		2010Q1	0.0020	18.4520	0.0522	0.0058	0.0004	1.1756	5.0054
	International Travel	2007Q1	0.1973	8.5182	0.5964	0.0000	0.1091	3.2091	0.8209
		2010Q1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
USA	no weight	2007Q1	0.0123	2.9173	0.0074	0.0341	0.0193	0.3065	0.1482
		2010Q1	0.0005	4.8818	0.0137	0.0044	0.0004	0.4455	0.6307
	Trade Value	2007Q1	0.0265	3.3228	0.0674	0.0042	0.0430	0.4968	0.0424
		2010Q1	0.0001	12.8481	0.1582	0.0004	0.0001	1.5158	0.5506
	Geographic distance	2007Q1	0.0527	4.4112	0.0354	0.0386	0.0631	0.6936	0.2205
		2010Q1	0.0006	6.6046	0.0552	0.0050	0.0006	0.9339	0.9809
	International Travel	2007Q1	0.2291	41.3636	0.2364	0.0000	0.1873	6.4545	1.9545
		2010Q1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Finland	no weight	2007Q1	0.0216	3.0260	0.0356	0.0341	0.0245	0.4580	0.1500
		2010Q1	0.0012	4.9746	0.0302	0.0044	0.0004	0.6510	0.6868
	Trade Value	2007Q1	0.0434	18.7342	0.1291	0.0008	0.0367	1.2595	0.9082
		2010Q1	0.0006	3.7025	0.0207	0.0000	0.0003	0.2057	1.1044
	Geographic distance	2007Q1	0.0300	13.1303	0.0627	0.0534	0.0298	0.8083	0.6268
		2010Q1	0.0019	16.9396	0.0498	0.0069	0.0005	1.2781	3.0709
	International Travel	2007Q1	0.0088	1.7545	0.0248	0.0190	0.0050	0.1755	0.0875
		2010Q1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table4: International network effects of selected countries by technologyes (cont)

International Network Effects			2G					3G	
			cdmaOne	GSM	iDEN	PDC	TDMA	CDMA2000	W-CDMA
Brazil	no weight	2007Q1	0.0198	2.9448	0.0343	0.0341	0.0122	0.4259	0.1507
		2010Q1	0.0012	4.7673	0.0267	0.0044	0.0001	0.6423	0.6760
	Trade Value	2007Q1							
		2010Q1	0.0010	1.1234	0.0421	0.0000	0.0000	0.2864	0.1408
	Geographic distance	2007Q1							
		2010Q1	0.0014	3.0928	0.0508	0.0029	0.0000	0.6621	0.4629
	International Travel	2007Q1							
		2010Q1							
Russia	no weight	2007Q1	0.0216	2.8407	0.0356	0.0341	0.0244	0.4575	0.1507
		2010Q1	0.0012	4.7278	0.0302	0.0044	0.0004	0.6503	0.6677
	Trade Value	2007Q1	0.0000	0.3139	0.0000	0.0000	0.0000	0.0000	0.0203
		2010Q1	0.0000	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000
	Geographic distance	2007Q1	0.0000	1.3064	0.0000	0.0000	0.0000	0.0009	0.1127
		2010Q1	0.0000	5.3899	0.0020	0.0000	0.0000	0.7700	0.2125
	International Travel	2007Q1	0.0318	4.1727	0.0890	0.0287	0.0169	0.7182	0.2082
		2010Q1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
India	no weight	2009Q1	0.0045	4.0450	0.0285	0.0099	0.0026	0.4359	0.4533
		2009Q4							
	Trade Value	2009Q1	0.0006	4.4304	0.0053	0.0002	0.0002	0.2123	0.2826
		2009Q4	0.0003	4.8418	0.0056	0.0001	0.0000	0.3060	0.4272
	Geographic distance	2009Q1	0.0079	11.4335	0.0294	0.0208	0.0023	0.7173	0.8609
		2009Q4	0.0035	12.3402	0.0308	0.0115	0.0005	0.8447	1.1806
	International Travel	2009Q1							
		2009Q4							
China	no weight	2007Q1	0.0216	2.4731	0.0356	0.0341	0.0245	0.4083	0.1507
		2010Q1	0.0023	3.9660	0.0302	0.0055	0.0006	0.5420	0.6221
	Trade Value	2007Q1	2.1835	56.3291	6.4873	0.4177	1.2437	38.9241	2.9051
		2010Q1	0.2427	56.3291	2.5759	0.1434	0.0014	38.2911	18.9873
	Geographic distance	2007Q1	0.0453	4.6647	0.0409	0.1995	0.0204	1.3467	0.4882
		2010Q1	0.0069	8.3177	0.0339	0.0321	0.0007	1.5123	1.8109
	International Travel	2007Q1							
		2010Q1							

Table 5: Estimation results (OLS/GMM/Firststage)

	OLS			FE			GMM		
Number of observations	1075			1075			1075		
Number of groups	146			146			146		
Number of IV							113		
R/Hansen J	0.6331			0.5797			105.52 (107)		0.522
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	3.0818	***	0.5763	−2.0980	***	0.6835	−5.2121	**	2.3818
Service charge/GDP Per Capita	−2.6821	***	0.5658	−1.5682		1.2299	12.6141		12.1068
World Analog diffusion	−1749.9150	***	486.0059	−31.7389		257.3508	−404.1499	***	92.9466
International network effect	1.1704	**	0.4564	1.9634	***	0.2146	2.2597	***	0.2468
Within share	0.5774	***	0.0344	0.5150	***	0.0366	1.0751	***	0.0733
Year fixed effects by technology	Yes			Yes			Yes		
Country fixed effects by technology	No			Yes			Differenced		
First stage estimates	Price			International network effects			Log within share		
Number of observations	1075			1075			1075		
F value / p	8.34		0.0000	8149.61		0.0000	69.25		0.0000
R-squared	0.1715			0.9951			0.6321		
Adj R-squared	0.151			0.995			0.6230		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Not use countries GDP	−0.0994	*	0.0517	0.0608		0.0545	0.0127		0.0839
Not use countries Population	0.0021	***	0.0005	0.0072	***	0.0005	−0.0002		0.0079
Number of othe technology films	−0.0025	***	0.0005	−0.3368		0.5654	−0.0463	***	0.0087
Year fixed effects by technology	Yes			Yes			Yes		

Table 6: Estimation results

Weighting variables	Without international network effects			No weight		
Number of observations	1075			1075		
Number of groups	146			146		
Number of IV	136			136		
Hansen J	111.30(109)		0.421	105.52(107)		0.522
	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−6.7135	***	2.1027	−5.2121	**	2.3818
Service charge/GDP Per Capita	−18.0162		19.9721	12.6141		12.1068
World Analog diffusion				−404.1499	***	92.9466
International network effect				2.2597	***	0.2468
Within share	1.0739	***	0.1044	1.0751	***	0.0733
Year dixed effects by technology	Yes			Yes		

Weighting variables	Trade Value			Geographic distance			International Travel		
Number of observations	1075			1075			1075		
Number of groups	146			146			146		
Number of IV	136			136			136		
Hansen J	110.17(108)		0.959	106.48(108)		0.523	106.85(108)		0.463
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−6.5379	***	2.1455	−6.9798	***	1.9174	−6.7630	***	2.0817
Service charge/GDP Per Capita	−18.2406		20.1316	−2.7794		9.2503	−17.0455		19.1422
World Analog diffusion									
International network effect	0.0086		0.0055	0.0269	***	0.0069	0.0018		0.0012
Within share	1.0680	***	0.1041	0.9792	***	0.1071	1.0675	***	0.1037
Year dixed effects by technology	Yes			Yes			Yes		

Table 7: Estimation results of cross generation compatibility

Weighting variables	No weight			Geographic distance			Travel Person			Trade Value		
Number of observations	946			946			946			946		
Number of groups	132			132			132			132		
Number of IV	221			194			194			194		
Hansen J Value (D.F)	95.17 (190)		1	100.81 (192)		1	109.32 (164)		0	112.47 (164)		0.999
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−5.7218	**	2.4325	−6.8609	**	2.8945	−8.9848		6.5653	−8.9952		5.4318
Service charge/GDP Per Capita	8.2663		8.0269	−2.6224		8.9667	−9.3772		15.8300	−10.0735		15.4658
World Analog diffusion	−136.4529		200.3006									
International network effect	2.0605	***	0.4933	0.0298	**	0.0118	−0.0019		0.0023	0.0000	**	0.0000
Forward compatibility	−0.3338		1.7019	−0.0010		0.0160	0.0094		0.0073	0.0000		0.0000
Backward compatibility	2.1159	***	0.4807	0.0202	*	0.0103	0.0016		0.0010	0.0000		0.0000
Within share	0.6516	***	0.1144	0.6996	***	0.1106	1.0514	***	0.1074	0.9450	***	0.1076
Year fixed effects by technology	Yes			Yes			Yes			Yes		
Country fixed effects by technology	Differenced			Differenced			Differenced			Differenced		
Weighting variables	No weight			Geographic distance			Travel Person			Trade Value		
Number of observations	946			946			946			946		
Number of groups	132			132			132			132		
Number of IV	108			108			108			108		
Hansen J Value (D.F)	74.05 (77)		0.574	76.14 (77)		0.506	90.92 (77)		0.133	88.35 (77)		0.177
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−5.6404	*	3.3419	−9.2168	***	2.6882	−9.4112	*	4.9939	−10.7632	***	3.7947
Service charge/GDP Per Capita	9.9684		10.2071	−2.4743		8.7194	−15.6717		20.6022	−12.5679		16.9326
World Analog diffusion	32.7640		38.0812	0.1255		0.1875	−0.0657		0.0585	−0.0001		0.0001
International network effect	2.0337	***	0.5029	0.0147	**	0.0115	−0.0045		0.0037	0.0000	**	0.0000
Forward compatibility	−0.1184		1.7631	0.0409		0.0283	0.0157		0.0113	0.0000		0.0000
Backward compatibility	2.4950	***	0.5068	0.0314	***	0.0121	0.0042		0.0027	0.0000		0.0000
Within share	0.5048	***	0.1239	0.5380	***	0.1350	1.1346	***	0.1309	0.9337	***	0.1233
Year fixed effects by technology	Yes			Yes			Yes			Yes		
Country fixed effects by technology	Differenced			Differenced			Differenced			Differenced		

Table 8: Price and International network elastisity

	2007Q1	2007Q2	2007Q3	2007Q4	2008Q1	2008Q2	2008Q3	2008Q4
Price Elasticity	−1.6668	−1.6047	−1.5376	−1.3852	−1.3723	−1.3231	−1.2642	−1.0965
International network elasticity	5.0659	5.4178	5.6690	5.8493	6.2790	6.3725	6.5450	6.6542
Ratio of Elasticity	3.0393	3.3763	3.6870	4.2229	4.5755	4.8163	5.1774	6.0685

	2009Q1	2009Q2	2009Q3	2009Q4
Price Elasticity	−0.9821	−0.9831	−1.0348	−1.2868
International network elasticity	6.9651	7.1406	7.4130	7.6556
Ratio of Elasticity	7.0922	7.2633	7.1637	5.9494

		1G			2G			3G	
	average	analog	cdmaOn	GSM	iDEN	PDC	TDMA	CDMA2000	W−CDMA
Price Elasticity	−1.8629	−1.8697	−3.0489	−0.1827	−1.6825	−4.4550	−1.6448	−1.1487	−1.8026
International network elasticity	2.2895		0.0430	4.0376	0.0941	0.0000	0.0486	1.9548	1.4616
Cross generation elasticity			−0.3636	−0.0601				0.0385	16.3288
Ratio of Elasticity	1.2290		0.0141	22.0995	0.0559	0.0000	0.0295	1.7018	0.8108

Table 9. Correlation of W-CDMA diffusion rate and unobserved utility

	Japan	Korea	Slovenia	France	Malta	Malaysia	USA
Rank of average residuals of W-CDMA	8	7	3	9	1	5	11
W-CDMA diffusion rate in 2007 Q1	45.9%	18.7%	13.9%	12.3%	11.9%	5.1%	3.6%

	South Africa	Latvia	Indonesia	Sri Lanka	Colombia	Argentina	Egypt
Rank of average residuals of W-CDMA	4	2	15	19	13	6	18
W-CDMA diffusion rate in 2007 Q1	3.4%	2.2%	1.2%	1.1%	0.8%	0.6%	0.4%

	Brazil	Tajikistan	Morocco	Mexico	Chile	Angola	Peru
Rank of average residuals of W-CDMA	14	21	12	17	10	16	20
W-CDMA diffusion rate in 2007 Q1	0.3%	0.3%	0.3%	0.3%	0.2%	0.1%	0.1%

Corr(residuals, diffusion)	0.45

Table 10. Correlation of CDMA2000 diffusion rate and unobserved utility

	Korea	USA	Puerto Rico	Canada	Japan	Chile	Brazil
Rank of average of residuals of CDMA2000	1	3	5	4	2	6	7
cdma2000 diffusion rate in 2007 Q1	71.2%	44.0%	38.5%	32.3%	23.3%	13.3%	9.5%

	India	China	Colombia	Thai	Ukraine	Czech Republic
Rank of average of residuals of CDMA2000	9	10	8	11	12	13
cdma2000 diffusion rate in 2007 Q1	6.0%	3.3%	2.7%	1.7%	1.5%	1.3%

Corr(residuals, diffusion) 0.77

Figure 2: The partial counterfactual equilibrium in Japan with GSM technology.

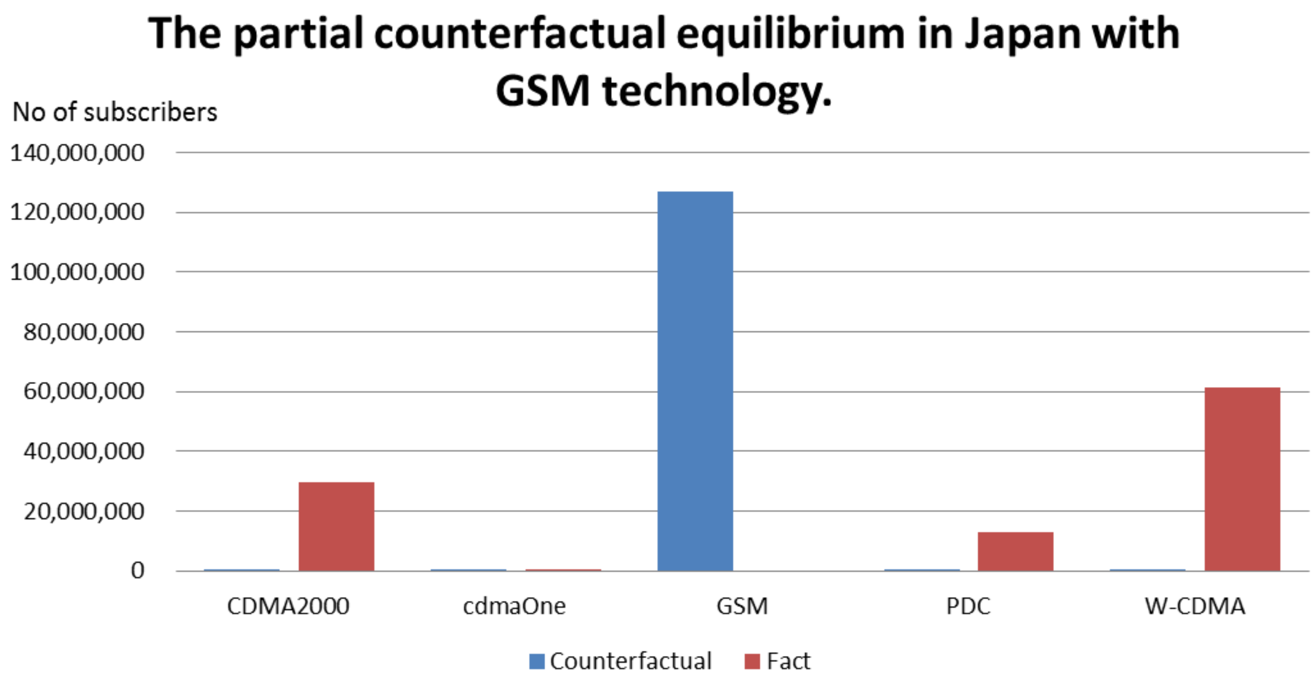

Table 11: Estimation results of other falsification test

Weighting variables	No weight			Trade Value			Geographic distance			International Travel		
Number of observations	1075			1075			1075			1075		
Number of groups	146			146			146			146		
Number of IV	179			179			179			179		
Hansen J Value (D.F)	104.74 (150)		0.998	113.18 (150)		0.989	110.15 (150)		0.994	108.08 (148)		1
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−4.9107		7.7722	−5.8919		7.0836	−5.6074		5.1785	−6.3848		6.9610
Service charge/GDP Per Capita	15.4065		21.4585	−12.7346		21.2627	0.1049		12.9293	−11.3558		20.4184
Local technology	−135.4360	***	36.1244	−0.0002		0.0001	−0.1489		0.1319	−0.0367		0.0279
International network effect	2.2125	***	0.2563	0.0000		0.0000	0.0266	***	0.0071	0.0016		0.0010
Within share	1.3843	***	0.1615	1.2521	***	0.1629	1.0446	***	0.1353	1.2360	***	0.1529
Year fixed effects by technology	Yes			Yes			Yes			Yes		
Country fixed effects by technology	Differenced			Differenced			Differenced			Differenced		

Weighting variables	No weight			Trade Value			Geographic distance			International Travel		
Number of observations	1075			1075			1075			1075		
Number of groups	146			146			146			146		
Number of IV	72			72			72			72		
Hansen J Value (D.F)	53.47 (43)		0.132	58.50 (43)		0.989	43.78 (43)		0.438	65.61 (43)		0.015
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Service charge	−3.5519		8.6089	−8.3050		8.2973	−7.1706	**	3.5630	−6.6696		8.5042
Service charge/GDP Per Capita	14.2782		18.7309	−17.8292		24.9605	13.1547		13.4396	−27.9531		32.3369
Local technology	−179.8958	***	45.6877	−0.0005		0.0005	0.0164		0.3172	−0.1379		0.1207
International network effect	2.2208	***	0.2599	0.0001	*	0.0000	0.0573	***	0.0111	0.0060		0.0042
Within share	1.6442	***	0.2227	1.4633	***	0.5754	0.6856		0.4445	1.5288	***	0.2659
Year fixed effects by technology	Yes			Yes			Yes			Yes		
Country fixed effects by technology	Differenced			Differenced			Differenced			Differenced		