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Supply and Demand for Telecommunication Infrastructure

Tobias Veith

Zentrum für Europäische
Wirtschaftsforschung GmbH

Centre for European
Economic Research

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Non-technical summary
Telecommunication infrastructure availability at an adequate quality level has considerably changed communication habits since the 1990s. The physical infrastructure and its quality are the key pre-requisites for higher-level service infrastructure (such as the internet) or offered services (such as SMS or telephony). Consequently, telecommunication infrastructure, investment incentives and the effect of service level competition have gained importance in economic research. Although new technologies demand an active usage of infrastructure by customers offering own information and services (Web 2.0), only a low number of infrastructure providers shoulder investment costs and investment risks. Therefore, it becomes more and more difficult for infrastructure providers to internalize the value added for customers by the provision of a high-quality infrastructure.
This paper analyzes whether and how the demand for infrastructure affects infrastructure provision. So far, the empirical literature assumes investments to be only driven by supply side characteristics. Thus, service level competition is considered as a direct driver for infrastructure provision. However, it is ignored that service competition increases information supply which requires an adequate level of infrastructure. Consequently, service competition should also have an impact on infrastructure demand and, thus, should indirectly affect infrastructure investments.
In a two-equation model, I disentangle service competition as a driver for infrastructure demand and as a driver for infrastructure supply and compare the results of the simultaneous estimation approach with the standard closed-form approach, i.e. when the indirect effect of competition is ignored. I do this exercise both for fix-line infrastructure and for mobile infrastructure and show that the impact of competition on investments is downward-biased when the demand side is ignored.
Moreover, I also analyze cross-effects between fix-line and mobile infrastructures. While the demand for fix-line infrastructure is found to be independent of the demand for mobile infrastructure, the demand for mobile infrastructure depends on fix-line infrastructure demand. Similarly, mobile investments depend on fix-line investments but fix-line investments are found to be independent. While fix-line infrastructure is installed at a point in time without a competitive infrastructure being already in place, mobile supply and also mobile demand depend on the fix-line market situation. These findings support the idea of asymmetric substitutability effects between competitive infrastructures in European telecommunication markets.

Das Wichtigste in Kürze

Die Verfügbarkeit von Telekommunikationsinfrastruktur adäquater Qualität hat seit Ende der 1990er Jahre zu einer erheblichen Veränderung von Verhaltensmustern in der Kommunikation beigetragen. Die physische Infrastruktur und ihre Qualität gelten als zentrale Voraussetzung für die Qualität von aufgesetzten Infrastrukturen (Internet) oder Dienstleistungen (SMS, Sprachtelefonie). Aus diesem Grund hat die Untersuchung der Telekommunikationsinfrastruktur, die Anreizsetzung für Investitionen und insbesondere auch der Einfluss von Dienste-Wettbewerb für Investitionen im wissenschaftlichen Umfeld besondere Bedeutung erlangt. Obwohl neue Technologien eine immer stärkere Einbindung von Nachfragern als aktive Nutzer der Infrastruktur begründen, die Inhalte bereitstellen und Dienste und Informationen aktiv anbieten (Stichwort Web 2.0), werden Investitionskosten und -risiken nur von einigen wenigen Infrastrukturanbietern getragen. Für die wenigen Infrastrukturanbieter wird es kontinuierlich schwieriger, den durch die Infrastruktur geschaffenen Mehrwert zu internalisieren.

Dieses Papier untersucht, ob und in welchem Umfang die Nachfrage nach Infrastruktur einen Einfluss auf deren Bereitstellung hat. Bislang wird in der empirischen Forschung davon ausgegangen, dass Investitionen (nur) durch anbieterseitige Faktoren bestimmt werden. Daher wird Wettbewerb auf der Diensteebene als direkter Einflussfaktor für das Infrastrukturangebot unterstellt. Dienstewettbewerb führt allerdings zu einer Steigerung der Informationsbereitstellung, was wiederum die Verfügbarkeit einer hinreichenden Infrastrukturqualität voraussetzt. Daher sollte Wettbewerb auf der Diensteebene auch die Nachfrage nach Infrastruktur bedingen und daher einen indirekten Effekt auf Investitionen haben.

In einem 2-Gleichungssystem unterscheide ich die Bedeutung von Dienstewettbewerb als Einflussfaktor für das Infrastrukturangebot und die Infrastrukturnachfrage. Ich vergleiche die Schätzergebnisse eines strukturellen Schätzansatzes, der die Nachfrage in der Investitionsgleichung endogenisiert, mit den Ergebnissen von unabhängigen Schätzungen. Die Ergebnisse zeigen eine Unterschätzung der Bedeutung von Dienstewettbewerb auf Investitionen, wenn man die Nachfragerseite vernachlässigt.

In einem weiteren Schritt wird die Beziehung zwischen Festnetz- und Mobilfunkinfrastruktur untersucht. Während die Nachfrage nach Festnetzinfrastruktur unabhängig von der Nachfrage nach Mobilfunkinfrastruktur ist, hängt die Nachfrage nach Mobilfunkinfrastruktur von der Nachfrage nach Festnetzzugang ab. Ähnliches ist bei Mobilfunkinvestitionen bezüglich Festnetzinvestitionen zu beobachten. Während Festnetzinfrastruktur zu einem Zeitpunkt installiert wird, zu dem noch keine vergleichbare Mobilfunk-Übertragungstechnologie zur Verfügung steht, hängen Mobilfunk-Nachfrage und -Angebot von der Festnetzsituation ab. Diese Ergebnisse bestätigen eine asymmetrische Substituierbarkeit zwischen Festnetz- und Mobilfunkinfrastruktur in europäischen Telekommunikationsmärkten.

Supply and Demand for Telecommunication Infrastructure

Tobias Veith[†,*]
ZEW Centre for European Economic Research, Mannheim, Germany

Abstract The interplay of infrastructure supply and demand is of central interest in line with Web 2.0. As the role of customers turns from a service users' role to an information providers' role, the traffic on existing lines increases and, simultaneously, customers' demand for high-quality infrastructure. On the other hand, infrastructure providers carry investment risks but can hardly internalize the value provided for service providers. In consequence, politicians have to think about how to initiate adequate investment incentives.
Using a two-equation estimation approach, a direct competition effect (more service competition increases the supply of infrastructure) can be disentangled from an indirect effect (more service competition increases the demand for infrastructure quality and, as a consequence, increases the supply of infrastructure). While the direct investment effect is only partially confirmed, the analysis provides evidence for an indirect investment effect for both fix and mobile infrastructure investments.
Taking into account cross effects between fix line infrastructure markets and mobile phone infrastructure markets even broadens the view: While the indirect own-market competition effect is still found, the estimation results confirm the idea of asymmetric substitutability between telecommunication infrastructures.

Keywords telecommunications, infrastructure supply and demand
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[†]ZEW, P.O. Box 103443, 68034 Mannheim, Germany. Phone: +49 621 1235-296, Fax: +49 621 1235-170. E-mail: veith@zew.de

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1 Introduction

Telecommunication markets have entered their second fundamental phase of restructuring during the last couple of years. Until the end of the 1990s, telecommunication markets were provider-driven markets with fully integrated monopolistic providers. These providers decided about the quality of services and even the services themselves. As more and more services evolve with the installation of more recent transmission technologies[1], the profit from infrastructure provision and the profit from service provision continuously diverge. Simultaneously, the role of service users turned from a passive to an active role as users demand for adequate infrastructure which is necessary for higher-quality services. Moreover, with Web 2.0, users even start to provide services themselves and use peer-to-peer platforms, which requires symmetric or at least higher bandwidth accesses in the near future.[2] The demand for high-quality infrastructure increases as physical infrastructure turns from an originally provider-determined to a customer-determined product and infrastructure providers and regulators have to contemplate how to handle this fundamental restructuring. This issue is even more striking when taking into account the steps implemented by the European Parliament in coordination with national governments to install the Third Regulatory Package.[3] It is therefore most relevant to know more about how the market structure and service competition influence investments, how the transition from one market structure to another affects the supply and, in particular, the demand for infrastructure and how they interact. With this paper, I want to provide some more insights into these aspects by analyzing the first structural change in telecommunication markets from former monopolistic to competitive markets. Closed-form models are the standard approach chosen in the literature to explain the impact of service competition on infrastructure provision. However, this approach ignores potential indirect effects of competition on the demand for infrastructure. For taking into account such indirect effects, I estimate an equation system for infrastructure supply and infrastructure demand as recommended in Röller and Waverman (2001). Such a more structural approach separates demand-related impact variables from supply-related ones and considers how competition and other explanatory variables of standard closed-form models affect the supply side or the demand side, respectively.

[1]Examples are internet platforms like Ebay, search engines like Google, MMS and mobile internet access.

[2]Examples are video platforms like YouTube or social networks like Facebook.

[3]http://ec.europa.eu/information_society/policy/ecomm/doc/tomorrow/reform/better_regulation_directive/st03677_re06.en09.pdf

In doing so, I find service competition increasing infrastructure investments both in fix and in mobile markets. However, competition does not directly affect investments, i.e. I find no or only weakly significant supply-side effects of competition on investments. Instead, competition influences the demand for infrastructure which then affects investments.

Taking into account cross effects between fix and mobile infrastructure markets, I find that higher mobile prices lead to a lower demand for mobile infrastructure but to a higher demand for fix infrastructure access. On the other hand, no such effect is found the other way round. Similarly, the supply of mobile infrastructure depends on the situation in fix infrastructure markets but not vice versa.

The paper is organized as follows: In section 2, a short overview over the literature on investments in telecommunication infrastructure and competition is provided. Section 3 describes the main changes in European telecommunication infrastructure markets and derives three hypotheses, which are either based on the observation of the European situation or which are based on findings in the literature. Section 4 explains the estimation models and introduces the underlying database. In Section 5, estimation results are displayed and discussed in more detail. Section 6 concludes the paper.

2 Related Studies on Telecommunication Infrastructure Supply and Demand

Since the liberalization of European telecommunication markets, telecommunication infrastructure is in the focus of an ongoing political debate. In particular with the consideration of open access, the question of adequate infrastructure quantity and quality is a central issue on the agenda of infrastructure providers, politicians and also user associations. Despite the huge political relevance, there is still a very low number of papers addressing the debate from an empirical perspective and nearly no paper analyzes the interplay of infrastructure supply and demand. In this short review, I concentrate on papers, which take up the question of infrastructure provision, and papers, which address the topic of infrastructure demand and customers' choice between alternative infrastructures from an empirical perspective.

The seminal paper of Röller and Waverman (2001) provides the basic estimation framework of this paper. The authors analyze the impact of infrastructure provision on economic performance measures for a selection of OECD countries. In doing so, they find a significant impact of the availability of telecommunication infrastructure on GDP, which is not linear. Moreover, due to network effects in the telecommunication sector, they identify a critical level of telecommunication infrastructure, above which increasing returns on GDP growth exist. While Röller and Waverman consider telecommunication infrastructure as a driver of economic growth, the following papers concentrate on telecommunication market performance itself.

In a cross-country study of multiple African and South American countries, Wallsten (2001) analyzes how infrastructure liberalization and privatization affect investment patterns. He identifies a positive correlation between mainline competition and connection capacity. However, for privatization, no positive effect on competition exists. In a subsequent study, Wallsten takes a closer look at the sequence of privatization and deregulation (Wallsten, 2002) and concludes that the sequence significantly affects the performance of telecommunication markets. If regulation follows privatization, this structure decreases market concentration and market power of the former monopolistic firm more than the other way round.

Henisz and Zelner (2001) also analyze the role of the government on telecommunication market performance. They focus on how countries can close the gap to other countries with a more advanced telecommunication infrastructure in place since, in line with Röller and Waverman (2001), telecommunication infrastructure is assumed to be the central pre-requisite for economic performance. Henisz and Zelner argue that the catch-up of less developed countries should not only be based on the economic characteristics of a country. Moreover, they find that governmental interventions to coordinate and support the development are a key aspect, which determines the speed of catching-up.

In contrast to the previous papers, Heimeshoff (2007) uses a data set of developed countries. He considers the main drivers of telecommunication investments, adopting a time series approach for a selection of OECD countries and identifies market concentration as a driver of infrastructure investments. Moreover, Heimeshoff includes an indicator of governmental and democracy drivers (comprising measures for the procedure of government election or alternative types of civil rights) and finds that "more democracy" has a significantly positive impact on investments in telecommunication infrastructure.

The paper of Grajek and Röller (2009) is one of the first studies in which a firm-level data set is employed. Using a new regulatory index, the Plaut Economics Regulatory Index[4], they analyze the effect of regulation on investments for a database of European

[4]See Zenhäusern et al. (2007) for a more detailed description.

telecommunication companies. By controlling for endogeneity of regulation with various instrumental variables, including political variables and levels of regulation in other European countries, they identify a negative effect of regulation on investments.

Besides the consideration of supply-side aspects and the performance of infrastructure deployment, a number of papers address a demand-related topic of infrastructure availability, the substitutability between fix-line and mobile services and fix-line and mobile infrastructure. While particularly in developed countries at least basic fix-line infrastructure access is available, the major issue lies on an upcoming new infrastructure and the substitutability between the quality of fix-line and mobile access lines.
Rodini et al. (2003) apply an empirical analysis for a U.S. household survey, in which they consider access substitutability between mobile access and second fix lines.[5] By estimating cross-price elasticities, they find that both access modes are selected substitutively. Following the authors, substitutability has a strong impact on policies concerning the restructuring of a fix-line network.
In contrast to Rodini et al., Hamilton (2003) considers the role of infrastructure substitutability and complementarity for developing countries. She points out that in this context, substitutability and complementarity depend on a country's economic development. Particularly in less developed countries with a lower roll-out of fix-line infrastructure, mobile access is a substitute to fix-line access. In countries with an existing fix-line infrastructure, mobile access could also be complementary to fix access lines. Moreover, at a state of lower fix-line roll-out, the introduction of mobile infrastructure increases the competitive pressure on fix-line providers to extend fix-line infrastructure.

To the best of my knowledge, Röller and Waverman (2001) is the only empirical paper which takes into consideration both the supply side and the demand side of infrastructure. Papers based on infrastructure supply on a country-level aggregation mainly consider fix-line and mobile investments in general but ignore differences in supply patterns of the two infrastructures.[6] In contrast, papers on telecommunication demand mainly ignore the challenge of infrastructure availability and investments. I try to close

[5]The authors argue that the first fix-line access is the standard access. Households increase availability either by a second fix-line access or by a cellular phone access. While a second fix-line access is only available at home, it particularly guarantees a higher transmission rate for internet access.

[6]Grajek and Röller (2009) use data on the company level and control for fix-to-mobile differences in their model.

this gap by considering both the supply side and the demand side using an equation system of supply and demand to check, which factors are drivers of supply and/or demand. Moreover, I undertake the analysis for fix-line and mobile markets separately accounting for cross effects between the two infrastructures.

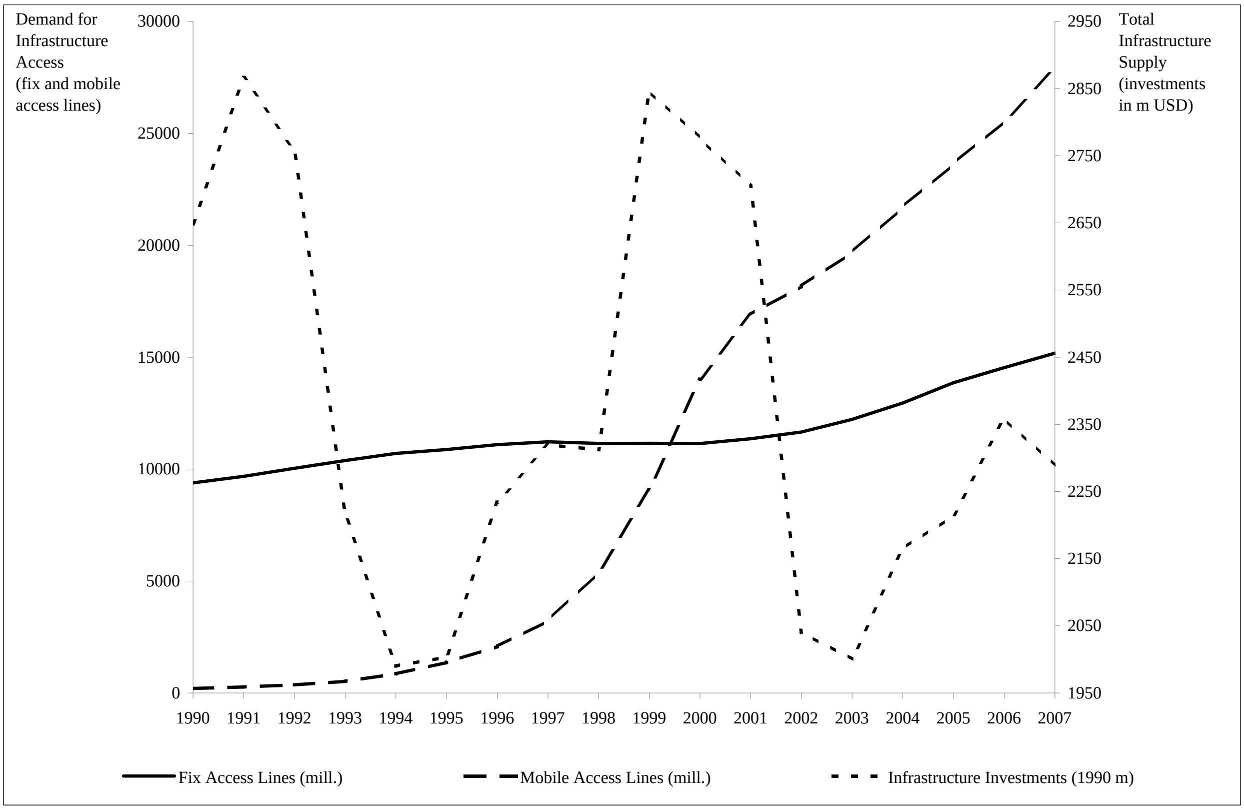
3 Infrastructure Supply and Demand with Platform Competition

In European countries, mainly two telecommunication infrastructures are installed which carry, to a far extent, identical services. While a basic fix-line infrastructure has been available for all households, mobile communication was established during the 1990s and is still on an ongoing growth path today. In consequence, the change from one infrastructure to two infrastructures affects the demand for services provided on the infrastructures and also the demand for infrastructure itself. Simultaneously, new transmission technologies and also new infrastructures were installed to increase capacity and, thus, to increase quality both in fix-line and in mobile markets. While the additional infrastructure capacity enables a higher quantity and a higher quality of services, the initiator for investments is unclear. In particular, the role of service competition for infrastructure investments with two competing access modes is of regulatory relevance due to comprehensive externalities provided by infrastructure availability.

In most economic studies on infrastructure supply, i.e. investments, a closed-form approach is chosen, which assumes demand for infrastructure being independent of other drivers of investments. On the other hand, when analyzing demand aspects like substitutability of infrastructure and how the demand for one infrastructure affects the demand for another infrastructure, the supply side has mainly been ignored. The consideration of both supply and demand simultaneously is particularly relevant when analyzing major structural changes either stemming from comprehensive technological deployments or from substantial changes in market structures, such as "shocks" to the markets.

During the 1990s until 2007, the European telecommunication sector has experienced a major change in terms of market structures from former monopolistic markets to competition. Moreover, the installation of mobile infrastructure and, thus, the availability of mobile services affected also the demand for fix-line infrastructure. As stated in the first proposal of the Second Regulatory Package, the new situation in market structures induced major adjustments in terms of transmission technology such as the introduction of broadband and the switch from GSM to UMTS technology.[7] While closed-form models consider *whether* there exists an effect of such market-structural or technological changes on investments, multi-equation estimation approaches allow to consider *how* this affects the interplay of supply and demand. By employing a more structural estimation approach, we are able to separate key drivers for changes in infrastructure demand from key drivers for changes in supply. Moreover, cross-infrastructure effects can additionally be considered. This provides more detailed insights into how alternative factors work together in situations of structural and also technological changes.

Figure 1: Infrastructure Supply and Demand in the EU-15, Norway and Switzerland



Source: Information taken from the OECD Communications Outlooks (2001, 2007, 2009) and from the SourceOECD Telecommunications Database.)

A first impression whether the fundamental changes in ownership and market structures have had an impact on infrastructure supply and demand could be derived from

[7]The technological change is one reason among others for the introduction of the Second Regulatory Package as stated in an EC communication: `http://ec.europa.eu/archives/ISPO/infosoc/telecompolicy/en/com2000-239en.htm#_Toc478275739`

Figure 1. Total supply is represented by total investments in telecommunication infrastructure deflated to 1990 using the Consumer Price Index (CPI). Demand is separated into demand for fix-line access, i.e. the number of standard fix lines, and demand for mobile, i.e. the number of subscribers.

Ambiguous explanations exist for the impact of service competition on infrastructure provision. On the one hand, more service competition triggers the provision of more and higher-quality infrastructure as service providers require a high level of infrastructure capacity to distinguish from each other in service competition. Thus, the demand for infrastructure motivates infrastructure operators to invest (an argument brought forward by the EC based on comparisons with the United States). On the other hand, service competition might also have an investment-reducing effect due to too low expected returns on investments. Service competition is mostly Bertrand-like competition (with differentiated products). Therefore, tougher competition reduces the rents which could be extracted by the infrastructure provider and, thus, reduces the incentive to invest (Aghion and Howitt, 1992, or Heimeshoff, 2007).

Employing data for EU-15 markets as well as Norway and Switzerland allows for a comparison of these hypotheses under a common regulatory regime and market structural background. Figure 1 provides evidence that aggregated total investments across all countries follow a long-run investment circle. The increase in total investments after 1994 slowed down around 1997 but afterwards strongly accelerated until 1999, which is in line with the introduction of competition. Even after the investment increase was interrupted by the burst of the IT bubble, deflated investments did not fall below the level of 1994 anymore due to the technological development.[8] These graphical findings are in line with the interpretation of the EC. Following Commissioner Viviane Reding, a positive effect of service competition on investments should be expected.[9]

> **H1:** Upcoming service competition initiates telecommunication infrastructure supply.

Turning to the demand for infrastructure (proxied by the number of access lines in Figure 1), mobile subscription follows the expected S-shape relation known from the literature on network-based markets (see e.g. Cabral, 1990; Grajek, 2003). Moreover, the

[8]Non-deflated investments even increased slowly.

[9]See e.g.
http://ec.europa.eu/commission_barroso/reding/docs/speeches/brussels_20070321.pdf

development is of particular interest as, from the standard theoretical approaches, we should have expected a concave functional form after around 1999, but we observe a second acceleration in demand. This new acceleration is driven by technological upgrades, as around 2000/2001, UMTS licences were allocated. The subsequent European-wide upgrade from GSM-based infrastructure to UMTS-based infrastructure was mainly motivated by the provision of higher-quality services, which demand for mobile "broadband" internet access.[10]

A similar but much weaker increase in demand is found with the fix access curve. While there is a stagnation of growth between 1997 and 2001, the upward orientation continues afterwards, which is also based on the demand for higher-quality services in line with broadband infrastructure. The latest OECD Communications Outlook (2009) describes the increase in fix-line and mobile service quality and the extensive price reductions as the results of upcoming competition.

> **H2:** Upcoming service competition increases the (derived) demand for telecommunication infrastructure of adequate quality and, thus, increases infrastructure supply.

While the first two hypotheses consider infrastructure supply and demand separately, I now turn to cross effects of fix-line and mobile infrastructure supply and demand. A central issue, which has been frequently discussed in the literature, is the topic of substitutability between infrastructures. Mobile and fix access lines are considered to be either complements or substitutes with regard to services and with regard to infrastructure itself (Rodini et al., 2003; Hamilton, 2003; Sugolov, 2005; or Plank, 2005). Evidence for both outcomes is found in dependence of the underlying data set. Until the critical mass for a new substitutive network is reached, this network strongly depends on the already existing network. Therefore, the established network is a complement for the newer alternative and probably also the other way around. Nevertheless, if the newer network has reached its critical mass of users, both networks (might) get substitutes.

In European countries, basic fix-line infrastructure access must be accessible for households at an affordable price due to Directive 1998/10/EC and the subsequent Universal Service Directive (2002/22/EC). Even before the liberalization, national laws already guaranteed access to public telecommunication networks. Therefore, most households

[10]Note that UMTS was not the first technology for mobile internet access. Nevertheless, it is the most advanced at the time of its introduction.

had access to fix-line infrastructure already at the beginning of the observation period. In contrast, mobile subscription is not covered by the Universal Service Directive or national laws. Moreover, following Rodini et al. (2003) and the fix-line and the mobile demand development in Figure 1, customers take mobile access as a secondary access mode. As fix access has been less expensive, mobile access is no substitute when customers decide about the first fix access. In contrast, a secondary fix access has been a substitute to mobile access during the phase of mobile-infrastructure roll-out.[11]

> **H3a:** Due to fix-line availability, customers demand more fix-line access when mobile access is more expensive. However, due to its novelty, the demand for mobile access is only weakly affected by lower fix-access prices.

Turning to the supply side, the technological lag of mobile infrastructure capacity enables fix-line infrastructure upgrade decisions to be independent of mobile infrastructure provision. In contrast, mobile infrastructure is a follower technology and therefore depends on the fix-line infrastructure quality and the access price.

> **H3b:** The more fix-line infrastructure is provided/the lower the price for fix-line access, the less mobile infrastructure investments are implemented. In contrast, no reverse effect exists due to a first-mover advantage of fix-line infrastructure capacity.

4 Empirical Analysis

In this section, I first derive a model to analyze the interrelationship of supply and demand for fix-line and mobile infrastructure. Afterwards, I provide a descriptive consideration of the data and give a short overview of the necessary adjustments of investment data and the resulting pitfalls to be taken into account when interpreting the estimation results.

4.1 Econometric Model

Two complementary equations are used to characterize supply and demand of telecommunication infrastructure. Supply is determined as infrastructure investment. The

[11] Please note that due to new contract structures and higher-quality mobile services, fix and mobile accesses have become closer substitutes to each other today than during the observation period.

higher investments are, the "more" infrastructure is provided or the higher is the capacity of the existing infrastructure. Infrastructure expansions, in particular backbone investments, reduce congestion on the available infrastructure. In consequence, infrastructure investments either lead to an expansion in terms of geographical reach or in terms of quality of the existing infrastructure.

While Röller and Waverman (2001) concentrate on the impact of telecommunication infrastructure on GDP and, therefore, instrument infrastructure using supply and demand functions, I want to analyze the determinants of infrastructure supply and demand themselves and specify the supply function in more detail using approaches provided in more recent literature (Henisz and Zellner, 2001; Wallsten, 2001, and Wallsten, 2002; Heimeshoff, 2007). Infrastructure supply is described by the following equation:

$$\begin{aligned} log(inv_{t,i}) &= \alpha^s_{t,i} + \beta^d_{accpr} log(access\ price_{t,i}) + \beta^s_{acc} log\frac{access_{t,i}}{pop_{t,i}} + \beta^s_{comp} comp_{t,i} \\ &+ log(pop_{t,i})'\beta^s_{pop} + \beta^s_{pub} log(pub_{t,i}) + \beta^s_{int.\ rate} log(int.\ rate_{t,i}) \\ &+ \beta^s_{time} time + country'_{t,i}\beta^s_{country} + \epsilon^s_{t,i} \end{aligned} \quad (1)$$

Investments *inv* are assumed to be a function of access prices *access price*, the number of mainlines in operation per households (number of mobile subscribers per capita) $\frac{access}{pop}$, entrants' market shares in the fix-line or the mobile market *comp* and the following control variables: population characteristics *pop* like the population, GDP per capita and the share of urban population as a measure of population concentration, the public ownership share *pub*, the costs of capital, *int. rate*, trend variables *time* and country control variables *country*.

Unfortunately, no public information is accessible on the telecommunication capital stock in European countries. It is proposed in the literature to calculate the capital stock based on the number of mainlines, i.e. the number of accesses to the telecommunication infrastructure. However, mainlines are a measure of infrastructure demand as customers ask for the installation. Thus, mainlines are not installed without customers' desire to do so. I therefore refrain from using mainlines as a measure of provided infrastructure and rather apply the share of mainlines in operation per households (mobile subscribers per capita) as a measure of infrastructure demand (see below).[12]

Cadot et al. (2006) use the Perpetual Inventory Method (PIM) to calculate infrastructure stocks. They allocate information on a cross-regional infrastructure stock based on the average past-years investment shares. However, such an approach can hardly

[12]Moreover, additional criticisms are brought forward in the literature (see e.g. Wallsten, 2001) as mainlines cover only the last-mile infrastructure but do not measure backbone capacity and availability.

be adopted to markets which are subject to comprehensive technological deployments. Moreover, no data are available for the time period before 1990 (even no mainline figures for all EU-15 countries). Thus, a starting level for the European telecommunication capital stock can hardly be calculated.[13]

As infrastructure investments tie up capital in the long-run, it is important to control for the long-run costs of capital. I include interest rates based on 10-years government bonds which are expected to have a negative impact on infrastructure supply but no effect on demand.

Usually, infrastructure demand is assumed to be exogenously given in closed-form models. It either enters the estimation equation as a proxy for existing infrastructure or it is ignored. However, taking demand as an exogenous variable neglects the impact of service competition and other variables on demand. Standard approaches in the literature estimate the effect of alternative impact factors on infrastructure provision with closed-form investment models. These models implicitly assume a black-box structure with regard to the interplay of infrastructure supply and demand and ignore any interactions of infrastructure demand characteristics and service competition. By giving a more structural form to demand, I try to disentangle this black box.

Röller and Waverman (2001) express infrastructure demand as the number of mainlines in operation. I adopt this measure for fix-line access and, correspondingly, use the number of mobile subscribers as the measure for mobile infrastructure demand.[14] The dependent demand variable differs from the demand specification in Röller and Waverman (2001) in the sense that they construct demand as the sum of per-capita access and the per-capita waiting list for infrastructure access. I ignore the waiting-list term as it is stated in the OECD Communications Outlook 2001 that the waiting time and, thus, the number of customers waiting for infrastructure availability is negligible for the period since about 1990 (p. 211 and Table 8.1). Moreover, it is stressed that due to this fact most countries have even stopped listing waiting time (Table 8.2).

Using a measure based on the number of mainlines or mobile subscribers for infrastructure demand holds some pitfalls, firstly, as it excludes the individual quantity of usage and, secondly, as it ignores quality differences. However, infrastructure usage and the

[13] Grajek and Röller (2009) employ data on the company level and, therefore, proxy the infrastructure stock based on financial data.

[14] Röller and Waverman only consider (fix) mainlines as mobile telephony is of no interest for the period of their model.

quality level of the access mode relate to the services provided on the lines and do not necessarily express the singular demand for access lines.[15]

The demand equation therefore has the following structure:

$$\begin{aligned} log\frac{access_{t,i}}{pop_{t,i}} &= \alpha^d_{t,i} + \beta^d_{accpr} log(access\ price_{t,i}) + \beta^d_{acc} log\frac{access_{t-1,i}}{pop_{t-1,i}} + \beta^d_{comp} comp_{t,i} \\ &+ log(pop_{t,i})'\beta^d_{pop} + \beta^d_{pub} log(pub_{t,i}) + \beta^d_{int.\ rate} log(int.\ rate_{t,i}) \\ &+ \beta^d_{time} time + country'_{t,i}\beta^d_{country} + \epsilon^d_{t,i} \end{aligned} \quad (2)$$

I assume a very similar structure for supply and demand as no information about drivers of infrastructure demand could be found in the literature. By adopting an equation system for supply and demand, I use the variables typically provided in the literature to affect infrastructure investments and consider whether they better explain supply or demand or even both.[16] Simultaneous-estimation methods allow for such a specification as the common variance-covariance matrix accounts for correlations between the error terms as well as endogenous variables and the exogenous variables of the two equations. While infrastructure demand enters the supply equation, I include the one period lagged demand into the demand equation as a customer's decision about infrastructure demand is a singular decision and is not changed every period. Thus, the demand for infrastructure in period t should strongly depend on infrastructure demand in period $t-1$. I also include a price approximation for infrastructure access, which is the total infrastructure revenue per access, *access price*, as is done in Röller and Waverman (2001). Unfortunately, there is no consistent information about access prices due to highly distinct pricing methods across countries and due to repeated adjustments of access price calculations in individual EU member states.

For analyzing whether substitutive effects exist between fix-line and mobile infrastructure, I additionally include mobile revenues per subscriber in the fix-line supply function and fix-line revenues per mainline in the mobile supply function. Similarly, I include the number of mainlines in operation per household in the mobile demand equation and the number of mobile subscribers per capita in the fix-line demand equation.

[15] For the analysis of infrastructure quality differences, alternative measures such as broadband availability or UMTS technology subscriptions could be used. Nevertheless, this is not the aim of the analysis in this paper.

[16] Thus, the results of my estimations provide more information of how one could specify infrastructure supply and demand.

4.2 Data Description and Data Adjustments

Data Sources

I apply data aggregated on the country level for the EU-15 countries as well as Norway and Switzerland between 1990 and 2007. Data are mainly taken from OECD sources, which include information from the biannual OECD Communications Outlooks (1999, 2001, 2009). Additionally, I also use data from the OECD International Regulation Database about regulation and competition and information from SourceOECD and Eurostat on long-run interest rates. Population concentration data is taken from the UNECE website.

Data Description

Table 1 provides an overview of the variables used in the analysis for the first and the last year of the observation period as well as for 1998 as this is the year of the transposition of the EC directives to national laws in most EU member states. All financial variables are deflated using the CPI 1990 and are expressed in US Dollars (USD) for reasons of comparison between countries.

The strong reduction in fix-line infrastructure investments and the simultaneous increase in mobile infrastructure investments is mainly due to the ongoing increase in mobile roll-out during the observation period. While total investments decreased from nearly 2650m USD in 1990 to about 2290m USD in 2007 in a cyclical move, the share dedicated to mobile investments increased.

Concerning the demand for infrastructure access, the aggregated figures correspond to the graphs in Figure 1. A weak increase in the demand for fix-line access and a very strong increase in the demand for mobile access during the observation period is observed. Figures on the relative change in demand provide some descriptive impression of the slope of the demand curves. The relative change in fix access lines experienced a weak downward slope between 1993 and 1999 but afterwards continuously increased at a low rate. Concerning the relative change in the number of mobile subscribers, a strong increase exists which corresponds to the slope of the demand curve as seen in Figure 1. Nevertheless, with a higher number of mobile subscribers, the relative change in mobile subscriptions slows down. While fix-line and also mobile revenue per access remained at a nearly constant level or even decreased during the first half of the observation

Table 1: Descriptive Statistics

1990	Mean	Std. Dev.	Min	Max	Obs.
Fix Investments (m)	2601.5	3261.8	442183	10344.0	17
Mobile Investments (m)	47.0	51.9	0	198.4	17
Fix Access/Pop.	0.456	0.114	0.240	0.689	17
Mobile Access/Pop.	0.015	0.018	0	0.054	17
Rel. Change Fix Lines*	3.7	2.6	0.4	11.8	17
Rel. Change Mobile Lines*	29.1	14.0	11.6	53.1	16
Fix Rev./Acc.*	706.9	192.1	453.4	1190.3	14
Mob. Rev./Acc.*	188.8	620.1	5.9	2429.4	15
Population (mill.)	21053.0	22886.1	378.4	62063	17
GDP/Pop.	21235.6	7639.8	7150.9	34363.5	17
Share Urban Population	72.2	12.3	47.9	96.4	17
Long-Run Interest Rate	0.111	0.025	0.065	0.154	15
Fix Market Share Entrant	0.471	1.940	0	8	17
Mobile Market Share Entrant	3.5	10.1	0	37	17
Gov. Share Fix Inc.	93.2	19.3	35	100	17
Gov. Share Mob. Inc.	93.2	19.3	35	100	17
# Fix Prov. > 1	5.9	24.3	0	100	17
# Mob. Prov. > 1	17.6	39.3	0	100	17

* 1991

1998	Mean	Std. Dev.	Min	Max	Obs.
Fix Investments (m)	1576.6	1711.1	16.2	4987.6	17
Mobile Investments (m)	735.6	700.3	9.3	2062.5	17
Fix Access/Pop.	0.511	0.079	0.386	0.688	17
Mobile Access/Pop.	0.291	0.116	0.170	0.554	17
Rel. Change Fix Lines	-1.8	6.1	-17.4	5.1	17
Rel. Change Mobile Lines	40.0	10.8	19.1	54.4	17
Fix Rev./Acc.	764.9	254.5	253.9	1405.2	17
Mob. Rev./Acc.	104.5	41.6	45.7	218.3	17
Population (mill.)	22617.7	25579.9	419	82035	17
GDP/Pop.	26162.0	8713.3	11726.4	46181.4	17
Share Urban Population	73.6	11.8	53.1	97.0	17
Long-Run Interest Rate	0.050	0.011	0.030	0.085	16
Fix Market Share Entrant	8.4	16.1	0	63	17
Mobile Market Share Entrant	36.7	18.0	0	66	17
Gov. Share Fix Inc.	56.9	38.5	0	100	17
Gov. Share Mob. Inc.	58.5	39.8	0	100	17
# Fix Prov. > 1	47.1	0.514	0	100	17
# Mob. Prov. > 1	100	0	0	100	17

2007	Mean	Std. Dev.	Min	Max	Obs.
Fix Investments (m)	820.2	831.3	27.0	2488.2	17
Mobile Investments (m)	1467.8	1446.0	48.3	4178.2	17
Fix Access/Pop.	0.645	0.100	0.440	0.808	17
Mobile Access/Pop.	1.2	0.162	0.902	1.5	17
Rel. Change Fix Lines	2.8	5.8	-7.1	14.6	17
Rel. Change Mobile Lines	7.0	4.0	-4.4	14.4	17
Fix Rev./Acc.	1419.6	712.9	362.9	3235.1	17
Mob. Rev./Acc.	328.5	97.8	185.7	499.3	17
Population (mill.)	23580.2	26341.7	473	82376	17
GDP/Pop.	49593.5	20073.9	21112.1	105065.3	17
Share Urban Population	75.2	11.1	58.9	97.3	17
Long-Run Interest Rate	0.041	0.004	0.029	0.049	16
Fix Market Share Entrant	35.2	10.0	21.2	60	17
Mobile Market Share Entrant	55.3	8.0	41	74	17
Gov. Share Fix Inc.	26.3	28.5	0	100	17
Gov. Share Mob. Inc.	23.4	28.5	0	100	17
# Fix Prov. > 1	100	0	100	100	17
# Mob. Prov. > 1	100	0	100	100	17

period, both strongly increased with upcoming competition. During the first half of the observation period, incumbents chose prices under weak or no competition. In contrast, upcoming competition increased customers' attention, which increased the demand for services. Moreover, innovative transmission technologies reduced congestion and enabled higher-quality services on the lines. Combining both infrastructure demand and higher-quality service enabled a, in total, higher revenue per access in the second half of the observation period.

Other telecommunication-related variables in Table 1 correspond to upcoming competition and privatization. As the access to mobile infrastructure markets has been regulated by licensing from its early beginnings and as multiple licenses have been issued at a very early point in time, the concentration in mobile infrastructure markets has always been lower (or at most as high) as in fix-line markets. Concerning competition in fix-line markets, the 1998 liberalization proves to be much more important as only a few countries had installed fix-line infrastructure competition before this year. Even today, fix-line infrastructure access is provided mostly by one operator in European national markets. This operator is obliged to provide access to its infrastructure, to give access for interconnection to its Main Distribution Frame (MDF) or to allow for interconnection in the street cabinets.[17]

In line with the liberalization, governmental ownership of former fix-line incumbents and also of the first mobile operator have been continuously reduced in many countries leading to special governmental control and voting rights, "Golden Shares". The EC regularly intervenes to prevent these control and voting rights as they deter the influence of shareholders in telecommunication companies.

Table 2 provides an overview of the expected estimation outcomes. Taking revenues per access as a measure for prices (see e.g. Röller and Waverman, 2001), a negative impact of prices on own demand is usually assumed. Nevertheless, upcoming competition after 2000 resulted in new services and new pricing structures such as bundle offers of multiple services and infrastructure-access modes, which blur the assumed price-demand structure. Figure 2 in the appendix provides an impression on this issue. The figure displays a cross-country consideration for 2007. While I find an on average negative relationship for mobile markets ($R^2 = 0.256$), no clear-cut results could be drawn for fix-line markets.[18]Two ambiguous explanations exist for the effect of prices on infrastructure provision: *Ceteris paribus*, a higher price enables infrastructure providers to invest

[17]Nevertheless, this step to infrastructure competition has been a legal issue in most countries for an extended period of time after the liberalization and it is also a major problem for high-quality service

Table 2: Expected Outcomes

	Fix Infrastructure		Mobile Infrastructure	
Dependent Var.	**Supply**	**Demand**	**Supply**	**Demand**
Revenue/Access	-	0	-	-/0
Access/Population	+		+	
Access/Population (-1)		+		+
Liberalization	+	+	+	+
Market Share Entrants	+	+	+	+
Other Infrastr. Rev./Acc.	+	+	+	0
Other Infrastr. Acc./Pop. (-1)		-		-
Governmental Share	+	0	+/0	0
GDP per population	+/0	+	+/0	+
Population	+	0	+	+/-
Share Urban Population	-	-/0	-	-/0
Long-Run Interest Rate	-	0	-	0

more, thus, increasing infrastructure availability and quality. On the other hand, to set apart from competitors, service providers demand for higher infrastructure quality. However, competitive pressure on the service level in combination with access price regulation (Framework Directive, 2002/21/EC, Article 8) forces providers to choose lower prices. In line with the literature on telecommunication liberalization, I therefore expect a negative price effect on infrastructure supply as this second effect should outweigh the first (Röller and Waverman, 2001, Model (1), Hassett and Kozlikov, 2002; Hassett et al., 2003).

Lagged demand is assumed to have a positive impact on current demand as the decision for a new access mode is a singular decision. Thus, if a customer had infrastructure access in year $t-1$ this access is in place also in year t. Moreover, in countries with a higher demand for infrastructure access also the supply of infrastructure is expected to be higher, which corresponds to the findings in Röller and Waverman (2001).

The following variables are used as proxies: *Market Share Entrants* as a proxy for competition, *Other Infrastr. Rev./Acc.* as a proxy for cross-infrastructure price effects and *Other Infrastr. Acc./Pop.*(-1) as a proxy for cross-infrastructure demand effects. The remaining assumptions on control variables correspond to the findings from the literature on infrastructure investments and infrastructure demand.

provision on the infrastructure.

[18]The positive slope is very low and the R^2 is even below 0.05.

Data Adjustments

While the other information is available in the relevant specification, fix-line and mobile investments have to be calculated from total investments. Unfortunately, no detailed investment information is publicly available to separate fix-line from mobile investments in European telecommunication markets for the period before the market liberalization. The consideration of a low number of available data points for fix-line infrastructure investments provides indication of how one could separate fix-line from mobile investments. Mainly two approaches for the calculation qualify to be equally valuable methods which are either a measure based on lagged revenues or a measure based on the number of access lines. For mainly technical reasons, which will be discussed in more detail below, I use the approach based on access lines. In doing so, fix-line infrastructure investments are calculated from total investments as the share of fix access lines per total access lines times total investments:

$$fix\text{-}line\ inv._t = total\ investments_t \frac{fix\ access\ lines_t}{fix\ access\ lines_t + mob.\ subscribers_t} \tag{3}$$

and mobile investments as total investments weighted by mobile subscription lines:

$$mobile\ inv._t = total\ investments_t \frac{mob.\ subscribers_t}{fix\ access\ lines_t + mob.\ subscribers_t} \tag{4}$$

Fix-line revenues is a second variable which has to be derived. Nevertheless, this is a minor challenge as mobile revenues and also total revenues are available from the database. Thus, fix-line access revenues are calculated as total telecommunication revenues minus mobile revenues.

5 Estimation Approaches, Results and Discussion

I first derive the estimation approaches taking into account the results of multivariate specification test.[19] Afterwards, I provide the results and discuss them in more detail.

[19]Further information and results of alternative specification tests are provided in the appendix.

Estimation Approaches

Equation system (1) and (2) is estimated first assuming independence of both equations and then taking into account potential structural dependencies by adopting a simultaneous estimation approach. In the independent estimation approach, the demand equations are estimated using the standard Arellano-Bond approach with robust standard errors and restricting the dependent variable lag structure to 1 (Arellano and Bond, 1991). For the investment equation, no lag dependence is expected. The derived investment measures follow a cyclical structure as they are linear transformations of total investments. I estimate the investment equation using a GLS estimator with random effects controlling for country differences and assuming a robust variance-covariance matrix taking into account the Huber-White correction.[20]

In the independent estimation approach, $log(access/pop.)$ is assumed to be exogenous in the supply function as this is the standard model structure to explain investments known from the literature. In contrast, the two-equation estimation takes $log(access/pop.)$ as an endogenous variable in the investment function and instruments $log(access/pop.)$ with its one-period lag and, additionally, with the one-period lag of demand for the other infrastructure when considering cross effects. I estimate the equation system using an IV-GMM-based approach as it is proposed in Baum et al. (2003) for panel data. The estimator is a two-step GMM method, in which, firstly, endogenous variables are estimated on all exogenous variables and, afterwards, the second equation is estimated taking into account the estimation results of the first step. In contrast to the standard IV approach, the GMM method is more efficient as it employs the optimal weighting matrix, which is the inverse of an estimate of the covariance matrix of orthogonality conditions (Baum et al., 2003). Thus, the standard IV approach uses one particular weighting matrix out of the set of the alternative GMM weighting matrices.[21, 22]

[20] Estimation results are identical to the fixed effects approach except for the constant term.

[21] Hayashi (2000) provides more detailed information on the construction of the efficient GMM estimator.

[22] I have also tested the results with heteroscedasticity- and autocorrelation-robust standard errors but the estimation results and also their significance levels remain the same.

Estimation Results and Discussion

Estimation results are provided in Tables 3 and 4. Columns 1 and 3 show the results of the independent equation estimations. Columns 2 and 4 show the results of the simultaneous estimation approach.

Following **Hypotheses 1 and 2**, a positive effect of service competition both on infrastructure supply and infrastructure demand should exist. Based on observations from other telecommunication markets, the EC expects service competition to provide direct incentives to increase infrastructure availability and quality as infrastructure providers are vertically integrated with service providers. In line with the literature, service level competitors require adequate infrastructure quality to offer their services and to set apart from each other. In consequence, service competition increases the demand for infrastructure.

Competition is found to have a significantly positive impact on the demand for fix-line infrastructure only for the two-equation estimations. In contrast, no direct effect on investments is found in neither of the specification. However, service competition has a significantly positive impact on infrastructure demand and also on infrastructure supply in the mobile estimations.[23] Moreover, the demand coefficients are significantly positive in all simultaneous estimation approaches. In consequence, ignoring the indirect effect of competition on investments deters the conclusions derived from the estimations results: Considering fix-line supply and demand (Table 3), the impact of competition on infrastructure investments would have been completely ignored with the single-equation model. Turning to mobile supply and demand, the impact of competition on investments would have been under-estimated without taking into account the indirect effect of competition on the demand variables and, thus, on investments. On the one hand, new entrants offer existing services at significantly lower prices, which initiates price wars à la Bertrand. This is supported by the mobile-demand estimation results as mobile service provision is strongly tied to the infrastructure provider. However, it is not found for fix-line access.[24] On the other hand, advertising and other professional communication channels are used to provide more information to customers about innovative services and forthcoming price reductions and, thus, to increase the interest and the demand for infrastructure. These findings support the discussion in Plank (2005) that upcoming

[23] In specification 3a of the mobile estimation approach, the p-value of the competition coefficient is 0.108.

[24] Please see also the plotted cross-country estimations in Figure 2 in the appendix.

competition on the service level stimulates the demand for infrastructure as service competition forces companies to provide product information to customers. Based on this information, customers demand more services and, consequently, directly and indirectly demand for higher quality infrastructure. Thus, the estimation results support Hypothesis 1 that service competition directly increases investments only partially, for mobile infrastructure but not for fix-line infrastructure. In contrast, the indirect competition effect on investments is found in all simultaneous estimation equations both for fix-line and mobile investments, which is in line with Hypothesis 2.

Cross-effects between infrastructures are taken into account with specifications 3 and 4. Following Rodini et al. (2003), upcoming mobile availability is a substitute for fix-line access. In Europe, fix-line infrastructure has been in place at the time when mobile access became publicly available. Moreover, mobile infrastructure capacity is lagging behind fix-line capacity. Therefore, **Hypothesis 3** states that fix-line infrastructure investments are the reference when deciding on mobile infrastructure supply and demand whereas fix-line infrastructure supply and demand are independent from the mobile market situation.

While the demand for one infrastructure is independent from the demand for the other, an ambiguous effect of cross prices exists: mobile prices positively affect fix-line infrastructure demand, whereas fix-line prices negatively affect mobile infrastructure investments. These findings support the idea of a first-mover advantage of fix-line infrastructure markets over mobile-infrastructure markets: When deciding about an additional access mode, customers compare the prices of the secondary access option. As long as mobile infrastructure is comparably expensive, mobile demand is the less preferable option. Thus, customers choose fix-line access instead of mobile access. In consequence, in countries where mobile subscription is more expensive, customers increase their availability by additional fix-line access modes. This has not been a particular issue for private customers but rather for companies. In contrast, for customers interested in a fix-line infrastructure access, mobile access is no adequate substitute as in all European countries mobile access is a lower-quality access in terms of transfer rates.[25]

[25]Please note that the observation period covers, to a far extent, the years of introducing mobile communication and upcoming mobile competition. Today, mobile-to-fix substitutability is probably significantly higher than ten years ago.

Table 3: Estimation Results – Fix-line Infrastructure

Fix-Line Infrastructure Supply and Demand	**log(fix a./pop) A.-Bond (1 a)**	**log(fix inv.) RE est. (1 b)**	**log(fix a./pop) 1st stage IV (2 a)**	**log(fix inv.) 2nd stage IV (2 b)**	**log(fix a./pop) A.-Bond (3 a)**	**log(fix inv.) RE est. (3 b)**	**log(fix a./pop) 1st stage IV (4 a)**	**log(fix inv.) 2nd stage IV (4 b)**
log(fix rev./acc.)	-0.025	-0.318 **	0.011	-0.349 *	-0.002	-0.313 **	0.015	-0.446 ***
	(0.023)	(0.131)	(0.018)	(0.132)	(0.018)	(0.137)	(0.018)	(0.133)
log(mob. rev./subs.)					0.025 *	0.027	0.040 ***	0.011
					(0.013)	(0.106)	(0.015)	(0.099)
fix m. sh. entr.	0.001	0.002	0.001 **	0.001	0.001	0.002	0.001 **	0.001
	(0.000)	(0.003)	(0.001)	(0.003)	(0.000)	(0.003)	(0.001)	(0.003)
log(pop.)	0.471 *	3.905 **	0.158	3.601 **	0.436	3.949 **	0.168	2.563
	(0.254)	(1.731)	(0.224)	(1.695)	(0.268)	(1.746)	(0.253)	(1.680)
log(GDP/pop.)	0.036 *	0.476 **	0.048	0.419 **	0.009	0.423	0.014	0.472 *
	(0.018)	(0.212)	(0.030)	(0.201)	(0.025)	(0.281)	(0.047)	(0.265)
log(share urban pop.)	-0.222	-2.610	-0.510 ***	-2.077	-0.102	-2.397	-0.224	-1.601
	(0.158)	(1.672)	(0.168)	(1.574)	(0.188)	(1.767)	(0.185)	(1.672)
gov. sh. fix inc.	0.001 ***	0.003 **	0.000	0.003 **	0.001 ***	0.003 **	0.000	0.002 *
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
log(long-term interest rate)	0.014	0.144	-0.028	0.170	0.012	0.116	-0.051	0.391
	(0.044)	(0.332)	(0.042)	(0.317)	(0.047)	(0.342)	(0.042)	(0.320)
log(km2)	-0.613 *	0.196	0.045	0.148	-0.597	0.211	0.054	0.106
	(0.372)	(0.361)	(0.047)	(0.354)	(0.381)	(0.371)	(0.055)	(0.355)
trend	0.003	-0.067 ***	-0.002	-0.078 ***	0.004	-0.063 **	0,001	0.076 ***
	(0.003)	(0.020)	(0.003)	(0.020)	(0.003)	(0.026)	(0.004)	(0.025)
log(fix acc./pop.)		0.366		0.913 *		0.341		1.077 ***
		(0.347)		(0.532)		(0.368)		(0.539)
log(fix acc./pop.) (-1)	0.850 ***		0.955 ***		0.843 ***		0.937 ***	
	(0.079)		(0.085)		(0.076)		(0.077)	
log(mob. subs./pop.) (-1)					0.008		0.006	
					(0.007)		(0.007)	
constant	--	-49.694	-1.367	-45.669	--	-51.193 *	-2.516	-28.899
		(30.287)	(3.854)	(29.68)		(31.048)	(4.303)	(30.026)
country dummies included		yes	yes	yes		yes	yes	yes
Chi2 / F (df)	3656.64 (9)	6457.56 (24)	762.69 (24)	237.40 (24)	11384.19 (12)	6124.43 (25)	875.79 (26)	258.57(25)
R2		0.484	0.636			0.472	0.637	
prob. A-Bond test (first order)	0.100				0.016			
prob. A-Bond test (sec. order)	0.862				0.547			
Anderson canon. corr. LR stat.				229.213 (1)				230.141 (2)
Hansen J								10.249(1)
Obs.	223	227	227	242	223	242	227	227

Note: ***, **, * represent significance at the 1, 5 and 10 percent significance level, standard errors are displayed in brackets.

Table 4: Estimation Results – Mobile Infrastructure

Mobile Infrastructure Supply and Demand	log(m.s./pop.) A.-Bond (1 a)	log(mob. inv.) RE est. (1 b)	log(m.s./pop.) 1st stage IV (2 a)	log(mob. inv.) 2nd stage IV (2 b)	log(m.s./pop.) A.-Bond (3 a)	log(mob. inv.) RE est. (3 b)	log(m.s./pop.) 1st stage IV (4 a)	log(mob. inv.) 2nd stage IV (4 b)
log(fix rev./acc.)					-0.185 **	-0.335 **	-0.013	-0.293 **
					(0.084)	(0.138)	(0.061)	(0 .133)
log(mob. rev./subs.)	-0.015 ***	0.062 *	-0.014	-0.078	-0.517 ***	-0.082	-0.491 ***	-0.472 ***
	(0.051)	(0.032)	(0.096)	(0.059)	(0.094)	(0.136)	(0.074)	(0 .174)
mob. m. sh. entr.	0.008 **	0.007 *	0.005 **	0.013 ***	0.005	0.007 *	0.074 **	0.012 ***
	(0.004)	(0.004)	(0.002)	(0.004)	(0.003)	(0.004)	(0.002)	(0.004)
log(pop.)	-2.694 *	3.357 **	-1.283	4.188 ***	-1.484	3.534 *	-0.486	4.634 ***
	(1.418)	(1.706)	(0.962)	(1.625)	(1.503)	(1.822)	(0.883)	(1.799)
log(GDP/pop.)	-0.017	0.225	-0.158	-0.002	0.664 ***	0.505 *	0.344 ***	0.484 *
	(0.245)	(0.204)	(0.170)	(0.204)	(0.156)	(0.266)	(0.133)	(0.264)
log(share urban pop.)	0.619	-2.056	0.039	-1.331	-1.675	-1.981	-3.148 ***	-3.012 *
	(1.291)	(1.541)	(1.020)	(1.497)	(1.145)	(1.735)	(0.770)	(1.727)
log(long-term interest rate)	-0.027	0.004	0.022	-0.297	-0.150	0.118	-0.100	-0.273
	(0.201)	(0.337)	(0.302)	(0.357)	(0.113)	(0.350)	(0.230)	(0.382)
gov. sh. mob. inc.	0.000	0.003 **	0.000	0.004 ***	0.000	0.003 **	-0.000	0.004 ***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log(km2)	3.495 *	0.189	-0.289	0.377	2.338	0.111	-0.13	0.361
	(1.906)	(0.365)	(0.232)	(0.355)	(1.784)	(0.395)	(0.221)	(0.401)
trend	-0.005	-0.101 ***	0.004	-0.067 ***	-0.037 ***	-0.092 ***	-0.021 *	-0.066 ***
	(0.022)	(0.020)	(0.014)	(0.019)	(0.013)	(0.021)	(0.012)	(0.020)
log(fix acc./pop.) (-1)					0.207		0.210	
					(0.232)		(0.187)	
log(mob. subs./pop.)		0.972 ***		0.743 ***		0.917 ***		0.589 ***
		(0.063)		(0.081)		(0.080)		(0.114)
log(mob. subs./pop.) (-1)			0.849 ***				0.709 ***	
			(0.049)				(0.048)	
constant		-41.022	24.826	-57.236 *		-45.221	21.984	-59.542 *
		(30.730)	(16.853)	(29.369)		(32.192)	(15.233)	(31.327)
country dummies included		yes	yes	yes		yes	yes	yes
Chi2 / F (df)	11250.04 (10)	9273.37 (24)			34294.93 (12)	7371.42 (25)		
R2			0.7169				0.6716	
prob. A-Bond test (first order)	0.982				0.996			
prob. A-Bond test (sec. order)	0.187				0.164			
Anderson canon. corr. LR stat.				291.505 (2)				252.780 (2)
Hansen J								0.915 (1)
Obs.	215	232	231	231	209	227	227	227

Note: ***, **, * represent significance at the 1, 5 and 10 percent significance level, standard errors are displayed in brackets.

No significant impact of mobile prices on fix-line infrastructure provision is found. However, a significantly negative effect of fix-line prices exists on mobile infrastructure supply. As the upgrade of fix-line backbone infrastructure took place at a time when only low-quality services like telephony or short messages could technically be transmitted on the mobile infrastructure, it was a lower-quality substitute to fix-line infrastructure. Moreover, the upgrade of mobile infrastructure for 3G services occurred at a time when similar fix-line broadband quality has already been established. Due to this lag of quality between fix-line and mobile infrastructure, fix-line infrastructure is a stronger substitute to mobile infrastructure than vice versa. Consequently, fix-line infrastructure market prices affect mobile infrastructure supply more than the other way around. This finding is strongly in line with Hamilton (2003) but extends her results also to a data set of developed countries. Moreover, the results also support the discussion in Rodini et al. (2003). The estimation results confirm Hypothesis 3: As fix-line infrastructure is the primary infrastructure available, mobile infrastructure supply and demand depend on the conditions of fix-line infrastructure availability whereas only weak evidence is found for the opposite direction.

Let us shortly consider the coefficients of the control variables. A significantly positive population effect is found for mobile and also for fix-line investments.[26] Telecommunications is a social network, i.e. the more customers are available in a network, the more traffic is provided on the lines, which requires higher investments. Therefore, the larger the population size, the more infrastructure investments are necessary to cover this higher traffic.

Per capita GDP has a significantly positive effect both on mobile infrastructure demand and supply when controlling for cross-infrastructure effects. In contrast, its impact on fix-line infrastructure demand is, to a far extent, insignificant, whereas it is weakly significantly positive for fix-line infrastructure supply. Following the correlation matrix provided in Table 5 in the appendix a significantly negative correlation exists between per-capita GDP and mobile demand (-0.73). Dropping per-capita GDP in the demand equation changes the remaining coefficients only slightly. However, the coefficient of the GDP variable can hardly be interpreted due to these cross-effects.

Governmental ownership of infrastructure providers has a significantly positive impact on investments. While it is found to have a positive effect also on demand for fix-line

[26]Only in the cross-infrastructure estimation, this effect turns weakly insignificant (p-value = 0.127).

infrastructure for the separate estimations (Columns 1a and 3a), this effect vanishes with the system estimations. In contrast to profit-maximization aims, governments follow macroeconomic aims with the telecommunication sector. As investments provide a strong positive externality also on other sectors, which cannot be internalized by the investors, they would under-invest from a macroeconomic perspective.[27] In contrast, governmental participation forces infrastructure providers to increase investments above the level optimally from the single company perspective.

Long-term interest rates are used as a measure for the costs of capital as infrastructure investments are very long-term oriented. However, I find no significant impact of interest rates on investments. As the correlation analysis provides evidence for strong correlations between interest rates and other explanatory variables, I excluded interest rates in other estimation specifications not presented here. However, results remained very similar. Even significance levels did not change.

In a nutshell, I find service competition to increase infrastructure investments, which is in line with the literature. However, in particular for fix-line infrastructure, the competition-impact is not a direct driver of investments. Service competition increases the demand for infrastructure and, subsequently, increases infrastructure supply. In contrast to the EC's expectations, these findings provide first evidence that it is not necessarily competitive pressure which motivates providers to invest. Moreover, there must be a sufficient (derived) demand for infrastructure.

With regard to cross-infrastructure effects, I find that mobile infrastructure supply and demand strongly depend on relative access prices. On the one hand, customers prefer a secondary fix-line access as long as mobile access prices are too high. On the other hand, mobile infrastructure supply benefits from tougher fix-line infrastructure competition. However, no reciprocal effects exist. These findings strongly demand the consideration of both demand and supply and, in particular, cross-infrastructure interrelationships when analyzing telecommunication infrastructure investments with competing platforms. While I have focused on a period of comprehensive technological improvements in fix-line transmissions and the roll-out of basic and higher-capacity mobile infrastructure, these issues become even more relevant for fix-line and mobile broadband analyses as more and more services could be used on both infrastructures substitutively.

[27]Please see also Cave (2006a) and the cited literature.

6 Conclusion and Limitations

Infrastructure availability and adequate quality are the central pre-requisites for higher-value telecommunication services. In this paper, I considered the driving impact factors of fix-line and mobile telephony infrastructure investments. In contrast to closed-form approaches, which are usually taken in the literature, I separated infrastructure supply from demand. In doing so, it can be analyzed *how* service competition affects investments. The analysis is implemented for mobile and fix-line infrastructure separately so that I can distinguish and compare the results across competitive infrastructures.

As in previous works, I find a significantly positive effect of upcoming service competition on infrastructure expansion. However, upcoming service competition does not only directly influence investments, but it particularly increases the demand for infrastructure which, subsequently, initiates investments. During the transition process of the liberalization, service market entrants stimulate the demand for new services and, as a precondition, the demand for infrastructure of higher quality. This "demand pull" is found for both established fix-line infrastructure and also mobile infrastructure where competition occurred at an earlier point of the technological development. Therefore, service competition, as a driver of demand, enables and supports the comprehensive technological developments, which we have experienced during the last decade.

A political question arising from these findings is how service providers and customers could be involved in the process of infrastructure roll-out. This is of particular interest as infrastructure operators currently bear the risk of re-funding investments and, simultaneously, provide comprehensive positive externalities for service providers and other industries. With more service competition but only one or two physical infrastructure providers in fix-line markets, the challenges for infrastructure providers continuously aggravate. My results support the proposal in line with the Third Regulatory Package that service providers and customers should be integrated in the financing process of infrastructure investments.[28] However, the actual way of its implementation is an open point of discussion for future economic research.

[28] The EC is aware of the drifting apart of service level profits and infrastructure investments and therefore proposes that investment risks should be explicitly taken into account by regulators when obliging local loop access (Directive 2009/140/EC).
http://ec.europa.eu/information_society/policy/ecomm/doc/tomorrow/reform/better_regulation_directive/st03677_re06.en09.pdf

In a next step, I have considered whether cross effects exist between mobile demand and fix-line demand and also mobile supply and fix-line supply. While other coefficients remain nearly unaffected, higher mobile prices reduce the demand for mobile infrastructure and, simultaneously, increase the demand for fix-line infrastructure. In contrast, fix-line prices do not affect mobile infrastructure demand. As fix-line infrastructure quality is at each point in time at least as high as mobile infrastructure quality, the decision for (higher quality) fix-line infrastructure access takes place when there is no adequate mobile substitute. In contrast, the decision about mobile access occurs when fix-line infrastructure of similar transmission quality is already available. Therefore, when deciding on a secondary access to increase availability, customers (in particular professional users) choose an additional fix-line access if mobile prices are too high.[29]
Similarly, the provision of mobile infrastructure depends on the situation in the fix-line market. The higher the market price for fix-line access, the less mobile infrastructure is provided. While mobile network operators derive their investment decision from fix-line market competition, fix-line infrastructure supply is independent as no adequate infrastructure of comparable quality is installed. These results provide evidence that mobile infrastructure is always a secondary infrastructure for service provision following fix-line infrastructure due to the lack of transmission capacity. In contrast, fix-line market competition directly affects the mobile market situation both in terms of supply and in terms of demand.

Opening the black box of closed-form investment models allows us to specify results already known from the literature in more detail and to learn more about the structure behind the findings. In doing so, this paper provides first evidence that (derived) infrastructure demand plays a central role in the roll-out of infrastructure. The situation of Web 2.0 where customers themselves become active information providers and where web-based communication turns more and more to peer-to-peer communication will definitely foster the demand pull of infrastructure.

From the findings of the analysis of upcoming platform competition, fix-line infrastructure should be expected to be the first affected by this development. Dependent on access prices for mobile infrastructure of comparable capacity, mobile investments follow the development.

[29]Please note again that I consider infrastructure competition between one established platform and a growing platform. Doing the exercises with current data will provide other results as mobile infrastructure is completely rolled out at least at a basic level in all EU member states today.

Some pitfalls of the analysis should not be ignored: I have considered investments on the aggregated level in monetary terms. In consequence, even by controlling for country differences, it cannot be stated that more investments are "better", firstly, as investments also include doubled lines resulting not necessarily in a reduction of congestion and, secondly, as no information about existing infrastructure and its quality is available. Moreover, due to data constraints at the current point in time, I have to accept some drawbacks with the specification of supply and demand, which have been discussed in the previous sections and which leave broader room for follow-up studies using a more structural estimation approach to revise the outcomes of this paper in the future.

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Appendix

Stationarity and Specification Tests

The graphs in Figure 1 let assume non-stationarity of the demand variables and the investment variables. It is therefore necessary to test for non-stationarity of the dependent variables to select an estimation specification which takes up the potential challenge or to adjust the data set. I have employed a panel Dickey Fuller Test, the Multivariate Augmented-Dickey-Fuller Test (MADF test), as described in Taylor and Sarno (1998) and in Sarno and Taylor (1998) and the Levin-Lin (-Chu) test presented in Levin et al. (2002) for considering non-stationarity of the panel as a whole. The MADF test provides evidence for stationarity of all four time series, investments in fix-line infrastructure, investments in mobile infrastructure and demand for demand for fix-line infrastructure and mobile infrastructure. However, following Sarno and Taylor (1998), the MADF test requires all individual time series of the panel to be stationary. Moreover, the MADF test is criticized as it provides adequate test results only for a long panel data set, i.e. the number of periods should comprehensively exceed the number of countries. In contrast, my data set is a short panel as the number of years ($t = 18$) does not comprehensively exceed the number of countries ($i = 16$). Therefore, I have also employed the Levin-Lin test to compare the results with those of the MADF test but find similar results.[30] As both test specifications reject the null hypothesis of no stationarity, I use the data set without further adjustments for the multivariate time-series estimations.

The Arellano-Bond approach performs a linear dynamic panel-data estimation of the difference in the dependent variable on the differences and the levels of the independent and the lagged dependent variables. Following Arellano and Bond (1991) and Blundell and Bond (1998), it is thus necessary that no higher order correlations exist in the panel data set. The Arellano-Bond test for first- and second-order serial correlation in first-difference residuals are displayed in Tables 3 and 4.[31] While the first-order tests show ambiguous results, the second-order test results provide evidence that the hypotheses of no higher-order first-difference autocorrelation cannot be rejected. The test of the fix-line specifications rejects the hypothesis of no first-order autocorrelation in contrast to the test of the mobile specifications. While the second-order test of no autocorrelation must not be rejected due to the linearity requirement for the estimation specification, Arellano and Bond (1991) explain that the first-order test results are of minor relevance for employing the dynamic panel-data estimator.

Time-series estimations are prone to the consideration of over-identification in particular if an autocorrelated estimation structure is assumed. I employ Hansen's J test for system estimations and find evidence for over-identification in the fix-line infrastructure estimation approach but not in the mobile-infrastructure estimation approach when analyzing cross-infrastructure effects. Over-identification of an endogenous variable means

[30] While the fix-line infrastructure demand has been found to be non-stationary, the logarithm, which I employ in the econometric analysis, is stationary at the ten percent significance level.

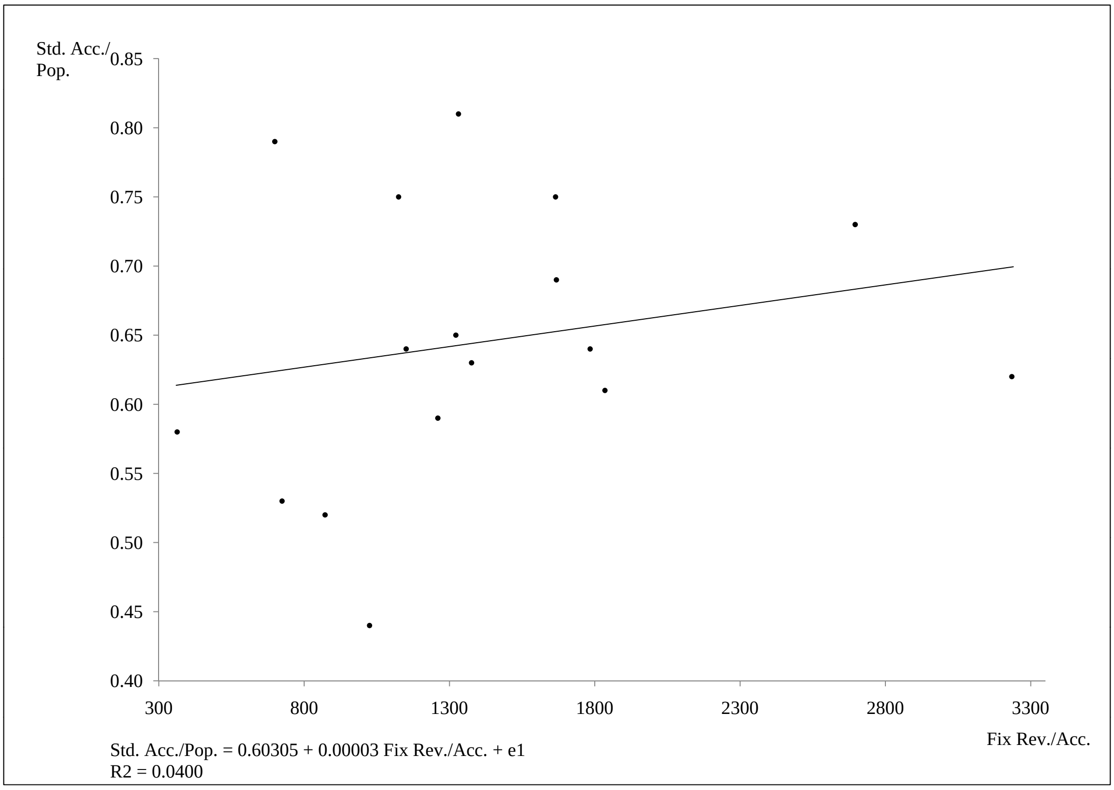
[31] Greece has been excluded from the mobile demand estimations due to strong volatility in the dependent variable.

that its coefficient has no explanatory power as multiple (here two) ways for calculation exist which might lead to alternative values for the instrumented variable. Following Wooldridge (2002) the coefficient of the instrumented variable cannot be interpreted. However, the coefficient product of the instrument and the instrumented variable does not suffer from the reduced-form coefficient calculation. Thus, while direct effects of the instrumented variable cannot be used, indirect effects are unbiased.

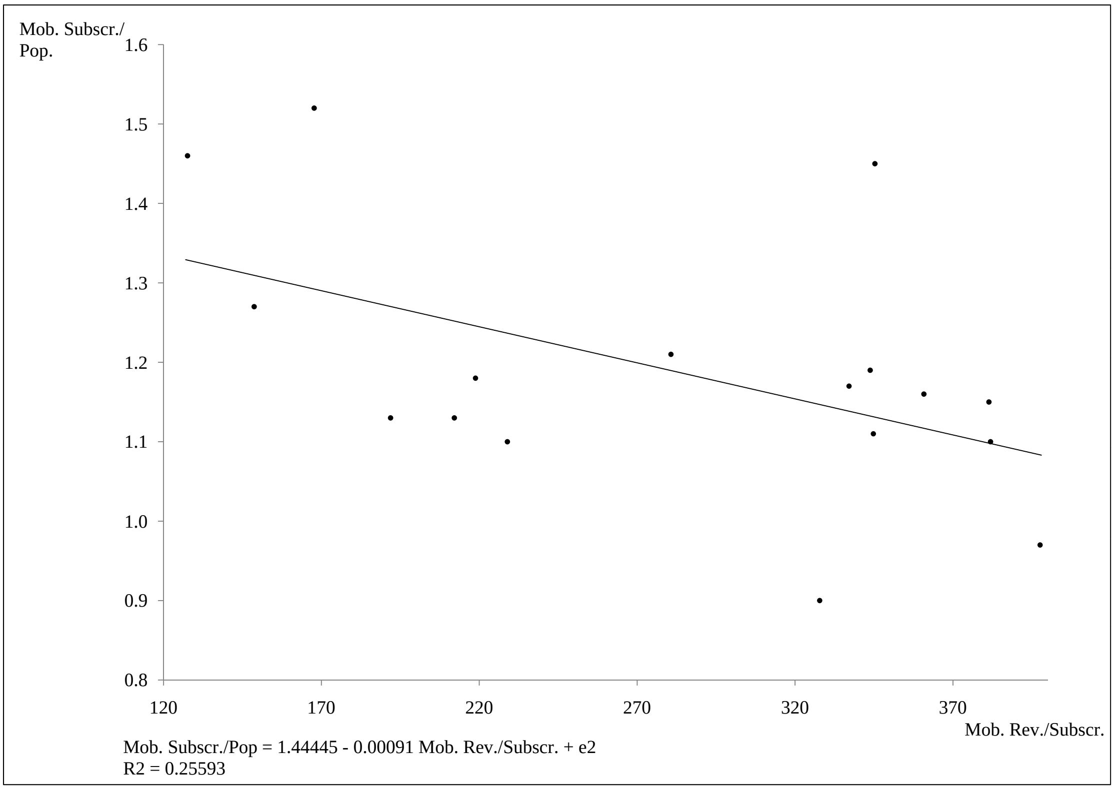
Price-Demand Interrelation

Figure 2 displays the price-demand interrelation for fix-line and for mobile markets in 2007. While mobile access follows the expected downward slope across the states under scrutiny, a positive interrelation is found for fix-line markets. However, in contrast to the mobile situation, the linear demand-curve of the fix-line graph only weakly explains the price-demand scatter across the countries.

Figure 2: Price-Demand Relationship in Fix-line and Mobile Markets



(a) Fix-line Access Demand



(b) Mobile Access Demand

Table 5: Correlation Matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
log(fix inv.)	(1)															
log(mob. inv.)	(2)	0.651														
log(fix acc./pop.)	(3)	-0.148	0.072													
log(mob. subs./pop.)	(4)	-0.334	0.491	0.387												
log(fix acc./pop.) (-1)	(5)	-0.150	0.054	0.974	0.365											
log(mob. subs./pop.) (-1)	(6)	-0.324	0.489	0.417	0.991	0.390										
fix m. sh. entr.	(7)	-0.036	0.458	0.404	0.640	0.382	0.666									
mob. m. sh. entr.	(8)	0.106	0.643	0.234	0.681	0.189	0.686	0.586								
log(fix rev./acc.)	(9)	-0.063	0.153	0.447	0.313	0.420	0.336	0.352	0.014							
log(mob. rev./subs.)	(10)	0.228	-0.454	-0.120	-0.803	-0.115	-0.781	-0.364	-0.616	0.071						
log(gdp/pop.)	(11)	-0.334	-0.050	0.723	0.406	0.706	0.429	0.341	0.038	0.710	0.024					
log(pop.)	(12)	0.899	0.753	-0.247	-0.116	-0.266	-0.102	0.091	0.352	-0.162	-0.033	-0.441				
log(share urban pop.)	(13)	0.150	0.084	0.506	0.008	0.497	0.022	0.046	0.040	0.380	0.082	0.445	0.012			
gov. sh. fix inc.	(14)	-0.224	-0.570	0.107	-0.418	0.149	-0.418	-0.319	-0.580	-0.026	0.453	0.161	-0.412	0.047		
gov. sh. mob. inc.	(15)	-0.220	-0.565	0.083	-0.421	0.125	-0.421	-0.331	-0.596	-0.012	0.460	0.148	-0.409	0.026	0.990	
log(long-term interest rate)	(16)	0.221	-0.673	-0.496	-0.817	-0.471	-0.809	-0.601	-0.621	-0.585	0.526	-0.614	0.022	-0.163	0.493	0.491

Table 5 provides an overview of the pairwise correlations of the variables used in the estimations. Correlations are calculated pooled across time and countries.