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Institutions and Infrastructure Investment in Low and Middle-Income Countries: The Case of Mobile Communications

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Department of Economics
Discussion Paper Series
No. 07/06

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Institutions and Infrastructure Investment in Low and Middle-Income Countries: The Case of Mobile Communications*

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March 14, 2007

Abstract

This paper studies the relationship between regulation and performance in the mobile telecommunications sector. The analysis takes account of the economic impact of telecommunications infrastructure on aggregate income and of the role of country institutions in promoting economic growth. More specifically, we try to separate the impact of regulation from the potential indirect effects due to country institutions. We address these questions by estimating a system of equations for a panel of 30 low and middle-income countries over the 1990 - 2004 period. In summary, the evidence we present confirms the positive effect of regulatory institutions on telecommunications penetration and also highlights the contribution of a more widespread mobile telecommunications infrastructure to higher levels of GDP per capita.

Keywords: Telecommunications, Regulation, Institutions, Growth
JEL Classification: L51, L96, O43

1 Introduction

In developing countries, liberalization, restructuring, privatization and the introduction of independent regulatory agencies for infrastructure industries appear to have generally been successful in improving sector performance in terms of higher investment and service availability, particularly in telecommunications.

*We are grateful to Peter Burridge, Xeni Dassiou, Barbara Veronese and Lisa Correa for their useful comments and suggestions. We also thank Francesc Trillas and the participants at the Workshop of the Centre for Competition and Regulatory Policy, City University, in July 2006. All remaining errors are our own responsibility.

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However, the specific policies and factors behind both reform successes and failure are the subject of intense debate. There has also been much discussion of their relative contributions, positive and negative.

The relationship between the existence of an independent regulator and the development of infrastructure industry investment and productivity levels has been a particular focus of debate and this specific issue has been investigated in numerous papers, with reference both to the telecommunications and electricity sectors (Gutierrez, 2003; Cubbin and Stern, 2006). These studies focus on the characteristics of regulatory institutions that tend to be associated with higher levels of certain performance indicators in public utilities, such as the electricity produced or the number of telephone lines per inhabitant. The independence of the regulator is generally a major explanatory variable, following the literature on central bank independence (e.g. review in Stern and Trillas, 2003). However, this literature does not, with some exceptions, pay much explicit attention to the institutional setting within which the new regulatory agencies operate.

This paper takes a fresh look at the relationship between regulation and performance in the telecommunications sector, by drawing lessons from strands of the economic literature that are sometimes neglected in previous studies and, in particular attending to the role of the institutional setting. In consequence, we also take account of further interrelated effects, in particular (a) the economic impact of telecommunications infrastructure on the growth of aggregate income; and (b) the role of country institutions in promoting economic growth.

Concerning the relationship between telecommunications penetration and national income, income is considered one of the most important determinants of demand for telecommunications services. But, in addition, investment in telecommunications infrastructure can contribute to economic growth directly by an increase in production and, indirectly, by facilitating communications between firms, thus increasing their production possibilities (Röller and Waverman, 2001).

We explicitly include this feedback effect in the present analysis to provide a fuller picture of the interrelationship between income and telecommunications infrastructure capacity. We do this by focusing on the case of mobile telephony where recent research has suggested sizeable impacts of the rapid expansion of mobile telephones subscribers on GDP levels and growth rates in middle and low income countries.[1] (See Waverman et al. (2005) for a major recent example).

Another related issue that is considered in the paper is the role of country institutions. When investigating the impact of regulation on telecommunications development, it is crucial to ensure that this effect does not capture other factors which are not explicitly included in the analysis. More specifically, the paper tries to separate the impact of regulation from the potential indirect effects due to country institutions.

The present study attempts to bring together these questions into a unified framework of analysis. We do this by estimating a system of equations for a

[1] Following the International Telecommunications Union (ITU), the definition of subscribers includes both pre-paid and post-paid users of telephone mobile services.

panel of 30 low and middle-income countries over the 1990 - 2004 period.

In summary, the evidence we present confirms the positive effect of regulatory institutions on telecommunications penetration and also highlights the contribution of a more widespread telecommunications infrastructure to higher levels of GDP per capita at least for mobile telecom services. However, explaining regulatory governance choices, on the basis of country institutions and other factors, is more challenging and the results we have so far obtained in this area are less convincing.

The structure of the paper is as follows. Section 2 reviews the most relevant results from the related literature. Section 3 sets out the approach adopted in the paper; Section 4 provides a description of the data; Section 5 sets out the empirical strategy; Section 6 discusses the main results; and Section 7 provides some short concluding comments.

2 Related Literature

The standard perspective on utility industries is that the existence of very long-lived, sunk assets means that the relationship between governments and investors gives rise to a time inconsistency problem. This time inconsistency problem is very similar to that which affects macroeconomic policy.[2] In essence, this inconsistency is the inability of the public authority to commit credibly to an optimal policy. When the ability to commit is key to effective policy making, this lack of credibility may lead to inefficient outcomes.

In the telecommunications industry, if the public authority cannot commit to future price levels credibly, that is to refrain from lowering prices beyond the originally declared targets, the operator will anticipate the authority's incentive to appropriate its return on sunk investment. As a result, the operator may choose a lower than optimal level of investment. The establishment of an independent regulator is seen as a way of addressing this commitment problem and of safeguarding consumers at the same time, mainly because it should be better insulated from political pressure and therefore less inclined to pursue policy objectives through arbitrary intervention in the regulated sector.[3]

In consequence, there is a growing body of empirical evidence looking at the relationship between the presence of an independent regulator and investment in the telecommunications network, mirroring the extensive literature testing the impact of independent central banks on inflation and growth. The most relevant papers for the present work are discussed in this Section.

Gutierrez (2003) is the recent contribution which is the most closely related to our study. Using a panel of 22 Latin American countries over the period 1980 -1997, he finds that good regulatory governance has a positive impact on fixed lines' deployment and efficiency (measured as employees per main lines).

[2] See Levine, Stern and Trillas (2005).

[3] For instance, see Levine and Rickman (2002) for the theoretical underpinnings in a model of price regulation under asymmetric information.

In Gutierrez (2003), the main explanatory variables are privatization, competition and regulatory development, where the latter is represented by an index covering, for instance, whether there is separation of telecom operations and regulatory activities and whether the creation of the regulator is backed by law or by a minor legal norm.

The main advantage of Gutierrez's index is the attempt to characterize regulatory governance in a more comprehensive way than allowed by a simple dummy variable for the presence of the regulator, thus recognizing that the mere existence of an independent regulator is not by itself informative of the quality of institutions. Moreover, he addresses the potential endogeneity of the regulatory variable in his dynamic model. However, his analysis is based on a reduced-form equation that neglects the potential interactions among network deployment, income level and regulatory governance. In addition, the results from his dynamic model should be treated with caution, as explained in Section 6 below.

In a recent paper, Gual and Trillas (2006) investigate the determinants of reforms concerning regulators' independence and entry barriers in the telecommunications sector. In particular, they define independence by an index covering the regulator's functions, its funding, the years since establishment and the percentage of private ownership, among other factors. Regulatory independence is regressed on explanatory variables, which include proxies of country institutions used in the growth literature, such as the legal origin of the country, the general quality of government and the rule of law.[4]

Gual and Trillas find that the rule of law variable has a significant negative impact on independence. They explain this result arguing that "independence is a substitute for other ways to achieve commitment not to expropriate".[5] This interpretation is consistent with the view of the independent regulator as an answer to the commitment problem, as summarized above. However, other researchers (e.g. Cubbin and Stern, 2006) find that the rule of law is a complement to better quality regulation rather than a substitute.

An alternative approach is to look at specific policy outcomes rather than actual network development. In Edwards and Waverman (2005), for instance, interconnection rates are the dependent variable which is explained by an index of regulatory governance and other controls in a panel data context. This approach has the appeal of narrowing the focus to an outcome which is more related to institutional quality than measures of performance, and of simplifying the empirical methodology.

However, the Edwards-Waverman approach does not seem suited for the research question of the present study. Firstly, there are no available time-series

[4] Those variables relating to the wider institutional environment have been used as the explanatory variable of interest by Henisz and Zelner (2001), who focus on institutions at the macro-political level. They create an index of political constraints for 147 countries over the period 1960-1994 and they find that it has a positive impact on telecommunications infrastructure development.

[5] Interestingly, other measures of institutions, such as the Polcon index developed by Henisz and Zelner (2001), a measure of procedural complexity (i.e. the number of steps a new firm has to take to operate) and a variable of government effectiveness were not significant.

data on policy outcomes for a sufficiently large set of low and middle-income countries. In addition, as a more general point, this type of approach would implicitly assume that a given policy outcome automatically leads to a higher degree of development of telecommunications networks. The more relevant question for this paper is precisely to explain the development of telecommunications, rather than assuming that it would follow from the "right" type of policies.

Most papers on regulatory institutions usually analyze the direct impact of regulatory governance on outcomes, while other types of institutions are not considered.[6] A notable exception is Cubbin and Stern (2006), who try to estimate the impact of country institutions on outcomes in the electricity sector and find that there is no significant statistical evidence of the impact of country governance in models that incorporate country fixed effects, once regulatory governance is controlled for. The methodology proposed in the present paper will address this issue in the context of a system of simultaneous equations.

Finally, all these studies rely on formal measures of institutional quality which, in developing countries, may not be indicative of the effective degree of regulatory governance (Pande and Udry, 2005). Attempts to provide de facto measures of independence, i.e. taking account of how regulators and governments actually operate in practice, have been introduced in the literature on central banks independence by Cukierman (1994) and Haan and Koi (2000) and are currently being developed for utilities (Montoya and Trillas, forthcoming).

3 Main Issues and Methodology

The focus of this paper is the relationship between measures of telecommunications development and regulatory governance, while taking explicit account within a system framework of (a) the role of income and (b) other institutions and country governance. In this section we outline a framework to address these issues. We firstly describe the scope of the study; and, secondly, briefly explain the approach followed in the paper.

The present work studies the penetration of telecommunications infrastructure, as measured by the number of mobile telephone subscribers per head. Analyzing the overall performance of a sector (e.g. penetration, productivity, quality of service) addresses wider questions than focusing only on specific regulatory outcomes, such as the level of interconnection prices, as explained in Section 2.

Among the factors that may affect penetration, we consider the effect that income may have on the uptake of mobile telephone subscriptions. This is related to the question of whether penetration is demand-constrained or supply-constrained in developing countries. Case-study evidence, as well as the substantial waiting lists for fixed telephone lines, points to supply-side limits, rather

[6] The paper by Henisz and Zelner (2001) focuses on the effect of country institutions on telecommunications investment. Esfahani and Ramirez (2003) study the impact of executive constraints on growth and on the growth of telephones per capita.

than low levels of demand, as the main reason for the limited penetration of telecommunications services in developing countries (World Bank, 2005).

Another consideration relates to the possible feedback effects between penetration and income. Network infrastructure services, including telecommunications, play a crucial role for the economy.[7] There is now considerable evidence that higher telecommunications capacity fixed and mobile can have sizeable effects on the level of income.[8]

The importance of the telecommunications sector in improving a country's income level is a major complication when analyzing the factors that influence telecommunications penetration rates. While it is usually maintained in the literature that income is among the variables affecting infrastructure development, the economic feedback impact of telecommunications infrastructure capacity also needs to be modelled if we are not to have a misleading picture. This is represented by the two-sided arrow in the top row of Figure 1.

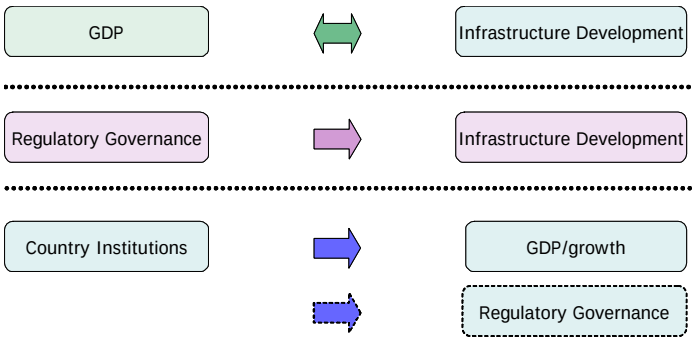

Figure 1: Factors Potentially Affecting Infrastructure Development

Considering the second row of Figure 1, the economic importance of the telecommunications industry has been among the factors contributing to the active role of governments in this sector. The reform process that has taken place in developed countries and in many low and middle-income countries aims at achieving public interest targets by complex policy changes, in which the establishment of a regulatory framework is accompanied by sector restructuring, the liberalization of the market and the privatization of the incumbent. Put at its simplest, introducing private finance and privatizing expanding telecommunications industries has been the main force behind the development of new regulatory organizations as well as, arguably, encouraging general improvements in country governance in the areas of commercial law enforcement.

The present study concentrates on the regulatory framework for telecommunications per se and, in particular, on key aspects of regulatory governance (e.g. the autonomy of the regulator). As described in the literature review, regulatory reform has the stated objective of promoting better infrastructure

[7] See Canning (1999) and Canning and Bennathan (2000).

[8] See Correa (2006), Esfahani and Ramirez (2003), Röller and Waverman (2001) and Waverman et al. (2005).

development, among other targets, by attracting investment and lowering the cost of capital. This effect is symbolized by the arrow in the middle panel of Figure 1.[9]

Typically, the regulatory framework is adapted to the country's specificity and, in particular, to its quality of governance. This is shown in the third part of Figure 1. A possible interpretation of this relationship views the establishment of an independent regulator as a substitute for strong country institutions (i.e. that could commit credibly to a given policy). However, it is equally sensible to assume that a country with strong institutions may be more likely to engage in reform, which is likely to result in high quality regulatory governance. This tentative relationship is represented by the dotted lines in the lower panel of Figure 1.

Finally, as highlighted by the literature on institutions and growth, the potential effect of country institutions on income should also be incorporated in the analysis.

3.1 Summary of the Approach

In order to deal with the interactions described above and represented in Figure 1, a system of simultaneous equations is estimated in which the dependent variables are infrastructure development, income and regulatory governance. This approach assumes that these variables are endogenous, i.e. they are assumed to be determined within the model rather than as being given from outside it.

As will be explained in more detail in Section 5 below, the basic econometric specification consists of three equations, which have been derived from theory or from previous empirical studies. In the first equation, the penetration of telecommunications infrastructure is explained by income, regulatory governance, investment in telecommunications and other variables. The second equation relates income levels to the penetration of telecommunications, a measure of country institutions and other variables. Finally, in the third equation, regulatory governance is explained by income, country institutions and other variables.

Jointly estimating the system of equations presents the advantage of improving the efficiency of the estimates, compared to the results obtained by instrumental variables estimators on each equation. However, with systems estimation, if the structure of the model is misspecified, any modelling error in any one equation will be propagated through the system. In consequence, in Section 5, we compare estimates for the system with those obtained for the single equations, also using instrumental variables to handle the endogeneity issue.

[9] It may be argued that countries with more widespread telecommunications penetration are more likely to set up regulators and that therefore there may be some feedback effects from infrastructure development to regulatory governance. In fact, this apparent feedback may instead be related to other factors, such as liberalization or privatization, affecting both regulatory governance and infrastructure development.

The limitations of the analysis are mainly related to the measurement of the governance variables. Firstly, in common with other studies (but see a new dataset in Montoya and Trillas, forthcoming), regulatory governance is measured on the basis of formal characteristics of the legal framework, such as the existence of the regulator and the way it is funded. However, this may not coincide with the actual governance of the regulatory authority i.e. how the regulator operates and is allowed by the government to operate - in practice.

Secondly, related to the previous point, in this paper the only available measure of regulatory governance for all our countries is a dichotomous variable which takes value one when a certain characteristic is present (e.g. regulator separate from Ministry, autonomous funding) and zero otherwise. This type of variable does not allow us to quantify differences between countries' regulators in any detail. However, compared to an index-type variable,[10] it is more suitable for system estimation.

Thirdly, country institutions are among the explanatory variables in the system. There is an open question of the potential endogeneity of country institutions. This is a key and hotly debated theme in the literature on institutions and growth. In the present study, the issue is addressed by treating the proxies for country institutions as predetermined for the year in question.[11] This approach is motivated by institutions' strong persistence over time, especially in relation to the limited timeframe of the present sample.

Unlike previous studies on regulatory governance in telecommunications, this paper focuses on mobile communications, in order better to tailor the analysis for low and middle-income countries. Given the substantial sunk investments to deploy the fixed network and the chronic waiting lists, mobile phones have proved formidable substitutes for fixed lines in developing countries.

In terms of methodology, the main advantage of this approach is that we estimate a system of equations rather than a single reduced form equation that is informed by the underlying economic relationships. This should allow to investigate much more thoroughly the interactions described above, which perforce are either ignored or only implicitly modelled in the single equation reduced form model. For instance, our approach can shed light on the economic factors that determine the quality of regulatory governance and, potentially, on mobile telecom penetration. In particular, it allows testing whether and how far country general institutions are a driver of mobile penetration through their indirect effects on infrastructure regulation and on income levels.

Secondly, a key difference compared with previous papers is that they do not consider the effect of telecommunications infrastructure on income. The

[10] For example, as explained in Section 2, Gutierrez (2003) measures regulatory quality by an index which includes six different components, such as whether the regulator is separate from the Ministry and whether it is independently funded. A similar approach is also followed by Cubbin and Stern (2006). In both studies, the index of regulatory quality is an explanatory variable, rather than a dependent variable as in the present paper. Such indexes typically can take only a discrete number of values and, therefore, cannot be treated as continuous variables in the estimation. For this reason, it is simpler to have a dummy variable rather than the ordered data that would result from an index.

[11] For instance, see Rajan and Zingales (1998).

failure to treat income as endogenous can readily lead to biased results in a reduced-form equation. The approach proposed in the paper should provide more reliable results by explicitly allowing for income to be endogenous.

Thirdly, the paper also relates to studies measuring the impact of telecommunications penetration on income. In this respect, this paper's contribution is the explicit inclusion of regulatory governance and country institutions in the framework of analysis.[12]

Finally, the present dataset includes a reasonably large set of developing countries only (30 countries). Hence, we have a more homogenous group of countries than in most previous studies. The latter have generally combined both developed and developing countries and therefore implicitly assume that a common model holds for very different countries (e.g. Wallsten (2003) and Waverman et al. (2005) for the cross-section results).

4 Description of the Sample

Our dataset consists of an unbalanced panel of yearly data on 30 low-income and middle-income countries over the period 1990 to 2004. The main sources for the data are the International Telecommunications Union (ITU) World Telecommunications Indicators and the World Development Indicators from the World Bank. This Section describes the main variables, while details on the other variables included in the analysis are provided in Appendix 1.

Telecommunications penetration is measured by the number of mobile subscribers per 100 inhabitants, as explained in Appendix 1. In line with other studies (Gutierrez, 2003; Roller and Waverman, 2001), GDP per capita is measured in constant U.S. dollars.

For regulatory governance, a limited number of indicators have been chosen. These include: whether (a) the country has passed a framework law for the telecommunications sector; (b) the country has established a regulator as a separate entity from the policy maker;[13] and (c) the regulator is not funded by the Government's budget. In addition, the years since the creation of the regulator is also considered in order to capture the time necessary to build up staff numbers and competences and reputation, as in Cubbin and Stern (2006).

Data sources for these regulatory variables include the International Telecommunications Union (ITU) online database on country and regulators profiles,[14] Henisz, Zelner and Guillen (2004), Wallsten et al. (2004)[15] and the regulators' websites.

[12] Waverman et al. (2005) include a rule of law measure, while Esfahani and Ramirez (2003) include a dummy for private ownership.

[13] The year in which the law establishing the regulator was passed may differ from the year when the regulator was actually set up. In most countries in our sample, they coincide. For Belize, it was not possible to identify the law setting up the regulator.

[14] http://www.itu.int/ITU-D/treg/profiles/guide.asp?lang=en

[15] http://www.aei-brookings.org/publications/abstract.php?pid=724 Scott Wallsten, George Clarke, Luke Haggarty, Rosario Kaneshiro, Roger Noll, Mary Shirley, and Lixin Colin Xu. "New Tools for Studying Network Industry Reforms in Developing Countries: The Telecommunications and Electricity Regulation Database." AEI-Brookings Joint Center

Variable	Obs	Mean	Std. Dev.	Min	Max
Mobile penetration (subscribers per 100 pop)	449	9.93	17.31	0	105.64
GDP pc (US$ 2000)	450	2,783.39	1,873.62	299.87	8,234.93
Share of private credit (% GDP)	443	44.83	34.12	0	165.72
Openness (% GDP)	443	80.57	40.42	13.75	228.87
Multilateral debt (% public debt)	422	30.98	23.03	0	96.79
Mobile revenue per subscriber (US$)	329	807.99	2,030.18	39.83	26,873.31
Fixed revenue per subscriber (US$)	410	981.84	4,192.07	71.96	53,509.78

Source: ITU, World Bank.

Table 1: Summary Statistics

The variable for privatization is an indicator which takes value one when the fixed incumbent has been privatized and zero otherwise. Privatization is defined in this paper as the sale of more than 50% of the incumbent's shares by the government. Similarly, the liberalization dummy takes value one if competition for long-distance services is permitted.

Regarding privatization, the data collected by Henisz, Zelner and Guillen (2004) for the period up to 1999 were updated using the World Bank Privatization Database and other publications.[16] The liberalization variable was also drawn from Henisz, Zelner and Guillen (2004) and was updated using case studies from a variety of sources.

The countries considered in the analysis are very diverse, as shown in the summary statistics in Table 1. Even though all the countries in the sample are characterized by the World Bank as low and middle-income, the level of GDP per capita in constant dollars ranges from USD 300 to more than USD 8,000. Similarly, if we only restrict our attention to the last year in the sample, the number of mobile subscribers per 100 inhabitants (mobile penetration) ranges from 7 in Kenya to 105 in the Czech Republic in 2004. For this variable, the table excludes the 35 observations for which mobile penetration is zero, i.e. the years in which countries in the sample had not yet launched a mobile telephony service.

In the Table 1, and in all the estimated equations, monetary variables are included on an exchange rate basis, in constant 2000 US dollars, rather than in PPP terms. This approach follows, for instance, Röller and Waverman (2001), Cubbin and Stern (2006), Gutierrez (2003), Estache et al. (2006) and the panel data analysis in Waverman et al. (2005).

When looking at the behavior of the variables across time, it appears, not surprisingly, that mobile penetration and GDP per capita, as well as capital and labour per capita, show an upward trend. Conversely, other variables, such as the index of political constraints (Polcon), show little variation over time. As explained further in the next section, we explicitly take into account in the estimation the various considerations on the dynamic behavior of the variables, especially mobile penetration and GDP per capita.

Related Publication 04-05. March 2004.

[16] http://rru.worldbank.org/Privatization/

The variables regarding sector reform are summarized in Figure 2, which shows higher mobile penetration in countries that have implemented different types of reforms (telecommunications law, separate regulator, liberalization of long-distance services and majority privatization of the incumbent) compared to the others. At first glance, this would suggest the reform may well have had a positive impact on penetration.

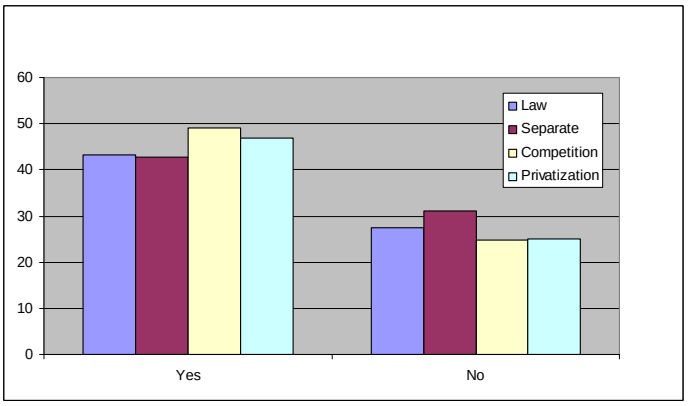

Figure 2: Mobile Subscribers per 100 Inhabitants

It is interesting to note that the countries that have reformed the telecommunications sector by 2004 almost coincide with the entire sample. Out of 30 countries, 26 have enacted a law reforming the telecommunications sector and most of them had done so by year 2000. In theory this could reduce the degree of inter-country variation needed to identify the effect of regulatory reform; but, in practice, the time dimension from the very different dates at which countries introduced their reforms should provide the necessary variation to discriminate between countries.

In order to analyze differences across countries in the timing of reform, the age of the regulator is a good proxy. It also provides an indication of the authority's staff expertise and reputation, which may be important in addressing the commitment problem. Figure 3 shows a histogram of the age of the regulator as of 2004, the last year in the sample. The variable indicates the number of years since the establishment of the regulator, starting with the year after the law introducing a regulator was passed.[17] The average age is around 6 years and the median is 5, that is around half the regulators have more than 5 years of operation.

[17] The first group includes countries that do not have a separate regulator or that passed the law in 2004. The second group includes countries that passed the law establishing the regulator in 2001 - 2003, i.e. age of the regulator is between 1 and 3 years. The third group consists of countries that passed the law in 1997 - 2000 (i.e. age is between 4 and 7 included), while the fourth includes those that passed the law between 1990 and 1996. The last includes only the Philippines, that established a regulator before the first year in the sample, i.e. 1990.

	Telecom Law	Separate Regulator	License Fee Funding	Competition	Privatization
Telecom Law	1				
Separate Regulator	0.6147	1			
License Fee Funding	0.4389	0.6543	1		
Competition	0.4358	0.2980	0.0469	1	
Privatization	0.4591	0.4940	0.1355	0.2675	1

Table 2: Correlation Matrix

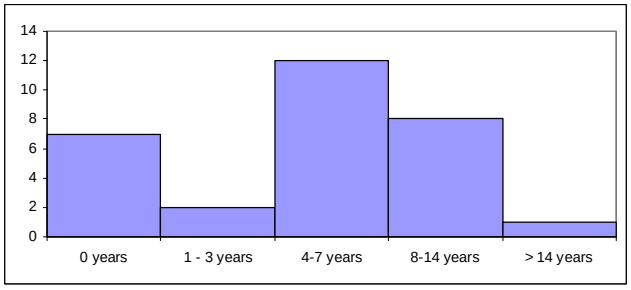

Figure 3: Age of the Regulator

The correlation between the different elements of regulatory reform is shown in Table 2. However, the correlation between enacting a modern telecom law and having a separate regulator is high, but weaker than expected. This is due to a number of countries that do not have a separate regulator even though they have passed a sector law (Benin, Chile and China as of 2004) and vice versa (Gambia and Surinam). In addition, most countries that have privatized the fixed incumbent operator have also introduced some liberalization measures in the long-distance market, even though the two events have not usually been contemporaneous. In consequence, the degree of inter-correlation on the regulatory variables that we find for telecommunications is quite high but lower than Cubbin and Stern (2006) found for electricity.

The relationship between GDP per capita and the rate of mobile penetration is crucial to this paper and is plotted in Figure 4. The two variables exhibit a positive correlation, in line with expectations. In addition, the wide variation which was highlighted in the summary statistics is also clearly visible in the graph. Finally, the positive relationship is consistent both with (a) GDP driving mobile subscription, a demand-side effect; and (b) mobile availability and usage increasing GDP, a supply-side effect. We discuss the implications of this in the next section.

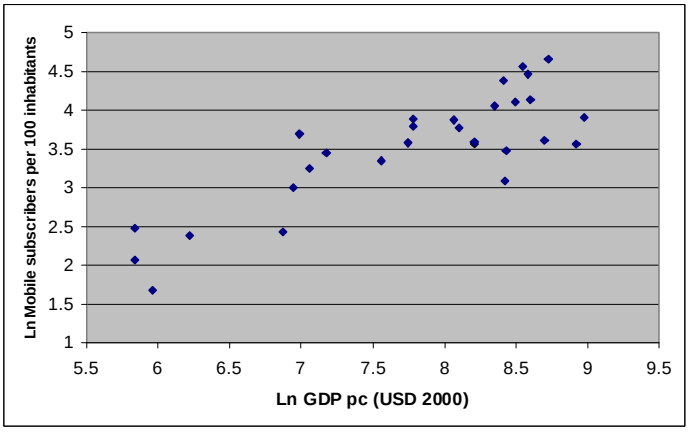

Figure 4: Income and Mobile Penetration (2004)

5 Econometric Methodology

On the basis of the discussion above, the variables that are considered endogenous in the present analysis are (i) the penetration rate of mobile telecommunications, (ii) GDP per capita and (iii) a measure of regulatory governance. Hence, we need a three equation model, which consists of an equation describing the behavior of telecommunications penetration and two further equations for the other potentially endogenous variables.

The actual model that we estimate is set out below. In the basic formulation of the system, it is assumed that the three endogenous variables have an impact only on the contemporaneous values of other endogenous variables i.e. we assume no lagged effects. Other restrictions, derived from the previous discussion, are also imposed in the following equations.

The estimation relies on a panel of countries over time from 1990 to 2004, and we assume that the parameters of the model are constant both across countries and over time.

The penetration of mobile subscribers (PEN_{it}) in country i at time t, is assumed to be a function of the other potentially endogenous variables in the system, per capita income ($GDPpc_{it}$) and regulatory governance (RG_{it}) and of some exogenous variables. This gives us the following equation for mobile penetration rates:

$$\begin{aligned} \ln PEN_{it} &= \alpha_{0,i} + \alpha_1 \ln GDPpc_{it} + \alpha_2 \cdot RG_{it} + \alpha_3 \ln PM_{it} + \alpha_4 \ln PF_{it} \quad (1) \\ &+ \alpha_5 \ln Density_{it} + \alpha_6 \ln InvRatio_{it} + \alpha_7 \Pr ivat_{it} + \alpha_8 Liberal_{it} \\ &+ \mu_t + \varepsilon_{1,it} \end{aligned}$$

The variables that we treat as exogenous are: PM_{it}, the average price of mobile telecommunications services; PF_{it}, the average price of fixed telecommu-

nications services; $Density_{it}$, the country population density;[18] and $InvRatio_{it}$, the telecommunications investment/GDP ratio (as in Ros (1999)). Moreover, as privatization and liberalization are likely to affect penetration, these variables are also included in the mobile penetration equation. $\varepsilon_{1,it}$ is an error term for this first equation. We also include time dummies, μ_t.

In the above equation, for the reasons discussed in the previous section, the estimated coefficients on and in (1) are expected be positive. The estimated coefficient on $InvRatio_{it}$ is also expected to be positive (because more investment allows higher usage in a supply constrained industry) as is that on $Density_{it}$ (because it is more cost efficient for the operators to cover densely populated areas).

Regarding the price of services, standard demand considerations imply that a higher price of mobile services (PM_{it}) is likely to depress penetration, while an increase in the price of fixed services (PF_{it}) should encourage a switch to the mobile network. Hence, the estimated coefficient on the mobile price is expected to be negative and that on the price of fixed services positive. Lastly, the effects of fixed line privatization and liberalization are indeterminate. They may have a negative effect on mobile penetration, as it may be sensible to assume that those reforms would improve availability and quality of fixed services. However, there are also reasons why the impact could be positive e.g. if one of the mobile operators is part of a newly commercialized incumbent fixed line operator.

The equations describing the other two potentially endogenous variables are:

$$\begin{aligned} \ln GDPpc_{it} &= \beta_{0,i} + \beta_1 Inst_{i,t-1} + \beta_2 \ln PEN_{it} + \beta_3 \ln K_{it} + \\ &\quad \beta_4 \ln HK_{it} + \beta_5 \ln Openness_{it} + \eta_t + \varepsilon_{2,it} \end{aligned} \tag{2}$$

$$\begin{aligned} RG_{it} &= \gamma_{0,i} + \gamma_1 Inst_{i,t-1} + \gamma_2 \ln GDPpc_{it} + \gamma_3 \ln IntlEffect_{it} \\ &\quad + \gamma_4 \operatorname{Pr}ivat_{it} + \gamma_5 Liberal_{it} + \nu_t + \varepsilon_{3,it} \end{aligned} \tag{3}$$

The equation for GDP per head takes the form of an aggregate production function, but a production function that also includes mobile telecoms as an input. In this equation, $Inst_{i,t-1}$ is a proxy for country institutions, HK_{it} is a proxy for human capital, K_{it} is a measure of physical capital, $Openness_{it}$ is the ratio between trade and GDP, η_t are time dummies and $\varepsilon_{2,it}$ is an error term. In the model that we estimate, it is assumed that country institutions are pre-determined. For this reason, we include in the system , which pre-date the period of analysis, rather than Insti,t on the grounds that institutions in previous years cannot be affected by income levels in subsequent periods (see Rajan and Zingales, 1998; Esfahani and Ramirez, 2003 for previous use of this approach). All variables in equation (2) are expected to have a positive effect on income levels.

[18] As an alternative, the significance of the percentage of rural population is also tested.

In equation (3) regulation is modelled as a dummy variable, which takes the value of 1 if a given characteristic (e.g. sector law or separate regulator) is present and zero otherwise. Different measures of 'good regulation' will be employed in the estimation. We treat regulation as an endogenous variable in this model, and it is assumed that the choice of whether to have a regulatory framework in place depends on country institutions and some other factors. As argued in the previous Section, the other factors that we consider include the country income level ($GDPpc_{it}$) and pressure by international organizations (e.g. conditionality conditions imposed by international financial institutions), as proxied by multilateral lending ($IntlEffect_{it}$). $\varepsilon_{3,it}$ is the error term for equation (3).

The functional form of the third equation is a linear probability model. While this model does not constrain predicted values to lie in the interval between 0 and 1 (Greene, 2003), it is particularly suitable for estimation in a multi-equation system. In order to alleviate the potential problem of out-of-range estimates, we check predicted probabilities after estimation to verify that they belong within the correct interval.

As we have a panel data set, we include country-specific fixed effects in all three equations. The fixed effects approach allows for correlation between the country-specific intercept and the regressors and is therefore less restrictive than the random effects model in this context. Therefore, in line with other studies on regulatory institutions (e.g. Estache, Goicoechea and Manacorda, 2006) and on the impact of telecommunications of GDP (Röller and Waverman, 2001), the model is estimated under the hypothesis of fixed effects. However, to test the appropriateness of this specification, we test the results against a random effects model.

Finally, year dummies are included to account for period effects common to all the countries in the sample.

6 Results

This section is divided into two main parts. In the first part, we report estimates of each equation estimated separately and, in the second part, we report the system estimates.

It is useful to present the results obtained estimating each equation separately. This can provide a better insight on the data and can be also used as a comparison for the coefficients when the equations are jointly estimated as a system. In addition, separate estimation of each equation implies that, although system interactions are not fully captured, specification errors in any individual equation are not transmitted to the other equations.

6.1 Equation-by-Equation Estimates: Equation 1

The results for the penetration of mobile services (Equation 1) are shown in Table 3. The specifications shown provide estimates from random effects (Col-

umn 1) and fixed effects (Column 2) models. The third column shows results for a fixed effect model, where insignificant variables have been removed, except for the logarithm of GDP per capita which is one of the key variables of interest in the present study. All columns include time dummies to take account of any common cross-country time period effects.[19] The reported standard errors are robust to heteroscedasticity and serial correlation.[20] All the explanatory variables in Table 3 are treated as exogenous, except for Column 5 which reports the results of using an instrumental variable (IV) estimator. For comparison purposes, Column 4 reports standard errors that are not robust to heteroscedasticity and serial correlation. Given that robust standard errors are not available for the system estimation, we check that this adjustment does not affect the significance of the estimates. The differences arising from this correction are very small, as shown by comparing Columns 3 and 4.

All the estimated equations in Table 3 (and Tables 6 - 7) are static equations which provide estimates of long-run coefficients.[21]

Evidence regarding the main explanatory variables, and , is mixed. The dummy indicating the presence of a regulator is significant but, when the existence of a telecommunications law and independent funding of the regulator are used as proxies for an autonomous regulator they are not significant either in a fixed effects model or in a random effects model.

Counter to expectations, the age of the regulator has a significant negative coefficient. However, the implication of this result is far from clear-cut. Omitting the time dummies leads to a significant and positive coefficient. Hence, in this case time series data cannot identify the effect of the variable even with a cross-section dimension. This appears to be due to the fact that mobile telecommunications usage has far stronger trend elements than, for instance, electricity generation capacity or fixed line telecommunication penetration growth, at least in our sample of developing countries.[22]

The logarithm of GDP per capita is not significant in a fixed effects model but its coefficient becomes significant and markedly larger when a random effects model is estimated. This may seem to indicate that the heterogeneity across countries, as represented by different income levels, is absorbed by the fixed effects, while within country variation provided by GDP per capita seems to play a more limited role as indicated by an insignificant coefficient when time dummies are included.

In line with expectations, the coefficient on the price of mobile services is

[19] When a time trend was included, instead of time dummies, the coefficients had the same sign and were slightly larger.

[20] This adjustment follows the result in Wooldridge, J. M. (2002), Econometric Analysis of Cross Section and Panel Data, MIT Press (Chapter 10). It allows both for heteroscedasticity and for correlation across observations for the same country.

[21] After estimating the model, we performed residual diagnostics and found residuals were well-behaved. Moreover, outliers and leverages were very few and did not affect the main results.

[22] In an alternative specification, the age of the regulator was modeled as a set of dummy variables, none of which was significant. Moreover, lagged values of the regulatory variable (1 to 3 lags) were not significant unless time dummies were excluded from the specification.

Dependent variable: Ln mobile penetration 1990 – 2004

	(1)	(2)	(3)	(4)	(5)
	Random Effects	Fixed Effects	FE omitting non significant variables	Uncorrected Std. errors	IV
Ln GDP pc	1.103	0.353	0.368	0.368	0.113
	[0.130]***	[1.179]	[1.003]	[0.439]	[0.656]
Separate regulator	0.366	0.389	0.452	0.452	0.463
	[0.185]**	[0.228]*	[0.185]**	[0.109]***	[0.111]***
Price mobile	-0.00038	-0.00039	-0.00038	-0.00038	-0.00039
	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***
Price fixed	-0.000	0.000			
	[0.000]	[0.000]			
Majority privat.	0.150	0.141			
	[0.208]	[0.262]			
Liberalization	-0.282	-0.349	-0.364	-0.364	-0.356
	[0.164]*	[0.171]**	[0.154]**	[0.105]***	[0.107]***
Ln Investment ratio	0.295	0.268	0.307	0.307	0.313
	[0.106]***	[0.112]**	[0.102]***	[0.055]***	[0.059]***
Ln Pop. Density	0.128	0.946			
	[0.100]	[2.729]			
Constant	-10.266	-8.310	-4.337	-4.337	-2.388
	[1.323]***	[16.930]	[7.686]	[3.350]	[4.987]
Fixed Effects	No	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes	Yes
Corrected std. errors	Yes	Yes	Yes	No	No
R-squared	0.8711	0.6095	0.7705	0.7705	0.6996
Countries	30	30	30	30	29
Observations	307	307	311	311	301

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in brackets under coefficients; corrected std. errors are robust to heteroscedasticity and serial correlation. In column 5, GDP per capita is treated as endogenous and instrumented with labour per capita, capital per capita and lagged credit ratio (the regressors in Equation 2), in addition to the other exogenous variables included in Equation 1.

Table 3: Results for Equation 1

negative (and statistically significant at the 1% level). The rate of telecommunications investment makes a strong and highly significant positive contribution to mobile penetration, strongly supporting the notion of mobile penetration being supply constrained in developing countries.

The negative coefficient on the dummy Liberalization, which indicates the opening to competition of long-distance services provided on fixed networks, seems to suggest substitutability between fixed and mobile services, which is particularly likely in developing countries, as discussed earlier in the paper.

The results from the IV estimator in Column 5, where GDP per capita is treated as endogenous and instrumented with the exogenous explanatory variables in Equation 2 are very similar to those in Columns 1-4. These instrumental variables estimates provide an intermediate step between the results in Columns 1 4 and the full system estimates. In Table 3, the instruments for GDP per capita are only exogenous variables. In the system (Section 6.2), one of the regressors is mobile penetration, which is assumed to be determined jointly with GDP per capita in the system.

Throughout the analysis, the fixed effects model was considered the basis for the estimates, as is very often the case with models like those estimated in Table 3. By allowing for correlation between the regressors in Equation 1 and the country-specific unobserved effect, the fixed effects model is more suitable than the random effects estimator in the present setting and less restrictive in its underlying assumptions. The standard procedure in these circumstances is to compare fixed effects and random effects estimators using the Hausman test. In our case, the test results were not conclusive. However, we prefer the fixed effects estimator for the reasons explained above. Therefore, in the rest of the paper we focus primarily on fixed effects models and report the random effects estimates for comparison.

As mentioned above, the main difference between the results from the fixed effects and the random effects estimators is that the coefficient on GDP per capita becomes significant in the random effects model. However, it is unclear whether this reflects, at least in part, that GDP per capita is acting as a proxy for other variables (e.g. general country governance) which are captured by the country-specific intercept in the fixed effects model.

In order to investigate these issues, an alternative approach could be to replace the unobserved fixed effects with environmental variables or to group countries on the basis of geography or other criteria (e.g. see Durlauf et al., 2005). Such an analysis is beyond the scope of the present paper but is a topic for further work.

6.1.1 Dynamic Single Equation Models

The specification proposed so far is static while, similarly to the models estimated in the growth literature, it may be argued that the penetration of mobile phones in the current period is affected by penetration in previous periods. For instance, Gutierrez (2003) and Cubbin and Stern (2006) find evidence that the lags of the dependent variable have significant and large coefficients. This for-

mulation assumes that the impact of past values of the regressors is persistent and is captured by the coefficient on the lagged dependent variable.

For this reason, the following dynamic model seems more appropriate.

$$\begin{aligned} \ln PEN_{it} &= \alpha_{0,i} + \delta_1 \ln PEN_{i,t-1} + \delta_2 \ln PEN_{i,t-2} + \alpha_1 \ln GDPpc_{it} + \alpha_2 \cdot RC_{it} \\ &+ \alpha_3 \ln PM_{it} + \alpha_4 \ln PF_{it} + \alpha_5 \ln Density_{it} + \alpha_6 \ln InvRatio_{it} \\ &+ \alpha_7 \Pr ivat_{it} + \alpha_8 Liberal_{it} + \mu_t + \varepsilon_{1,it} \end{aligned} \tag{4}$$

For comparison purposes, we firstly report results from the dynamic equation estimated with fixed effects (Table 4) and then we compare the results with those obtained using the Arellano and Bond estimator (Table 5).

The dynamic model (Table 4) broadly confirms the results in Section 6.1 above. In particular, on the basis of the estimated coefficient on the regulatory variable (0.019), the corresponding long-run coefficient would be 0.1.[23] This is significant, but lower than the coefficient obtained in the static model (0.452 in Table 3) and the estimates in Gutierrez (2003), which is 0.36.[24] Moreover, the estimates in Table 4 highlight the importance of lagged values of mobile penetration.

The results in Table 4 are subject to a degree of bias. When the number of time periods is small (T = 15 in our sample), the fixed effects estimator of a dynamic model is biased. This is due to the correlation between the lags of the dependent variable and the error term in the model. For this reason, as in Gutierrez (2003), the Arellano and Bond (1991) estimator is used in order to overcome the bias created by the introduction of lagged values of the dependent variable in Equation 4.

We report the results from the Arellano-Bond estimator in Table 5. In the first column, all explanatory variables are included and is treated as endogenous. In order to limit the size of the instrument matrix, which can increase very quickly with the number of endogenous or predetermined variables, and which depends on the number of time periods in the panel, the maximum number of lags that can be used as instruments is set to 4. In addition, is considered pre-determined in the second column. While coefficients appear broadly similar in size and significance between the two columns, the latter model is more computationally demanding.

Compared with Gutierrez (2003), who estimates the model for fixed line penetration, the coefficient on is pretty similar (Gutierrez finds 0.7748 and 0.7287 depending on the specification) and the coefficient on GDP per capita is higher.[25]

There are some common conclusions that can be drawn from the estimates of the dynamic models in Tables 4 and 5. In both cases, unlike the static models of

[23] Therefore, the establishment of a separate regulator would be associated, in the long-run, to a level of mobile penetration higher by about 11%.

[24] Gutierrez (2003), Table 6, Column 1.

[25] Gutierrez (2003) treats liberalization, privatization and regulation as predetermined variables.

Dependent variable: Ln mobile penetration 1990 – 2004

Ln mobile penetration (t-1)	1.099
	[0.070]***
Ln mobile penetration (t-2)	-0.282
	[0.058]***
Ln GDP pc	0.168
	[0.040]***
Separate regulator	0.019
	[0.045]***
Liberalization	-0.010
	[0.035]
Majority privatization	0.020
	[0.034]
Price mobile	-0.00011
	[0.000]**
Price fixed	-0.00014
	[0.000]*
Ln Investment ratio	0.124
	[0.031]***
Ln Population Density	-0.004
	[0.018]
Constant	-0.648
	[0.356]*
Time dummies	Yes
Countries	30
Observations	287

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in brackets under coefficients are robust to heteroscedasticity.

Table 4: Dynamic Specification for Equation 1 (Fixed Effects)

Table 3, the estimated coefficient on GDP per capita is significant and positive. This holds both for the fixed effects estimator and the Arellano-Bond estimator, even though in the latter case it is much larger.[26] Further similarities between Tables 4 and 5 include the significance of the price of mobile services and of the investment ratio. However, in both cases again, the estimated coefficients using the Arellano-Bond method are larger.

Regarding the policy variables, the main difference between the results in Tables 4 and 5 is that the dummy representing the regulatory variable is significant in the fixed effects model but insignificant with the Arellano-Bond estimator. Moreover, contrasting results are also obtained on liberalization and privatization. Both variables are insignificant in the fixed effects model, but become significant when the equation is estimated using the Arellano-Bond estimator.

Neither of the alternative dynamic model estimates are entirely reliable, as the estimators used in this Section are not ideal for our sample. The results in Table 4 are biased due to the small number of time periods in the sample, although the degree of bias should be relatively small.[27] The Arellano-Bond estimator addresses this issue under the assumption of a small number of time

[26] The Arellano-Bond estimator treats the country-specific intercepts are random effects and this may explain the similarity of the coefficient on GDP per capita with that obtained for the static model using a random effects estimator (1.103 in Table 3).

[27] Nickell (1981) finds that, in an autoregressive model of order 1, if the coefficient on the lag of the dependent variable is 0.5 the bias is -0.167 (assuming 10 time periods).

Dependent variable: Ln mobile penetration 1990 – 2004

	(1) Endogenous GDP	(2) Endog. GDP and pre-determined regulation
Ln mobile penetration (t-1)	0.805	0.786
	[0.047]***	[0.047]***
Ln mobile penetration (t-2)	-0.165	-0.158
	[0.045]***	[0.046]***
Ln GDP pc	1.104	1.212
	[0.626]*	[0.570]**
Separate regulator	0.048	0.063
	[0.079]	[0.103]
Liberalization	-0.137	-0.161
	[0.057]**	[0.051]***
Majority privat.	-0.120	-0.083
	[0.067]*	[0.072]
Price mobile	-0.00023	-0.00024
	[0.000]**	[0.000]**
Price fixed	-0.000	-0.000
	[0.000]	[0.000]
Ln Investment ratio	0.147	0.136
	[0.050]***	[0.047]***
Ln pop. Density	0.195	0.380
	[0.967]	[1.001]
Constant	-0.051	-0.045
	[0.105]	[0.103]
Time dummies	Yes	Yes
Wald test	3989.83	3702.73
2nd order serial correlation	- 0.22	- 0.18
p-value	0.8296	0.8564
Countries	30	30
Observations	254	254

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in brackets under coefficients in all columns are robust to heteroscedasticity. The Arellano-Bond test for 2nd order serial correlation fails to reject the null hypothesis of no serial correlation in the residuals.

Table 5: Dynamic Specification for Equation 1 (Arellano-Bond)

periods and a number of cross-sections going to infinity.[28] However, in our study the size of the cross-section dimension is relatively small compared to the number of time periods. For this reason, the estimator is also far from ideal[29] either for our sample – or for the dataset in Gutierrez (2003).[30]

Nevertheless, each estimation method provides useful and corroborative evidence on the sizeable and significant impact of per capita GDP and telecommunications investment on mobile penetration. The long-run coefficients on these variables are 0.92 and 0.68, respectively (Table 4), as compared to 0.368 and 0.307 in Column 3 of Table 3 for the static model.

6.2 Equation-by-Equation Estimates: Equation 2

The results for Equation (2), the GDP per capita production function are shown in Table 5, We estimate this equation taking as proxy measures of the quality of country institution both (a) the Polcon index and (b) the logarithm of the share of credit to GDP. As in our estimate of Equation (1), all explanatory variables are considered exogenous and year dummies are included. Results from fixed effects (Column 1) and random effects (Column 2) models are provided, and standard errors are robust to heteroscedasticity and serial correlation, except for Column 4, which shows the impact of this adjustment on the significance of the coefficients.[31]

The coefficient of the impact of mobile penetration on GDP per capita is positive and significant in all specifications, as expected and as found in Waverman et al. (2005). Its size is also robust to alternative specifications. Compared to Waverman et al. (2005), who obtain an estimate of 0.075 in their panel data model, the magnitude of our estimate (0.014) is significantly smaller.[32]

However, the proxies used for country institutions are never significant and this confirms the low correlation found between these variables and the logarithm of GDP per capita in the present sample, both at a cross-section level and within a given country. While this result may be attributable to the poor quality of the measures used in the study, it may also be a symptom of a methodological issue or some other underlying factors.

Finally, a methodological issue arises from the choice of the time horizon

[28] In their article, Arellano and Bond (1991) apply the estimator to an unbalanced panel of 140 companies over at least 7 periods.

[29] Recognizing the importance for applied work of panels where the cross-section and time dimensions are of similar size, Alvarez and Arellano (2003) investigate the properties of the estimator when they both go to infinity. Concerns on the small sample properties of the Arellano-Bond estimator, due to the large size of the instrument matrix, are for instance discussed in Kiviet (1995).

[30] That dataset includes 22 countries over 18 years.

[31] The correction to standard errors affects the significance of the coefficient on the lagged credit ratio.

[32] The results are not directly comparable, as Waverman et al (2005) transform penetration as PEN / (35 PEN). In addition, Waverman et al. (2005) prefer the estimates from the cross-section model, which implies that if, in a given country, there were one additional mobile phone for 100 people the country would experience a per capita GDP growth higher by 0.059 percent.

Dependent variable: Ln GDP per capita 1990 – 2004

	(1) Random Effects	(2) Fixed Effects	(3) FE omitting non significant variables	(4) Uncorrected Std. errors	(5) Fixed Effects (Polcon)
Ln Credit/GDP (t – 1)	0.023	0.032	0.033	0.033	
	[0.027]	[0.028]	[0.030]	[0.011]***	
Ln Mobile penetration	0.014	0.016	0.014	0.014	0.013
	[0.005]***	[0.005]***	[0.005]***	[0.003]***	[0.005]***
Ln Labor/pop.	-0.228	-0.260			
	[0.231]	[0.246]			
Ln Capital/pop.	0.662	0.563	0.576	0.576	0.604
	[0.048]***	[0.053]***	[0.051]***	[0.028]***	[0.047]***
Ln Openness	-0.004	0.011			
	[0.038]	[0.037]			
Polcon (t – 1)					-0.007
					[0.033]
Constant	1.614	2.351	2.516	2.516	2.393
	[0.443]***	[0.438]***	[0.418]***	[0.233]***	[0.405]***
Fixed Effects	No	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes	Yes
Corrected std. errors	Yes	Yes	Yes	No	Yes
R-squared	0.9456	0.9398	0.9419	0.9419	0.9471
Countries	29	29	29	29	28
Observations	380	380	382	382	376

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in brackets under coefficients in all columns are robust to heteroscedasticity and serial correlation.
Countries: capital is not available for Fiji; Polcon is not available for Suriname.

Table 6: Results for Equation 2

in the GDP equation. The theoretical models that inform empirical studies generally address the question of steady-state growth. As a result, empirical growth studies have traditionally used cross-sections of countries, where data for each country were averaged over long periods of time. However, the estimation of growth models relies increasingly on panels where data have been averaged over five or ten years. This raises the question of whether it is appropriate to use long-run models to interpret short-intervals of data (Levine, 2005; Durlauf, Johnson and Temple, 2005) and this potential pitfall seems even more acute if annual data are used.

6.3 Equation-by-Equation Estimates: Equation 3

Finally, our estimates of Equation (3) for the presence or absence of a telecommunications regulator are reported in Table 6. They provide no evidence of any systematic link between country institutions and regulatory governance. This is counter to the results in Gual and Trillas (2006). However, we confirm their finding that Polcon (which, when lagged, we interpret as a measure of political stability) is not significant in a model explaining an index of regulatory quality. Another interesting result from their analysis that we corroborate is the finding that the creation of an independent regulator is not systematically related to the level of GDP per capita.

The specifications shown in Table 6 (Equation 3) compare estimates from

Dependent variable: Separate regulator (Yes/No)

	(1) Fixed Effects (Polcon)	(2) FE Omitting not significant vars	(3) Fixed Effects (Credit)	(4) FE Omitting not significant vars
Ln GDP per capita	0.000	-0.022	-0.043	-0.081
	[0.410]	[0.387]	[0.418]	[0.388]
Polcon (t – 1)	0.029	0.054		
	[0.162]	[0.156]		
Majority privat.	0.361	0.378	0.374	0.376
	[0.109]***	[0.107]***	[0.108]***	[0.108]***
Liberalization	0.149		0.153	
	[0.109]		[0.110]	
Ln Multilateral lending	-0.058		-0.054	
	[0.053]		[0.052]	
Ln Credit/GDP (t – 1)			0.053	0.027
			[0.097]	[0.084]
Constant	0.754	0.244	0.892	0.608
	[3.173]	[2.900]	[3.152]	[2.871]
Fixed Effects	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes
R-squared	0.3797	0.4086	0.3541	0.3671
Countries	29	29	30	30
Observations	391	404	390	412

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in brackets under coefficients in all columns are robust to heteroscedasticity and serial correlation.
Countries: Polcon is not available for Suriname.

Table 7: Results for Equation 3

different models, all of which include fixed effects and time dummies. In the third column, insignificant variables have been removed, except for the logarithm of GDP per capita and of the credit variable, which are among the variables of interest in the present study. Standard errors are robust to heteroscedasticity and serial correlation and all variables are treated as exogenous. Fitted values are then computed and it is verified that they lie within the interval between 0 and 1.[33]

The share of private credit over GDP is the proxy for institutions included in the other two columns but it does not have any statistically significant impact.

The equation is relatively unsuccessful in explaining the emergence of a telecommunications regulator. The only significant variable, once fixed effects and time dummies are included in the model, is the dummy indicating the majority privatization of the incumbent.[34] This coefficient is positive and significant in all the specifications and its value does not change much across the

[33] In addition, fitted values are compared with the actual values of separate. When there is a separate regulator (i.e. separate = 1), the median of the fitted values is 0.8 and three-quarters of the values are greater than 0.69. The model correctly predicts the existence of a separate regulator in about 71% of observations (i.e. the fitted values are between a threshold value we set at 0.5 and 1). When there is not a separate regulator (i.e. separate = 0), the median of the fitted values is 0.16 and three-quarters of the values are less than 0.3. However, the fitted values are between 0 and the threshold value of 0.5 for only 58% of the observations.

[34] If errors are not corrected for heteroscedasticity and serial correlation, liberalization is also significant.

different models. When the dependent variable is the dummy indicating that a telecommunications law was passed in the country, the liberalization of long-distance services is also significant while coefficients of other variables are similar to the results in Table 6. However, telecom regulators are frequently established as part of a package with liberalization and privatization with one law covering all three. This is consistent with the commonly made observation that an independent regulator is frequently introduced when governments wish to privatize state-owned infrastructure companies.

Finally, as a robustness check, the equation was re-estimated for the subset of observations used in the system. In addition, a logit model including the same variables was estimated. Both models confirmed the results presented in Table 7. The estimates from the logit model are reported in Appendix 3.

6.4 System Estimates

The system of simultaneous equations given by Equations (1) (3) is estimated by three-stage least squares, where all right-hand variables are considered exogenous, and used as instruments, while the proxy for country institutions, i.e. the ratio of private credit to GDP, is treated as pre-determined and lagged one period.

The results are presented in Table 8. Fixed effects and time dummies are included in all equations.

In the first column, the signs and significance of the coefficients confirm the results obtained for the penetration equation (Table 3, Column 4), except for the separate regulator dummy, whose coefficient is more than double the one obtained for the single equation and is also clearly statistically significant at the 1% level. However, the magnitude of the coefficient seems unrealistically high. In the mobile penetration equation, the other coefficients have broadly the same sign and magnitude as in the single equation variant, which is an indication of the general robustness of this relationship.[35]

Similarly, in the GDP equation in Column 2, the significant effect of mobile penetration on GDP per capita is confirmed by the analysis. However, again, the magnitude of the coefficient is much higher once the endogeneity of the variables is taken into account (0.044 compared with 0.014 in Table 6, Column 4), but still rather smaller than in Waverman et al. (2005). In addition, the (lagged) credit-GDP ratio is also strongly significant.

Finally, in the last equation to explain the presence or absence of an independent regulator (Column 3), the results are again disappointing and add little to the model. The liberalization of fixed services and the privatization of the incumbent are associated with higher probability that the country establishes a separate regulator. This is in line with expectations but provides little additional insight into the underlying causes of when and why independent regulators are introduced.

[35] The coefficient on liberalization is - 0.364 and the coefficient on the investment ratio is 0.307 in the estimates of Equation 1.

	Ln Mobile penetration	Ln GDP per capita	Separate regulator
Ln GDP per capita	0.360		
	[0.582]		
Separate regulator	1.099		
	[0.381]***		
Price mobile	-0.00040		
	[0.000]***		
Ln Investment ratio	0.303		
	[0.052]***		
Liberalization	-0.417		0.208
	[0.126]***		[0.054]***
Ln Credit/GDP (t – 1)		0.035	-0.018
		[0.013]***	[0.066]
Ln Mobile penetration		0.044	
		[0.010]***	
Ln Capital/pop.		0.531	
		[0.040]***	
Majority privat.			0.308
			[0.069]***
Constant	0.000	3.422	0.000
	[0.000]	[0.409]***	[0.000]
Fixed Effects	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
R-squared	0.9558	0.9966	0.7603
Observations	297	297	297

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 8: Results for the System

Modelling the development of economic institutions in general is far from easy (e.g. see examples in Acemoglu et al., 2005). Regarding telecommunications regulatory agencies, Gual and Trillas (2006) study this issue using a cross-section of countries, as explained above. This aspect of the analysis needs further consideration in future work. The problems in estimating this relationship are also revealed in the fact that, in the system results reported in Table 8, around 30% of the predicted values from the equation are outside the 0-1 interval.[36]

7 Conclusions

This paper studies the link between GDP, mobile telecommunications penetration and regulatory governance (general and sector-specific) in a sample of low and middle-income countries over a 15-year period. The main new element in the analysis is the estimation of a system of simultaneous equations, in which mobile penetration, income level and a proxy for regulatory governance are all treated as endogenous. As far as we aware, this is an approach that has not been adopted elsewhere for infrastructure industry models.

[36] After estimating the model we performed residual diagnostics. We found that residuals were well-behaved and outliers were negligible.

The potential benefits from the approach are shown by the noticeably larger estimate, in the jointly estimated system relative to the single equation, of the effect of the regulator in the mobile penetration equation. However, the equation to endogenise the presence of a telecommunications regulator is not particularly successful either as an explanation of regulatory choices or in adding extra information to the system.

The other main findings are:

(i) We find some evidence that the existence of an autonomous infrastructure industry regulator increases penetration rates for mobile telecommunications in developing countries, with estimates varying widely depending on the specification. However, the results are less robust than in other studies; this may be due to our relatively simplistic regulatory variable or to the possibility that the role of regulators is not as crucial for mobile operators as it is in the fixed market.

(ii) Other indicators of regulatory governance were, however, not found to have any significant impact on mobile penetration rates. For instance, neither the existence of a sector law nor the funding of the regulator through license fees had any apparent statistically significant impact on mobile penetration, both in the single equation and in the system estimates.

(iii) This study found no systematic effect of general country governance in affecting mobile penetration or per capita income or regulatory governance. However, we are unclear whether this is because we have inadequate proxies for country governance or whether there is genuinely no apparent effect.

(iv) Finally, we find a sizeable and strongly significant impact of mobile telecoms infrastructure on per capita GDP in our sample of developing countries. This result confirms the findings of the literature on the economic impact of infrastructure and is also strongly consistent with the study by Waverman et al. (2005) on a sample of high and low income countries.

Overall, the results from the system modelling approach on which we have reported in this paper show that explicitly taking account of endogeneities results in higher and better-determined coefficients at least for mobile telephony. This is particularly obvious for the impact of mobile penetration on the level of GDP per capita. In addition, although our modelling of regulation was not very successful, the system results indicated a more powerful effect of the presence of an autonomous regulator on mobile penetration than the single equation results.

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A Construction of Variables

A.1 Telecommunications Penetration

In this study telecommunications penetration is measured in terms of mobile phones. In less developed countries, mobile phones have shown high growth rates since their introduction and have proved formidable substitutes for fixed lines. For this reason, mobile telephony cannot be ignored in the analysis and focusing on fixed lines only would not capture the reality of developing countries.

Measuring penetration solely on the basis of mobile lines seems the preferable option, compared to using the total number of lines (i.e. fixed and mobile). In particular, it can be reasonably assumed that regulatory institutions have a different impact in markets in which there are competing firms, rather than

a single state-owned operator. Given that mobile telephony is usually characterized by a certain degree of competition almost from its commercial launch, the role of regulation appears to be significantly different from that exercised in the fixed market, where the development of fixed telephony often takes place for a long time in the absence of competition and the infrastructure is deployed entirely by a state-owned monopolist.

In fact it could be argued that, in the mobile market, the role of regulators is not as crucial as it is for the fixed market, where the very asymmetric structure often requires regulatory intervention to grant new entrants access to the portions of the incumbent's infrastructure that cannot be economically replicated. By combining the fixed and mobile markets together, one would in fact constrain the impact of regulatory institutions to be the same in both, even if the two markets were in different stages of development. On the basis of the above considerations, the variable of interest in the analysis is mobile penetration.

A.2 Explanatory Variables

There are different variables that are used in the literature as proxy for country institutions. The institutional characteristics considered in this study are: (a) protection against expropriation risk (e.g. POLCON index on executive constraints[37]); (b) financial market development (e.g. share of credit to the private sector on GDP).[38]

More specifically, it is assumed that the most relevant institutional characteristics that impact the main variables mentioned above are protection against expropriation risk (e.g. POLCON index on executive constraints) and financial market development.[39] In particular, it has been shown that protection against expropriation risk affects GDP per capita and investment positively in a cross-section of countries (Acemoglu and Johnson, 2005).

In addition, a large body of literature (e.g. review by Levine, 2005) estimate that financial sector development has a positive impact on per capita GDP, by facilitating those sectors which are typically more dependent on access to external funding. This factor may also be important for investment in the

[37] POLCON III from Henisz, W. J. (2002). "The Institutional Environment for Infrastructure Investment." Industrial and Corporate Change 11(2).

[38] Another important aspect of a country's endowment is given by the functioning of the legal system, measured for instance by an index of procedural complexity. Djankov et al. (2003) find that higher procedural formalism is a strong predictor of longer duration of dispute resolution [and] higher corruption. Formalism is defined by Djankov et al. (2003) as the extent to which regulation causes dispute resolution to deviate from the neighbor model. They refer to the neighbor model as a situation in which a controversy is resolved by a third on fairness grounds without resorting to courts. Given that regulators' decisions are normally subject to appeal to courts, the threat of litigation may represent a constraint for the regulator to provide 'good' decisions. This threat is credible only if the legal system is capable of dealing with it efficiently and justly. Unfortunately, this dimension cannot be captured in a panel setting due to data limitations.

[39] These variables differ from those used in Gual and Trillas (2006), which are not available for the whole time frame of the present study.

telecommunications industry, especially due to the large investments required.[40]

In addition to the variables described in the text, other variables that may affect telecommunications penetration are the average price of mobile services and the average price of fixed services. These are also measured in constant U.S. dollars, consistently with GDP per capita. They are calculated as service revenue divided by mobile subscribers and by total mainlines, respectively.[41]

The share of investment on GDP is obtained from annual telecommunication investment, which includes equipment as well as land, buildings and non-tangible assets both for fixed and mobile services. Other variables, such as population density and the percentage of urban population, are included in the analysis to account for different operating conditions across countries.

In the GDP per capita equation, in addition to the variables already described above, the following variables are included. Human capital is proxied by labour force and physical capital stock is from Miketa (2004), and is calculated using the perpetual inventory method in US$ at constant 2000 prices.[42] Openness is defined as the sum of exports and imports of goods and services as a share of GDP.

The variable measuring the effect of international pressure is multilateral debt service, which is defined as the sum of interest and principal due to the World Bank, regional development banks, and other multilateral agencies, as a percentage of public and publicly guaranteed debt service.

B Results from a Logit Model for Equation 3

Equation 3 was estimated using a logit model in order to check the results in the main text. The results presented below confirm the significance of the privatization dummy, as in Table 7 from the text. However, the results are from a random effects model, as the model did not converge when fixed effects were included.

[40] For developing countries, other factors may be important, such as loans from international institutions and foreign direct investment.

[41] The average price of fixed services is calculated so as to include also revenue from public payphones. Total fixed revenues are then divided by the number of mainlines, which includes not only fixed subscribers but also public payphones. Given that the average price of any type of fixed services may be a factor explaining the substitution effect between fixed and mobile services, it seems appropriate to take also public phones into account, as these are often important means of communication in low and middle-income countries. Moreover, it could be argued that prices should be expressed in relative terms, compared with the general level of prices in a given country. However, already provides an indication of the cross-country differences which are also likely to be reflected in consumers' purchasing power. Therefore, in line with Röller and Waverman (2001) and Waverman et al. (2005), and are included in the penetration equation.

[42] Miketa, A., 2004: Technical description on the growth study datasets. Environmentally Compatible Energy Strategies Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, October 2004. http://www.iiasa.ac.at/ECS/data_am/index.html

Dependent variable: Separate regulator (Yes/No) 1990 – 2004

Ln GDP per capita	0.333
	[0.665]
Majority privat.	3.960
	[1.045]***
Liberalization	0.9619
	[1.011]
Ln Multilateral lending	-1.331
	[0.728]
Ln Credit/GDP (t – 1)	-0.025
	[0.016]
Constant	-3.750
	[5.106]
Fixed Effects	No
Time Dummies	Yes
Wald chi	135.47
Countries	29
Observations	390

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.

Standard errors in brackets.

Table 9: Equation 3: Logit Model