The Impact of Telecoms on Economic Growth in Developing Countries

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Summary

There is a long tradition of economic research on the impact of infrastructure investments and social overhead capital on economic growth. Studies have successfully measured the *growth dividend* of investment in telecommunications infrastructure in developed economies.[2] But few have assessed the impact of telecommunications rollout in developing countries. Given the importance of telecommunications to participation in the modern world economy, we seek to fill the void in existing research.

Investment in telecoms generates a growth dividend because the spread of telecommunications reduces costs of interaction, expands market boundaries, and enormously expands information flows. Modern revolutions in management such as 'just-in-time' production rely completely on efficient ubiquitous communications networks. These networks are recent developments. The work by Roeller and Waverman (2001) suggests that in the OECD, the spread of modern fixed-line telecoms networks alone was responsible for one third of output growth between 1970 and 1990.

Developing countries, however, experience a *low telecoms trap* – the lack of networks and access in many villages increases costs, and reduces opportunities because information is difficult to gather. In turn, the resulting low incomes restrict the ability to pay for infrastructure rollout.

In the OECD economies, modern fixed-line networks took a long time to develop. Access to homes and firms requires physical lines to be built – a slow and expensive process. France, which had 8 fixed line telephones per 100 population (the 'penetration rate') in 1970, doubled this by 1976, and reached 30 main lines per 100 population in 1980. Mobile phones are lower cost and far quicker to rollout than fixed lines. In 1995, Morocco had 4 fixed lines per 100 inhabitants after many years of slow investment, and zero mobile phones per 100 inhabitants. In 2003, only eight years later, the mobile phone penetration rate in Morocco was 24, while fixed line penetration had stagnated at its 1995 level.

We find that mobile phones in less developed economies are playing the same crucial role that fixed telephony played in the richer economies in the 1970s and 1980s. Mobile phones substitute for fixed lines in poor countries, but

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[2] These studies include Hardy (1980), Norton (1992), and Roeller and Waverman (2001). Full bibliographical details are given in footnotes 8, 9 and 3 respectively.

complement fixed lines in rich countries, implying that they have a stronger growth impact in poor countries. Many countries with under-developed fixed-line networks have achieved rapid mobile telephony growth with much less investment than fixed-line networks would have needed.

We subjected the impact of telecoms rollout on economic growth in poorer nations to a thorough empirical scrutiny. We employed two different approaches– the Annual Production Function (APF) approach following the work of Roeller and Waverman (2001) and the Endogenous Technical Change (ETC) approach similar to the work of Robert Barro (1991). The latter provided us with the most robust and sensible estimates of the impact of mobile telephony on economic growth. We used data on 92 countries, high income and low income, from 1980 to 2003, and tested whether the introduction and rollout of mobile phone networks added to growth.

We find that mobile telephony has a positive and significant impact on economic growth, *and this impact may be twice as large in developing countries compared to developed countries*. This result concurs with intuition. Developed economies by and large had fully articulated fixed-line networks in 1996. Even so, the addition of mobile networks had significant value-added in the developed world: the value-added of mobility and the inclusion of disenfranchised consumers through pay-as-you-go plans unavailable for fixed lines. In developing countries, we find that the growth dividend is far larger because here mobile phones provide, by and large, the main communications networks; hence they supplant the information-gathering role of fixed-line systems.

The growth dividend of increasing mobile phone penetration in developing countries is therefore substantial. All else equal, the Philippines (a penetration rate of 27 percent in 2003) might enjoy annual average per capita income growth of as much as 1 percent higher than Indonesia (a penetration rate of 8.7 percent in 2003) owing *solely* to the greater diffusion of mobile telephones, were this gap in mobile penetration to be sustained for some time.

A developing country that had an average of 10 more mobile phones per 100 population between 1996 and 2003 would have enjoyed per capita GDP growth that was 0.59 percent higher than an otherwise identical country.

For high-income countries, mobile telephones also provide a significant growth dividend during the same time period. Sweden, for example, had an average mobile penetration rate of 64 per 100 inhabitants during the 1996 to 2003 period, the highest penetration of mobiles observed. In that same period, Canada had a 26 per 100 average mobile penetration rate. All else equal, we estimate that Canada would have enjoyed an average GDP per capita growth rate nearly 1 percent higher than it actually was, had the mobile penetration rate in Canada been more-than-doubled.

Our research also provides new estimates of demand elasticities in developing countries – we find both the own–price and income elasticities of mobile phone demand to be significantly above 1. That is, demand increases much more than in proportion to either increases in income or reductions in price. We also find that mobile phones are substitutes for fixed-line phones.

Introduction

Economists have long examined the importance of social overhead capital (SOC) to economic growth. SOC is generally considered as expenditures on education, health services, and public infrastructure: roads, ports, and the like. Telecommunication infrastructure, whether publicly or privately funded, is a crucial element of SOC. We in the west tend to forget what everyday life would be like, absent modern telecommunications systems. These networks enable the ubiquitous, speedy spread of information. Alan Greenspan, the Chairman of the US Federal Reserve Board, coined the term "New Economy" to represent how the spread of modern information and communications technology has enabled high growth with low inflation. This "New Economy" is the direct result of the networked computer – the ability of higher bandwidth communications systems to allow computer-to-computer communications.[3] The "New Economy" enables greater competition and new means of organising production.

In earlier periods, telecommunications networks helped generate economic growth by enabling firms and individuals to decrease transaction costs, and firms to widen their markets; Roeller and Waverman (2001)[4] estimated the impact on GDP of investment in telecoms infrastructure in the OECD between 1970 and 1990. They showed it significantly enhanced economy-wide output, allowing for the fact that the demand for telecoms is itself positively related to GDP. One must remember that in 1970 telecoms penetration was quite low in a number of OECD countries. While the US and Canada had near-universal service in 1970, in the same year France, Portugal and Italy for example, had only 8, 6, and 12 phones per 100 inhabitants respectively. It is then not surprising that the spread of modern telecommunications infrastructure between 1970 and 1990 generated economic growth over and above the investment in the telecoms networks itself.

Roeller and Waverman also demonstrated that the scale of impact of the increased penetration of telecoms networks on growth depended on the initial level of

[3] The "Networked Computer" is the focus of a major research programme at London Business School funded by the Leverhulme Trust.
[4] Roeller, Lars-Hendrik and Waverman, Leonard. "Telecommunications Infrastructure and Economic Development: A Simultaneous Approach." *American Economic Review*, 2001, *91*(4), pp.909-23.

penetration, with the biggest impact occurring near universal service – a phone in every household and firm. The standard government policy of universal service was, then, not only a question of equity, but was also implicit recognition of the growth-enhancing properties of telephony expansion.

In 1995, just under half of the membership of the International Telecommunications Union (ITU), an international organisation comprising 214 countries, had telecoms penetration rates below 8, the level attained by France in 1970. Much of the world still lacked a major component – the telephone – of a modern, efficient economic system in 1995.

In the 1970 to 1990 period analysed by Roeller and Waverman mobile phones were not important: telecoms networks were fixed-line systems. Today, when we consider telephone networks, the importance of mobiles stands out, especially when we examine the 102 members of the ITU that had low phone penetration in 1995.

Table 1 lists these countries (*i.e.,* with less than 8 phones per 100 population in 1995, when virtually all phones were fixed lines) and the penetration rate in 2003 for both fixed lines and mobiles. The average fixed-line penetration rate of these 102 countries in 1995 was 2.5 phones per 100 population, and this level was achieved after decades of investment. With the subsequent rapid growth of mobile phones in many, but not all, of these countries, the average penetration rate of mobile phones alone rose to 8 per cent in 2003. In 22 of the 102 countries, mobile penetration reached double digits in 2003. And in 7 countries, over one-quarter of the population had mobile phones in 2003 - Albania, Bosnia, Botswana, the Dominican Republic, Paraguay, the Philippines and Thailand.

The story is clear. In developing countries, modern telecoms systems are largely mobile systems and not fixed lines. The reason is the lower cost and faster rollout of mobile systems as compared to fixed lines. It has been estimated that a mobile network costs 50 percent less per connection than fixed lines and can be rolled out appreciably faster. The cost advantages of mobile phones as a development tool consist not only of the lower costs per subscriber but also the smaller scale economies and greater modularity of mobile systems. Morocco is a good example of the spread and impact of cell phones. In 1995, the Moroccan telecoms penetration rate was 4 fixed lines per 100 people and zero mobile phones per 100 people. Only eight years later, mobile penetration alone in Morocco was 24 per 100 people, while fixed-line penetration stayed essentially the same.

Table 1: The Emergence of Mobile Telephony in 102 Low and Middle-Income Nations

Country	Main lines per 100 population in 1995	Main lines per 100 population in 2003	Mobile Subscribers per 100 population in 1995	Mobile Subscribers per 100 population in 2003
Afghanistan	0	0	0	1
Albania	1	8	0	36
Algeria	4	7	0	5
Angola	0	1	0	..
Bangladesh	0	1	0	1
Benin	1	1	0	3
Bhutan	1	3	0	1
Bolivia	3	7	0	15
Bosnia and Herzegovina	6	24	0	27
Botswana	4	7	0	30
Burkina Faso	0	1	0	2
Burundi	0	0	0	1
Cambodia	0	0	0	4
Cameroon	0	..	0	7
Cape Verde	6	16	0	12
Central African Rep.	0	..	0	1
Chad	0	..	0	1
China	3	21	0	21
Comoros	1	2	0	0
Congo	1	0	0	9
Congo (Democratic Republic of the)	0	..	0	2
Cote d'Ivoire	1	1	0	8
Cuba	3	..	0	..
Dem. People's Rep. of Korea	2	4	0	..
Djibouti	1	2	0	3
Dominican Rep.	7	12	1	27
Ecuador	6	12	0	19
Egypt	5	13	0	8
El Salvador	5	12	0	18
Equatorial Guinea	1	2	0	8
Eritrea	0	1	0	0
Ethiopia	0	1	0	0
Gabon	3	3	0	22
Gambia	2	..	0	..
Ghana	0	1	0	4
Guatemala	3	..	0	..
Guinea	0	0	0	1
Guinea-Bissau	1	1	0	0
Guyana	5	..	0	..
Haiti	1	2	0	4
Honduras	3	..	0	..
India	1	5	0	2
Indonesia	2	4	0	9
Iraq	3	..	0	..
Jordan	7	11	0	24
Kenya	1	1	0	5
Kiribati	3	..	0	1

Country	Main lines per 100 population in 1995	Main lines per 100 population in 2003	Mobile Subscribers per 100 population in 1995	Mobile Subscribers per 100 population in 2003
Kyrgyzstan	8	..	0	..
Lao P.D.R.	0	1	0	2
Lesotho	1	..	0	..
Liberia	0	..	0	..
Libya	6	14	0	2
Madagascar	0	0	0	2
Malawi	0	1	0	1
Maldives	6	..	0	..
Mali	0	..	0	2
Marshall Islands	7	8	1	1
Mauritania	0	1	0	13
Mayotte	4	..	0	22
Micronesia (Fed. States of)	7	10	0	5
Mongolia	4	6	0	13
Morocco	4	4	0	24
Mozambique	0	..	0	2
Myanmar	0	1	0	0
Namibia	5	7	0	12
Nepal	0	2	0	0
Nicaragua	2	4	0	9
Niger	0	..	0	0
Nigeria	0	1	0	3
Oman	8	..	0	..
Pakistan	2	3	0	2
Palestine	3	9	1	13
Papua New Guinea	1	..	0	..
Paraguay	3	5	0	30
Peru	5	7	0	11
Philippines	2	4	1	27
Rwanda	0	..	0	2
Samoa	5	7	0	6
Sao Tome and Principe	2	5	0	3
Senegal	1	2	0	6
Sierra Leone	0	..	0	..
Solomon Islands	2	1	0	0
Somalia	0	..	0	..
Sri Lanka	1	5	0	7
Sudan	0	3	0	2
Swaziland	2	4	0	8
Syria	7	..	0	..
Tajikistan	4	4	0	1
Tanzania	0	0	0	3
Thailand	6	10	2	39
Togo	1	1	0	4
Tonga	7	..	0	..
Tunisia	6	12	0	19
Turkmenistan	7	..	0	..
Tuvalu	5	..	0	0
Uganda	0	0	0	3
Uzbekistan	7	7	0	1

Country	Main lines per 100 population in 1995	Main lines per 100 population in 2003	Mobile Subscribers per 100 population in 1995	Mobile Subscribers per 100 population in 2003
Vanuatu	3	3	0	4
Viet Nam	1	5	0	3
Yemen	1	..	0	3
Zambia	1	1	0	2
Zimbabwe	1	3	0	3

Average Fixed Penetration in 1995: 2
Average Fixed Penetration in 2003: 5

Average Mobile Penetration in 1995: 0
Average Mobile Penetration in 2003: 8

The Importance of Conveying Information

Consider what communicating in France must have been like 35 years ago, in 1970, with only 8 phones per 100 people. The description of Geertz (1978) as applying to developing countries, "information is poor, scarce, maldistributed, inefficiently communicated and intensely valued"[5], must have applied equally to France. Residents of remote villages with no phone connections would have enormous difficulty in discovering prices of commodities. Farmers would not have access to alternative sources of fertilisers or access to alternative buyers of their products. As recent studies on the use of mobile phones in South Africa show, the substitute for telecommunicated information would have been physical transport.[6] Instead of a quick phone call, never mind Internet usage, determining selling or buying prices would require costly, time-consuming physical contacts and transport. Thus without telecommunications, the costs of information retrieval and of transacting in general would be high. Besides greater transaction costs, the range of supply would be much smaller, or for transactions across large distances, risks would be higher as prices and conditions of sale would not be known exactly. Modern telecom networks, then, are crucial forms of Social Overhead Capital. But how important are they?

There are two basic ways in which economists determine the extent of the economic growth impact of some factor such as increased education or telecoms infrastructure investment – aggregate production function (APF) estimation and the endogenous technical change (ETC) approach.

In the first approach – the APF – the level of economy-wide Gross Domestic Product (GDP) each year is assumed to be determined by that year's aggregate capital, aggregate labour, and other specific factors such as education or the spread of telecommunications. The growth dividend of telecoms would be measured by its annual contribution to GDP growth. The second approach – the ETC – relates the average rate of growth of GDP over a substantial period (we use the 24-year period 1980 to 2003) to the initial level of GDP, average investment as a share of GDP during that period, the initial stock of labour represented in terms of its educational

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[5] Geertz, Clifford. "The Bazaar Economy: Information and Search in Peasant Marketing." *American Economic Review*, 1978, *68*(2), pp.28-32.

attainment[7], and the initial or average telephone penetration rate. The contribution of telecoms to growth is here measured by its boost to the long-term growth rate. The ETC approach is *not* an average over time of the APF approach, as the two models rest on different theoretical underpinnings.

Empirically, the two methods differ as well: the production function approach uses annual data, so errors or missing observations cause significant difficulties. The endogenous technical change approach uses period averages and initial period values instead, and it is thus less prone to data errors. Given the paucity of reliable data in developing countries, the ETC approach should prove more robust and tractable.

Because demand for telecoms services rises with wealth, it is crucial in the APF approach to disentangle two effects – the impact of increased telecoms rollout on economic growth and the impact of rising GDP itself on the demand for telecoms. This is called the two-way causality issue, or 'endogeneity', as the demand for telecoms is itself dependent on the level of GDP. Hence estimating an APF alone would lead to biased and likely exaggerated measures of the growth dividend of telecoms.

This endogeneity problem is handled in Roeller-Waverman by developing a four-equation model: the first equation is the output equation or economy-wide production function; the second equation determines the demand for telecoms; a third equation determines the investment in telecoms infrastructure and a final equation relates investment to increased rollout. In this model, the explicit causality from GDP to demand is recognised in equation two, allowing any estimated effect of telecoms on growth (equation one) to be net of the demand-inducing effects of rising GDP.

The two-way causality problem cannot be dealt with explicitly in the endogenous growth model approach but is unlikely to be a central issue. One cannot, for example, add a demand equation defined as the average demand over the

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6 See (for example) World Resources Institute. *Digital Dividends Case Study: Vodacom Community Phone Shops in South Africa*, www.digitaldividend.org

7 In this, we follow the endogenous growth literature, which postulates increasing returns to human capital.

period. Instead one has to use data analysis, instrumental variables and statistical tests to determine whether there is any reverse causality present.[8]

Existing literature

The notion that telecoms infrastructure is an important part of SOC is not new. Various researchers beginning with Hardy[9] in 1980, Norton[10] in 1992 and others[11] have all found that there is an "externality" component in enhanced fixed telecoms penetration – that is, GDP is higher, and growth faster in countries with more advanced telecoms networks. Of course, as noted, one has to worry about reverse causality in richer countries; there, as income rises, demand for luxuries such as a universal telephone service rises as well. Although these studies do not adjust for reverse causality, several facts bear out the existence of the telecoms externality. First, Hardy examined both radio and telephone rollouts, since if the telephone simply provides information, radio broadcasts might be good alternatives. Hardy found no significant impact of radio rollout on economic growth, in contrast to telephones. Secondly, telephones (unlike radios, for example) have strong network effects – the value of a telephone to an individual increases with the number of other telephone subscribers.

Hence, as networks grow, their social value rises. This suggests that the social return – the value to society of an additional person connected or of an additional dollar invested in the network – exceeds the private return to the network provider, if that provider cannot price so as to extract these externality values. The Roeller-Waverman paper shows strong network effects. In the OECD in from 1970 to 1990, incremental increases in penetration rates below universal service levels generated only small growth dividends. Only at near universal service (30 mainline phones per 100 inhabitants which is near 70 or so mainline phones per 100 households) were there strong growth externalities from telephone rollout.

[8] The data requirements of the full 4 equation APF model are much larger than for the one equation endogenous growth model.

[9] Hardy, Andrew. "The Role of the Telephone in Economic Development." *Telecommunications Policy*, 1980, *4*(4), pp. 278-86.

[10] Norton, Seth W. "Transaction Costs, Telecommunications, and the Microeconomics of Macroeconomic Growth." *Economic Development and Cultural Change*, 1992, *41*(1), pp. 175-96.

[11] Among these others are Leff, Nathaniel H. "Externalities, Information Costs, and Social Benefit-Cost Analysis for Economic Development: An Example from Telecommunications." *Economic Development and Cultural Change*, 1984, *32*(2), pp. 255-76. And Greenstein, Shane and Spiller, Pablo T. "Estimating the Welfare Effects of Digital Infrastructure." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 5770, 1996.

Several more recent papers extend this analysis to mobile phones – among these are Torero, Choudhary and Bedi[12] (2002) and Sridhar and Sridhar[13] (2004). Several points need to be made on this research.

First, for economies without many fixed lines, or where mobiles supplement low fixed-line rollout, there should be no inherent difference in the growth dividend of a phone, whether it is mobile or fixed. In developing countries, an additional phone, whether fixed or mobile, increases the small network size and adds to the economy's growth potential. Secondly, where mobile phones complement fixed lines (in advanced economies), their externality effects will probably be different from those found for fixed lines. As individual lifestyles change and as firms utilise mobiles in productivity-enhancing ways, we should see new economic growth from mobile networks as well. For penetration rates of fixed lines are not 100 percent in developed economies. For example, in the USA in 1995, the penetration rate was 60 phones per 100 people. Mobile phones move the developed economies closer to universal service because pre-pay contracts allow exact monitoring of use, something very difficult to manage with fixed-line phones, making them accessible to other groups of users.

Some of the recent empirical studies specifically examine the impact of mobile phone expansion on growth in developing countries, using the Roeller-Waverman (RW) framework. Three caveats must be mentioned here. First, in many of these countries, growth has been low due to a host of issues – poor governance, lack of capital, low skill levels, and the like. It is difficult to show that mobile telephony increases growth rates where growth is low. Secondly, advances in telecoms penetration rates in developing countries are recent, so there is little real trend as yet. Finally, since mobiles are so new, there has been extremely rapid growth in mobile penetration starting from zero. Thus, if one tries to explain economic growth by changes in capital, labour, education and mobile phones, one could find either that *all* economic growth is due to the explosive growth in mobile phones, or conversely that mobile phones *decrease* growth since their use increases so quickly with little underlying economic growth occurring. Good econometrics requires careful consideration of underlying facts.

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[12] Torero, Maximo; Chowdhury, Shyamal and Bedi, Arjun S. "Telecommunications Infrastructure and Economic Growth: A Cross-Country Analysis." Mimeo, 2002.

[13] Sridhar, Kala S. and Sridhar, Varadharajan. "Telecommunications Infrastructure and Economic Growth: Evidence from Developing Countries, National Institute of Public Finance and Policy (New Delhi, India) Working Paper No. 14, 2004

Sridhar and Sridhar (2004) apply the RW Framework to data for 28 developing countries over the twelve-year period 1990 to 2001. The average compounded annual growth rate (CAGR) of GDP per capita in this period was *minus* 2.03 per cent, while the CAGR of mainlines was 6.60 and of mobile phones 78.0 percent. In their regression, they find that mobile phones explain all growth – a 1 percent increase in mobile phones penetration increases growth by 6.75 percent. Below, we provide our own analyses of the RW aggregate production function approach. We do find more plausible although still exceedingly high impacts of mobile phones on growth. But the result is not robust to alternative specifications or to changes in countries included in the sample, and we do not rely on these estimates to draw any conclusions. We provide the APF model also to show the demand equation estimates – these are also most interesting, and robust.

The Aggregate Production Function

In order to estimate the impact of mobile phones in developing countries, we gathered information from the World Bank's World Development Indicators (WDI) database for basic variables such as GDP, population, labour force, capital stock and so on for both low-income and lower-middle-income countries. The International Telecommunication Union (ITU) produces a World Telecommunications Indicators database, updated annually, and we used this for data on our major telecoms-related variables – such as revenue, investment, and subscriber numbers. We also relied on the World Bank's Governance Indicators, so that we could incorporate some measures of institutional quality, which most certainly has an impact on growth. We included 38 developing countries for which full data are available for the period we used is 1996 to 2003.[14]

The framework employed was a three-equation modification of the Roeller-Waverman approach. **Appendix A** provides further details. We summarise briefly the model that we used:

[14] Since the production function approach is so data-intensive, the sample used in this regression consisted of 38 countries and 260 observations. Even from this sample, 95 observations were eliminated in the course of the regression analysis due to missing data. Of these 38 countries, 19 are low income countries (Bangladesh, Benin, Burkina-Faso, Central African Republic, Cote d'Ivoire, Gambia, India, Indonesia, Kenya, Lesotho, Madagascar, Mali, Mozambique, Myanmar, Nepal, Pakistan, Senegal, Tanzania and Vietnam) and 19 are lower middle income countries (Armenia, Bolivia, Brazil, China, Colombia, Egypt, Fiji, Iran, Jordan, Morocco, Namibia, Peru, Philippines, South Africa, Sri Lanka, Swaziland, Thailand, Tunisia, and Turkey).

1. The **Output** equation models the level of output (GDP) as a function of the total physical capital stock net of telecoms capital, the total labour force, a variable that captures the extent of the "rule of law", and the mobile telecoms penetration rate. To account for the fact that output generally increases over time, we included a time trend term. We also included indicator variables capturing the level of external indebtedness of the country (there were three levels – High, Medium and Low). Roeller and Waverman used a dummy variable for each country (a so-called "fixed effects" or "Least Square Dummy Variables" approach). This approach controls for unobservable or otherwise unmodelled characteristics that are peculiar to each country; our approach here is similar in spirit, since it captures the impact of particular characteristics (such as the indebtedness level) on output.[15]

2. The **Demand** equation models the level of mobile telecoms penetration as a function of income (the level of GDP per capita), mobile price (revenue per mobile subscriber), and the fixed-line price (which is revenue per fixed line subscriber). The demand equation also allows for a time trend, since demand for a new product such as mobiles could also feature a strong trend.

3. The **Investment** equation simplifies the Roeller-Waverman "supply" and "investment" equations. It assumes that the growth rate of mobile penetration depends on the price of telecoms (the relationship should be positive since higher prices should invite additional supply), the geographic area (the relationship should be negative), and a time trend term.

We estimated the system of equations described above using the Generalised Method of Moments (GMM) method.[16] This approach uses all the exogenous variables in the system of equations (*i.e.,* those that we can reasonably assume are not determined by the other variables in the system, such as the amount of labour and the amount of total capital) as "instruments" for the endogenous variables (output, the level of mobile and fixed penetration, and the mobile and fixed prices). [17]

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[15] Because we had very few observations for some of the countries in the sample, a model with full fixed effects collapsed.

[16] GMM estimation offers some advantages in terms of efficient estimation and ability to correct for serial correlation over other methods available for estimating a model comprised of a system of equations.

[17] Instrumenting the endogenous variables essentially involves isolating that component of the given endogenous variable that is explained by the exogenous variables in the system (the "instruments"), and then using this component as a regressor.

The results for the output and demand equations from running this GMM regression are summarised in **Tables 2** and **4** respectively (see **Appendix A** for the full set of results):

Table 2: Output Equation (Dependent variable is log of output)

Variable	Coefficient	T-Statistic
Capital	0.776	13.79
Labour	0.204	3.91
Mobile Penetration[18]	0.075	3.60

The coefficients obtained above are encouraging at first glance. The coefficients on capital and labour sum to close to 1, which is roughly consistent with the standard hypothesis of constant returns –to scale for the economy as a whole. The coefficient of the log of mobile penetration (which is a transformed version of the original variable) is 0.075. However, the interpretation of this is not straightforward: the impact of penetration on output depends on the level of penetration.

Table 3 shows the average levels of mobile penetration and GDP in those countries that the ITU classifies as "Low Income" and "Lower-Middle-Income" for 1996 and 2002 respectively.[19] For the average country, with a mobile penetration of 7.84 phones per 100 population in 2002, the coefficient of 0.075 on the transformed mobile penetration variable implies that a doubling of mobile penetration would lead to a 10 percent rise in output, *holding all else constant*.

Table 3: Mobile Penetration and GDP for "average" developing country, 1996-2002.

Year	Mobile Penetration	GDP
1996	0.22	$41 billion
2002	7.84	$47 billion

[18] Following Roeller-Waverman, we used a transformed and "unbounded" version of the penetration variable, namely (PEN/0.35-PEN) in the regression analysis. We do so to increase the range of the observed penetration rates.
[19] It should be noted that this is a larger set of countries than we were able to include in our actual regression analysis.

Considering that the average CAGR of GDP in these nations has been roughly 2 percent, this seems to high an estimate of the impact of mobile penetration. A growth rate of GDP of 2 percent over 8 years for the average country would imply total (compounded) growth of 19 percent. Meanwhile, the average CAGR of mobiles has been 64 percent in these same countries: mobile penetration more than doubles every two years in the average country. Given the estimated impact of mobile penetration presented in Table 2, if a developing country were enjoying "typical" growth rates of GDP and mobile telephones, then increased mobile penetration explains *all* the growth over the sample period.

The problem here is the one of weak output growth in many of the countries, but robust growth in mobile phone penetration. The model does not adequately control for the other factors affecting growth in the economy.[20] We attempted to extend the sample – both by adding more countries and increasing the time period back to 1980,[21] and also to modify the specification somewhat, but the results did not prove robust to either changes in the sample or changes in the model specification.

On the other hand, the demand equation from the aggregate production function model always performed well. **Table 4** shows the results of the GMM estimation for the demand equation:

Table 4: Demand equation (dependent variable is mobile penetration)

Variable	Coefficient	T-Statistic
Mobile Price	-1.50	-6.06
Fixed-line price	0.31	2.79
GDP per Capita	1.95	23.30

Table 4 shows that mobile demand falls when the price of mobiles increases, but increases when the price of fixed lines increases, suggesting that there is substitution between fixed line telephony and mobiles. Mobiles demand is also strong positively correlated with increases in income. The equation is in double-log form so

[20] Appendix A shows the sign on the time-trend term is negative and statistically significant, implying that there is large-scale technological regression: unlikely and troublesome. This also suggests that the mobile penetration rate variable is explaining too much growth.

[21] Since there were no mobiles in 1980, we ran a model for the effects of total telecoms penetration with the demand equation adjusted so that both fixed lines and mobile demand are estimated when mobile penetration is non-zero.

the coefficients can be interpreted as elasticities of demand, at the average penetration rate.

The own-price-elasticity of mobile phones is minus 1.5, which implies that demand is elastic: a 10 percent price increase would reduce demand by roughly 11.6 percent for a country in which mobile penetration is about 8 percent, the average level of mobile penetration for the developing countries.[22] The cross-price elasticity between mobile and fixed lines is positive, indicating that in these countries, mobiles and fixed telephones are substitutes: an increase in the price of fixed-line phones by 10 percent increases the demand for mobiles by 2.4 percent, assuming mobile penetration at the "average" level of 8 percent. Moreover, mobiles are 'luxuries' (in the technical sense) as the income elasticity is significantly above one – for the "average" developing country with 8 percent mobile penetration, a 1 percent increase in per capita GDP is associated with a 1.5 percent increase in the level of mobile penetration. The structure of the demand equation is much simpler than that of the output equation and since the equation deals with demand for one particular characteristic – mobile penetration – it is relatively easier to capture the factors that affect this demand than it is to capture all the factors that serve to increase or reduce output over time.

Ultimately, though, in light of the problems with the APF approach, especially the significant difficulties of obtaining adequate data across a large group of developing countries, we turn to the endogenous growth model.

The Endogenous Growth Model

We follow the work of Barro,[23] who ran growth regressions for a cross-section of countries for the time period 1960 to 1985. The basic questions Barro was addressing were two-fold: was there 'convergence' between rates of growth between poorer and richer countries as economic theory predicts; and how did differences in skill levels affect growth rates? Barro took average growth rates of per capita GDP for a cross-section of 98 countries and regressed these growth rates against regressors which included initial levels of GDP per capita and human capital stock,[24]

[22] Since we use a transformed version of mobile penetration, the impact of an increase in GDP per capita or increase in the price level varies according to the level of mobile penetration.
[23] Barro, Robert J. "Economic Growth in a Cross Section of Countries." *The Quarterly Journal of Economics*, 1991, *106*(2), pp. 407-43.
[24] Measured by school enrolment rates in 1960.

the average government consumption to GDP ratio for the period 1970-1985, and measures of stability.[25]

Barro found that, conditional on the initial human capital stock, average GDP per capita growth was negatively correlated with initial GDP per capita.[26] Thus, all else equal, poorer countries should close the income gap with richer countries, albeit only over long periods of time. The initial level of human capital stock was positively correlated with GDP per capita growth, so countries that were initially rich might actually grow faster than poorer countries if there were sizeable differences in their initial endowments of human capital. Only by controlling for these differences could he verify that there is indeed economic convergence between richer and poorer nations.

Our approach is similar. We took the average growth rate of per capita GDP from 1980 to 2003 as our dependent variable, and regressed this average growth rate on variables which included the initial level of GDP, the average ratio of investment to GDP, the stock of telecoms in 1980 (measured by the level of fixed-line penetration in 1980), the proportion of the 15-and-above population that had completed *at least* primary schooling in 1980, and the *average level* of mobile penetration for the period 1996 to 2003 (the period in which mobile penetration increased rapidly). Our sample consisted of 92 countries – developing and developed alike. The data came from the same sources – the World Development Indicators and the ITU – that we used for the APF estimation.

We are not primarily examining the issue of 'convergence' in income levels but instead in whether the increase in mobile penetration increases growth rates, and whether it does so equally in rich and poor countries. As mobile growth starts in essentially the same recent period for all countries, rich and poor alike, this is an interesting and important question. Our hypothesis is that increased mobile rollout should have a *greater* effect in developing countries than in rich countries. The reason is simple: while in developing countries the benefits of mobile are two-fold –

[25] The average numbers of revolutions per year and assassinations per million population during the sample period.

[26] Standard neoclassical growth theory predicts long-run convergence of income levels between countries as richer, more capital-intensive countries run into the problem that the returns to capital diminish beyond a certain level of capital intensity. In the later growth literature, initiated by Romer (1986), there are increasing returns to particular factors- such as human capital- that also play a significant role in determining the speed of convergence. See Romer, Paul M. "Increasing Returns and Long-Run Growth." *Journal of Political Economy*, 1986, *94*(5), pp.1002-37.

the increase in the network effect of telecoms *plus* the advantage of mobility — in developed economies the first effect is much more muted.

In this model, there are no mobile phones in 1980, as there is for other stock variables (*e.g.,* we have proxied the stock of human capital in 1980, and have included the stock of telecom capital in 1980). We can assume that the 1980 levels of human and telecom capital are exogenous – that is, they ought not to be the result of income growth between 1980 and 2003.[27] We cannot, however, assume that there is no reverse causality between income growth in the 1980 to 2003 period and average mobile penetration over a portion of the same period with quite the same safety. Thus, mobile penetration is potentially endogenous, and we must examine whether or not this is so.

We started with an initial specification that did not attempt to capture differential effects of telecoms between developing and developed countries. **Table 5** (also reported in fuller form in **Appendix B**) reports the results of a simple Ordinary Least Squares (OLS) regression:[28]

Table 5: Baseline results from the ETC model (dependent variable is average per capita GDP growth)

Variable	Coefficient	T-Statistic
GDP80	-0.0026	-4.00
K8003	0.0017	4.73
TPEN80	0.0418	1.63
MPEN9603	0.0003	2.76
APC1580	0.0002	2.43
Constant	-0.0289	-3.93

Table 5 shows that the average GDP growth rate between 1980 and 2003 was positively correlated with the average share of investment in GDP (taken over the entire period), with the 1980 level of primary school completion, and with the average level of mobile penetration between 1996 and 2003. It was negatively correlated with the level of initial GDP per capita (GDP80). The results confirm Barro's convergence hypothesis: conditional on other factors such as human capital and physical capital endowments (captured by school completion rates and telecom penetration), poorer countries grow faster than richer ones. Every additional $1,000

[27] However, it is possible that these variables proxy for subsequent flows of income into human and telecom capital, a subtlety that Barro (1991) explored for human capital, and rejected.
[28] All results are corrected for heteroscedasticity.

of initial per capita GDP reduces average growth by roughly 0.026 percent. Considering that average growth is typically in the 1 to 2 percent range, a $10,000 difference in initial per capita GDP would imply growth that would be 0.26 percent lower, which is a substantial difference in the light of typical rates of growth.

The initial level of telecoms (*i.e.,* fixed line) penetration was not significant in this model (TPEN80). However, the average level of mobiles penetration (MPEN9603) was significant – a unit increase in mobile penetration increased growth by 0.039 percent, all else being equal. In line with Barro, the coefficient on primary school completion (APC1580) was positive and significant.

As mentioned above, we were concerned about a potential problem of endogeneity of the mobile penetration rate (as a regressor). We performed a Hausman test,[29] which showed that endogeneity was not likely to be an issue.[30] (See Appendix B for fuller details of the IV estimates and the Hausman test).

Having tested for endogeneity, we then divided the sample into four income quartiles according to their level of GDP per capita in 1980. We classified countries as "low income" (or potentially fast-growth) if they were in quartiles 1, 2 or 3, while quartile 4 countries were classified as "high income." Our "low income" sample included a mix of some countries that had (and still have) much catching-up relative to the highest-income nation, and some countries (like Hong Kong) that were on the verge of becoming advanced economies in 1980. We created dummy variables for high and low income countries and then split the effects of penetration by generating new variables that were the product of these dummy variables and initial telecoms penetration, and the dummy variables and average mobile penetration from 1996 onwards. **Table 6** (reported also in Appendix B) illustrates the results:

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[29] Loosely speaking, the Hausman test computes the "distance" between an estimator that is potentially inconsistent under the alternative hypothesis of endogeneity bias and one that is always consistent. See Hausman, Jerry. "Specification Tests in Econometrics." *Econometrica*, 1978, *46*(2), pp. 1251-71.

[30] In this context, the Hausman test compares the OLS estimates with estimates from an instrumental variables regression (IV). We used average fixed line penetration between 1960 and 1979 as an instrument for average mobiles penetration between 1996 and 2003: the correlation coefficient between the two variables is 0.81.

Table 6: Table 5 regression separating out effect of telecoms variables

Variable	Coefficient	T-Statistic
GDP80	-0.0025	-3.68
K8003	0.0018	4.67
TPENH80	0.0005	1.92
TPENL80	-0.0002	-0.32
MPENL	0.0006	2.46
MPENH	0.0003	1.99
APC1580	0.0002	2.22
Constant	-0.0284	-3.83

Here, we found that the effect of initial telecoms stock in 1980 was not significant for the low-income countries (TPENL80) but was almost significant (at the 5 percent level) for high-income countries.[31] This is to be expected in view of the fact that fixed penetration was extremely low for low-income countries in 1980 (an average of 3.3 main telephone lines per 100 inhabitants).

The coefficient on the average mobile penetration from 1996 to 2003 (MPENL for low-income countries and MPENH for high-income countries) was positive and significant for both cases, but the impact was twice as large for the low-income countries. The results suggest a noticeable growth dividend from the spread of mobile phones in low-income and middle-income countries.

All else equal, in the "low income" sample[32], a country with an average of 10 more mobile phones for every 100 people would have enjoyed a per capita GDP growth higher by 0.59 percent. Indeed, the results suggest that long-run growth in the Philippines could be as much as 1 percent higher than in Indonesia, were the gap in mobile penetration evident in 2003 to be maintained. The Philippines had 27 mobile phones per 100 inhabitants in 2003, compared to 9 per 100 in Indonesia. Another estimate of the importance of mobiles to growth can be seen by comparing Morocco to the "average" developing country. In 2003, Morocco had 24 mobile phones per 100 inhabitants, compared to 8 in the typical developing country. Were this gap in

[31] This is also consistent with Roeller and Waverman (2001) who report an inability to derive consistent results for low-income countries.

[32] Because data for more advanced countries is more widely available, and because we only treated the very advanced nations (top quartile) of 1980 as "high income", our "low income" sample probably underweights the most underperforming developing countries and overweights middle-income countries. Clearly, better data availability – particularly of historical data – would enable us to expand our sample and thereby gauge how robust our results really are.

mobile penetration maintained, then Morocco's long-run per capita growth rate would be 0.95 percent higher than the developing country average.[33] Thus, current differences in mobile penetration between developing countries might generate significant long-run growth benefits for the mobile leaders. Finally, while Argentina and South Africa both had disappointing economic performance over the 1980 to 2003 period, both registering negative average growth in per capita incomes, the analysis suggests that South Africa's higher level of mobile telecoms penetration over the period (17 for South Africa versus 11.4 for Argentina) prevented this difference from being even larger – South Africa's negative average per capita growth of 0.5 percent compares with Argentina's negative average per capita growth of 0.3 percent, but this difference would have been 0.3 percent wider had it not been for the greater spread of mobiles in South Africa.

For the high-income countries, mobile telephones still provide a significant growth dividend. Sweden, for example, had an average mobile penetration rate of 64 per 100 inhabitants during the 1996 to 2003 period, whilst Canada had a mere 26 per 100 average penetration rate. All else equal, Canada would have enjoyed an average GDP per capita growth rate 1 percent higher than it actually registered, had it been able to achieve Swedish levels of mobile penetration over the 1996 to 2003 period.

Conclusions

In summary, telecommunications is an important prerequisite for participation in the modern economic universe. There is a long-standing literature attempting to gauge the economic impact of telecommunications, with the findings of Roeller and Waverman (2001) suggesting a substantial growth dividend in OECD nations.

We have modelled the impact of mobile telecommunications in poorer countries, since in these countries mobile phones are fulfilling the same role as fixed lines did previously in the OECD nations. Initially we attempted to use the Roeller-Waverman framework, but data problems and econometric problems made it difficult to get truly sensible estimates of the growth impact of mobile telecommunications

[33] It should be noted that Morocco is not part of the sample from which our results were actually derived.

that were also robust to changes in the sample and small changes in the specification of the model.

We turned to a purely cross-sectional model that looked at long-term averages of growth, and our results were more robust and sensible than under the previous framework.[34] They suggest the following:

- Differences in the penetration and diffusion of mobile telephony certainly appear to explain some of the differences in growth rates between developing countries. If gaps in mobile telecoms penetration between countries persist, then our results suggest that this gap will feed into a significant difference in their growth rates in future.
- As Romer (1986) and Barro (1991) hypothesised for human capital stocks, there are also increasing returns to the endowment of telecoms capital (as measured by the telecoms penetration rate).
- Given the speed with which mobile telecoms have spread in developing nations, it is unlikely that large gaps in penetration will persist forever. However, differences in the speed of adoption will affect the speed with which poor countries converge to rich countries' level. Relative poverty still poses serious political problems, such as instability and increased demand for emigration. Our analysis suggests the need for regulatory policies that favour competition and encourage the speediest possible rollout of mobile telephony.

[34] However, we need to examine whether our sample can be expanded, and while we have tested for the endogeneity of the mobile phones penetration variable, we still need to examine some more subtle issues such as the potential endogeneity of some of the other regressors. We also need to test for the possibility that some third factor (such as institutional quality) that we have not captured influences both growth and the level of mobile penetration, thereby generating a spurious relationship between the two.