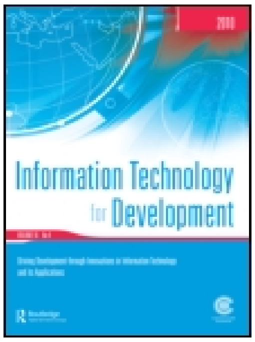

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On the endogeneity of telecommunications and economic growth: Evidence from Asia

John Levendis[a]* and Sang H. Lee[b]

[a]*Department of Economics, Loyola University New Orleans, New Orleans, LA 70118, USA;* [b]*Department of Management and Business Administration, Southeastern Louisiana University, Hammond, LA 70402, USA*

The impact of mobile and fixed telephones on economic growth has been the subject of increasing scrutiny in the literature on economic development. It is even of interest to theoretical macroeconomists, as it provides a useful test of the positive network externalities that should be present if endogenous growth theory is correct. We study the relationship between teledensity and growth in Asia, as the countries there have experienced wildly different levels of telephone penetration *per capita*, and of rates of growth of GDP *per capita*. We estimate several econometric models, one which explicitly treats telecom as strictly exogenous, and others which treat it as endogenous. Our conclusions are robust to the econometric specification. We find that the impact of teledensity on growth is positive, and increases with the level of telephone penetration. This provides support for endogenous growth theory.

Keywords: telecommunications; development; economic growth
Jel Codes; O1; O3; O4; E1; E2

1. Introduction

Infrastructure in general, and telecommunications infrastructure in particular, effectively extends the frontiers of local markets into the global marketplace, increases the number of buyers and sellers, and increases the amount of information with which they can make economic decisions.

This efficiency enhancing aspect of the first telecom revolution – the one involving landlines – were first felt where they were developed: in the developed world of the USA, Europe, and parts of Asia. The more recent telecom revolution – the current one involving mobile telephony and its near simultaneous integration with the Internet – has recently been associated with growth in the developing world.

There are several reasons why it is important to determine the relationship between the number of telephone lines and national income. First, it has been suggested as a developmental springboard for less-developed countries (LDCs). If causation runs from telephones to GDP, then policies which remove barriers to telecom investment may be viable development strategies. On the other hand, if economic growth facilitates the investment in telecommunications, then subsidies could be less efficient and even costly. Second, the answer to the question provides key insights into the nature of economic growth itself, and to the resolution of a long-standing debate about the nature of macroeconomic growth.

Asia is a useful case study because there is a wide disparity in the number of telephone lines per person across Asia. Seven countries have reached perfect saturation, with over one phone line per person. In Hong Kong, there were almost two lines per person by 2006. At the other extreme, nine countries had not achieved one line for every 10 people; Myanmar, Papua New

*Corresponding author. Email: jlevendi@loyno.edu
Mina Baliamoune-Lutz is the accepting Associate Editor for this article.

Guinea, and the Solomon Islands had fewer than three lines per 100 people. At the same time, Asia has experienced some of the most rapid growth in recent memory, with China and India leading the way with sustained double-digit growth rates of *per capita* GDP. Thus, Asia is fertile ground for empirical research into the nature of economic growth.

The paper is structured as follows. First, we explain how the question of causality between teledensity and growth relates to the broader macroeconomic discussions on the nature of growth. Then, we turn to a more focused review of how the telecom/growth literature has evolved. After this we describe our data and present our econometric approach. We conclude with a discussion of our findings and directions for future research.

2. Why the question matters (the larger debate)

Why are some countries still under-developed? The neoclassical growth model (Solow, 1956), with diminishing marginal product of capital as its centerpiece, implies that there should be convergence in income levels and growth rates across countries, irrespective of a country's initial amount of capital.

It seemed, however, that dissimilar countries were not converging. The conditional convergence literature emphasizes that countries are different because exogenous factors decrease the marginal productivity of capital. Cases of lingering underdevelopment were then blamed on exogenous factors such as education,[1] political stability and the rule of law,[2] or on property rights.[3]

Endogenous growth theory was advanced as a viable alternative to neoclassical growth. Endogenous growth theory (Romer, 1986, 1990) focused on increasing marginal productivity, specifically in knowledge and technology. The crucial feature of Romer's theory is that positive externalities create increasing social returns, which in turn lead to sustained positive growth rates.

The debate over the direction of causation between telecom and growth is really a debate over neoclassical *vs*. endogenous growth theory.[4] It has become popular in the development literature to look upon mobile telephony as the savior of the LDCs. Mobile phones decrease information costs and increase efficiency. But unlike other forms of investment which have diminishing marginal products, telephones are subject to positive network externalities so that they exhibit increasing marginal products in the aggregate. Thus, diminishing marginal productivity might be present at the micro level, while positive externalities may induce increasing returns at the aggregate level. If there is reciprocal causality between telephones and incomes, then there is a multiplier effect at work which greatly increases the social impact of telephones over its direct private impact to the subscriber.

The theory of endogenous growth draws on the distinction between micro and macro, between private and social returns. At the individual level, giving the same person additional phones results in diminishing marginal productivity. That is, if the number of phones an individual has doubles, his productivity does not double. This is because phones are useful when other people also have phones. There are positive externalities to teledensity, the so-called network externalities, so that doubling the number of phones in a village more than doubles the number of connections each villager may make. The result is increasing the marginal social product. Telephones are currently the best candidates for identifying increasing marginal products, and thus, for distinguishing between neoclassical and endogenous growth.

3. How the more narrow debate has progressed

As we shall explain in increasing detail, research on the relationship between telecom and growth has been extended primarily along three margins. The first margin is driven by the availability of data, the second by econometric theory, and the third by professional specialization.

Along the first margin, earlier research was focused on the developing world (usually countries in the Organization for Economic Co-operation and Development) as this was where the phones were located and where the best data were available (Aschauer, 1989). Most of the recent research, however, has centered on Africa, leaving South America and Asia relatively neglected.

Progress along the second margin centers around the use of increasingly sophisticated econometric models. Cross-sectional regressions represent the earliest phase of the telecom/growth debate. Seminal studies include those by Barro (1991), and Levine and Renelt (1992). A finding common to both studies was that there is a robust and positive relationship between investment and national income.

More recent research has focused on the issue of temporal ordering. Granger-causal models were used to estimate (usually no more than) two equations separately, where each equation contains lags of itself and the other potentially endogenous variable. These studies originally relied on data from one country and then from a panel of countries. More recent econometric modeling has emphasized that, in situations of true endogeneity, the two equations should be estimated simultaneously, or, at least using methods that mimic simultaneous estimation. Along this dimension, econometricians such as Arellano, Bond, and Bover developed dynamic panel data models that treat variables as endogenous, partially endogenous, and exogenous. Considering that the crux of the current research question is the potential endogeneity of telecom investment and GDP, this is a welcome addition to the econometric arsenal.

The third and final margin has been a sharpening of focus. The earliest research focused on infrastructure investment in general. This was later narrowed toward telecommunications infrastructure. Currently, there has been much research isolating the unique impact of mobile telephony.

In general, there were several competing hypotheses that were considered: (a) telecom encourages growth in income, (b) growth in income allows for investment in telecom, or (c) there is reciprocal causation between telecom and income growth. The tools of cross-sectional analysis, unfortunately, were not well suited for such issues as temporal ordering and causality.

The various mechanisms whereby telecom increases incomes were laid out neatly by Leff (1984). Each of the mechanisms has the common feature that costs (inefficiencies) are decreased, either through better information about relative prices, knowledge of profit opportunities, better monitoring of resources, knowledge of impending market changes, etc. Taking his cue from Leff's theoretical paper, Norton's (1992) paper was an empirical investigation into the existence and magnitude of the impact of telecom on GDP. The study was international, but cross-sectional, and thus was poorly suited for truly differentiating between the three types of causality. Norton did, however, find a significant and positive correlation between the average number of phones per person and growth in GDP.

Raising the methodological ante, Madden and Savage (1998) estimated a Granger-causal model using data from Central and Eastern European countries. They found strong evidence that telecom causes growth, and only weak evidence of causation in the other direction.

Datta and Agarwal (2004) estimated the impact of telecom on a panel of 22 OECD countries using an early type of dynamic panel estimator (which did not correct for dynamic panel bias). They estimated a single equation model where GDP was regressed on lagged values of GDP and on present and lagged values of telecom. However, unlike the traditional Granger-causality approach, they did not estimate a second model which would have allowed for effects in the "other direction." That is, they assumed telecom was strictly exogenous in their regression. They did, however, include a squared telecom variable on the right-hand side which was found to be negative and significant, indicating diminishing marginal returns to telecom, and supporting the neoclassical convergence hypothesis.

In their theoretical piece explaining lingering under-development, Azariadis and Drazen (1990) drew a distinction, similar to Romer's, between private and public rates of return. Their innovation was a model where, at low levels of investment, these positive externalities do not accumulate enough to overcome diminishing marginal productivity. Their result: poor countries tend to stay poor.

Roller and Waverman's (2001) influential study examined data from 21 OECD countries over a time period of 20 years. They provided evidence that was contrary to the neoclassical convergence hypothesis and seemed to confirm Azariadis and Drazen (1990) and by extension, Romer's endogenous growth theory. They found that the largest impact of telecom on growth is not enjoyed by the LDCs, but by already developed countries. Their paper was not strictly Granger-causal. Rather, they estimated a simultaneous system of four equations using a non-linear generalized method of moments (GMM) estimator. Their research was, therefore, situated in the third and most recent econometric stage of the telecom/growth debate. A follow-up piece by Waverman, Meschi, and Fuss (2005), however, drew the contrary conclusion. They differentiated between the initial levels of development of 92 countries and concluded that mobile telephones have a larger impact on developing countries than on developed ones. This is consistent with the neoclassical convergence hypothesis.

Dutta (2001) used yearly data on the level of GDP and teledensity for 30 countries for 24 years. Of the 30 countries, 15 were developing countries (three of which were from Asia), and 15 were industrialized (four of which were from Asia). Dutta then computed 30 pairs of Granger-causality tests, and reported the number of instances where causality was found in each direction. Dutta concluded that (1) the causal link was stronger from telecom levels to income levels, and weaker, though still detectable in the other direction, and (2) this result was independent of the level of development of the countries studied. Dutta's study was not without weaknesses, however. First, his Granger-causal model did not account for other intervening variables; it was, in effect, a model with two variables. Second, by conducting separate regressions rather than nesting them within one dynamic panel model, Dutta limits the degrees of freedom in each regression, possibly making the effect of each variable less detectable. Failure to find evidence is not the same, however, as evidence of failure.

Beil, Ford, and Jackson (2005) (BFJ) disagree with Dutta (2001), as well as Waverman's two studies, and try to show that an increase in economic activity leads to an increase in telecommunications investment, at least in the USA. They find no Granger-causality in the other direction. They derisively describe the reverse causal hypothesis in terms of a Field of Dreams wish that "if you (the telecom companies) build it (make telecom investments), they (the customers, as measured by their purchasing power) will come" (p. 8). They argue that this does not work. Rather, at least in the USA, businessmen perceive the demand and build telecom to accommodate that demand. One weakness of the BFJ study, however, is that it did not make use of a panel of countries, but instead used time-series data from only one country, the USA.

More recently, Wolde-Rufael (2007) published an article that is directly critical of BFJ'. Using the same USA data as BFJ (but in the logarithmic form) and a version of the Granger test proposed by Toda and Yamamoto (1995), Wolde-Rufael concluded that causality in the USA was bi-directional.

Rouvinen (2006) found that greater competition results in speedier diffusion of mobile phones. Moreover, the hard work of diffusion is incurred at the entrance phase, so that late entrants can expand more easily. The implication is that there is potential for cross-country convergence along the standard neoclassical lines: investment leads to greater growth rates and, hence, convergence. Lee and Levendis (2006) added that a competitive political environment increases the likelihood that a country employs an independent telecommunications regulator – the hope being that more efficient regulation increases the diffusion of cellular technology.

Subsequent work by Lee, Levendis, and Gutierrez (2012) focused on the role of cell phones in the development of Sub-Saharan Africa. Modeling cell phones and land-lines as imperfect substitutes, they found that the marginal impact of cell phones has been increasing with the level of cell phone penetration.

In a micro-level study, Samuel, Shah, and Hadingham (2005) used surveys from South African, Tanzanian, and Egyptian cell phone users, collected in 2004. They documented a decrease in travel time. The conclusion, left unsaid, is that mobile telephony leads to more efficiency and thus, potentially, to growth in the overall economy.

We now turn to reviewing the few studies that have focused more specifically on Asia.

Yoo (2001) studied South Korean data from 1965 to 1998, and detected bi-directional causality between telecommunications investment and economic growth. Their data were restricted to national data for South Korea, and thus were not a panel; the study was also Granger-causal, placing it in the second econometric phase of the telecom/growth debate.

Chakraborty and Nandi (2003) examined 12 Asian countries from 1975 to 2000. They distinguished between privately and governmentally run telecom industries. They found that where the industry is private, there is a dual causality between incomes and telecommunications. However, in countries where the telecommunications industry is governmentally run, there is only causality from telecom to incomes. The implication seems to be that the lack of privatization prevents a virtuous cycle from making the growth self-sustaining and truly endogenous.

Shinjo and Zhang (2004) apply the same dynamic panel estimators which we use in our study. They examine sector-specific telecom investment and productivity growth (measured two different ways) in USA and Japanese sectors for 1987–2001. The results were largely ambiguous, possibly due to the fact that much of the data were missing, so that Shinjo and Zhang had to resort to estimating on interpolated data.

Finally, Jensen (2007) examined the impact of telecommunications from a microeconomic perspective, examining fish prices in the Indian state of Kerala. Mobile phones saved time, eliminated waste and facilitated sales at the most efficient prices. The study concludes that cell phones lead to economic growth. As Jensen put it, "Information makes markets work" (p. 919). The microeconomic nature of the study, however, does not allow exploration of causation in the other direction, nor does it help clarify the greater debate on the nature of growth.

4. The model

We estimate a growth model similar to that of Barro (1991), Levine and Renelt (1992), and Datta and Agarwal (2004):

$$\mathrm{GDPPCGR}_{it} = \alpha \mathrm{GDPPC}_{it-1} + \mathbf{X}'_{it}\boldsymbol{\beta} + \mu_i + v_{it},$$

where

$$\mathbf{X}'_{it} = \left[\frac{\mathrm{TRADE}_{it}}{\mathrm{GDP}_{it}}, \frac{\mathrm{GDFI}_{it}}{\mathrm{GDP}_{it}}, \frac{\mathrm{G}_{it}}{\mathrm{GDP}_{it}}, \mathrm{POPGR}_{it}, \mathrm{TELEDENSITY}_{it}, \mathrm{TELEDENSITY}^2_{it}, \mathrm{FINANCIALCRISIS}_{it}\right],$$

and

$$E[\mu_i] = E[v_{it}] = E[\mu_i v_{it}] = E[v_{it} v_{it-k}] = 0 \quad \forall k > 0.$$

In the above equation, $GDPPCGR_{it}$ denotes the growth rate of real *per capita* GDP of country i in period t. $GDPPC_{it-1} = GDP_{it-1}/POP_{it-1}$ denotes the level of real *per capita* GDP. $TRADE_{it}/GDP_{it}$ denotes the sum of exports and imports of a country as a percent of its GDP. Thus, it is a measure of a country's openness to international trade. $GDFI_{it}/GDP_{it}$ is the size of a country's gross domestic fixed investment as a percent of its GDP. The share of a country's GDP that is due to government expenditures is denoted G_{it}/GDP_{it}. The growth rate of the population in country i, period t, is $POPGR_{it}$. $TELEDENSITY_{it}$ indicates the degree of saturation of telephony within a country; this is measured as the number of telephone lines per 100 people. It is possible for a country to have more telephones than it does people. Asia experienced a significant financial crisis, with 1997–1998 as the most severe years. Therefore, we remove the impact of this event through a dummy variable that takes on the value of 1 for these crisis years, and zero otherwise. Finally, μ_i denotes unobserved country-specific shocks which are unobserved and time-invariant. In each period, each country is subject to its own idiosyncratic shocks, denoted by ν_{it}. The two types of shocks are assumed to have zero means, and are not serially correlated, nor are they correlated with each other.

The square of teledensity is included to allow for the marginal impact of telephone lines to depend upon the level of telephone lines. That is, since

$$\text{Growth in } \textit{per capita} \text{ GDP} = \alpha + \cdots + \beta_5 \text{TELEDENSITY} + \beta_6 \text{TELEDENSITY}^2 + \cdots$$

then the marginal impact of telephones on growth

$$\frac{\partial(\text{Growth in } \textit{per capita} \text{ GDP})}{\partial \text{TELEDENSITY}} = \beta_5 + 2\beta_6 \text{TELEDENSITY}.$$

If $\beta_6 > 0$, then the more phones a country has, the more impact additional phones will have. This is the hallmark of the network externalities of Romer's endogenous growth theory. If $\beta_6 = 0$, then telephones have a constant marginal impact upon *per capita* growth. A value of $\beta_6 \leq 0$ would provide evidence against endogenous growth. Notice that the test of endogenous growth theory depends upon the nonlinear impact of telephones on growth (via $TELEDENSITY^2$ and β_6), and not on β_5, the coefficient on TELEDENSITY.

5. The data

All data are from the World Bank's *World Development Indicators, 2008*. The sample includes 29 countries or semi-autonomous regions, as listed in Table 1. The sample years are the 26 years from 1981 to 2006 (Table 2 and Figures 1 and 2).

Table 1. Sample countries.

Australia	Japan	Pakistan
Bangladesh	Kiribati	Papua New Guinea
Bhutan	Korea, Rep.	Philippines
Brunei Darussalam	Lao PDR	Singapore
Cambodia	Macao, China	Sri Lanka
China	Malaysia	Thailand
Fiji	Maldives	Tonga
Hong Kong, China	Mongolia	Vanuatu
India	Nepal	Vietnam
Indonesia	New Zealand	

Table 2. Summary statistics.

Variable	Mean	Standard deviation	Minimum	Maximum
Growth rate of GDP *per capita*	2.72	4.70	−22.27	32.11
Real GDP *per capita*	8679.44	11,889.71	328.48	62,017.95
Trade/GDP	86.23	64.94	1.53	473.51
GFDI/GDP	25.86	9.97	6.18	92.44
G/GDP	15.03	8.90	3.47	58.31
Population growth rate	1.79	1.07	−3.29	7.19
Teledensity	20.39	32.67	0.03	192.59
Financial crisis	0.08	0.27	0.00	1.00

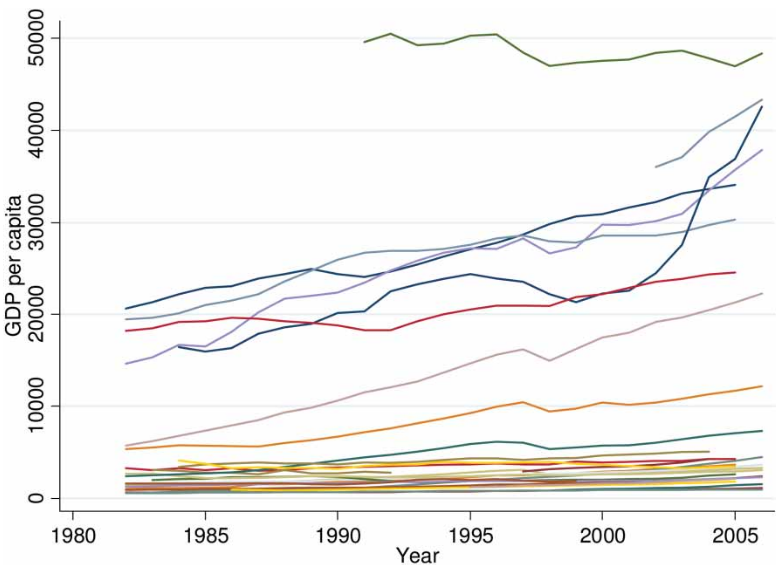

Figure 1. Real GDP *per capita* in Asia.

The telecommunications variable that we focus upon is teledensity, or the number of telephones per 100 people. We acknowledge that telecommunications infrastructure has many different aspects; looking at the number of telephone lines alone will miss quite a few dimensions of this. However, the telephone is the most basic visible technology that captures any potential increasing returns to scale from network externalities: with people being able to communicate with increasing numbers of people.

An ideal course of action would be to use an aggregate variable for telecommunications – one that combines various different telecommunications indicators such as mobile phones and internet. This solution, however, presents its own problems, as there is no such widely agreed upon proxy variable.

> Several research organizations have attempted to quantify the extent of investment in IT at the national level, by deriving generalized indexes of IT or "e-readiness". It is important to note that such indexes are not precise measures of this construct, since there are limited data on this phenomenon and some rather heroic assumptions (e.g., perfect competition in input or output markets) must be invoked to derive them. (Indjikian & Sigel, 2005, p. 683)

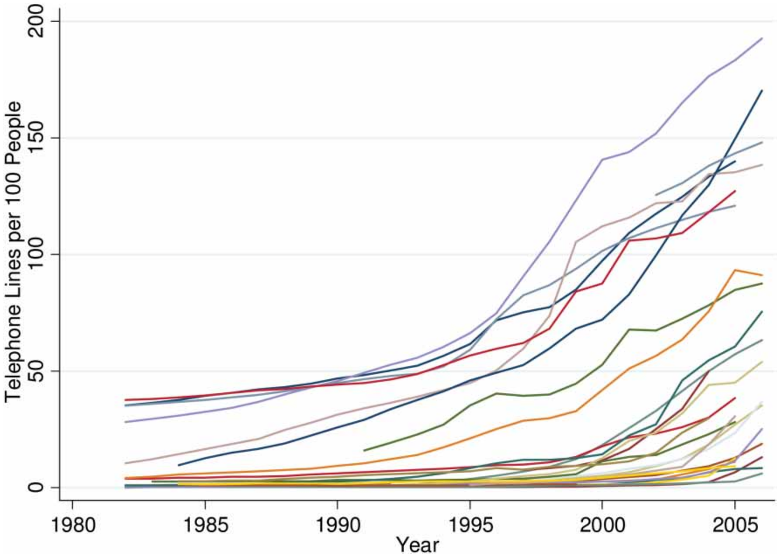

Figure 2. Telephone lines per 100 people in Asia.

Although there has been a significant increase in the access to mobile phone services in the region, such development has been made over a relatively short period and observations are rather sparse to estimate its impact on economic growth. Thus, using a controversial IT aggregate would put us on shakier ground. We opt for the concreteness of teledensity – of telephones per 100 people.

Moreover, we choose to use only one measure – teledensity – to capture the telecommunications construct for the sake of econometric simplicity. We estimate several econometric specifications, using a wide variety of estimators. Repeating these estimations for each alternative telecom variable would exponentially increase the size of the paper.

We control for many of the usual macroeconomic variables found in growth studies. First, we control for the initial level of real GDP *per capita*, in order to test the convergence hypothesis found in neoclassical growth models. We also control for a country's openness to trade (trade as a percentage of GDP), for government spending as a percentage of GDP, and for any impact from the Asian financial crisis by including a dummy variable which is equal to the one during 1997–1998, and zero otherwise.

A common empirical specification in the economic growth literature controls for the levels of capital and labor as determinants of either the level of real GDP or the level of labor productivity. In the context of telecommunications, for example, Roller and Waverman (2001) jointly estimated a simultaneous equations model. In their macro production function, they controlled for real capital stock, total labor force, and teledensity. On the other hand, our study uses the growth rate of real GDP *per capita* as the dependent variable and, accordingly, we control for changes in gross fixed domestic investment as a percentage of GDP and population growth. Controlling for the population growth rate has been common in the literature on the correlation between economic growth and investment in telecommunications. For example, Datta and Agarwal (2004) and Lee et al. (2012) used similar specifications in their studies on telecommunications and economic growth. In summary, it is important to control for rates of change in capital and population – not their levels – when analyzing rates of change in real GDP *per capita*. A summary table of the data is provided below.

6. The estimation method

Telecommunications services are crucial for almost all modern economic activities; on the other hand, investment in telecommunications depends upon a country's level of economic development. Hence, it is conceivable that all telecommunications variables are endogenous, meaning that higher economic growth can be the result of higher telecommunications investments and vice versa. If this is the case, then special econometric adjustments need to be made to the standard models to accommodate the endogeneity. We use the difference GMM estimator of Arellano and Bond (1991). The Arellano–Bond difference GMM estimator allows independent variables to be specified in different ways according to their types – strictly exogenous, not strictly exogenous, and endogenous – so that a likely dynamic panel bias caused by (potentially) endogenous independent variables is corrected.[5] Estimation can be done by a one-step or by a two-step (or optimal) difference GMM. The two-step difference GMM estimation is more efficient than the one-step difference GMM.[6]

First, as is common for panel data models, fixed effects are removed by taking first-differences. That is, the previous cross-country growth model is differenced to yield:

$$\mathrm{GDPPCGR}_{it} - \mathrm{GDPPCGR}_{it-1} = \alpha(\mathrm{GDPPC}_{it-1} - \mathrm{GDPPC}_{it-2}) + (\mathbf{X}'_{it} - \mathbf{X}'_{it-1})\boldsymbol{\beta} + (\upsilon_{it} - \upsilon_{it-1})$$

or

$$\Delta\mathrm{GDPPCGR}_{it} = \alpha\Delta\mathrm{GDPPCGR}_{it-1} + \Delta\mathbf{X}'_{it}\boldsymbol{\beta} + \Delta\upsilon_{it}.$$

Suppose that x_{it} is an *endogenous* regressor in $\mathbf{X}$. Although first-differencing eliminates any fixed effects (μ_i), it is still the case that the x_{it} in $\Delta x_{it} = x_{it} - x_{it-1}$ is correlated with the υ_{it} in $\Delta\upsilon_{it} = \upsilon_{it} - \upsilon_{it-1}$. The Arellano–Bond estimator corrects for the bias caused by this remaining endogeneity by exploiting the following moments $E(x_{it-s}\,\Delta\upsilon_{it}) = 0$ for $s \geq 2$; $t = 3, \ldots T$. In other words, the Arellano–Bond estimator instruments the first differences with lags of the levels of the endogenous variable. However, the validity of using lagged levels as an instrument for the endogenous variable in the first differences depends heavily on the assumption that υ_{it} is *not* serially correlated. For that reason, the Arellano–Bond estimator examines the autocorrelation structure of the residuals in first differences to ensure the consistency of the estimator. Suppose that, for instance, υ_{it} is *not* serially correlated of order 1. Then, x_{it-2} becomes a valid instrument as it is not mathematically correlated to $\Delta\upsilon_{it} = \upsilon_{it} - \upsilon_{it-1}$.[7] However, if υ_{it} is serially correlated of order 1, x_{it-2} becomes an invalid instrument, because x_{it-2} is endogenous to υ_{it-1} in $\Delta\upsilon_{it} = \upsilon_{it} - \upsilon_{it-1}$ through the autocorrelation between υ_{it-1} and υ_{it-2}. Thus, if we have to reject the null hypothesis of the Arellano–Bond test for AR(2) which detects autocorrelation in levels, we need to instrument an endogenous variable in the first differences, Δx_{it}, with even deeper lags of difference.[8] Since we will assume that all telecommunications-related variables are potentially endogenous, valid instruments will be determined according to the Arellano and Bond (1991) test for autocorrelation.

In addition, this study departs from previous studies by imposing a less restrictive assumption of exogeneity on the other independent variables. The previous literature in telecommunications economics has treated telecommunications and economic growth as, at least potentially, endogenous variables, while also assuming that all other non-telecom variables are strictly exogenous. We instead assume that these independent variables are correlated with past realizations of the idiosyncratic error term. Suppose now that x_{it} is *not strictly exogenous*. Then $E[x_{it}\ v_{it-s}] \neq 0$ for $s>0$ as x_{it} is possibly correlated with the idiosyncratic error term from previous periods. However, it is assumed that $E[x_{it}\ v_{it+s}] = 0$ for $s \geq 0$ because the error term v_{it-1} might have some impact on the subsequent realization of x_{it}, but v_{it} would not influence past realizations of the variable, for example, x_{it-1}. That is, causation cannot go backward in time. With this in mind, the Arellano–Bond difference GMM estimation instruments a not-strictly exogenous variable x_{it} with lags one and longer of the independent variable since, for example, $E[x_{it-s}\ v_{it}] = 0$ for $s > 0$.

7. Results

Estimation results are summarized in Tables 3–6. *P*-values for the fixed-effects and Arellano–Bond one-step difference GMM estimators were calculated using robust standard errors; those for the Arellano–Bond two-step (optimal) difference GMM estimators used the Windmeijer (2005) finite-sample corrected standard errors since the non-transformed standard errors have been shown to have a downward bias (Arellano & Bond, 1991; Blundell & Bond, 1998).

Three sets of results are presented in Tables 3–6. In each table, the first two columns, columns (1) and (1′), show standard fixed-effects regressions. Fixed-effects regressions do not take into account any possible endogeneity – an assumption that runs contrary to the purpose of the paper. That is, we cannot *presume* that growth in *per capita* GDP does not have a reciprocal impact on the number of telephones, since exploring this possibility is the purpose of the paper. These columns are included for the sake of comparison and completeness.

The second set, columns (2) and (2′), shows the results from the Arellano–Bond one-step difference GMM estimation. This one-step estimation delivers consistent and robust variances so that the reported standard errors are robust to panel-specific heteroskedasticity.[9] Columns (1) through (2′) were included as checks of robustness.

The third set of results is shown in columns (3), (3′), (4), and (4′). These are the results of the Arellano–Bond two-step difference GMM estimation whose two-step covariance matrix is robust to both panel-specific heteroskedasticity and autocorrelation. The reported two-step standard errors are the Windmeijer (2005) finite-sample corrected standard errors. The results in (3) and (3′) are conducted under the assumption that the telecommunications variables are strictly endogenous while the remaining variables are strictly exogenous. Results in (4) and (4′) are conducted under the less restrictive assumption that the remaining variables are not strictly exogenous.

The results show a remarkable consistency across different regression techniques, instrumental variables, and endogeneity assumptions.

Across all the two-step difference GMM estimates, we detect the presence of AR(1) residuals in the estimated equation (recall, it is estimated in first-differences). The Arellano–Bond test for AR(1) in first differences is usually rejected, because $\Delta v_{it} = v_{it} - v_{it-1}$ and $\Delta v_{it-1} = v_{it-1} - v_{it-2}$ both have v_{it-1}. However, in all two-step difference GMM regressions, the null of no-AR(2) is not rejected. As explained in the previous section, it is second-order correlation in differences that detects first-order serial correlation in levels. Because the null of no-AR(2) in first differences is not rejected, we restrict the instrument sets to lags 3 and deeper and thus have some confidence that our model provides consistent estimates. The presence of second-order autocorrelation would have indicated inconsistency.

We employ the Hansen *J*-test for over-identification. Under the null hypothesis, the model is correctly specified and consists of valid identification restrictions. Thus, large *p*-values call for not rejecting the null, and therefore concluding that there is not enough evidence to doubt the

Table 3. Estimation results: linear specification.

Dependant variable: growth rate of real GDP *per capita*								
	Coefficients and (*P*-values)							
	Fixed effects reg.		Arellano–Bond one-step difference GMM		Arellano–Bond two-step difference GMM			
Variables	(1)	(1′)	(2)	(2′)	(3)	(3′)	(4)	(4′)
rGDPPC growth rate ($t-1$)			0.053	0.042				
			(0.477)	(0.571)				
GDP *per capita* ($t-1$)	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.009)***	(0.012)**
Trade/GDP	−0.002	−0.001	0.006	0.007	−0.006	0.000	−0.036	−0.294
	(0.867)	(0.965)	(0.760)	(0.696)	(0.666)	(0.993)	(0.247)	(0.349)
GFDI/GDP	0.151	0.144	0.187	0.181	0.168	0.187	0.187	0.182
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.002)***	(0.001)***
Government expenditure/GDP	−0.367	−0.366	−0.602	−0.609	−0.401	−0.431	−0.786	−0.507
	(0.000)***	(0.000)***	(0.001)***	(0.001)***	(0.001)***	(0.006)***	(0.017)**	(0.066)*
Population growth rate	−0.403	−0.483	−0.115	−0.169	−0.357	−0.683*	−0.361	−0.237
	(0.280)	(0.235)	(0.696)	(0.622)	(0.138)	(0.059)	(0.509)	(0.617)
Teledensity	0.029		0.016		0.023		0.047	
	(0.150)		(0.489)		(0.184)		(0.282)	
Teledensity^2	0.000	0.000	0.001	0.001	0.000	0.000	(0.001)	0.001
	(0.057)*	(0.009)***	(0.013)**	(0.003)***	(0.033)**	(0.004)***	(0.001)*	(0.004)***
Financial crisis	−2.554	−2.604	−2.447	−2.539	−2.692	−2.989	−2.743	−2.697
	(0.002)***	(0.001)***	(0.000)***	(0.000)***	(0.000)***	(0.001)***	(0.001)***	(0.010)***
Constant	10.056	10.034	15.334	15.793				
	(0.000)***	(0.000)***	(0.000)***	(0.000)***				
Observations	602	602	561	561	567	567	567	567
Groups	29	29	29	29	29	29	29	29

Prob. Wald > χ^2	0.000	0.000	0.000	0.000
Arellano–Bond test for AR(1)				
Prob. > z	0.002	0.002	0.002	0.002
Arellano–Bond test for AR(2)				
Prob. > z	0.098	0.087	0.071	0.095
Hansen *J*-test of Over-identification				
Prob. > χ^2	1.000	1.000	1.000	1.000

Notes: Regression assumptions are as follows: (1) and (1′) standard fixed effects panel regression; (2) and (2′) Arellano–Bond dynamic panel one-step difference GMM estimation; (3) and (3′) Arellano–Bond dynamic panel two-step difference GMM estimation with telecommunications variables as endogenous, and all others strictly exogenous. *P*-values (shown in brackets) were computed based on robust standard-errors (standard fixed effects model), standard errors consistent with panel-specific autocorrelation and heteroskedasticity (Arellano–Bond one-step difference GMM), or the Windmeijer finite-sample corrected standard errors (Arellano–Bond two-step difference GMM).

Table 4. Estimation robustness: linear-log specification.

Dependant variable: growth rate of real GDP *per capita*								
	Coefficients and (*P*-values)							
	Fixed effects reg.		Arellano–Bond one-step difference GMM		Arellano–Bond two-step difference GMM			
Variables	(1)	(1′)	(2)	(2′)	(3)	(3′)	(4)	(4′)
rGDP *per capita* growth rate ($t-1$)			−0.043	−0.052				
			(0.537)	(0.492)				
log(rGDPPC) ($t-1$)	−4.391	−3.064	−10.43	−7.676	−8.575	−8.842	−1.908	−1.602
	(0.002)***	(0.002)***	(0.001)***	(0.001)***	(0.000)***	(0.000)***	(0.686)	(0.520)
Trade/GDP	0.010	0.009	0.002	0.003	0.012	0.012	−0.019	0.000
	(0.381)	(0.461)	(0.900)	(0.875)	(0.277)	(0.330)	(0.444)	(0.984)
GFDI/GDP	0.17	0.149	0.179	0.133	0.198	0.177	0.210	0.156
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.0105)**	(0.036)**
G/GDP	−0.384	−0.377	−0.677	−0.667	−0.418	−0.450	−0.554	−0.314
	(0.000)***	(0.0001)***	(0.0010)***	(0.001)***	(0.000)***	(0.004)***	(0.135)	(0.221)
Population growth rate	−0.577	−0.628	−0.085	−0.216	−0.375	−0.990	−0.753	−0.442
	(0.178)	(0.173)	(0.829)	(0.651)	(0.287)	(0.026)**	(0.234)	(0.355)
Teledensity	0.053		0.102		0.0926		0.0648	
	(0.026)**		(0.003)***		(0.000)***		(0.159)	
Teledensity^2	−0.000	0.0002	0.000	0.0004	−0.0002	0.0003	0.0000	−2.924
	(0.452)	(0.099)*	(0.860)	(0.002)***	(0.066)*	(0.015)**	(0.673)	(0.000)***
Financial crisis	−2.751	−2.846	−2.623	−2.972	−2.834	−3.341	−3.018	
	(0.001)***	(0.001)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	
Constant	39.990	30.380	92.880	72.790				
	(0.000)***	(0.000)***	(0.000)***	(0.000)***				
Observations	602	602	561	561	567	567	567	567
Groups	29	29	29	29	29	29	29	29

Prob. Wald > χ^2	0.000	0.000	0.000	0.000
Arellano–Bond test for AR(1)				
Prob. > z	0.0023	0.0022	0.0013	0.002
Arellano–Bond test for AR(2)				
Prob. > z	0.086	0.081	0.081	0.104
Hansen *J*-test of Over-identification				
Prob. > χ^2	1.000	1.000	1.000	1

Notes: Regression assumptions are as follows: (1) and (1′) standard fixed effects panel regression; (2) and (2′) Arellano–Bond dynamic panel one-step difference GMM estimation; (3) and (3′) Arellano–Bond dynamic panel two-step difference GMM estimation with telecommunications variables as endogenous, and all others strictly exogenous. *P*-values (shown in brackets) were computed based on robust standard-errors (standard fixed effects model), standard errors consistent with panel-specific autocorrelation and heteroskedasticity (Arellano–Bond one-step difference GMM), or the Windmeijer finite-sample corrected standard errors (Arellano–Bond two-step difference GMM). Significance at the 0.90, 0.95, and 0.99 levels is denoted *, **, and ***, respectively.

Table 5. Estimation robustness: log-linear.

Dependant variable: log(growth rate of real GDP *per capita*)								
	Coefficients and (*P*-values)							
	Fixed effects reg.		Arellano–Bond one-step difference GMM		Arellano–Bond two-step difference GMM			
Variables	(1)	(1′)	(2)	(2′)	(3)	(3′)	(4)	(4′)
ln(rGDPPC growth rate) ($t-1$)			−0.0523	−0.0551				
			(0.585)	(0.556)				
Real GDP *per capita*	−0.0001	−0.0001	−0.0003	−0.0003	−0.0002	−0.0002	−0.0002	0.000
($t-1$)	(0.017)**	(0.015)**	(0.000)***	(0.000)***	(0.001)***	−0.014**	(0.031)**	(0.004)***
Trade/GDP	0.001	0.001	0.004	0.005	0.003	0.002	0.007	0.007
	(0.705)	(0.631)	(0.404)	(0.355)	(0.385)	(0.559)	(0.069)*	(0.097)*
GFDI/GDP	0.019	0.018	0.051	0.052	0.0238	0.008	0.034	0.036
	(0.159)	(0.162)	(0.000)***	(0.000)***	(0.267)	(0.838)	(0.216)	(0.159)
G/GDP	−0.056	−0.056	−0.104	−0.098	−0.086	−0.127	−0.029	−0.064
	(0.0126)**	(0.011)**	(0.000)***	(0.002)***	(0.002)***	(0.002)***	(0.822)	(0.597)
Population growth rate	0.003	−0.008	−0.014	−0.020	0.023	−0.057	0.014	−0.048
	(0.956)	(0.897)	(0.834)	(0.772)	(0.672)	(0.580)	(0.900)	(0.468)
Teledensity	0.004		0.002		0.010		0.016	
	(0.385)		(0.774)		(0.106)		(0.270)	
Teledensity^2	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001
	(0.0661)*	(0.0240)**	(0.0102)**	(0.00702)***	(0.163)	(0.0443)**	(0.777)	(0.0324)**
Financial crisis	−0.242	−0.251	−0.057	−0.049	−0.14	−0.164	−0.194	−0.203
	(0.159)	(0.134)	(0.692)	(0.735)	(0.337)	(0.419)	(0.182)	(0.182)
Constant	2.141	2.134	2.925	2.900				
	(0.000)***	(0.000)***	(0.000)***	(0.000)***				
Observations	509	509	370	370	424	424	424	424
Groups	29	29	28	28	29	29	29	29

Prob. Wald > χ^2	0.001	0.000	0.004	0.029
Arellano–Bond test for AR(1)				
Prob. > z	0.006	0.006	0.005	0.005
Arellano–Bond test for AR(2)				
Prob. > z	0.816	0.764	0.867	0.823
Hansen *J*-test of Over-identification				
Prob. > χ^2	1	1	1	1

Notes: Regression assumptions are as follows: (1) and (1′) standard fixed effects panel regression; (2) and (2′) Arellano–Bond dynamic panel one-step difference GMM estimation; (3) and (3′) Arellano–Bond dynamic panel two-step difference GMM estimation with telecommunications variables as endogenous, and all others strictly exogenous. *P*-values (shown in brackets) were computed based on robust standard-errors (standard fixed effects model), standard errors consistent with panel-specific autocorrelation and heteroskedasticity (Arellano–Bond one-step difference GMM), or the Windmeijer finite-sample corrected standard errors (Arellano–Bond two-step difference GMM). Significance at the 0.90, 0.95, and 0.99 levels is denoted *, **, and ***, respectively.

Table 6. Estimation robustness: linear-log(all).

Dependant variable: growth rate of real GDP *per capita*								
	Coefficients and (*P*-values)							
	Fixed effects reg.		Arellano–Bond one-step difference GMM		Arellano–Bond two-step difference GMM			
Variables	(1)	(1′)	(2)	(2′)	(3)	(3′)	(4)	(4′)
rGDPpc growth rate ($t-1$)			−0.032	−0.032				
			(0.665)	(0.692)				
ln(rGDPPC)	−5.020	−3.718	−12.580	−9.261	−10.590	−8.466	−2.059	−3.727
($t-1$)	(0.001)***	(0.001)***	(0.002)***	(0.003)***	(0.000)***	(0.000)***	(0.696)	(0.025)**
ln(trade/GDP)	1.852	1.949	−0.545	0.694	1.458	1.329	−1.062	2.056
	(0.151)	(0.147)	(0.820)	(0.773)	(0.305)	(0.455)	(0.792)	(0.197)
ln(GDFI/GDP)	3.564	2.899	3.684	2.043	4.666	3.218	2.996	2.86
	(0.004)***	(0.008)***	(0.002)***	(0.119)	(0.000)***	(0.013)**	(0.0864)*	(0.029)**
ln(G/GDP)	−5.065	−4.829	−12.070	−11.17	−6.813	−7.966	−1.935	−6.294
	(0.003)***	(0.005)***	(0.001)***	(0.001)***	(0.000)***	(0.000)***	(0.676)	(0.085)*
ln(pop. growth rate)	−0.841	−0.912	−0.743	−0.937	−0.839	−0.659	−0.719	−1.063
	(0.013)**	(0.006)***	(0.042)**	(0.031)**	(0.0254)**	(0.057)*	(0.122)	(0.006)***
Teledensity	0.0546		0.129		0.107		0.008	
	(0.035)**		(0.002)***		(0.001)***		(0.893)	
Teledensity^2	0.0000	0.0002	−0.0001	0.0004	−0.0002	0.0003	0.0000	0.0002
	(0.358)	(0.079)*	(0.393)	(0.000)***	(0.029)**	(0.002)***	(0.790)	(0.115)
Financial crisis	−2.748	−2.844	−2.616	−2.977	−2.843	−3.203	−2.648	−3.134
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.001)***	(0.000)***
Constant	37.950	29.070	126.800	99.040				
	(0.001)***	(0.001)***	(0.000)***	(0.000)***				
Observations	592	592	549	549	555	555	555	555
Groups	29	29	29	29	29	29	29	29

Prob. Wald > χ^2	0.00	0.00	0.00	0.00
Arellano–Bond test for AR(1)				
Prob. > z	0.00	0.00	0.00	0.00
Arellano–Bond test for AR(2)				
Prob. > z	0.15	0.13	0.19	0.13
Hansen *J*-test of Over-identification				
Prob. > χ^2	1.00	1.00	1.00	1.00

Notes: Regression assumptions are as follows: (1) and (1′) standard fixed effects panel regression; (2) and (2′) Arellano–Bond dynamic panel one-step difference GMM estimation; (3) and (3′) Arellano–Bond dynamic panel two-step difference GMM estimation with telecommunications variables as endogenous, and all others strictly exogenous. *P*-values (shown in brackets) were computed based on robust standard-errors (standard fixed effects model), standard errors consistent with panel-specific autocorrelation and heteroskedasticity (Arellano–Bond one-step difference GMM), or the Windmeijer finite-sample corrected standard errors (Arellano–Bond two-step difference GMM). Significance at the 0.90, 0.95, and 0.99 levels is denoted *, **, and ***, respectively.

model specification or the identification restrictions (Baum, 2006). All of the Arellano–Bond two-step difference GMM models in Table 3 pass the Hansen *J*-test.

Regardless of the model specification, the four sets of estimates in Table 3 are largely in agreement. First, all the estimates show that the coefficient on lagged *per capita* real GDP is negative. This supports the neo-classical, Solow-type, prediction of long-run convergence: countries with lower GDP will experience higher growth rates in the short-run in order that their GDPs "catch up."

All models are also all in agreement that the financial crisis decreased growth rates (a rather tautological result). Likewise, all find that the degree of trade openness and population growth insignificantly impacted the growth rates of real *per capita* GDP. These variables might have level-effects, but they do not seem to have growth effects.

Overall, higher levels of gross domestic fixed investment are associated with higher rates of growth. On the other hand, government expenditure tends to retard growth, as many previous studies in the literature have confirmed. The negative impact of government spending on the growth rate is twice as large as the positive impact of investment.

Finally, we turn to the telecommunications variables. Regardless of whether both teledensity variables were included, or only teledensity^2, the coefficient on teledensity^2 is statistically significant at the highest levels and is positive. This provides clear evidence that the impact of telephones on economic growth is *greater* when telephone penetration is higher. That is, it is likely that there are significant positive network externalities at play, which cause an increase in the marginal productivity of telephony. This supports Romer's theory of endogenous growth.

Of course, statistical significance is not the same as economic significance. Teledensity is measured as the number of main telephone lines per 100 people. So the addition of one main telephone line per 100 people is in fact a one percentage point increase in teledensity. Considering that the dependent variable, growth rate of real GDP *per capita*, is also expressed in percentage terms, relatively small but positive estimated coefficients on teledensity and teledensity^2 provide insight into the nature of the growth process. Disregarding the question of statistical significance, according to the estimated coefficients from Table 3, an increase of one telephone line per 100 people (an increase of one in teledensity) is associated with an increase in between 0.02 and 0.05 in the percentage growth rate of real *per capita* GDP. That is, a 1% increase in telephone lines *per capita* increases the growth rate of real wealth *per capita* by approximately 0.02–0.05 percentage points. Or, to put it differently still, it would take at least a 20% increase in the number of telephone lines *per capita* (a 20 pt. change in teledensity) to increase the growth rate of real living standards by 1%. That said, many of the countries in our sample have very low telephone penetration rates, so a 20% increase is not out of the realm of possibility. Moreover, such an increase accumulates; by the power of compound growth, differences in 1% growth – of, say, an increase from 2% to 3% – could cut the amount of time it would take to double a population's wealth from 35 to 24 years. That is not to say that governments should spend tax-money to encourage telecommunications growth. From the estimates in Table 3, it is clear that increases in governmental spending have a far greater ability to decrease growth rates. Perhaps, though, other means of encouraging the expansion of telephone lines may be pursued. Gutierrez (2003), for example, shows that an independent regulator helps increase teledensity.

8. Robustness

Often, econometric results are highly sensitive to the functional form that is estimated. Thus, we estimated other forms, and have found that they perform similarly to our original model.

Specifically, we include three additional tables – Tables 4–6 – to emphasize the robustness of our results to various functional forms.

Even in a logarithmic specification, though, not all variables can or should be logged. First, teledensity and teledensity^2 are never logged. The reason for this is that:

$\beta_1\ln(\text{teledensity}) + \beta_2\ln(\text{teledensity}^2) = (\beta_1 + 2\beta_2)\ln(\text{teledensity}) = \beta_3\ln(\text{teledensity})$.

That is, logging a squared variable effectively gets rid of the concavity that the squared variable introduces. Since the sign of the coefficient on teledensity^2 is one of the focuses of the study, and logging removes the squared term, we cannot log this variable. Recall that endogenous growth theory posits that the marginal product of telephones will increase, the more widely dispersed telephones are. Thus, the test of endogenous growth theory is whether the sign on teledensity^2 is positive.

We do not take the logarithm of the financial crisis dummy variable. As a dummy variable, it is equal to zero or one, and it is undefined if the dummy variable takes a value of zero.

We also do not advocate taking the logarithms of variables that are already expressed as percents. The reason for this is that percents of percents are awkward and unintuitive. That is, going from 20% to 22% is more intuitively expressed as a 2% change, rather than as a 10% change. For this reason, we do not suggest taking logarithms of openness to trade (as it is calculated as the percent of GDP that is exports or imports), GFDI/GDP (as this is the savings or investment rate), G/GDP (as this the percent of GDP that comes from governmental expenditures), and the population growth rate. For the same reason, we would not recommend taking the logarithm of the growth rate of *per capita* GDP, but do so in Table 5 at the suggestion of the referee. In Table 6, we even take logs of all the rate terms on the right-hand-side, again at the suggestion of the referee.

Specifically, we estimate the following three additional variants to our initial model:

Table 4: linear-log

$$\begin{aligned}\text{Growth of real } \textit{per capita} \text{ GDP} &= \beta_0 + \beta_1(\log(\text{lagged real } \textit{per capita} \text{ GDP})) + \beta_2(\text{trade}) \\ &\quad + \beta_3\left(\frac{\text{GFDI}}{\text{GDP}}\right) + \beta_4(\text{pop.growthrate}) + \beta_5(\text{teledensity}) \\ &\quad + \beta_6(\text{teledensity}^2) + \beta_7(\text{financialcrisis}).\end{aligned}$$

Table 5: log-linear

$$\begin{aligned}\text{Log(Growth of real } \textit{per capita} \text{ GDP)} &= \beta_0 + \beta_1(\log(\text{lagged real } \textit{per capita} \text{ GDP})) + \beta_2(\text{trade}) \\ &\quad + \beta_3\left(\frac{\text{GFDI}}{\text{GDP}}\right) + \beta_4(\text{pop.growth rate}) + \beta_5(\text{teledensity}) \\ &\quad + \beta_6(\text{teledensity}^2) + \beta_7(\text{financialcrisis}).\end{aligned}$$

Table 5: linear-log(all)

$$\begin{aligned}\text{Growth of real } \textit{per capita} \text{ GDP} &= \beta_0 + \beta_1(\log(\text{lagged real } \textit{per capita} \text{ GDP})) + \beta_2(\log(\text{trade})) \\ &\quad + \beta_3\left(\log\left(\frac{\text{GFDI}}{\text{GDP}}\right)\right) + \beta_4(\log(\text{pop.growth rate})) \\ &\quad + \beta_5(\text{teledensity}) + \beta_6(\text{teledensity}^2) + \beta_7(\text{financialcrisis}).\end{aligned}$$

Table 3 represents our baseline result. In Table 4, we take the logarithm of lagged real *per capita* GDP. This was the only variable that was not already a percentage rate, dummy variable, or teledensity^2 variable. Table 5 is a log-linear version of Table 3, where we take the logarithms of the endogenous variable (the growth rate of real per capital GDP). Finally, in Table 6 we estimate a linear-logarithmic model where we take the logarithms of all the right-hand-side variables (again with the exception of the telecom variables where logarithms would invalidate the purpose of the study, and of the financial crisis dummy variable where logs are undefined).

In Table 4, the marginal impact of a one unit increase in teledensity (or alternatively, a 1% increase in the number of telephones per 100 people) is associated with between a 0.05 and 0.10 percentage point increase in the growth rate of real *per capita* GDP. That is, adding 20 telephone liens per 100 people would increase a country's growth rate from, say, 2% to 4$. This could decrease the amount of time it would take to double the average person's standard of living from 35 years to a mere 18 years. Though the results are not as consistent with those from Table 3, it seems as though the theory of endogenous growth is supported here in Table 4, where most of the estimates of the coefficient on teledensity^2 are positive.

In Table 5, we estimate a log-linear version of Table 3, where we replace the endogenous variable, the growth rate of *per capita* real GDP, with its logarithm. Here, increasing the number of telephone lines by 20 per 100 people increases the growth rate of *per capita* real income by 0.004 percentage points.

Finally, in Table 6, the estimated impact of teledensity is even greater, with a 1% increase in the number of telephone lines per person is associated with an increase in the growth rate by as much as 0.13 percentage points. Thus, adding 20 telephone lines per 100 people would increase a country's growth rate by 2.6%. This represents an increase in the growth rate from, say 2% to 4.6%, which would double living standards in slightly over 15 years. Again, the theory of endogenous growth is supported as the estimated coefficients on teledensity^2 are mostly positive.

9. Conclusion

The relationship between telecommunications and economic growth has received a lot of attention lately among macroeconomists and development economists. This is for several reasons. First, and most importantly, telecommunications systems may enable economic growth. If this is the case, then it calls for lowering entry barriers to the telecommunications industry, or possibly subsidizing IT investment, as a development project. On the other hand, it could be that economic growth facilitates telecommunications investment. If this is the case, then lowering entry barriers or offering subsidies could be less efficient, more costly, or even counterproductive. Thus, the debate on the endogeneity of growth has important implications for development practice. Moreover, the empirical debate on telecommunications and growth provides a useful test between the two major theories of macroeconomic growth: the neo-classical and endogenous growth theories. This paper has viewed the impact of telecommunications under two different types of lenses: one assumed that telecom was exogenous to growth; the others assumed that telecom and growth are endogenous.

Regardless of the assumed relationship between telecom and growth, the two lenses provide the same view of the economy. First, poor countries exhibit higher growth rates – a finding that supports the neoclassical theory of growth. Second, telecom has a positive impact on growth rates, regardless of whether the relationship is modeled as endogenous or exogenous. More importantly, the impact of telephones on growth is increasing in the level of telephone penetration: clear support of endogenous growth theory. The evidence seems to suggest that "more phones, more growth" should actually state "more phones, even higher growth."

We do not mean to imply that a country can increase economic growth perpetually just by increasing the number of lines per household. Econometric results are summaries of data. A researcher moves onto shakier territory when making out-of-sample predictions. Currently, the highest value of teledensity in Asia belongs to Hong Kong which has almost two telephone lines per person (if it helps, the reader may think of this as a work line and a home line). We do not wish to extend any predictions to what might happen as countries push this envelope to more than two lines per person. However, the evidence seems to indicate that an increase of teledensity of 20 units is feasible. Many Asian countries have accomplished this task in the past 10 years. Between 2000 and 2006, of the countries in our sample, the average number of telephone lines increased from 29 to almost 75 per 100 people. This represents an increase of 156%.

Holding other factors constant, such increases are associated with growth rates increasing by up to 2.4 percentage points. Such an increased growth rate is not trivial. It can cut the time it would take to double a country's living standard from 36 years (with a growth rate of 2%) to 16 years (with a growth rate of 4.4%).

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Notes

1. See, for example, Barro (1991) and Mankiw, Romer, and Weil (1992).
2. For example, Knack and Keefer (1995), Keefer and Knack (1997), Knack (1996).
3. Examples include Gwartney, Holcombe, and Lawson (2004) and (2006).
4. The convergence debate is typified by the exchange in Mankiw, Phelps, and Romer (1995).
5. See Cameron and Trivedi (2009) and Roodman (2009) for an introduction to the Arellano–Bond estimator, as well as its implementation in Stata.
6. See Cameron and Trivedi (2009).
7. The discussion on the validity of lagged differences as an instrument is heavily drawn from Roodman (2009).
8. The null hypothesis of the Arellano–Bond test for AR(1) is that there is no autocorrelation in residuals in first differences.
9. See Baum (2006).

Notes on contributors

John Levendis is an Assistant Professor of Economics at Loyola University New Orleans. He received MA and MS degrees in economics and mathematics, and a Ph.D. in economics from the University of Iowa. He has taught at the Economics University of Prague, Cornell College, the University of Iowa, and Southeastern Louisiana University. His research focuses on the econometric study of economic development and corporate finance.

Professor Sang H. Lee received his Ph.D. in economics from the University of Florida in 1999 and currently teaches both undergraduate and graduate economics courses at Southeastern Louisiana University. His principal research focus has been on the issues associated with telecommunications and economic development.

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