Policy Research Working Paper 4516

Determinants of a Digital Divide in Sub-Saharan Africa:

A Spatial Econometric Analysis of Cell Phone Coverage

Piet Buys
Susmita Dasgupta
Tim Thomas
David Wheeler

The World Bank
Development Research Group
Sustainable Rural and Urban Development Team
February 2008

Abstract

Most discussions of the digital divide treat it as a "North-South" issue, but the conventional dichotomy doesn't apply to cell phones in Sub-Saharan Africa. Although almost all Sub-Saharan countries are poor by international standards, they exhibit great disparities in coverage by cell telephone systems.

Buys, Dasgupta, Thomas and Wheeler investigate the determinants of these disparities with a spatially-disaggregated model that employs locational information for cell-phone towers across over 990,000 4.6-km grid squares in Sub-Saharan Africa. Using probit techniques, a probability model with adjustments for spatial autocorrelation has been estimated that relates the likelihood of cell-tower location within a grid square to potential market size (proximate population); installation and maintenance cost factors related to accessibility (elevation, slope, distance from a main road, distance from the nearest large city); and national competition policy. Probit estimates indicate strong, significant results for the supply-demand variables, and very strong results for the competition policy index.

Simulations based on the econometric results suggest that a generalized improvement in competition policy to a level that currently characterizes the best-performing states in Sub-Saharan Africa could lead to huge improvements in cell-phone area coverage for many states currently with poor policy performance, and an overall coverage increase of nearly 100 percent.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to identify effective policies for narrowing the digital divide. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at sdasgupta@worldbank.org.

Produced by the Research Support Team

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* Authors' names in alphabetical order. We dedicate this paper to our friend, colleague and co-researcher Piet Buys, who died in a tragic accident during the latter part of our research. The authors are, respectively, Lead Economist and Consultant, World Bank, and Senior Fellow, Center for Global Development. Our thanks to Vivien Foster, Sudeshna Ghosh Banerjee, Ken Chomitz and Uwe Deichmann for information on Telecom reforms, useful comments and suggestions. The findings, interpretations, and conclusions in this paper are entirely those of the authors. They do not necessarily represent the view of the World Bank, its Executive Directors, or the countries they represent.

Corresponding author: Susmita Dasgupta, MC3-435, World Bank, 1818 H Street, N.W., Washington, DC 20433; E-mail: sdasgupta@worldbank.org; telephone: 202-473-2679; fax: 202-522-1151.

1. Introduction

Most discussions of the digital divide treat it as a "North-South" issue, but the conventional dichotomy doesn't apply to cell phones in Sub-Saharan Africa. As Table 1 shows, huge gaps in cell phone coverage divide Sub-Saharan countries that are all poor by international standards. The table provides statistics on country-level percentages of urban and rural populations within range of cell phone towers.[1] In both rural and urban sectors, population coverage in March, 2004 varied from 0 to 100%. Rural coverage was negligible or nonexistent in 17 countries[2], but above 47% in the top quartile. Urban coverage was below 56% in the lowest quartile, but above 98% in the top quartile.

In this paper, we investigate the sources of these huge disparities in African cell-phone coverage, with a particular focus on the role of differences in competition policy. Moving beyond cross-sectional analysis of country-level differences, we take a spatially-disaggregated approach that enables us to investigate the local determinants of coverage at thousands of grid points in Sub-Saharan Africa. This approach has several advantages. First, it enables us to control much more precisely for area-specific demand and supply factors that affect firms' decisions to install cell-phone towers. These include proximity to main roads and local population centers, as well as local topography. Such factors are potentially-important determinants of cross-country differences in coverage, because African countries differ greatly in geography, population distributions and infrastructure endowments. Second, introduction of better spatial controls permits clearer tests of the impact of competition policy on cell-tower expansion. Finally, the micro-spatial approach

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[1] We have produced the estimates by overlaying a digital map of GSM (Global System for Mobile Communications) cell phone towers and coverage areas with a map of urban and rural populations. Cell phone tower data in GIS format have been provided by GSM World, Inc. Spatial population distribution data have been drawn from CIESEN's Gridded Population of the World, version 3.

[2] Djibouti, Angola, Congo, Comoros, Somalia, Guinea, Guinea, Sudan, Central African Republic, Mali, Eritrea, Niger, Guinea Bissau, Sierra Leone, Chad, Ethiopia and Liberia.

enables us to project the impacts of policy reforms geographically. We can literally map projected new locations of cell phone towers, overlay them with population maps, and directly estimate the implications for rural and urban cell phone coverage.

The remainder of the paper is organized as follows. In Section 2, we introduce and discuss previous empirical work on the determinants of cell-phone expansion. Section 3 provides an overview of regulatory reform and cell-phone expansion in Sub-Saharan Africa. Section 4 motivates our modeling exercise and describes our spatial database. In Section 5, we develop alternative estimation strategies to deal with spatial autocorrelation and present our econometric results. Using these results, Section 6 simulates the country-by-country effect of policy reforms that would increase competitiveness to current top-tier levels in Sub-Saharan Africa. Section 7 provides a summary and conclusions.

2. Previous Research on Cell Phone Diffusion in Developing Countries

2.1 General Determinants of Cell Phone Diffusion

Numerous econometric studies have investigated cross-country cell phone penetration rates, using a variety of independent variables: geographic factors and income (Baliamoune-Lutz, 2003); income alone (Rouvinen, 2004); socio-cultural attributes and internet/telecom use (Kamssu, 2005); and national industry structure, pricing schemes and availability of cell-phone features (Kshetri and Cheung, 2002; Minges, 1999; Yan and Thong, 2003). Some studies have used country typologies to segment cross-country analyses, rather than imposing a single global coverage model (Banerjee and Ros, 2004; Dholakia, Dholakia, Lehrer, and Kshetri, 2004; Dholakia and Kshetri, 2002). Others have investigated the complementarity between cell phone diffusion and the presence of other communications technologies (Hamilton, 2003; Wauschkuhn, 2001). More technology-specific studies have looked at the effect of properly calibrating the connection of mobile and fixed systems (Srivastava and Sinha, 2001; Yan, 2001) and international connections (Newman, 1993).

None of the previously-noted econometric studies explicitly introduces relative rates of return to investigate the microeconomics of cell-phone adoption by businesses. Evidence on rates of return has been gathered in a survey exercise by Samuel, et al. (2005). Another relevant study takes a detailed look at the determinants of cell-phone banking use in South Africa (Irwin, Zaheeda, Douglas, and Shaun, 2003).

2.2 The Role of Policy and Industry Structure

Regulatory policy and industry structure have played a prominent role in many cell-phone diffusion analyses, which consider the impacts of regimes ranging from full competition to single-provider state-run companies on levels of mobile penetration and/or prices and service quality (Frempong and Atubra, 2001; Gebreab, 2002; Mureithi,2003; Stovring, 2004; Varoudakis and Rossotto, 2004; Wheeler, Dasgupta, and Lall, 2001; Ibarguen, 2003; Wallsten, 2001). These studies generally conclude that privatization and more vigorous competition lead to better overall outcomes.

Other researchers have argued that liberalization and privatization are insufficient to ensure broad coverage in rural areas (Bhuiyan, 2004; Harwit, 1998; Mutula, 2002; Panos, 2004). Courtright (2004) asserts that development institutions like the World Bank need to account for local socio-cultural and institutional conditions when designing rural connectivity programs. Specific intervention programs that have been studied include universal service funds (Dhawan, Dorian, Gupta, and Sunkara, 2001); community phone shops with shared access (Barendse, 2004; Reck and Wood, 2003); tailored franchise subscription and tariff models to enable lower-cost service or limited-mobility GSM coverage for rural areas (Dhawan et al., 2001; Engvall and

Hesselmark, 2004) ; and wireless-local loop approaches (Caspary and O'Connor, 2003; Kibati and Krairit, 1999; McDowell and Lee, 2003). Dymond and Oestmann (2002, 2003) argue that market liberalisation and intervention should be considered sequential rather than mutually exclusive. They distinguish between market efficiency, which can be achieved first through liberalization, and specific intervention to close the rural access gap that will persist without governmental mandates or incentives.

3. Public Policy and Cell Phone Diffusion in Sub-Saharan Africa

Telephone connectivity remains low in much of Sub-Saharan Africa, but public policy has begun to address this problem. Numerous governments, regional organizations, and private firms have identified the development of affordable "backbone"[3] infrastructure as a top priority for improving connectivity (Neto et al., 2005). A recent World Bank review of telecommunications reform in 24 countries[4] finds widespread reforms that are intended to improve service quality through privatization and competition, supported by a stable regulatory environment (World Bank, 2007). Specific reforms include enactment of formal regulations, creation of national regulatory authorities (NRAs), privatization of incumbent operators, and introduction of competition. Establishment of NRAs has typically included measures focused on competition, licensing, interconnection, allocation of scarce resources (e.g., numbering and spectrum) and pricing. Table 2 summarizes the recent history of telecommunications reform in Sub-Saharan Africa.

As these 24 countries have enacted reforms, competition has deepened and cell-phone networks have expanded steadily. In 1993, three-quarters of the countries studied had no cell

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[3] The term "backbone" refers to the use of communications infrastructure to connect major switching centers, as opposed to last-mile connectivity.

[4] Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Democratic Republic of the Congo, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Uganda and Zambia.

network and all existing networks were monopolies. By 2000, all but one had at least one cell network and 14 allowed competition. By 2006, all had cell networks and only three did not have competitive cell markets[5]; 12 of the countries had two or more operators. During the period 2000-2006, total cell subscribers in the 24 countries increased from 10 million to 110 million. The trend in regional subscription shares reflects the proliferation of cell networks. While South Africa accounted for 81% of Sub-Saharan subscribers in 2000, its share dropped to 34% in 2006. By 2003, South Africa, Mozambique, Zimbabwe, Tanzania, Zambia and Uganda had more cell subscribers than subscribers to fixed lines (Barnard and Vonk, 2003).

4. Determinants of Cell Phone Coverage

4.1 The Basic Economics of Cell Tower Location

Our analysis of coverage divides Sub-Saharan Africa into 2.5 arc-minutes (4.6 km at the equator), overlays those squares with cell-phone tower locations, and investigates the likelihood that each grid square contains at least one tower. We posit a basic model of locational economics, in which the provision of cell-tower services depends on a set of market demand and supply variables. Ceteris paribus, the likelihood of cell-tower installation will be greater for sites with higher potential demand and lower installation and maintenance costs. The basic determinant of demand is the size of the population within the transmission radius of the tower. On the supply side, we posit a set of cost factors that relate to the construction and maintenance of tower facilities: ease of access to material and service supply centers (distance from a main road, average travel time to the nearest city with 100,000 or more inhabitants); and topography (elevation, slope).

[5] Namibia issued a second cell provider license in 2006 and the new operator was expected to launch in 2007. In Cape Verde, there is no legal restriction against cell competition and efforts continue to license a second cell operator. This leaves Ethiopia as the only country where there is no process underway to liberalize the cell market.

We also posit a significant role for the competitive environment. In markets with limited competition, we would expect profit-maximizing firms to offer more limited services at higher prices. The spatial reflection of this limitation, relative to more competitive environments, would be fewer cell phone towers, concentrated in areas with larger populations and lower installation and maintenance costs.

4.2 Data

To test the model, we use the best available spatially-disaggregated data sets from various public sources, including the International Centre for Tropical Agriculture (CIAT), the LandScan, the Center for International Earth Science Information Network (CIESIN), the Digital Chart of the World (DCW) and the World Bank. The data on cell phone tower locations have been provided by the GSM Association in GIS polygon files for the period 1999: Q1 – 2006: Q3. We overlay the data on a rectangular grid of evenly-space points, with a separation of 2.5 arc-minutes covering Sub-Saharan Africa. This generates 1,138,835 points, which we plot in Figure 1. Table 3 summarizes our data sources; Table 4 provides basic descriptive statistics for model variables, which exhibit great variation across grid squares: Elevations vary from sea level to 5,800 meters; slope steepness from 1.2 to 99.0; distance to a main road from 0 to 1,160 km; travel hours to a major city from 0 to 102; and proximate population from 0 to 578,000. Our policy variable is an index of the competitive environment in 2004, provided by the World Bank's Country Policy and Institutional Assessment (CPIA) database. Globally, the CPIA competition index varies from 1 to 6. Among our sample countries in Sub-Saharan Africa, it varies from 2.0 to 4.5, with a mean value of 3.2.

Table 5 provides a quarterly time series of percentage land area covered by GSM cell towers. Overall, GSM service area coverage expanded from 2.7% in the first quarter of 1999 to 16.7% in the third quarter of 2006, with concurrent growth of population coverage from 9.1% to 54.5%. Among the 41 countries covered by our analysis, Gabon had the greatest percent increase in population coverage (80.1%) and Somalia had the least (0.1%). Djibouti, Guinea and Guinea-Bissau also had very small population coverage (below 5%). Table 6 presents GSM area and population coverage by country for 2000 and 2006.

5. Spatial Econometric Analysis

5.1 Specification

We cannot perform panel data analysis because most of our explanatory variables are time-invariant. We therefore focus on explaining GSM service coverage in the third quarter of 2006, the latest period for which information is available. We identify service coverage with a binary variable (GSM06q3) whose value is 1 if a grid square had cell phone coverage in 2006:Q3 and 0 otherwise.

Our coverage model relates the probability of service tower location in a grid square to its characteristics related to demand (population within transmission range) and supply cost (elevation, slope, distance to main road, travel time to nearest major city), as well as the competitive environment in the country.

5.2 Estimation

We estimate by probit for 993,401 grid cells, using logs of continuous variables with the exception of slope. For the latter, we use an index whose value is 1 for steeply-sloped areas and 0 otherwise. We also use an interaction term to test the joint effect of potential service population and the competitive environment. We present out basic probit estimates in Table 7, column 2.

Probit estimation with data from continuous grid squares can be subject to significant spatial autocorrelation, which leads to inconsistent and inefficient estimates. In order to correct for potential spatial error, we apply a Markov Chain Monte Carlo simulation method using the Gibbs sampler.[6] Although our approach uses relatively sparse matrices, our ability to correct for spatial autocorrelation is limited by computer memory and operating system capacity[7] Our application (Windows 32-bit operating system, MatLab software) cannot handle matrices larger than 16,000 square elements – far smaller than the 993,401 observation cells in our estimation dataset. We adjust to this limit by switching from 2.5 arc-minutes to 50 arc-minutes (93 km at the equator). We classify the data in 400 groups, with the weights matrix counting points within 150-kilometers of a given point as neighbors.[8] For each of the 400 groups, we assume a burn-in of 500 iterations, and save the simulated parameters from the following 500 iterations. This generates 200,000 parameter sets (for the 400 groups), which we use to compute average coefficients and their standard errors. We present these estimates in column 3 of Table 7.

Since reduced *t*-statistics are generally expected in smaller datasets, we also employ a third variant to aid interpretation of our results. We estimate a standard probit model for the same reduced data set of 400 groups, using Markov Chain Monte Carlo (MCMC) simulation methods, without controlling for spatial autocorrelation. Computed average coefficients and standard errors are presented in Table 7, column 4.

[6] The Gibbs Sampler allows us to simulate a joint distribution of parameters by simulating each set of parameters, one set at a time, conditional on all other parameters. The special advantage of the Gibbs Sampler for use in spatial probit stems from the fact that it also simulates the continuous latent variable (Albert and Chib, 1993). See Thomas (2007) or LeSage (1999) for detailed discussion of the methodology.

[7] The parametric approach to spatial probit requires a weights matrix to quantify the relationship of each observation to the rest. Since only observations in geographic proximity generally have non-zero influence, it is reasonable to use sparse matrices for computation.

[8] In practice, this approach specifies horizontal, vertical, and diagonal points within 150 km as neighbors (assuming the points exist on land (neither in the ocean nor an inland body of water))..

5.2 Results

Table 7, column 2 presents unadjusted probit estimates for the complete dataset of 993,401 observations. The results are all consistent with our expectations: The probability of a GSM cell tower location in a grid square increases significantly with population and the degree of competition, and decreases significantly with higher levels of installation and maintenance cost factors (higher elevation, steep slope, longer distance from the main road, longer travel time to the nearest major city).

Column 3 of Table 7 presents results from our MCMC estimation that adjusts for spatial autocorrelation. The large, significant spatial error estimate at the bottom of column 3 is consistent with significant spatial autocorrelation. As expected, the reduced data sample and MCMC adjustment change the coefficient estimates and substantially reduce the t-statistics. However, the signs and significance of the coefficients remain unchanged except for elevation, which retains the expected sign but loses significance.

Table 7, column 4, reports unadjusted probit estimates for the 400 100-km grid cells. These results are quite close to those in column 3, indicating that the differences in coefficients and t-statistics between column 2 and columns 3-4 are primarily due to reduction in the number of observations rather than spatial error. The small impact of the spatial error (despite its significance) may be due to a homoscedastic variance structure produced by our uniform weights matrix (Fleming, 2004; Anselin, 2002, Thomas, 2007).

Map a presented in Fig 2 documents the probability of cell phone coverage predicted by the probit estimates from our full spatial dataset (Table 7, column 2).

6. Policy Implications

Our results indicate that competition policy orientation is a powerful determinant of cell-phone coverage in Sub-Saharan Africa. To assess the potential implications of further reform, we perform a policy simulation using the probit estimates from our full spatial dataset (Table 7, column 2). For all 993,401 grid cells, using the observed values for our demand and supply variables, we simulate strongly pro-competitive policy by setting the CPIA index at 4.0 for all countries with CPIA index below 4.0. While this would require substantial reform in many Sub-Saharan countries, it has already been attained by Benin, Botswana, Namibia, Uganda and South Africa[9]. Our simulation increases the probability of cell-tower location in all grid squares that are in countries whose current CPIA scores are below 4.0. Map b in Figure 2 plots the full results for Sub-Saharan Africa, showing the probability of cell-tower location in each grid square. Higher-probability squares are colored blue; lower-probability squares green. The clustering pattern in the map reveals the critical roles of population, infrastructure and topography in determining coverage, even with uniformly-high levels of competition policy.

Numerically, our policy simulation results translate to very large changes in area coverage for cell phone towers. For the two cases (current CPIA, CPIA=4), Table 8 presents country-level percent differences in grid squares with cell-tower probabilities greater than 0.5. These are equivalent to expected percent differences in area coverage by country. For nine countries, the policy improvement translates to a coverage increase greater than 100%, and for all countries whose CPIA was below 4 in 2004, the predicted increase in coverage is 96%.

[9] For these countries, actual CPIA values were used for the simulation.

7. Summary and Conclusions

In this paper, we have identified and investigated a striking example of a digital divide within Sub-Saharan Africa. Although almost all Sub-Saharan countries are poor by international standards, they exhibit great disparities in coverage by cell telephone systems. We investigate the determinants of these disparities with a spatially-disaggregated model that employs locational information for cell-phone towers across over 990,000 4.6-km grid squares in Sub-Saharan Africa. Using probit techniques, we estimate a probability model that relates the likelihood of cell-tower location within a grid square to potential market size (proximate population); installation and maintenance cost factors related to accessibility (elevation, slope, distance from a main road, distance from the nearest large city); and national competition policy. We estimate a simple probit model, as well as a model that adjusts for spatial autocorrelation. We obtain strong, significant results for the supply-demand variables, and very strong results for our competition policy index. Using the results, we simulate the effect of a generalized improvement in competition policy to a level that currently characterizes the best-performing states in Sub-Saharan Africa. Our results indicate huge improvements in area coverage for many states with poor policy performance, and an overall coverage increase of nearly 100%.

Our results provide striking evidence of the power of policy reform to improve public access to telecommunications in Sub-Saharan Africa. Our policy reform results are particularly strong because they do not involve extrapolation from econometric estimation of reform impacts in other regions. Basing our work on the experience of Sub-Saharan African alone, we find that simply improving competition policy to the current levels of superior performers in the region would generate huge telecommunications benefits for the populations of the affected countries.

While these results are very hopeful, we feel compelled to close on one cautionary note. Inspection of the simulation map b in Figure 2 suggests that competition policy reform alone will not be sufficient to ensure universal coverage in Sub-Saharan Africa. On the map, coverage is concentrated in areas with relatively dense populations, near main transport arteries. The large swaths of brown and black reveal the extent of coverage exclusion for low-density rural populations that are off-road and uphill. As many analysts cited in Section 2 have noted, targeted interventions in such areas may be necessary to close Africa's digital divide completely.

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Table 1: Population Coverage by Country: Rural and Urban GSM Cell Phone Towers March, 2004

	% of Population Within Range of a GSM Cell Phone Tower[a,b]				
Location	Minimum	Quartile 1	Median	Quartile 3	Maximum
Rural	0.0	3.4	20.0	46.9	100.0
Urban	0.0	56.2	89.1	97.9	100.0

[a] Cell phone tower data source: GSM World, Inc.
[b] Spatial population distribution data source: Gridded Population of the World, version 3
Center for International Earth Science Information Network (CIESIN),
Earth Institute at Columbia University.

Table 2: Year of Telecommunications Reform: 24 Sub-Saharan African Countries

Country	Year
Namibia	1992
Zambia	1994
Cape Verde	1994
Cote d'Ivoire	1995
Ethiopia	1996
Ghana	1996
Chad	1998
Malawi	1998
Kenya	1998
Burkina Faso	1998
Cameroon	1998
Niger	1999
Lesotho	2000
Uganda	2000
Senegal	2001
Sudan	2001
Rwanda	2001
Benin	2002
Congo DRC	2002
Nigeria	2003
Tanzania	2003
Mozambique	2004
Madagascar	2005
South Africa	2006

Source: World Bank (2007).

Table 3: Summary of Data Sources

Dimension	Dataset Name	Unit	Resolution	Source(s)
Elevation	SRTM30	Meters	30 arc seconds	CIAT
Slope	LandScan 1998	Percent slope = 100 * rise / run	30 arc seconds	LandScan
Distance to main road		Meters	1 kilometer	World Bank
Hours to major city	UNEP	Hours (truncated)	1 kilometer	World Bank
Population	GRUMP	Population counts	30 arc seconds	CIESIN
Index of Competitive Environment for the Private Sector	CPIA-2004	1-6 scale	Country-level	World Bank

Table 4: Descriptive Statistics (based on 993,401 observations)[10]

	Mean	sd	Minimum	Maximum
GSM06q3	0.188	0.391	0	1.0
Elevation (m)	699.2	478.2	0	5,778
Slope (= 100 * rise / run)	1.247	3.062	0	99.0
Distance to main road (m)	159,971	191,096	0.3	1,157,475
Hours to major city	11.62	11.18	0	102.0
Population	586.4	2,960	0	577,619
Competitive Environment for Private Sector index, 2004 (1-6 scale)	3.236	0.556	2.0	4.5

Table 5: Area Covered by GSM Towers in Sub-Saharan Africa, 1999-2006

	1999: Q1	1999: Q2	2000: Q4	2001: Q3	2001: Q4	2002: Q1	2002: Q3	2003: Q1	2003: Q3	2004: Q1	2006: Q3
% of Land with GSM Service	2.7	3.1	5.2	6.3	6.9	7.5	7.5	8.6	8.6	10.7	16.7

[10] Central African Republic, Eritrea, Guinea, Guinea-Bissau, Sierra Leone, Niger were excluded from the analysis because GSM data for those countries were only available for 2006, Q3.

Table 6: GSM Population and Area Coverage by Country, 2000-2006

			% Covered			
Country	Total Area (sq. km.)	Total Population (2000)	Area 1999	Population 1999	Area 2006	Population 2006
Angola	1,250,465	13,091,350	0.0%	0.0%	0.9%	31.4%
Benin	116,377	6,297,060	0.0%	0.0%	6.1%	43.3%
Botswana	560,030	1,542,830	0.1%	0.3%	18.2%	66.7%
Burkina Faso	273,422	11,452,684	0.0%	0.0%	38.7%	60.3%
Burundi	25,505	6,403,703	0.0%	0.0%	49.6%	59.8%
Cameroon	463,813	14,787,480	0.0%	0.0%	17.6%	57.7%
Central African Republic	621,284	3,580,870	0.0%	0.0%	0.3%	17.1%
Chad	1,244,997	7,901,687	0.0%	0.0%	2.8%	23.5%
Congo	345,479	3,022,433	0.0%	0.0%	5.7%	67.6%
Cote d'Ivoire	320,254	15,644,741	0.0%	0.0%	21.8%	57.4%
Dem. Rep. of Congo	2,312,898	50,835,211	0.0%	0.0%	20.1%	52.5%
Djibouti	20,568	521,998	0.0%	0.0%	0.0%	0.0%
Equatorial Guinea	26,789	435,175	0.0%	0.0%	10.9%	37.1%
Eritrea	120,236	3,638,225	0.0%	0.0%	18.4%	50.1%
Ethiopia	1,123,309	62,907,122	0.0%	0.0%	1.4%	10.1%
Gabon	260,932	1,202,513	0.0%	0.0%	21.6%	80.1%
Ghana	231,537	19,290,950	0.6%	18.3%	26.5%	62.7%
Guinea	245,572	8,059,264	0.0%	4.2%	0.1%	3.8%
Guinea-Bissau	32,633	1,160,795	1.6%	1.6%	1.6%	1.3%
Kenya	571,726	30,546,856	0.0%	0.0%	32.1%	91.8%
Lesotho	30,502	2,024,104	1.3%	7.5%	33.8%	55.4%
Liberia	96,011	2,884,144	0.0%	0.0%	2.1%	21.6%
Malawi	95,509	11,264,638	0.0%	0.0%	79.8%	93.1%
Mali	1,250,186	11,385,518	0.0%	0.0%	1.1%	18.1%
Mozambique	774,844	18,017,410	0.6%	11.6%	10.0%	42.1%
Namibia	818,790	1,640,001	0.0%	0.0%	31.3%	73.6%
Niger	1,155,583	10,804,920	0.0%	0.0%	6.2%	43.6%
Nigeria	903,330	112,802,470	0.0%	0.0%	25.0%	59.7%
Rwanda	24,202	7,645,897	0.0%	0.0%	73.2%	81.2%
Senegal	195,437	9,157,484	8.6%	57.6%	39.3%	82.3%
Sierra Leone	72,351	4,314,767	0.0%	0.0%	50.0%	72.4%
Somalia	635,893	8,605,480	0.0%	0.0%	0.0%	0.1%
South Africa	1,218,199	43,157,036	49.8%	85.1%	86.0%	99.8%
Sudan	2,483,481	31,034,294	0.0%	0.0%	2.6%	32.7%
Swaziland	17,112	916,045	0.7%	0.8%	89.3%	92.0%
Tanzania	889,235	34,792,931	0.0%	3.0%	19.1%	55.7%
The Gambia	10,661	1,242,343	0.0%	0.0%	34.0%	64.0%
Togo	57,349	4,493,843	0.0%	0.0%	41.1%	64.3%
Uganda	207,452	23,327,621	1.1%	10.0%	79.3%	96.9%
Zambia	745,896	10,497,219	0.5%	19.5%	9.7%	44.9%
Zimbabwe	388,192	12,602,282	2.1%	28.2%	29.8%	58.5%

Table 7: Probit Estimates of GSM Coverage in Sub-Saharan Africa in 2006†

	Non-Spatial Probit (N=993,401)	400 Spatial Probits	400 Non-Spatial Probits
Log (Elevation)	-0.018 (9.55)	-0.042 (0.53)	-0.029 (0.43)
Dummy Slope	-0.308 (83.34)	-0.285 (1.96)	-0.429 (3.42)
Log (Population)	0.646 (100.66)	1.125 (4.12)	0.932 (4.09)
Log (Distance to main road)	-0.243 (154.96)	-0.312 (5.04)	-0.310 (5.45)
Log (Hours to major city)	-0.602 (235.33)	-0.751 (7.82)	-0.758 (9.15)
Private Competition Index (CPIA 2004)	1.744 (174.88)	2.691 (6.08)	2.425 (6.57)
Private Competition Index x Log (Population)	-0.175 (102.68)	-0.289 (4.09)	-0.249 (4.27)
Constant	-3.066 (68.47)	-5.925 (3.03)	-4.645 (2.93)
Spatial Error		0.426 (9.12)	

†Absolute values of t-statistics in parentheses. Marginal effects are available from the authors upon request.

Table 8: Impact of Policy Reform (to CPIA = 4):
% Increase in Area Coverage

Country	% Increase
Angola	1,289.2
Zimbabwe	287.2
Congo	193.6
Sudan	182.2
Chad	177.0
Mozambique	151.4
Mauritania	148.3
Congo, Dem Rep	142.3
Liberia	104.0
Gabon	96.1
Nigeria	79.9
Burkina Faso	79.0
Cote d'Ivoire	77.7
Togo	63.9
Mali	63.6
Zambia	56.2
Kenya	45.7
Malawi	37.4
Tanzania	37.3
Ethiopia	36.4
Senegal	33.9
Swaziland	33.3
Cameroon	32.7
Burundi	29.5
Ghana	24.9
Lesotho	24.3
Gambia	19.1
Rwanda	9.1
Total	95.8

Figure 1: GSM Cell Phone Expansion in Sub-Saharan Africa, 1999 – 2006

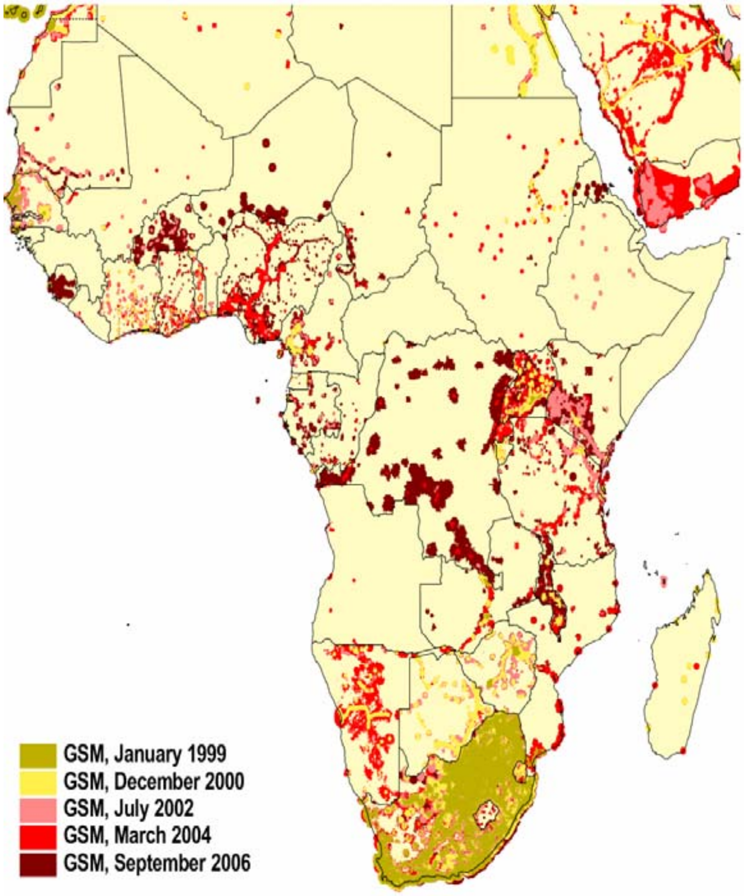
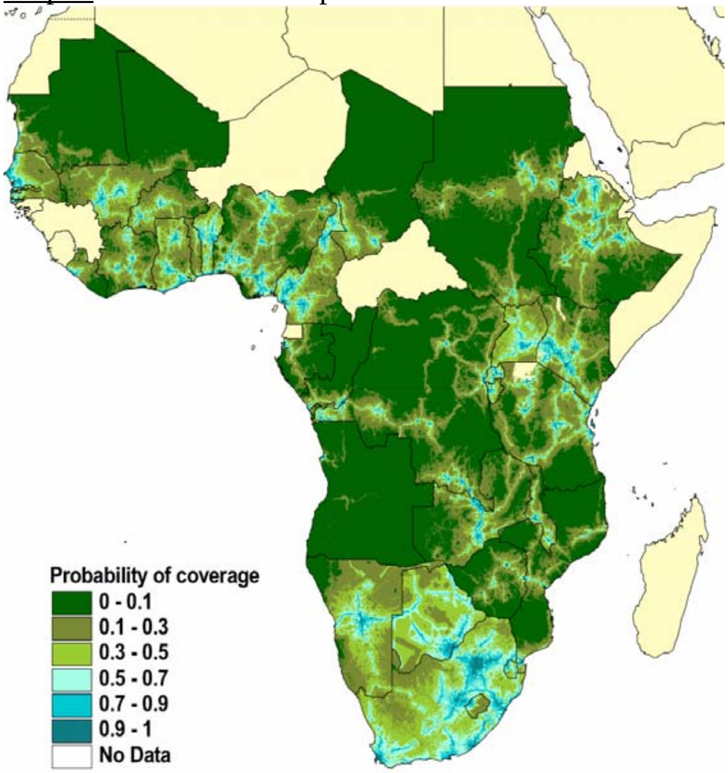


Figure 2: Predicted Probability of Cell Phone Coverage

Map a: Prediction from probit



Map b: prediction with World Bank CPIA competitiveness rating of at least 4.0