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Who Gets Public Goods? Using Satellite Imagery to Measure the Distribution of Rural Electrification

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Abstract

For scholars interested in the role of democracy on development outcomes, tracking the progress with which governments provide basic public services is hampered by inconsistent, inaccurate, or missing data. I propose a novel method to estimate the provision of rural electrification based on analysis of satellite imagery of the earth at night. Combined with high-resolution population maps, I generate new measures of the number of people living in unelectrified areas across the globe. Unlike data derived from official government statistics, the quality and precision of these new estimates are not correlated with political institutions or economic circumstances. After demonstrating the plausibility of my new estimates, I use regression analysis to show that democratization is associated with an 8% decrease in the share of unelectrified populations even after controlling for differences in wealth, population density, and other factors.

1 Introduction

In much of the world, tracking the progress with which governments provide basic public services is hampered by unreliable and problematic data. Impoverished countries lack the bureaucratic capacity to collect dependable statistics. Corrupt regimes routinely misreport their spending. Pressure from international lenders induce some governments to embellish their outlays. Countries overwhelmed by civil war and the destruction of life inevitably lose much of their data as well. As a result, we have only vague estimates regarding government provision of vital services like electrification, health, and sanitation for much of the world.

In the widely used World Bank Development Indicators, government expenditure data is missing for 31% of countries in 2001. Relying on official statistics alone, we lack the ability to track the impacts of democratization in Liberia, state failure in Somalia, famine in North Korea, and regime change in Afghanistan and Iraq. Even where data on expenditures do exist, evidence suggests that not all government funds reach their intended recipients in the developing world (Banerjee, Deaton & Duflo 2004, Pritchett 2001). As many have demonstrated, the quality of political and economic data is often endogenous with the very political

institutions whose effects we want to measure (Ross 2006). In short, the countries where basic public services are most needed are often the places where data is the least credible.

In this paper I propose the use of satellite imagery to derive objective estimates of the distribution of rural electrification. While this represents only a single category of public good, rural electrification is a vital service that continues to be underprovided in many parts of the world. More than a century after the introduction of electric power transmission, at least a quarter of the world's population still live without electricity and rely instead on wood, agricultural residues, and animal dung to meet their energy needs (International Energy Agency 2006). More than simply a modern convenience, access to electricity is a life-altering transformation that improves quality of life and enables development. Electric light extends a day's productive hours, allowing children to study after the sun has set and enhancing the safety of women at night. Refrigeration allows for the preservation of food and medicines. Electrical power enables the development of industries and creates new jobs. Powered water pumps reduce the effort needed to collect clean water. Electrical cooking stoves reduce the amount of time needed to gather wood and other biomass fuels.¹ For communities, electrification improves safety at night via streetlights, enables irrigation and drainage systems to improve agricultural productivity, and encourages entrepreneurship. Yet despite its importance, governments have varied widely in their ability to provide electricity to its rural citizens.

Drawing on satellite imagery of the earth at night and using the presence of observable lights as an indicator of the presence of electrical infrastructure, I identify all unlit areas of the world to generate new estimates of the proportion of a country's population that lacks electrification. The utility of the approach presented here is twofold. First, the quality of these estimates of rural electrification is wholly exogenous to political institutions and economic circumstances. Satellite images provide an objective and impartial picture that does not discriminate between democracies and dictatorship, honest and corrupt regimes, rich or poor. It is sensitive only to technical limitations of the satellite sensors and population maps (described further below). Thus this new data allow for a more adequate and convincing test of the effects of political institutions like democratic rule on the provision of basic public services. Second, it provides a direct measurement of the absence of rural electrification, measured bottom-up from local level measurements using a consistent instrument and methodology. It does not rely on indirect estimates derived from national-level energy data which depend heavily on energy production data, some of which may never get to intended recipients as a result of losses from poor infrastructure or graft. Household census data is good where available but their geographic and time coverage is generally poor and not uniform around the world.

¹In rural Africa, many women carry 20 kilograms of fuelwood an average of 5 kilometers every day (International Energy Agency 2002, p. 367)

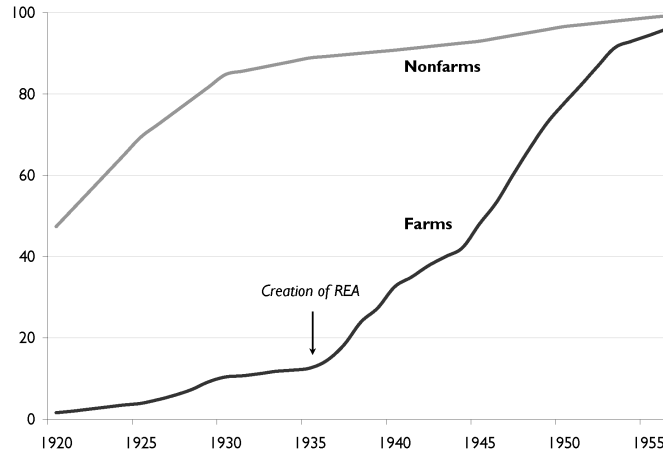


Figure 1: Electrifying America: Percentage U.S. dwelling units with electricity, 1920–1956
 Source: U.S. Census Bureau, Historical Statistics of the United States, 1975, S 108-119.

Studying variation in the provision of rural electrification also allows us to examine the effectiveness of governments around the world. The construction and maintenance of rural electrical infrastructure is so costly that its provision is unlikely without significant government investment. At the same time, access to electricity falls into a small class of basic needs that people care about deeply and are likely to desire almost uniformly across the globe. As a result, examining the ability of governments to provide electrification to its rural residents provides a critical test of its ability to meet the basic needs of its citizens.

Throughout history, politics has played a prominent role in the extension of electrification into rural lands. At the founding of the Soviet Union in the 1920s, Vladimir Lenin famously declared, “Communism is Soviet power plus the electrification of the whole country.” His State Commission for Electrification of Russia (GOELRO) sought to extend the power grid to the entire country and formed the basis of the first Soviet plan for national economic recovery. The plan reflected Lenin’s belief in a reorganized industry based “. . . on electrification which will put an end to the division between town and country and . . . overcome, even in the most remote corners of land, backwardness, ignorance, poverty, disease, and barbarism.” Implementation of GOELRO led to a near doubling of the country’s total national power output by 1931 (Kromm 1970) and full electrification of the entire Soviet Union in the years that followed. Meanwhile, in Germany, Holland, and Scandinavia, the electrification of every home was seen as a desirable political goal and 90% of homes were electrified by 1930 (Nye 1992, p. 140).

In the U.S., however, electric power distribution had been dominated by private utilities who focused their business in urban centers. Extending the power grid from cities to rural areas requires high fixed cost

investments in infrastructure including new power plants, long haul transmission lines, substations, and shorter distribution lines to the end user. Rural areas with low customer densities were unattractive markets to profit-minded firms. By the time of the Great Depression, only one in ten rural Americans had access to electricity compared to 90% of city dwellers. With the collapse of the economy, even private power utilities in the most lucrative urban markets were struggling to stay afloat. Farmers seemed destined to stay in the dark had it not been for Franklin Roosevelt's celebrated establishment of the Tennessee Valley Authority (TVA) in 1933 and Rural Electrification Administration (REA) in 1935. At the end of 1934, only 12.1% of all U.S. farms had electricity, while only 3% were electrified in Tennessee and less than 1% in Mississippi. By 1943, the TVA and REA had brought electricity to four out of ten American farms. Within one more decade, nine out of ten were connected (U.S. Census Bureau 1975, p. 827). Former U.S. Secretary of Agriculture Bob Bergland recalled, "The day the lights finally came on at our farm, I remember my mother cried." Another farmer reminisced, "I remember singing with robust glee in celebration as our little strip of houses along a dirt road was connected to electricity. We sang out with joy and no small amount of amazement: Oh the lights, the lights, Lottie Mae got light and we got lights! Oh the lights, the lights."²

Outside of the industrialized world, electrification has been pursued with uneven ambition and success. While access to electricity certainly is related to a country's level of development, the relationship is not absolute. One might reasonably assume that electrification spreads across a country as the state modernizes and gains the financial strength, bureaucratic capacity, and technological sophistication to operate significant electrical infrastructure. But if this were true, we would expect states with similar levels of wealth to have congruous rates of electrification. As figure 2 shows, many countries with comparable poverty levels have very different levels of access to electricity. The percentage poor in Bolivia and Armenia are identical but less than two-thirds of Bolivians have electricity compared to universal access in Armenia. Pandemic poverty in Nigeria is associated with higher levels of electrification than in Kenya. The Dominican Republic has lower levels of poverty than Jamaica but much lower levels of electrical provision. These variations suggest that while the level of development is important, it alone does not explain why some states are better able to provide electrification than others.

In China, purposeful government policies have led to the electrification of 700 million people's homes over the last two decades — an achievement of unprecedented scale and scope. In one program promulgated in State Council Document No. 190 in 1983, local development of rural hydropower facilities was mandated in 100 mostly remote rural counties and funded through subsidies and low-interest loans. By

²Campbell, Dan, "When the lights came on," <http://www.rurdev.usda.gov/rbs/pub/aug00/light.htm>

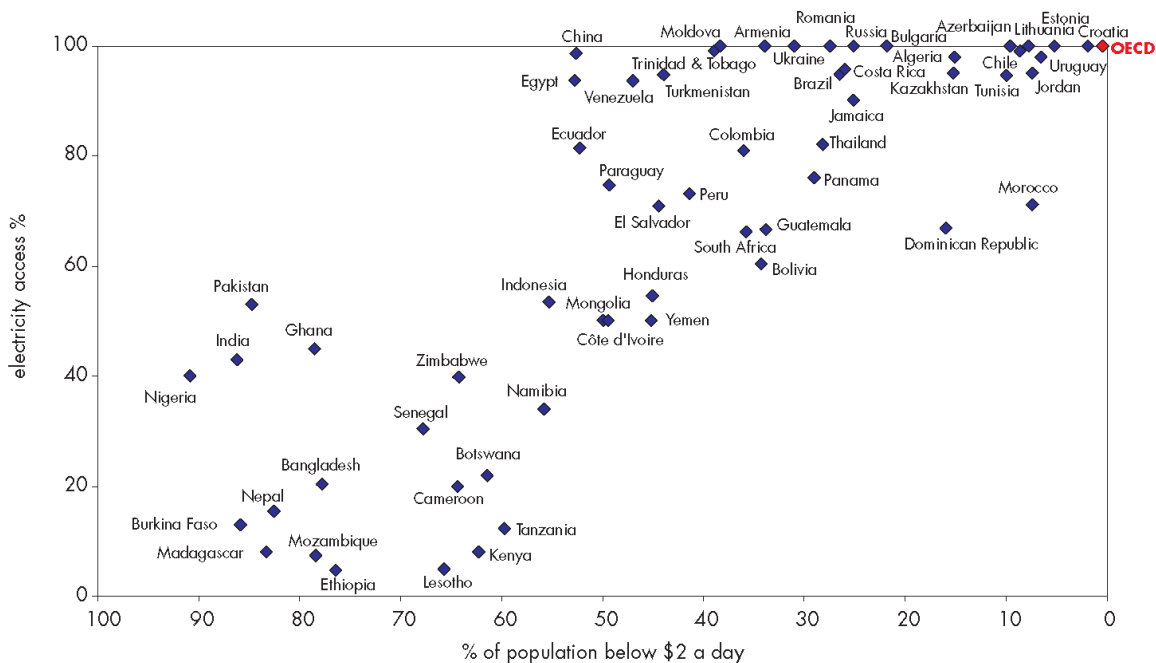


Figure 2: Electricity access and poverty, 2000
 Source: International Energy Agency (2002, p. 375)

2000, an additional 553 counties had also been electrified through the program, bringing the total number of beneficiaries of rural hydropower to nearly 140 million people. Overall, total electricity consumption in rural China increased tenfold between 1978 and 2000. The number of villages without electricity decreased from 55,000 in 1993 to 9,300 in 2002. According to official estimates, over 98% of Chinese homes have an electrical connection today (SHP News 2004, Pan et al. 2006).³

Meanwhile just west of China in the world's most populous democracy, India has faced enormous struggles to electrify its rural lands. More people in India lack electricity than any other country in the world, accounting for a full third of the world's powerless. Half a billion Indians living in over 100,000 villages still had no electricity as of 2005. Several government efforts have sought to electrify India's rural villages. In the late 1990s in Uttar Pradesh, Chief Minister Mayawati initiated the Ambedkar Village program (Ambedkar Gram Vikas Yojana) to provide over 11,000 of the poorest villages with electrification, roads, and irrigation. The program was widely regarded as a targeted effort to win Scheduled Caste votes and was closely associated with Mayawati and her Bahujan Samaj Party (BSP).⁴ Despite its intentions to alleviate poverty, the

³Interestingly, the satellite-derived estimates I describe below observes a much higher proportion of the Chinese population living without reliable electricity.

⁴The BSP was founded in 1984 to consolidate caste and religious minority interests in India. As a staunch advocate of Scheduled Caste issues, it has been most successful in Uttar Pradesh where it won nearly 60% of the Scheduled Caste vote in 1998 (Chandra 2004).

project has been criticized for its blatant politicization of caste differences. Some in the media have characterized the program as a mismanaged “pet” project of Mayawati’s, reflecting her “obsession with the Dalit agenda.”⁵

The Ambedkar Village program’s implementation showcases the powerful role of patronage in Indian politics. The program has been accused of mismanagement and corruption (\$50 million or 1/3 of program spending could not be accounted for, presumably lost to kickbacks and fraud). During the 1997 to 2001 period, audits revealed that numerous villages had been illegitimately electrified. In the Barabanki district just east of Lucknow, six villages that had not been authorized to receive electrification funds were nonetheless electrified. Several other villages were found to have been selected for electrification by intervention of the Energy Minister, contrary to program guidelines (Wilkinson 2006).

Similar patterns of politically motivated public goods provision have also been documented in Mexico. A massive poverty alleviation program, PRONASOL (Programa Nacional de Solidaridad), began in 1989 to provide or improve access to water, electricity, nutrition, and education in poor communities. Municipalities dominated by the ruling Institutional Revolutionary Party (PRI) received significantly higher per capita transfers than those voting for another party (Diaz-Cayeros, Magaloni & Estévez Forthcoming).

As these examples show, the state has played a central role in providing electrification to its rural citizens throughout the world.⁶ According to historian David Nye, “In no society was electrification a ‘natural’ or ‘neutral’ process; everywhere it was shaped by complex social, political, technical and ideological interactions” (Nye 1992, pp. 138-139).

Drawing on new estimates of the extent of rural electrification, I examine theories that link political institutions to the provision of basic public goods. After describing the satellite and population data, I present my new estimates of unlit populations for all countries in the world. I compare these numbers against conventional electrification data from official statistics. I then analyze variations across democratic and autocratic regimes and find large differences between political systems, especially among autocratic regimes. I test these results using regression analysis and find persistent differences between democracies and autocracies, even after controlling for income level, population density, and other controls. I conclude with a discussion of next steps, in particular the examination of sub-national variation to validate the country-level findings presented here.

The Ambedkar program gets its name from B.R. Ambedkar, an untouchable who rose to prominence as a jurist and architect of the Indian constitution in the post-independence period.

⁵Tripathi, Purnima S., “Mayawati in Deep Trouble,” *Frontline*, Volume 19, Issue 19, September 14-27, 2002.

⁶It may be true that in the poorest parts of the world, some governments are so ineffective and dysfunctional that NGOs and private donors are the only providers of rural electricity.

2 Measuring Rural Electrification from Above

High levels of uncertainty pervade official estimates of the portion of the global population without access to electricity, a vital and basic public service that is typically provided by governments in most of the rural world. I propose a new method that relies on the analysis of satellite images of the earth at night to identify all lit and unlit populated areas across the globe. Since 1970, the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has been flying in polar orbit capturing high resolution images of the entire earth every night between 20:00 and 21:30 local time.⁷ Captured at an altitude of 830 km above the earth, these images reveal concentrations of outdoor lights, fires, and gas flares at a fine resolution of 0.56 km and a smoothed resolution of 2.7 km.

Beginning in 1992, all DMSP-OLS images were digitized, facilitating their analysis and use by the scientific community. While daily images are available, the primary data products used by most scientists are a series of annual composite images. These are created by overlaying all images captured during a calendar year, dropping images where lights are shrouded by cloud cover or overpowered by the aurora or solar glare (near the poles), and removing ephemeral lights like fires and other noise. The result is a series of images of time stable night lights covering the globe for each year from 1992 to 2003 (Elvidge et al. 1997a, Imhoff et al. 1997, Elvidge et al. 2001). Since the DMSP program may have more than one satellite in orbit at a time, some years have two annual images created from composites from each satellite, resulting in a total availability of 18 annual composite images.

Images are scaled onto a geo-referenced 30 arc-second grid (approximately 1 km²). Each pixel is encoded with a measure of its annual average brightness on a 6-bit scale from 0 to 63. These are relative values and thus individual pixel values are not directly comparable from one year to the next. This does not affect the analysis of variation within a single annual composite image as I do here.

Figure 3 shows a reverse-color DMSP-OLS image of night-time lights in 2003 with darker dots indicating more brightly lit areas and white areas on the page indicating darkness. The image reveals large variation in light intensity around the world, with especially broad and brightly lit areas across the eastern U.S., western Europe, India, and east Asia. Meanwhile, inhospitable environments in the frozen Arctic deserts of Canada, Alaska, and Siberia and the hot deserts of Africa, China, and Australia are cloaked in darkness. At first glance, the distribution of lights might appear to be a reflection of population distributions. But closer examination reveals that there are important differences across the world and within countries. For example, much of

⁷Actually, usable data are unavailable from the polar regions and the typical geographic extent of DMSP coverage is -65 to +65 latitude. This results in missing data for portions of the world within the Arctic and Antarctic circles (home to only 0.0005% of the global population).

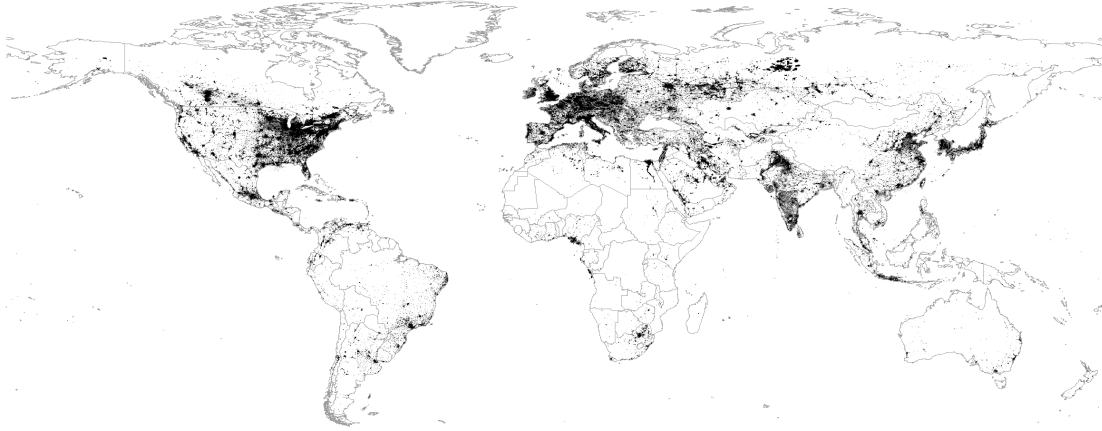


Figure 3: Nighttime lights of the world, 2003
Darker cells have higher light output. Source: NOAA National Geophysical Data Center

Africa is dark, even though it is home to 15% of the world's population. While more than one in three people in the world live in India and China, their light output accounts for only a tenth of the global total. A country's level of industrialization would appear to explain at least some of these patterns. South Africa has a similar population density but larger economy than neighboring Zimbabwe and a correspondingly higher light output. The difference across the 38th parallel on the Korean peninsula is particularly striking.

Numerous studies have validated the DMSP-OLS night lights images against measures of electric power consumption and gross domestic product (Elvidge et al. 1997b). More recently, scientists are using these data to model urbanization (Lo 2001, Small et al. 2005, Amaral et al. 2006) and the environmental impacts of fires and natural disasters (Fuller 2000, Kohiyama et al. 2004).

Three technical limitations complicate the use of nighttime lights to estimate the extent and intensity of use of electrical infrastructure: saturation, blooming and low sensitivity. *Saturation* occurs because of the limited dynamic range of the satellite sensor. To accurately detect dimly lit areas, the sensors are calibrated with high gain on the photomultiplier tube. This results in small areas of saturation (i.e. cells with encoded brightness values of 63) in the centers of large cities and other brightly lit zones. This does not affect the analysis here since we are interested primarily on unlit cells. *Blooming* occurs when lights from an area appear to spill into neighboring areas resulting in an overglow. *Blooming* increases in the presence of nearby water sources and other sources that reflect nearby light into space. This means that nighttime light images tend to overestimate the extent of light coverage, especially around large cities and coastal settlements. Despite this because this results only in a downward bias in the estimate of unlit populations

and because the effects of blooming are unlikely to be correlated at the country level with the political variables I use in my analysis. The *limited sensitivity* of the DMSP sensors mean that not all dimly lit regions are detectable in satellite images. In theory, the DMSP sensors are capable of detecting radiances as low as 10^{-9} watts/cm²/sr/μm, and field checks have revealed that lights from U.S. towns as small as 120 people are detectable. However, even sparse cloud cover and minor atmospheric disturbances can cloak the lights from a small settlement. Moreover, because DMSP annual composite images are produced through image processing algorithms designed to remove ephemeral light sources like lightning and fires, it is possible that some of the most dimly lit (or irregularly lit) areas also get blacked out. The result is that the annual composite DMSP images do not unambiguously detect the electrification of small settlements. More research is required to understand the limits of light detection at the low end of the sensitivity spectrum. As a result, I propose a conservative strategy below which only identifies an area as unlit if the underlying population count exceeds a certain minimum threshold.

To identify populated regions, I draw on the LandScan 2005 population count map produced by the Oak Ridge National Laboratory. This is the highest resolution population map currently available. Drawing on data from census counts at the sub-national level, population counts are apportioned onto a 30 arc-second grid using likelihood coefficients based on proximity to roads, slope, land cover, and other information. LandScan population counts estimate the ambient or average population distribution over a 24-hour period.⁸ The LandScan population maps have been thoroughly validated and are widely used by the United Nations, World Health Organization, and Food and Agricultural Organization. Early LandScan products used nighttime lights to identify urban areas (Dobson et al. 2000). However, the nighttime lights were subsequently dropped in favor of higher resolution imagery and land cover databases.⁹ As a result, the LandScan population data are generated independently of the DMSP-OLS night lights data.

A direct comparison of the raw LandScan and DMSP-OLS images reveals that a very large number of populated cells have no light output.¹⁰ An obvious reason for this is that areas with very low population densities may not produce enough outdoor light to be detectable by the satellite sensor. Moreover, the number of unlit populated cells is inflated by the large number of cells estimated by LandScan's population

⁸LandScan's 'population counts' differ from traditional estimates of population density. Population density measure residential settlement patterns and typically undercount the presence of people in commercial centers and airports, for example. LandScan's 'population counts' are an attempt to represent the spatial distribution of population based on person hours.

⁹Current LandScan products use the following satellite data: NASA MODIS land cover (Friedl et al. 2002), topographic data from the Shuttle Radar Topography Mission (Rodriguez, Morris & Belz 2006), and the high resolution Controlled Image Base (CIB) from the U.S. National Geospatial Intelligence Agency (NGA).

¹⁰In early research comparing light output and population density in the continental United States, Sutton et al. (1997) found that 17% of the population occupied unlit cells, despite virtually complete electrification across the country. These estimates were based on some of the first DMSP composites created with early image processing algorithms. It is likely that analysis of current DMSP composites would yield a much lower estimate of unlit population.

allocation algorithms to have population counts as low as 1. Thus a direct comparison of these data sources does not yield a reliable estimate of unelectrified populations.

A more reasonable identification strategy to link unlit areas with the lack of electrification should focus only on areas with a minimum population density below which we would not expect to detect light output in the DMSP images. The lower the minimum population threshold, the more dark cells are identified. After several trial runs, I adopted a minimum threshold by which only those unlit cells with at least 100 persons per cell made it into my count of people living in unelectrified areas.

The validity of this threshold rests on the important (and possibly tenuous) assumption that the emission of nighttime lights is primarily a function of population density and that this relationship is constant across the world. One reason such a claim might be credible is the remarkable level of similarity in outdoor lighting technology across the globe. Sodium vapor lights are the dominant form of street lighting around the world. Recognizable by their orange-yellow glow, sodium lights are prevalent in both rich and developing countries and are favored for their high energy efficiency. Older mercury vapor lights, first introduced in the 1940s, are much less efficient and are slowly being replaced in much of the United States and other “early adopters.” The metal halide lights is a newer technology that emits a bright white light. It is widely used in commercial districts and industrial applications, though their high operating costs are likely to limit their use in rural areas. However, it is possible that the concentration of outdoor lamps on a typical rural road is correlated with level of industrialization. More research is required to test this notion. If this were the case, an improved light detection scheme would estimate country-specific minimum population thresholds for light emission based upon level of industrialization and could be validated against data on the lowest detectable light emissions in each country.

These limitations aside, I propose that the 100-person threshold used here allows for a conservative yet plausible first estimate of unlit populations. To illustrate, I describe the method as applied to India. India is home to 1.2 billion people making it the second most populous country in the world and the largest democracy. The DMSP satellite image of India for 2003 is composed of 4 million cells with a mean light output of 2.2 (4.9 excluding unlit cells) on the 0–63 scale. Of the 4 million cells, 55% are dark with no detectable light output by the satellite sensors. Of these unlit pixels, about 446 thousand or 20% have a population of at least 100 according to LandScan estimates. Summing the population counts across all these unlit pixels with at least 100 people yields a total estimate of about 250 million Indians living in unlit cells.¹¹

¹¹As evident in the section below, the satellite-derived estimate of unelectrified population for India is among the less accurate estimates when compared against official statistics. However sub-national variations within India’s states appear to correlate well with official data.

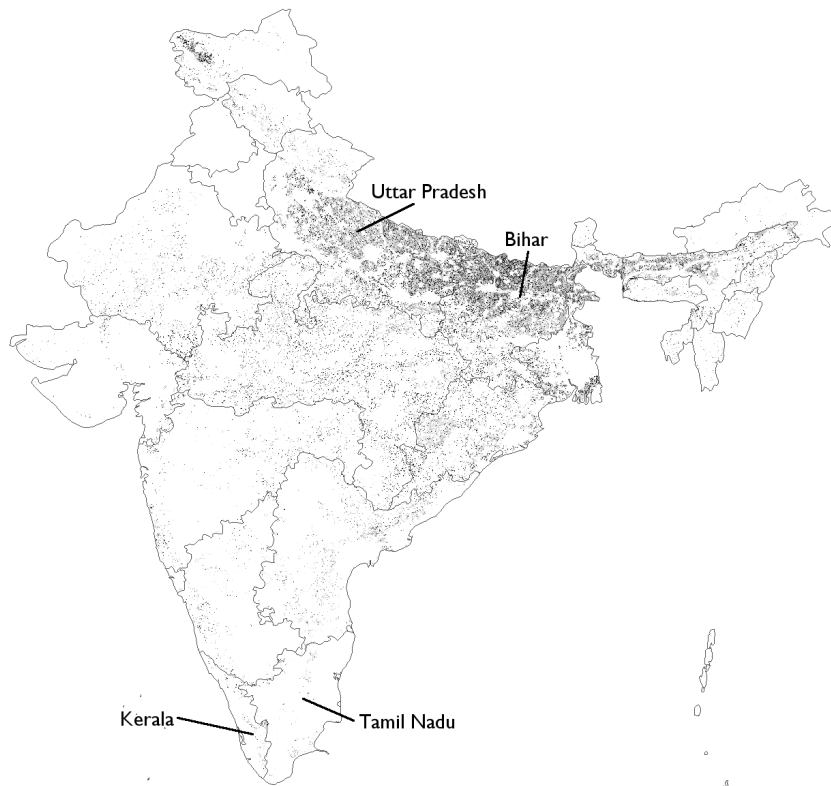


Figure 4: Estimated unlit populations in India, 2003

Each dot represents a 30 arc-second cell with no detectable light output and population of at least 100. Darker cells have higher population counts. Estimated using DMSP F152003 and LandScan 2005 data.

Region	Total population (millions)	Unlit population (millions)	Unlit population (%)
Western Democracies and Japan	856.5	2.3	0.3%
North Africa and Middle East	409.6	15.6	3.8%
Eastern Europe	407.5	15.6	3.8%
Latin and Central America	541.9	27.0	5.0%
Asia	3,422.7	823.0	24.0%
Sub-Saharan Africa	728.0	260.7	35.8%
Other	10.5	0.3	2.7%
World	6,376.6	1,144.5	17.9%

Table 1: Estimated unlit population from satellite images, 2003

Source: Author calculations from DMSP F152003 and LandScan2005 sources.

These unlit but populated pixels are plotted in Figure 4, with darker dots indicating higher population counts. The figure shows the distribution of populations living in unlit areas across India. The highest concentration of unlit populations are clearly visible on the northeast rim just south of Nepal. This area includes two of India's poorest states, Uttar Pradesh and Bihar. Note that even in these impoverished regions, urban cores including the state capitals Lucknow and Patna are white, indicating full urban electrification. In comparison, Kerala and Tamil Nadu on the southern tip of the Indian peninsula, have only small pockets of unelectrified communities. Indeed, India's Ministry of Power estimates that 42% of villages in Uttar Pradesh and 51% of Bihar lacked electricity in 2005. Meanwhile, the estimated rates for Kerala and Tamil Nadu were 3% and 0% respectively.

Applying the method described above, I estimate 1.1 billion people, or 18% of the global population, live in unlit areas of the world. Regional breakdowns are presented in Table 1. This global estimate compares reasonably well with the World Bank projection of 1.3 billion people living in unelectrified rural areas (International Energy Agency 2006). It is also possible to compare the estimates of electrification derived from DMSP satellite imagery against several sources of country-level data. Figure 5 contrasts satellite-derived estimates of the share of the unlit population against recent data on the electricity generating capacity of 149 countries. As expected, countries with lower levels of production capacity per person tend to be places where larger portions of the population live in unlit areas. These measures correlate at a level of 0.79. Figure 6 plots estimates of the total population living in unlit cells against International Energy Agency estimates of unelectrified populations derived from official government and UN statistics. Among this group of 76 developing countries for which IEA data exists, a few notable outliers including China and Egypt stand out for their poor fit with the overall trend. Still, the overall correlation of 0.87 is very high.

These encouraging comparisons provide confidence that estimates derived from satellite images can be

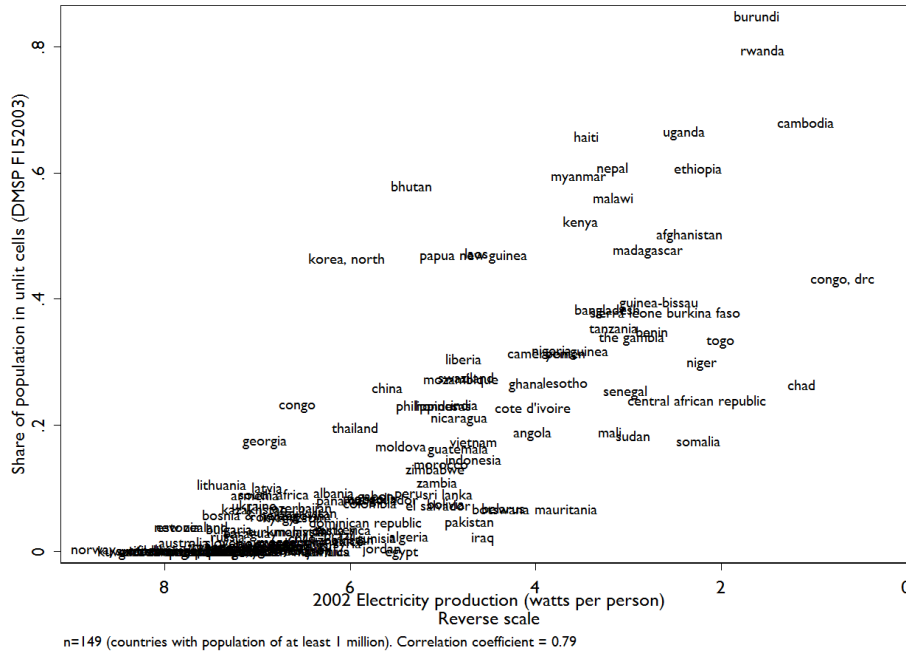


Figure 5: Comparison of unlit population with electricity production data
Sources: DMSP F152003, LandScan2005, 2007 update to Canning (1998)

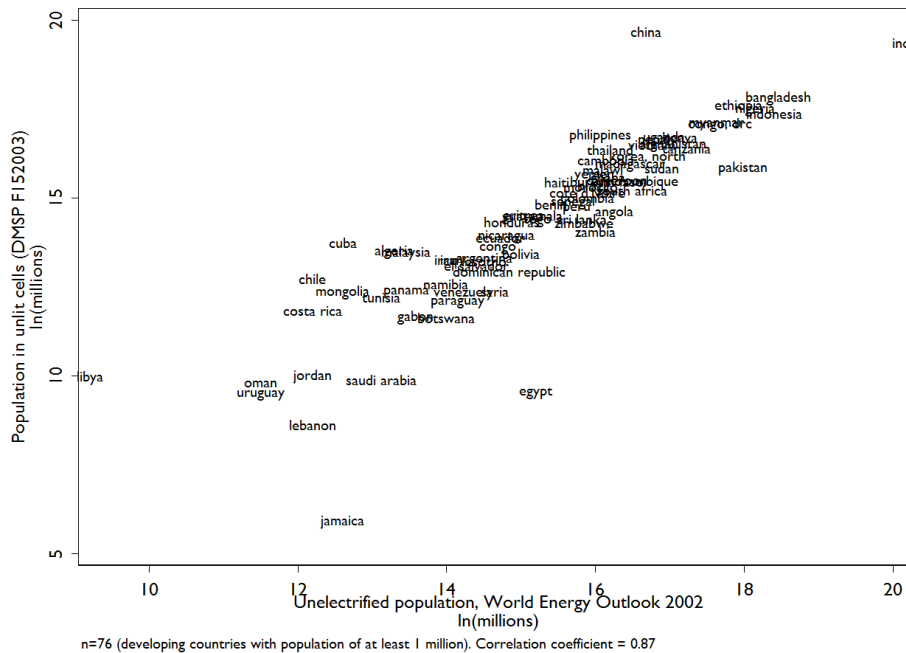


Figure 6: Comparison of unlit population with estimates of un electrified population
Sources: DMSP F152003, LandScan2005, World Energy Outlook 2002

used as a reliable measure of the extent of electrification around the world. Unlike country-level statistics from government sources, the quality of satellite-derived data are not affected by political and economic circumstances. The results here are unbiased and objective estimates of unlit populations that are not likely to be correlated with differences in the bureaucratic capacity of states, the consistency of record-keeping practices, or the honesty of state officials. Moreover, the satellite images provide detailed information at the local and sub-national levels, offering opportunities for new analysis not possible with country-level data alone. Before looking at the micro-level, however, the large variation across countries requires explanation. In the following section, I evaluate the role of political institutions, and especially the impact of democratic rule, on the provision of this basic public service.

3 Electrification and Politics: The Democracy Effect

Scholars in political science have long debated the effects of democracy on development outcomes. Sen (1999) famously argued that democracies never suffer from famine. Others have found that democracies provide higher levels of public goods than do dictatorships (Bueno de Mesquita et al. 2003, Lake & Baum 2001). Przeworski, Alvarez, Cheibub & Limongi (2000) suggest that even after applying statistical corrections for selection effects, democracy reduces infant mortality. According to Siegle, Weinstein & Halperin (2004, p. 57), “poor democracies are almost always stronger, calmer, and more caring than poor autocracies, because they allow power to be shared and encourage openness and accountability.” Yet given weaknesses in the quality and scope of data, some research challenges whether democratization actually has meaningful effects on basic measures of well being (Ross 2006).

There are two primary arguments why democratic governments should provide better basic services to its citizens than dictatorships. First, democratic governments must win elections. As a result of the pressure to perform induced by competitive elections, democratic leaders must deliver benefits to their constituents in order to stay in office. Representatives who underperform face public criticism and competition from opponents who campaign to defeat them. The ballot gives voters the ability to punish politicians who fail to live up to their promises. Dictators also require support to stay in power and can be punished for poor performance via coups. However, the institutional apparatus for removal from office is embedded into democracies, especially the holding of regular competitive elections, in a way that does not apply to authoritarian regimes. Because democratic politicians are likely to be evaluated on their ability to provide basic public services like electricity, this suggests that democratic leaders should provide higher levels of

basic public goods than dictators who do not need to win elections.

Second, democratic leaders require a larger base of support than do dictators. While specific electoral rules differ across democracies — including across presidential and parliamentary systems or proportional-representation and majoritarian-style voting rules — democratic leaders require a plurality or majority of the vote to win office. In contrast, dictators can stay in office without mass popular support. As Gandhi & Przeworski (2006, p. 2) state “dictators are dictators because they cannot win elections.” Unable to sustain the support of a majority of the population, dictators hold on to power by outlawing political competition and relying instead on the loyalty of a smaller coterie of military, political, and business allies. For both democratic leaders and dictators, the size of their minimum winning coalitions influences the means with which they secure the backing of their supporters. The support of individuals can most easily be bought off with jobs, cash, and other patronage. But as the size of the minimum winning coalition increases, Bueno de Mesquita et al. (2003) argue that provision of public goods becomes a more cost effective way to win support than by providing private transfers directly to individuals. As a result, the larger support coalitions needed by democratic leaders is likely to induce higher investments in the provision of broad classes of public goods and services.

These fundamental differences create disparate incentives for democratic and autocratic governments in the provision of basic public services, including electrification. Using the satellite-based estimates of unlit populations described above, I evaluate whether democratic governments differ systematically from autocracies in the provision of rural electrification to its citizens.

To assess the influence of democratic rule on rural electrification, I construct a measure of *Democratic history* which calculates the portion of years from 1946 until 2002 (or since independence for younger countries) that a country has been under democratic rule. I use the dichotomous coding of democracy from Cheibub & Gandhi (2004).¹² It is important to account for history since electrical infrastructure observed in 2003 is a stock measurement, accumulated through the flow of investments over years and decades. Looking only at the current level of democratization might yield incorrect inferences, since the extent of electrification in 2003 reflects the accumulation of decades and years of investments. That said, more than half of the countries in my sample of 151 countries do not change regime type at any point during the post-War period: 52 countries have always been autocratic while 31 have stayed democratic.

Among sustained democracies, the provision of rural electrification is impressively uniform. In these 31

¹²I also compare my results using a simple count of the number of years of democratic rule as well as two measures constructed from Polity2 data: the portion of years under “strong democratic” rule (i.e. Polity2 \geq 6) and years in which there were competitive elections (i.e. exrec = 8). I find similar results using these alternate measures though the effects are less statistically significant.

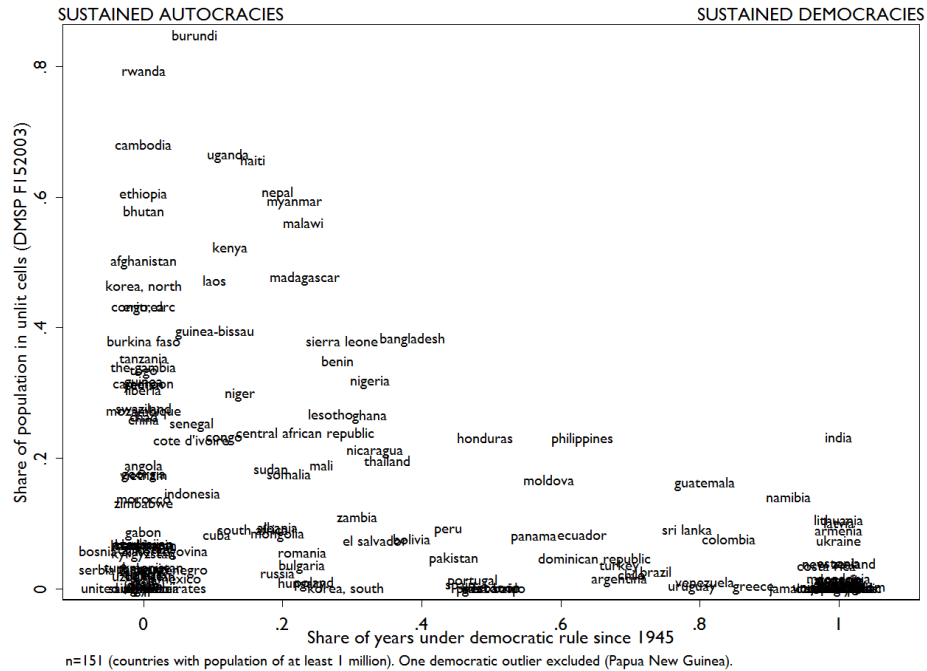


Figure 7: Unlit population by history of democratic rule
Sources: DMSP F152003, LandScan2005

countries, only about 2 out of every 100 people live in unlit areas.¹³ Excluding India — the poorest and most unelectrified country among this group of enduring democracies — drops the rate even lower. Among authoritarian regimes, the variance in electrification rates is much wider. In Rwanda and Burundi, more than three-quarters of the population live in unlit areas compared to less than 1% in Iran and Egypt. Some of these differences are likely to be linked to oil wealth in the Middle East, but variation exists even among non-oil producing dictatorships.

In the middle region of Figure 7 lie almost half of the world’s countries that have experienced some democratic and some autocratic rule since 1946. The pattern here remains consistent with the above: countries with a longer history of democratic rule have lower rates of unlit population. In addition, variation in electrification rates decreases at all levels of democratic history. While the figure provides only a cross-sectional snapshot and does not reveal whether individual democratizing countries have increased the rate of provision over time, the trend is consistent with a strong and clear democratic effect. Regression analysis allows for a more careful comparison of the effects of regime type on electrification provision.

¹³Note that several post-Communist countries like Lithuania and the Ukraine get included in this group since they have been democratic in every year since independence. An improved coding of their democratic history would take their years under Soviet governance into account.

Table 2: Variable Summary

Variable	Observations	Mean	Std. Dev.	Min	Max
Democratic past	154	0.387	0.402	0	1
Population density, 2005 (people/km ²)	146	96.105	119.367	1.774	995.326
GDP per capita, 2002 (in 2000 US dollars)	147	8.190	8.777	0.338	34.286
Number of violent civil conflicts, 1946–2002	147	1.333	1.685	0	11
Ethno-linguistic fractionalization	146	0.404	0.281	0.001	0.925
ln(Mountainous terrain)	147	2.158	1.410	0	4.421
Oil production per capita, 2002 (barrels/yr)	147	1.590	5.962	0	43.425

3.1 Regression Analysis of Unlit Populations

Table 3 presents ordinary-least squares regression results to test the effects of democracy on electrification. My dependent variable is the proportion of a country’s population living in unlit areas as of 2003, derived from nighttime DMSP satellite images and population estimates from the LandScan project. Regression analysis allows for the evaluation of regime effects, holding constant other variables that are likely to influence the provision of electrification.

Among non-political variables, the most likely determinants of electrification are a country’s level of industrialization and the distribution of its population. The level of industrialization is an indicator of a country’s ability to afford the provision of electrification. Moreover, the more advanced an economy, the higher the need and demand for electrical infrastructure. I estimate level of industrialization using a country’s *GDP PER CAPITA*. Data come from the Penn World Table 6.2 and are denominated in thousands of 2000 U.S. dollars. A country’s *POPULATION DENSITY* is also an important determinant of electrification. Countries with higher population densities can more affordably connect higher proportions of their population to the electrical grid. Conversely, sparsely populated countries must absorb much higher per capita costs to electrify rural areas. Population density data are in people per km² and is computed from LandScan 2005 population numbers and World Bank data on surface area.

I include several other control variables which I describe briefly here. Violent civil wars and conflicts can quickly destroy infrastructure that might have taken years to build. As a result, countries who have suffered from a higher *NUMBER OF CIVIL WARS* might have lower levels of electrification. This variable, derived from the PRIO Armed Conflicts Dataset 3.0, counts the total number of internal conflicts with at least 25 battle-related deaths from 1946-2002. Many scholars have found a relationship between ethnic diversity and public goods provision. I include a measure of *ETHNO-LINGUISTIC FRACTIONALIZATION* that comes from

Table 3: Regression Analysis of Unlit Populations

Dependent variable is share of country population in unlit areas					
	(1)	(2)	(3)	(4)	(5)
Democratic history	-0.2035** (0.0287)	-0.0828** (0.0298)	-0.0795* (0.0360)	-0.1750** (0.0411)	-0.1376** (0.0437)
GDP per capita		-0.0100** (0.0013)	-0.0078** (0.0017)	-0.0209** (0.0053)	-0.0234** (0.0052)
Population density		0.0003* (0.0001)	0.0003** (0.0001)	0.0007** (0.0003)	0.0008** (0.0003)
Democratic history \times GDP per capita				0.0181** (0.0055)	0.0215** (0.0055)
Democratic history \times Population density				-0.0009* (0.0004)	-0.0012** (0.0003)
Number of violent civil conflicts since 1946			0.0122 (0.0110)		0.0174 (0.0093)
Ethno-linguistic fractionalization			0.1061 (0.0589)		0.0940 (0.0531)
ln (Mountainous terrain)			0.0069 (0.0102)		-0.0001 (0.0081)
Oil production per capita			0.0000 (0.0018)		0.0061* (0.0028)
Constant	0.2303** (0.0240)	0.2403** (0.0205)	0.1416** (0.0440)	0.2702** (0.0315)	0.1824 (0.0504)
Observations	151	145	145	145	145
R-squared	0.18	0.35	0.39	0.47	0.54

Note: Huber-White robust standard errors in parentheses. ** p-value \leq .01, two-tailed test. * p-value \leq .05, two-tailed test.

Fearon & Laitin (2003). The physical geography of a country might make more difficult for a government to provide rural electrification. For example, the presence of rough and *MOUNTAINOUS TERRAIN* might increase construction and maintenance costs for electrical infrastructure. This measure also comes from Fearon & Laitin (2003). Access to natural resources like oil might affect the incentives of governments to electrify their rural populations, both by diverting state resources toward resource extraction activities and by diminishing the accountability of governments towards their populations. I include a measure of *OIL PRODUCTION PER CAPITA* in barrels as recorded for 2002, derived from (Humphreys 2005) and BP's *Statistical Review of World Energy 2007*. The distribution of these variables is summarized in Table 2. I run all models using the Huber-White sandwich estimator to correct for possible heteroscedasticity.

Model 1 shows the bivariate relationship between democratic rule and electrification. Going from fully sustained autocratic rule to fully sustained democratic rule is linked with a 20% decrease in the population living in unlit areas. While this is a large effect, it might be generated by other confounding factors not included in the model but correlated with democracy like differences in wealth. Moreover, we know from

Figure 7 that since there is so much variance among autocracies, regime type alone is a relatively poor predictor of electrification levels absent any other information. What we would like to know is whether autocracies and democracies at similar levels of income and population distributions provide different levels of electrification. I account for these and other potential factors in the next two models. Model 2 includes controls for population density and the average income level of the country. These two variables are highly significant. Wealthier countries are likely to have lower numbers of unlit people. An increase of \$1,000 in per capita income lowers the share of the unlit population by 1%. The population density result has a somewhat unexpected positive sign, suggesting that more densely populated countries are likely to have more people living in the dark. This result is not driven by outliers and the positive sign and statistical significance of the coefficient holds even after excluding the most and least densely populated countries. Model 3 includes controls for war history, ethnic diversity, rugged terrain, and oil production. None of these variables significantly affect the level of electrification. Even in the presence of these control variables, the democratic history effect remains robustly significant. These models predict that after accounting for wealth, population density, and other differences, democracies still provide electrification to 8% more of their populations than do autocracies. Given that in the average autocracy, 18% of citizens live in the dark, the potential effect of democratization is substantial.

While these results suggest that there are important differences by regime type after controlling for wealth and population effects, it seems plausible that the effects of income and population density might be different for autocracies and democracies. We can test for such differential effects by running an interacted model where the democratic history of a state is interacted with its income level and population density. The results of the interacted model are presented in Table 3, Models 4 and 5. Both the original main effects and the new interaction effects are highly significant, suggesting that accounting for the interaction between democracy and wealth and population provide increased predictive power to the model. Correspondingly, the adjusted R-squared measures of model fit improve substantially for the interacted models, increasing by up to 0.15 compared to their non-interacted counterparts.

To facilitate the interpretation of the interaction effects, I plot separately the effects of income and population density by regime type in Figure 8, holding other variables constant at their means. On the y-axis is the population share in unlit areas predicted using the parameter estimates from Table 3, Model 4. The x-axis shows income levels from low to high on the left panel and population density on the right panel. The graphs reveal that the effects of income and population density differ systematically depending on the regime type of a state.

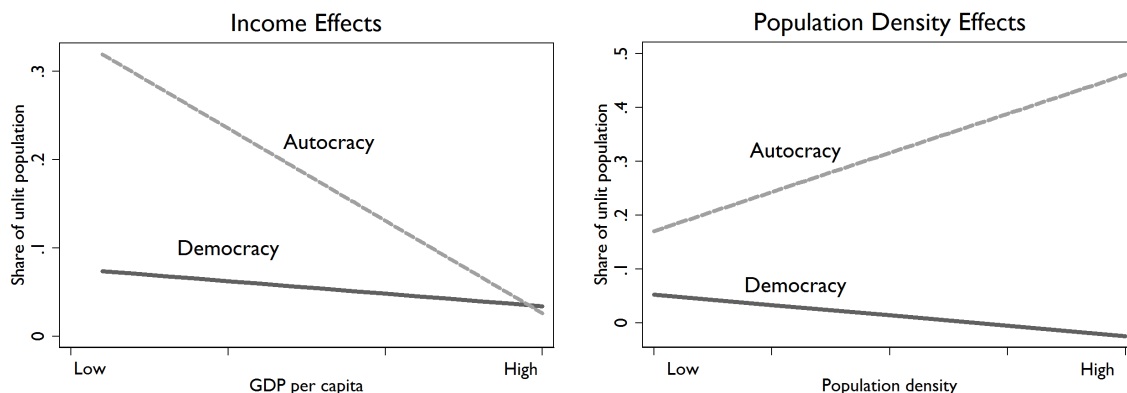


Figure 8: Regime effects on unlit population
 Predicted probabilities based on Table 3, Model 4. Other variables held at their means.

At the highest levels of income, autocracies and democracies are indistinguishable and provide full electrification to their citizens. But there are stark differences at lower levels of income. The share of the population in unlit areas is three times higher in the poorest autocracies compared to their democratic counterparts. Thus autocracies appear highly sensitive to wealth effects and provide increased electrification according to their ability to pay. Democratic governments are somewhat sensitive to wealth, but in general the differences in provision between the wealthiest and poorest democracies is very small. This finding is consistent with the expectation that democracies face higher expectations of public goods provision than do autocracies, regardless of income level.

The population density effects reveal additional differences between the two regime types. Dictators in countries with high population densities fail to provide electrification to up to twice as many rural residents than in low density autocracies. In democracies, variations in population density are much less important. Once again, democracies appear remarkably alike in their provision of electrification despite differences in population distribution across countries. The slight downward trend, while not statistically significant, is consistent with the theoretical expectations of Bueno de Mesquita et al. (2003) and Persson & Tabellini (2000) who argue that as the number of voters increases, democratic rulers can more efficiently win political support by providing more public goods and fewer private transfers.

Overall, the findings from the regression analysis above confirm the power of electoral incentives in democracies: democratic rulers provide basic public goods to win votes and are less sensitive to variations in income level or population distribution. That said, the results should be interpreted with some caution. Recent research has challenged the use of cross-sectional research methods in comparing democracies and

dictatorships. For example, it may be that the poorest democracies are more likely to fall into authoritarian rule and thus the sample of democracies is a result of selection effects.¹⁴ More importantly, these results rely only on national-level estimates of electrification provision. A more compelling account of the impact of wealth and population distributions would investigate differences at the sub-national level *within* democracies and autocracies. If the findings above are consistent with the theoretical claims about democratic provision of public goods, then democracies should be more likely to provide rural electrification universally across their populations, regardless of regional differences in wealth and population density.¹⁵ Meanwhile, in autocracies, rural electrification should be much more likely in wealthier areas with higher population densities.

4 Conclusion

What kinds of governments are most effective in providing basic public services? The answer to this question is difficult with traditional country-level statistics. Government reports and official data can provide aggregate measures of government expenditures, but they cannot tell us how effectively the money is spent, how it is distributed, and most importantly, who benefits from such investments. Moreover, the quality of such data is likely to be correlated with the quality, honesty, and ability of the governments providing the data. This paper demonstrates the use of satellite imagery as a promising indicator of how governments provide rural electrification around the world. By deriving estimates that are not sensitive to concerns about the endogeneity of data quality with political institutions, I am able to more adequately test the effects of democratic rule for the entire world. The findings suggest that democracies provide systematically higher levels of rural electrification. Autocracies, on the other hand, are sensitive to wealth and population effects in their provision of electrification.

While the analysis presented here focuses on aggregated national-level estimates, the satellite-derived data on electrified areas is recorded at the local level, offering great promise for more detailed sub-national analysis. With more data evaluated at multiple levels of geographic aggregation, the next step will be to conduct even more rigorous tests of the mechanisms linking democratic rule to public goods provision.

¹⁴Some of the concern regarding selection effects is mitigated by my measure of democratic history, which takes period under democratic rule into account and not just the current level of democracy.

¹⁵This is likely to be true since almost everyone receives electrification in democracies. An even more challenging test would be to examine whether countries that experience transitions from autocratic to democratic rule shift towards a more universalist modus operandi in the distribution of new electrification. This could be examined by looking at change over time among the new post-Communist democracies

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