Who Gets Public Goods?
Efficiency, Equity, and the Politics of Electrification

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Abstract

Do democracies provide more public goods than autocracies? Clear answers to this question have been hampered by inconsistent, unreliable, or missing data. To address the shortcomings of self-reported government data, I propose a novel method to generate unbiased estimates of the provision of electrical infrastructure across the entire globe using satellite imagery of nighttime lights. After demonstrating the validity of my measure, I show that democratization is associated with a substantial decrease in unelectrified populations, even after controlling for differences in per capita income, population density, and other factors. Exploiting the high spatial resolution of my data, I also explore within country variations in electrification. Preliminary analysis reveals only small or negligible differences in the way democracies and autocracies distribute electrification across their populations, especially to their poorest citizens. The results, drawn from statistical analysis at multiple spatial scales, affirm the power of democratic electoral incentives in inducing higher levels of public goods but call into question the distributional consequences of competitive electoral politics.

1 Introduction

If democracies are better at providing public goods than autocracies, why do 57% of people in India lack electricity compared to fewer than 2% in China? According to official sources, access to basic electrification is both dramatically lower and less evenly distributed in India than in China, despite similarly massive populations, large territories, and expanding but impoverished rural economies.[1] For theories that expect democracies to provide more public goods (Lake & Baum 2001, Bueno de Mesquita et al. 2003) and to distribute them more efficiently (Wittman 1989, Gradstein 1993) and equitably (Weingast, Shepsle & Johnsen 1981, Collie 1988), the track records of the world's most populous democracy and autocracy represent either an exceptional anomaly or suggest a limitation of these models.

How governments provide basic infrastructure and public services is critical for economic development. Places without electrification, clean water, public health, and education, are unlikely to escape from poverty and expand their local economies. Because such local public goods are likely to be underprovided by private

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[1] See for example International Energy Agency (2002) and Canning (1998).

firms, substantial government investment is typically required for the provision of basic infrastructure, especially in rural areas where customer densities are low. Yet despite the significant role governments play in the provision of local public goods, there is no consensus on what kinds of governments provide them most effectively. Do democracies provide more local public goods to their citizens? Do the benefits of local public goods reach those who need them most? On the one hand, many theories expect that democratic leaders are induced by competitive elections to provide more public goods and benefits to their citizens than autocrats who face no electoral accountability. Yet on the other hand, majority rule in democracies might lead to the persistent deprivation of peripheral minority groups who never enjoy the spoils of office. It may be that some autocracies provide lower levels of public goods but distribute them more broadly to the most needy because of ideologies like socialism.

To date, no systematic analysis has simultaneously evaluated the equity and efficiency with which governments provide local public goods for the full sample of countries. Cross-national research, with its focus on aggregate provision of goods, only uses information on the total level of provision and generates few conclusions about how these resources are distributed within a society. Sub-national research focuses on one or a few countries at a time, relying on a mix of methods and data sources and yielding results that are not easily generalizable or cumulative. Moreover, statistical findings are typically weakened by inconsistent, unreliable, or missing data. This paper presents analysis of a novel set of satellite imagery to derive objective estimates of the distribution of rural electrification around the world. While this represents only a single type of local public good, rural electrification is a vital service typically requiring substantial government investment. It is also underprovided in much of the world, with large variations across countries as well as within countries. It therefore offers great promise as an indicator to help understand how different political institutions shape the incentives of governments to provide and distribute local public goods. Using the presence of outdoor lights as an indicator of the presence of electrical infrastructure, I identify all lit and unlit areas of the world at a a resolution of 2.7 km to generate new estimates of the proportion of a country's population lacking electrification. The comprehensive coverage and high resolution of the data allow for both cross-national and sub-national analysis.

Drawing on my satellite-derived data of unlit populated areas, I examine the claim that democratic governments provide more local public goods and distribute them more equitably than autocratic rulers. The advantages of the approach presented here are twofold. First, the reliability and validity of these estimates of rural electrification is wholly exogenous to political institutions and economic circumstances. Unlike standard cross-national datasets that rely heavily on self-reported government data whose quality and accuracy are uncertain, the satellite-derived estimates are unbiased, consistent, and complete. Second, the estimates are generated bottom-up from local level measurements using a consistent instrument and methodology. Thus the aggregate national totals and the sub-national figures are derived from the very same set of data, unlike other data sets that rely on a mix of inputs at varying levels of geographic precision.

The paper proceeds as follows. In the next section, I briefly discuss theories of local public goods provision. After discussing the role of the state in providing electrification, I introduce the satellite data and describe the method to estimate the level and distribution of electrification around the world. Using regression analysis, I next present cross-national evidence showing that democracy is associated with a significant and substantial decline in unelectrified populations. I then present some preliminary sub-national analysis and end with concluding observations.

2 Explaining the Provision of Local Public Goods

Why and how do governments distribute local public goods? Institutional theories emphasize the role of political institutions in creating incentives for state leaders to provide public goods and services. All models predict that in democracies, the competitive pressures of elections induce politicians to provide more public goods than in autocracies where there is no electoral accountability. Because democratic politicians are likely to be evaluated on their ability to provide basic benefits to their constituents, democratic leaders need to provide higher levels of local public goods to win re-election than dictators who do not run in elections (Lake & Baum 2001). Moreover, elected leaders require a larger base of support than do dictators, typically requiring a plurality of popular support to hold power. In contrast, as Gandhi & Przeworski (2006, p. 2) state "dictators are dictators because they cannot win elections." As the size of the minimum winning coalition increases, Bueno de Mesquita et al. (2003) argue that provision of public goods becomes more cost effective than private transfers to win support. As a result, the larger support coalitions needed by democratic leaders is likely to induce higher investments in the provision of broad-reaching classes of public goods and services.

While these models predict higher levels of local public goods in democracies, there is no clear consensus on whether democracies distribute them any differently than autocracies. According to some, the political competition associated with democracy should yield efficient and equitable policy outcomes (Wittman 1989, Gradstein 1993). Median voter theory suggests that if the median voter has less income than the average voter, governments will be larger with more social expenditures benefiting the poor (Meltzer & Richard 1981). Given that the income distribution is typically skewed towards the high end of the spectrum in most countries, democracy should thus benefit the poor. Lindert (2004) finds strong historical evidence that democracy leads to an increase in redistributive spending. Many note that democracies seem to work harder to meet the needs of historically disadvantaged groups (Pande 2003). Explicit models of legislative behavior pivot around whether lawmakers cooperate or not in deciding distributional allocations. Non-cooperative models assume that public good distributions are decided by minimum winning coalitions in legislatures. Since the votes of those outside the coalition are not necessary to maintain power, only those within the power-holding alliance will have a say in determining public spending. Implicitly, legislative districts outside of the minimum winning coalition are unlikely to receive the same level of public spending as districts within the coalition. This logic is a central feature to many models of vote buying and coalition formation (Austen-Smith & Banks 1988, Baron & Ferejohn 1989). On the other hand, a cooperative legislative norm is likely to induce much broader distributions of public goods. Inspired by observations of legislative log-rolling in the U.S. Congress, Weingast, Shepsle & Johnsen (1981) propose that resource allocation will obey a norm of universalism in which each district gets what they want so long as all other districts do as well. Larger legislative coalitions may also be likely because they are cheaper to maintain (Groseclose & Snyder 1996) and because of strategic interaction between politicians and voters (Besley & Coate 2003).

Empirical support for the distributional benefits of democracy has been mixed. Many cross-national studies do not find systematic evidence that the higher levels of social expenditures made by democracies actually reach the poorest or most vulnerable segments of society (Keefer 2005, Ross 2006). Keefer & Khemani (2005, p. 2) observe that "policymakers in poor democracies regularly divert spending away from areas that most benefit the poor or fail to implement policies that improve the services that are known to disproportionately benefit poor people." A recent evaluation of 120 World Bank rural electrification projects reports that "the larger share of benefits from rural electrification is captured by the non-poor" (World Bank 2008, p. xv). Some argue that representative democracies are vulnerable to several types of "political failures" and are unlikely to produce economically efficient distributions (Besley & Coate 1998).

Aside from how legislative funds are distributed *across* districts, legislators must still make distributive decisions *within* their districts. An influential debate asks whether politicians will favor core supporters or swing voters with locally targetable resources. Cox & McCubbins (1986) conclude that if politicians are risk-averse, they will benefit most by providing patronage and services to their core supporters. In contrast, swing voter models (Lindbeck & Weibull 1987, Dixit & Londregan 1996) suggest that politicians' investments yield higher returns when targeted to swing voters who can be more easily swayed by promises of distribution.

This theoretical framework has informed empirical research on the distribution of local public goods in settings as varied as Italy (Golden & Picci 2008), Mexico (Diaz-Cayeros, Magaloni & Estévez forthcoming), and Ghana (Miguel & Zaidi 2003). But the formal models underlying the original core and swing voter models provide no direct prediction regarding the distribution of geographically targetable public goods. The original models assume that politicians can directly target individuals or groups of voters: Dixit & Londregan (1996, p. 1137) assume that, "The parties' redistributive policies can link taxes and transfers to the membership of one of these groups; for example, each farmer or senior citizen can be promised so many dollars." Cox &

McCubbins (1986, p. 384) state that "The kinds of governmental benefits most likely to be dealt with in a manner consonant with our theory are those that, like patronage, are finely targetable." In contrast, "Capital goods do not easily meet the basic requirements of our model. . . Local services that are not finely targetable may also fail to meet the conditions of our theory." Given the lumpiness of local public goods, they can only be targeted geographically and not directly to dispersed groups of voters like the elderly or poor. As a result, the core-swing voter models are unlikely to predict the distribution of local public goods in democracies except in cases where groups of core and swing voters can be distinguished geographically.

A separate literature emphasizes the ability of some citizen groups to overcome collective action problems. These explanations argue that when citizens share similar preferences, or where social norms of sanctioning exist to punish defectors and free-riders, groups can overcome the coordination problems that hinder public goods provision. Unified action is more likely where social capital is high, perhaps by the presence of civil society groups (Boix & Posner 1998, Tsai 2007) or because of shared kinship networks (Bates 1974). In this context, places where voters can communicate a clear policy preference are more likely to receive the local public goods they want. By extension, such coordination should be more likely in democratic systems. Empirical research has linked higher ethnic diversity to lower public goods provision at both the cross-national (Easterly & Levine 1997, Posner 2004, Montalvo & Reynal-Querol 2005) and sub-national levels (Alesina, Baqir & Easterly 1999, Wantchekon 2003, Besley et al. 2004, Banerjee, Somanathan & Iyer 2005, Miguel & Gugerty 2005). Such models imply that politicians can respond mechanically to the shifting desires of the median voter without specifying the conditions that lead some politicians to be more responsive than others to citizen demands.

Yet both the institutional and social capital theories explain only a portion of the variance in the distribution of public goods in the developing world: greater variation exists on the dependent variable than in electoral institutions; and the mechanisms by which ethnic diversity affect public goods provision are not well understood (Habyarimana et al. 2007). The result is that the provision of public goods remains poorly understood in the developing world, even though politics plays a dominant role in the distribution of public infrastructure in rural lands.

3 Electrification and the State

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 kerosene, wood, and agricultural residues 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 economic 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. Powered water pumps reduce the effort needed to collect clean water. Electrical cooking stoves reduces the amount of time needed to gather wood and other biomass fuels.[2] Electrical power enables the development of industries and creates new jobs. For communities, electrification improves safety at night via streetlights, enables irrigation and drainage systems to improve agricultural productivity, and encourages entrepreneurship.

No country has ever completed rural electrification without the intensive financial support of its government (Barnes & Floor 1996, p. 519). At the founding of the Soviet Union in the 1920s, Vladimir Lenin famously placed electricity at the center of his vision of the future: "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 solvent. 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

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

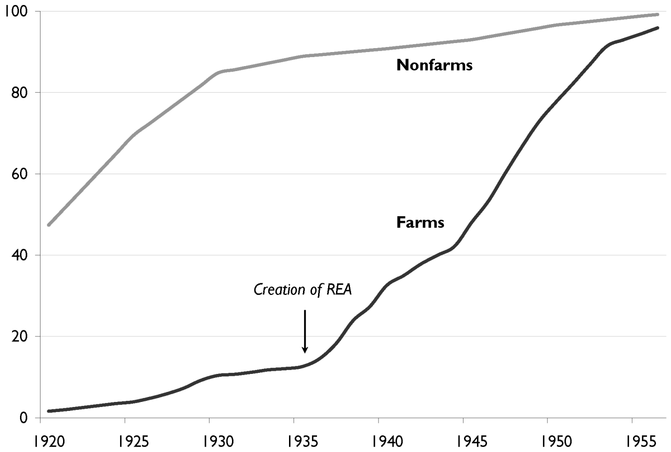

Figure 1: Electrifying America: Percentage U.S. dwelling units with electricity, 1920–1956
Source: U.S. Census Bureau, Historical Statistics of the United States, 1975, S 108-119.

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."[3]

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. The International Energy Agency (IEA) produces the most cited source of data on electrification levels around the world in its annual World Energy Outlook series. As the IEA data in figure 2 show, 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.

The IEA data illustrate some of the potential weaknesses that affect many commonly used datasets in cross-national analysis. Given the impossibility of collecting data through a single consistent and coherent process, IEA's data are derived from dozens of sources, including self-reported government data, NGO estimates, World Bank studies, and regional organization reports. Since no universal definition of electricity access exists, the comparability of country-specific estimates is difficult to gauge. Official definitions of electrification can differ

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[3] Campbell, Dan, "When the lights came on," `http://www.rurdev.usda.gov/rbs/pub/aug00/light.htm`

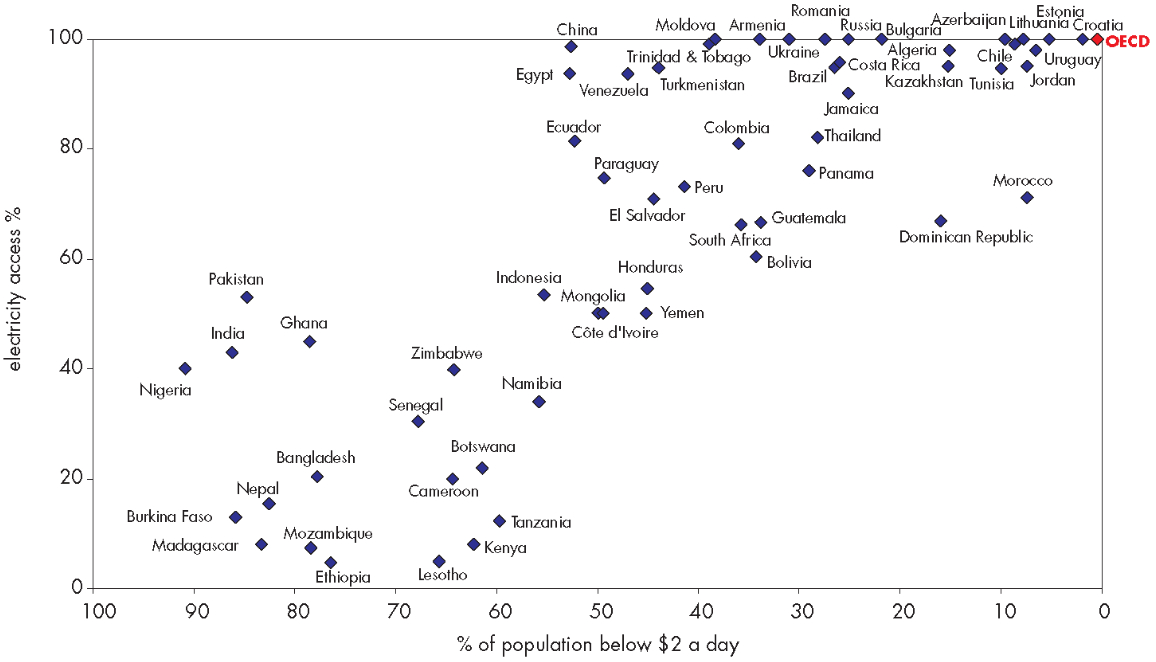

Figure 2: Electricity access and poverty, 2000
Source: International Energy Agency (2002, p. 375)

even within the same country. For decades in India, a village was officially declared electrified if it had a single electrical connection used for any purpose. But in 2004, the official definition changed, requiring the presence of basic infrastructure, electrification of public buildings, and at least a 10% household electrification rate. As an artifact of the definitional change, official government reports show a puzzling decline in village electrification rates over the last decade. In addition to differences in methodology in data collection, the bureaucratic capacity to collect dependable statistics varies by country. It is likely that the precision and reliability of electrification estimates is lower in poorer countries, places overwhelmed by civil war, and closed regimes inaccessible to outsiders. Finally, the IEA lists data for only 76 countries, resulting in missing data that is unlikely to be random.

4 Measuring Rural Electrification from Above

I propose a new method to estimate the provision of electrification 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's Operational Linescan System (DMSP-OLS) has been flying in polar orbit capturing high resolution images of the entire earth each night between 20:00 and 21:30 local time. 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.[4] 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. 1997*a*, 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 annual images.

Images are scaled onto a geo-referenced 30 arc-second grid (approximately 1 km^2). 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 present 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 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 explains a large portion of the global variation. 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, revealing the impact of political institutions and economic growth in a region with identical cultures and similar geography.

Numerous studies have validated the DMSP-OLS night lights images against measures of electric power consumption and gross domestic product (Elvidge et al. 1997*b*). 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). The great virtue of these data for social science research is that they are unbiased, consistent, and complete.

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[4] The geographic extent of usable DMSP data 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).

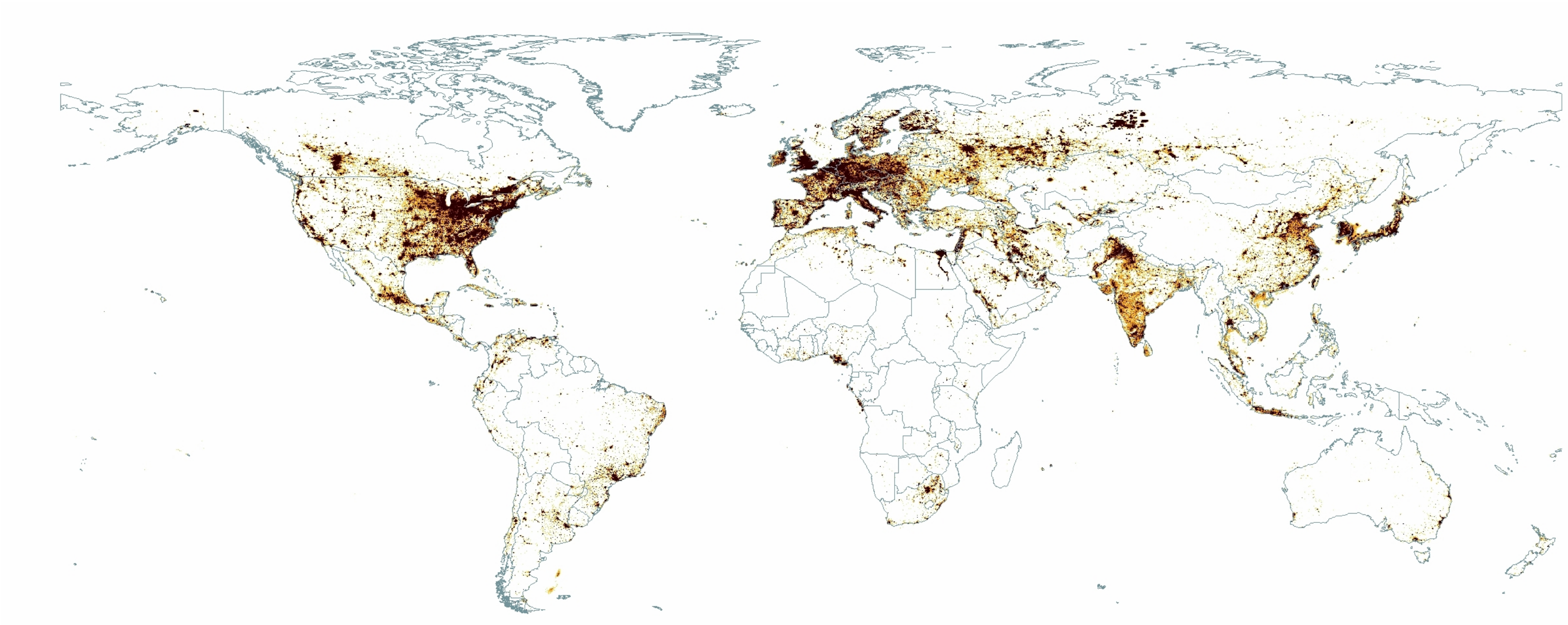

Figure 3: Nighttime lights of the world, 2003
Darker cells have higher light output. Source: NOAA National Geophysical Data Center

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. Fortunately, this results only in a downward bias in the estimate of unlit populations; moreover, the effects of blooming are unlikely to be correlated at the country level with the political variables I am most interested in. 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 $10^{-9}\mathrm{watts/cm^2/sr/\mu m}$, 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 (see Figure 4). This is the highest resolution population map currently available. Drawing on sub-national census data, population counts are apportioned onto a 30 arc-second grid using likelihood coefficients based on proximity to roads, slope, land cover, and other information. [5] The LandScan population maps have been thoroughly vetted 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.[6] As a result, the LandScan population data are generated independently of the DMSP-OLS night lights data.

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[5] LandScan population counts estimate the ambient or average population distribution over a 24-hour period. These differ from traditional population density estimates which measure residential settlement patterns, typically undercounting the presence of people in commercial centers and airports, for example.

[6] Current 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).

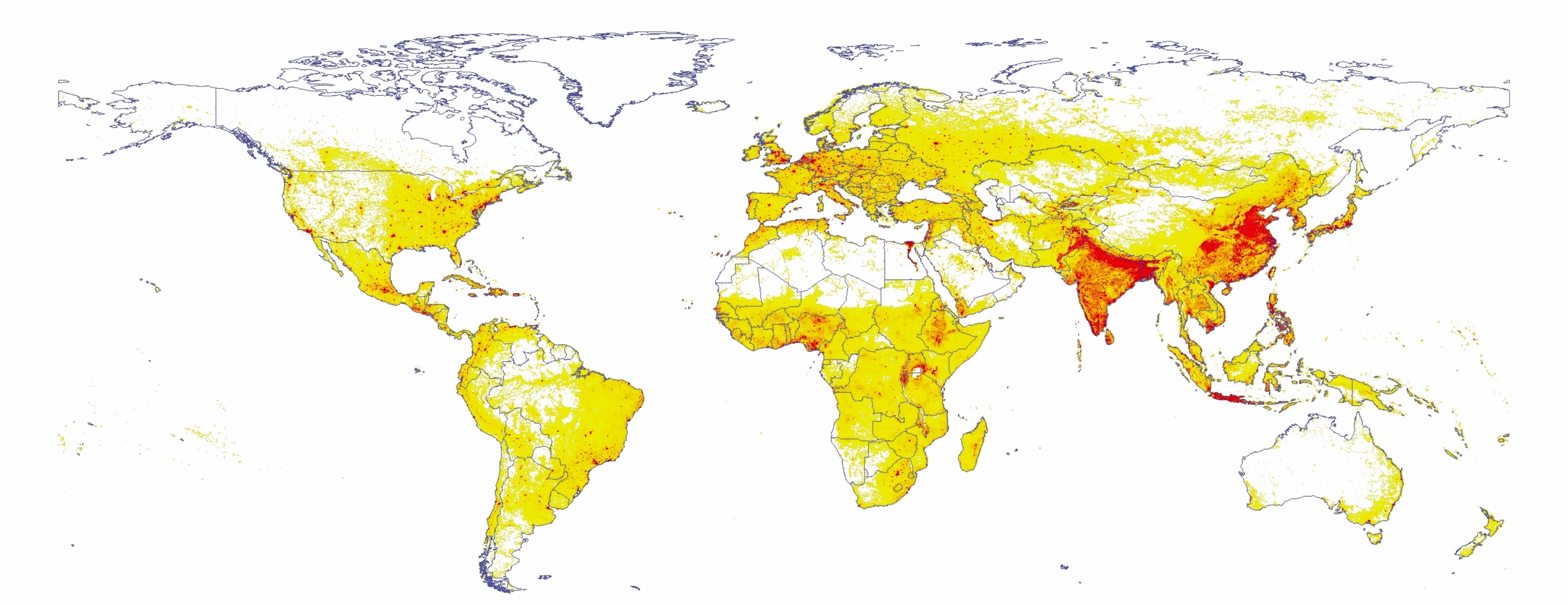

Figure 4: Population of the world, 2005
Darker cells have higher population counts. Source: Oak Ridge National Laboratory, LandScan 2005

A direct comparison of the raw LandScan and DMSP-OLS images reveals a very large number of populated cells with no light output. This is because even electrified areas with very low population densities do not emit sufficiently concentrated 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 allocation algorithms to have very low population counts (as low as 1 in many cases). Thus a direct comparison of these data sources does not yield a reliable estimate of unelectrified populations. A more reasonable identification strategy to identify unlit populated areas might focus only on areas with a minimum population density below which we would not expect to be able to detect light output in the DMSP images. The lower the minimum population threshold, the more unlit 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.[7]

The validity of this threshold rests on the important assumption that the emission of nighttime lights is primarily a function of population density and that this relationship is constant across the world.[8] One reason such a claim might be credible is the relative consistency 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 light 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.

These limitations aside, I propose that the 100-person threshold used here allows for a conservative and plausible fist 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 446,000 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.[9]

The distribution of unlit populations in India is plotted in Figure 5, with each dot indicating an unlit settlement and darker dots indicating higher population counts. The highest concentration of unlit populations

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[7] More details to be provided in a technical appendix.

[8] An improved light detection scheme might 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.

[9] In comparison, International Energy Agency (2006) estimates 440 million unelectrified homes in India, many of which are in electrified villages and towns. The population living in unelectrified villages, which my measure most closely resembles, has not been reported.

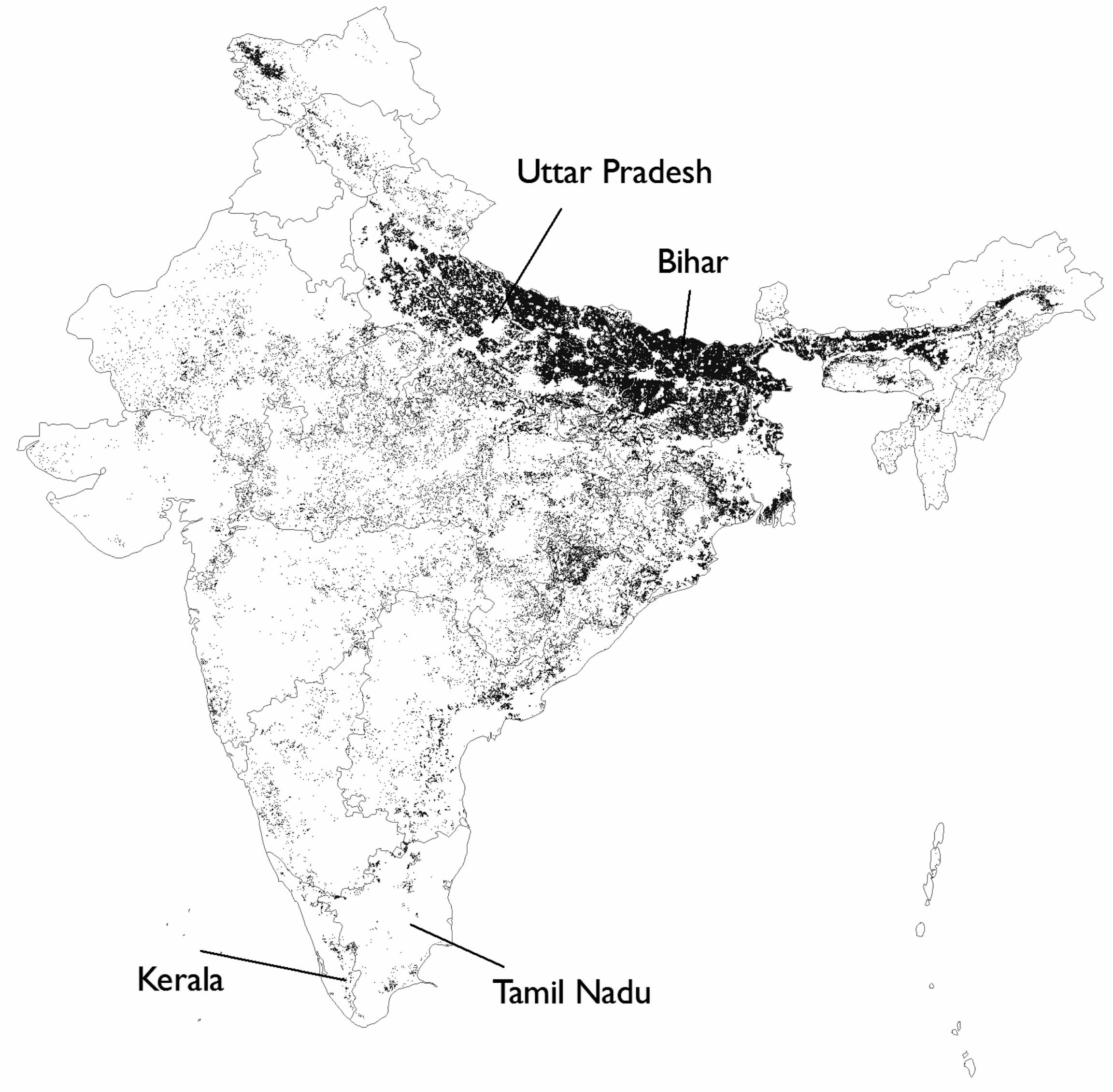


Figure 5: Estimated unlit populations in India, 2003
Each dot represents a 30 arc-second cell with no detectable light output and population of at least 100.
Darker cells have higher population counts. Estimated using DMSP F152003 and LandScan 2005 data.

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%

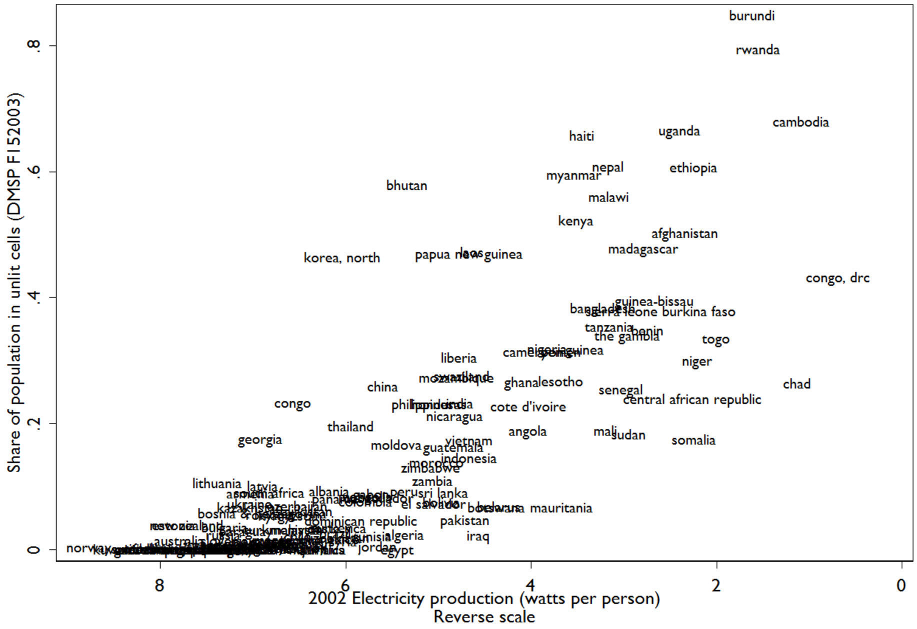
Table 1: Estimated unlit population from satellite images, 2003

Source: Author calculations from DMSP F152003 and LandScan2005 sources.

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 are white, including the state capitals Lucknow and Patna, indicating the prevalence of electrical infrastructure in urban areas. In comparison, Kerala and Tamil Nadu on the southern tip of the Indian peninsula, have only a scattering 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. In comparison, my satellite-derived method estimates that 37% of people in Uttar Pradesh live in unlit areas, 64% in Bihar, 3% in Kerala and 1% in Tamil Nadu.

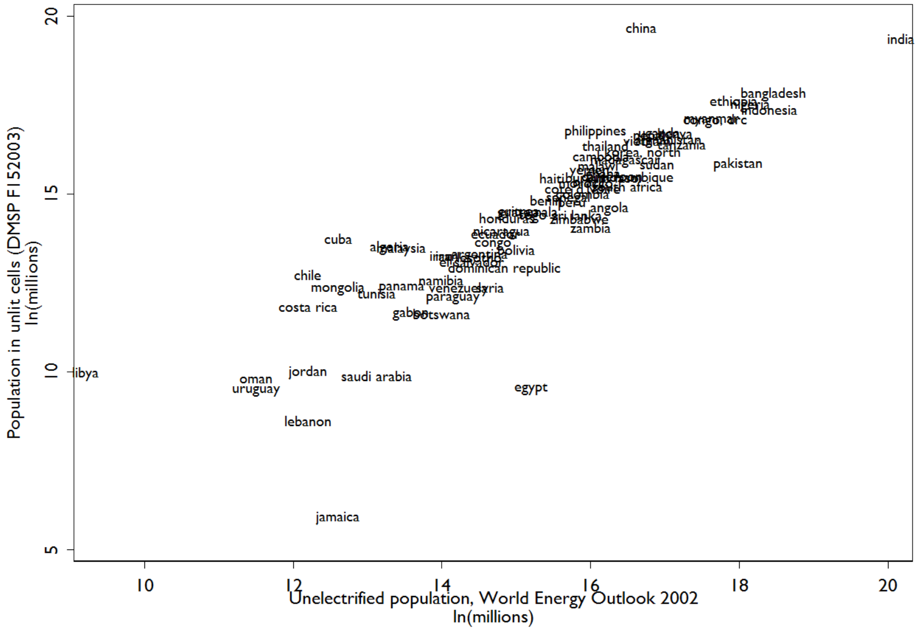
Applying the method described above, I estimate that 1.1 billion people, or 18% of the global population, live in unlit areas of the world. Regional breakdowns are presented in Table 1 (see Appendix B for country estimates). This global estimate compares reasonably well with the IEA's projection of 1.3 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 sources of country-level data. Figure 6 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 7 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 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



n=149 (countries with population of at least 1 million). Correlation coefficient = 0.79

Figure 6: Comparison of unlit population with electricity production data
Sources: DMSP F152003, LandScan2005, 2007 update to Canning (1998)



n=76 (developing countries with population of at least 1 million). Correlation coefficient = 0.87

Figure 7: Comparison of unlit population with estimates of unelectrified population
Sources: DMSP F152003, LandScan2005, World Energy Outlook 2002

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 types of analysis not possible with official country data alone.

5 Electrification and Democracy

Most theories of public goods provision expect that democracies will provide higher levels of basic infrastructure like electrification than autocracies. If these theories are correct, we should find that more citizens enjoy the benefits of electrification in democratic regimes, and that the positive benefits of democracy should compound over time in countries that have been accountable to their populations for longer periods, thus having more opportunities to win votes through the provision of electrical infrastructure. Many theories also assume that democratic rulers will distribute public goods more equitably and efficiently than dictators who are accountable to fewer stakeholders and are less easily punished for making poor policy choices. Should this be correct, then patterns of electrification in democracies should be markedly different and more predictable than in autocracies.

Using the satellite-based estimates of unlit populations described above, I evaluate the differences in the provision and distribution of rural electrification between democracies and autocracies. To assess the influence of democratic rule on rural electrification, I construct a measure of *Democratic history* which calculates the number of years from 1946 until 2002 that a country has been under democratic rule. I use the dichotomous coding of democracy from Cheibub & Gandhi (2004).[10] 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 a history of investment. That said, almost half of the countries in my data do not change regime type at any point during the post-war period: 52 countries have always been autocratic while 31 have stayed democratic.

Figure 8 shows electrification rates for 183 countries at all levels of democratic history (the sample size is limited only by the availability of regime-type data). Among sustained democracies, the provision of rural electrification is impressively uniform. In these 21 countries, only about 2 out of every 100 people live in unlit areas, with India appearing as a notable outlier. 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

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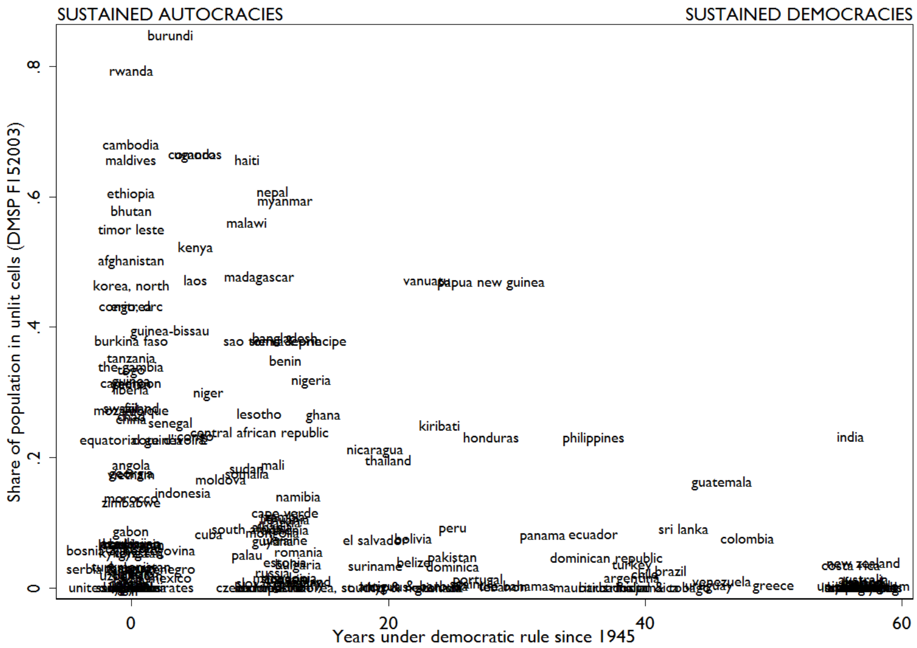
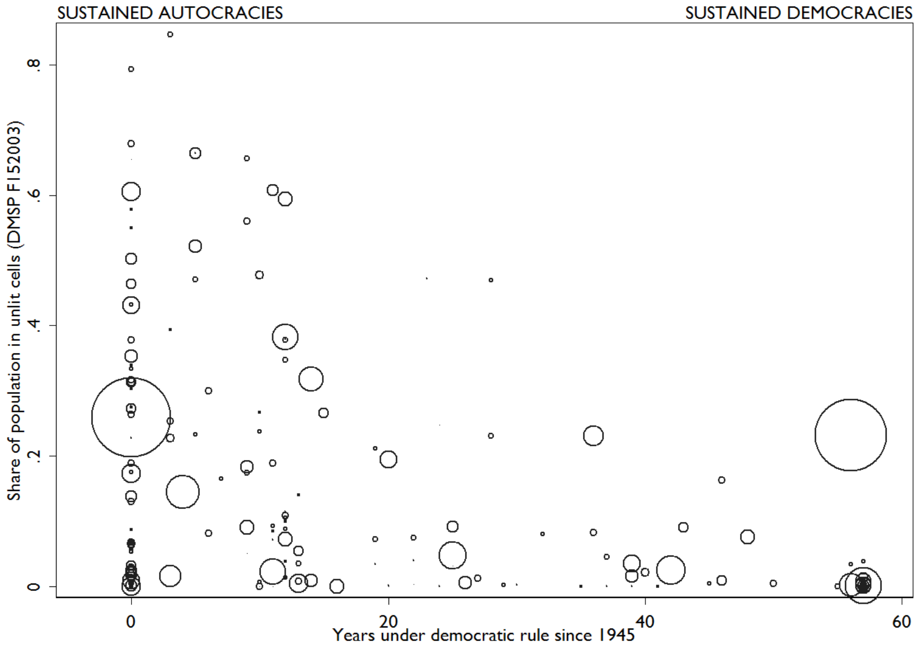
[10] I also compare my results using two measures constructed from Polity2 data: the number of years under "strong democratic" rule (i.e. Polity2 > 6) and years in which there were competitive elections (i.e. exrec $= 8$). I get very similar results using these alternate measures.



n=183. Correlation=-0.37

Figure 8: Unlit population by history of democratic rule
Sources: DMSP F152003, LandScan2005, Cheibub & Gandhi (2004)



n=183. Correlation=-0.37

Figure 9: Unlit population by history of democratic rule, markers weighted by population size
Sources: DMSP F152003, LandScan2005, Cheibub & Gandhi (2004)

compared to less than 1% in Egypt and Jordan. Some of these differences are likely to be linked to oil wealth, but variation persists even among non-oil producing dictatorships.[11]

In the middle region of the figure 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 appears to decrease at all levels of democratic history.

Figure 9 shows the same scatter plot but using markers weighted by the population size of each country. Dominating the plot are the large markers associated with China and India. In stark contrast with the official electrification estimates reported at the beginning of the paper, the share of unlit populations are very similar for China and India using the satellite-based methodology. The figure reveals substantial unit heterogeneity and reveals the limitations of cross-national regressions in which just a few influential observations can affect the results, even if they are associated with very small countries.[12]

Partially obscured in both figures is the large number of countries that are effectively fully electrified: 57 countries have less than 1% of their population in unlit cells, 84 countries have less than 4% unelectrified, and 91 have less than 6%. Many of these countries are wealthy (e.g. Norway, Saudi Arabia), have small territories (e.g. Jamaica, Lebanon), or both (e.g. Kuwait, Israel). The majority are democracies though about a quarter are autocracies, depending on the cutoff. Because the historical process leading up to the complete electrification of these states cannot be observed with my data, I conduct statistical analysis on a restricted sample of partially unlit countries.[13] For comparison, I also show results for the complete set of countries including fully electrified countries.

5.1 Cross-national analysis of unlit populations

I first present results of my cross-national analysis. The dependent variable is the proportion of a country's population living in unlit cells. Because the outcome of interest is bounded at 0 and 1, ordinary-least squares regression is generally not appropriate. Moreover, OLS generates predicted values that can be negative or greater than 1. Instead, I use a fractional logit model following Papke & Wooldridge (1996) and Wooldridge (2002, p. 661). In the fractional logit model, the dependent variable, y is assumed to be a proportion

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[11] Nighttime lights in oil producing countries is also likely to lead to an overestimate of the distribution of electrification: gas flares on oil wells and rigs generate high levels of outdoor light visible in the satellite images. Gas flaring is known to be particularly pronounced in Nigeria, Russia, Iran, Algeria, Mexico, Venezuela, and Indonesia.

[12] Papua New Guinea is a highly leveraged outlier that I exclude from my regressions.

[13] I use the 4% cutoff to identify partially unlit countries in the regressions below. Cutoffs of 2%, 3%, 5%, and 6% yield virtually identical results

Table 2: Country-Level Variable Summary

Variable	Observations	Mean	Std. Dev.	Min	Max
Share of country population in unlit areas	183	0.150	0.195	0	0.847
Democratic history, 1946–2002	183	17	19.418	0	57
ln (Population density), 2002	148	6.241	1.242	2.876	9.206
ln (GDP/capita), 2002	148	8.384	1.194	5.823	10.443
Civil armed conflicts, 1946–2002	148	1.338	1.676	0	11
Ethno-linguistic fractionalization	147	0.406	0.280	0.001	0.925
ln (Mountainous terrain)	148	2.141	1.415	0	4.421
Oil production per capita, 2002	148	1.625	5.954	0	43.425

generated by the logistic function,

$$E(y|\mathbf{x}) = exp(\mathbf{x}\beta)/[1 + exp(\mathbf{x}\beta)] \tag{1}$$

The β's are easily estimated in standard packages, including Stata by specifying a generalized linear model with a logit link function. The partial effects of a change in an independent variable in a fractional logit model are roughly comparable to the change based on the coefficients of an OLS model.[14]

The 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. My key independent variable is a simple count of the number of years a country has been under democratic rule between 1946 and 2002. 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 demand for electrical infrastructure. I estimate the level of industrialization using the natural log of a country's *GDP PER CAPITA* in 2002. Data come from the Penn World Table 6.2 and are denominated in thousands of 2000 U.S. dollars. A country's *POPULATION DENSITY* will also affect its electrification rate. Sparsely populated countries must absorb much higher per capita costs to electrify rural areas and extend the grid to remote settlements. I use the natural log of the population density, which is in people per km^2 and is computed from LandScan 2005 population numbers and World Bank data on surface area.

I include several other control variables. 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 ARMED CONFLICTS* might have lower levels of electrification. This variable, derived from the PRIO Armed

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[14] An alternative is to use the log-odds transformation, $\log[y/(1-y)]$, as the dependent variable, since $\log[y/(1-y)]$ ranges over all real values while y is bounded between 0 and 1. However, the log-odds transformation does not work when y takes on the boundary values of 0 and 1 since the transformation is undefined for these values.

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 Fearon & Laitin (2003). The physical geography of a country might make it more difficult for a government to provide rural electrification. For example, the presence of rough and *MOUNTAINOUS TERRAIN* increases 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. Gas flaring associated with oil production also generates excess nighttime light output. 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.

Table 3 presents fractional logit regression results to test the effects of democracy on electrification. I run all models using the Huber-White sandwich estimator to correct for heteroscedasticity. Models 1–3 show results for the restricted sample of partially unlit countries while models 4–6 present the same models for all countries including fully lit countries. The results are similar for both samples, though the democratic history variable just misses significance at the 5% level in model 5. 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 22.2% decrease in the population living in unlit areas.[15] While this is a large effect, it might be generated by other confounding factors not included in the model but correlated with democracy like country-level wealth. Moreover, we know from Figure 8 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 from the observed mean lowers the share of the unlit population by 4.9%. 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

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[15] By comparison, the predicted decrease in unlit population from model 4 is 20%

Table 3: Country-Level Fractional Logit Analysis of Unlit Populations

Dependent variable is share of country population in unlit areas, 2003

	Partially unlit countries only			All countries		
	(1)	(2)	(3)	(4)	(5)	(6)
Democratic history, 1946–2002	-0.0266**	-0.0151**	-0.0180**	-0.0442**	-0.0106	-0.0138*
	(0.0075)	(0.0057)	(0.0058)	(0.0066)	(0.0057)	(0.0055)
ln (Population density), 2002		0.3845**	0.3608**		0.3687**	0.3445**
		(0.0690)	(0.0681)		(0.0718)	(0.0683)
ln (GDP/capita), 2002		-0.8084**	-0.8306**		-1.1268**	-1.0799**
		(0.0873)	(0.1066)		(0.0878)	(0.1049)
Civil armed conflicts, 1946–2002			0.0618			0.0401
			(0.0422)			(0.0475)
Ethno-linguistic fractionalization			-0.1664			0.1798
			(0.3004)			(0.3156)
ln (Mountainous terrain)			0.0997*			0.1424**
			(0.0485)			(0.0504)
Oil production per capita, 2002			0.0592			-0.0734
			(0.0522)			(0.0831)
Constant	-0.7841**	2.7228**	2.7965**	-1.2189**	4.9732**	4.3522**
	(0.1265)	(0.6710)	(0.8768)	(0.1350)	(0.6773)	(0.8561)
Observations	98	86	85	182	147	146

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

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 factors, sustained democracies provide electrification to 14.6% more of their populations than do sustained autocracies. Given that in the average autocracy, 21% of citizens live in the dark, the potential effect of democratization is substantial. Very similar results linking democracy to higher levels of electrification hold for analysis of only the poorest half of the world's countries, those with per capita incomes below $5,000 (see Appendix A).

These results provide support for the claim that electoral incentives induce higher public goods provision in democracies. The analysis shows that democratic leaders provide substantially higher levels of electrification than do autocrats, even after controlling for differences in wealth and population density. That said, the results should be interpreted with some caution. Recent research has challenged the use of standard cross-sectional research methods in comparing democracies and dictatorships (Przeworski, Alvarez, Cheibub & Limongi 2000, Keefer 2005, Ross 2006). 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.[16] More importantly, these results rely only on national-level estimates of electrification. 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 more broadly across

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[16] Some 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.

their populations, with less sensitivity to regional differences in wealth and population density. Meanwhile, in autocracies, rural electrification might be more sensitive to variations in local wealth and population density.

5.2 Sub-national analysis of unlit populations

Do democracies distribute electrification more equitably than do autocracies? How to answer this question is not obvious since there is no straightforward criteria to define what an equitable distribution of a critical public good like electrification should look like, and comparisons against the distribution of some omniscient social planner have been argued to be unrealistic and impractical (Hettich & Winer 2006).

In the preliminary analysis presented here, I evaluate the claim that democracy is better suited to meeting the needs of the poor and vulnerable than autocracies. Specifically, I compare variations in the distribution of electrification to the poorest, most remote, and economically weakest areas of democratic and autocratic countries. I identify these regions by drawing on sub-national geo-coded data on infant mortality rates, population densities, and intensity of economic activity. Infant mortality data come from the Global Subnational Infant Mortality Rates project.[17] The variable estimates the number of children who die before their first birthday for every 1,000 live births in 2000 and is available for over 10,000 national and subnational units.[18] Data on cell population come from LandScan 2005, as before. Economic activity data come from Nordhaus et al. (2006), which estimates the 1990 gross cell product of all terrestrial 1-degree latitude by 1-degree longitude cells.

I organize all the sub-national data in cells at the same 1-degree latitude by 1-degree longitude level as the Nordhaus data (approximately 100 km^2 at the equator). When a cell lies across a national border, it is divided into smaller country-specific cells and thus not all cells are uniform in size. There are a total of about 27,000 terrestrial cells in my sub-national dataset; 21,000 once you exclude Antarctica. Russia, the world's largest territory is composed of 3,492 cells; India is made up of 355 cells; Vietnam has 60 cells. For my dependent variable I compute the proportion of the population in each cell that is lit and unlit using the same methodology as above. The proportion unlit data are presented in Figure 10, revealing large variations at the sub-national and cross-national levels. An analysis of variance (ANOVA) reveals that almost exactly half the variance in the proportion of the population living in unlit areas at the cell level is between countries and half within countries.

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[17] `http://sedac.ciesin.columbia.edu/povmap/`

[18] The level of sub-national detail varies substantially by country and includes as few as one data point for the entire country, as in Chad, and as many as 3,000 county-level observations for China.

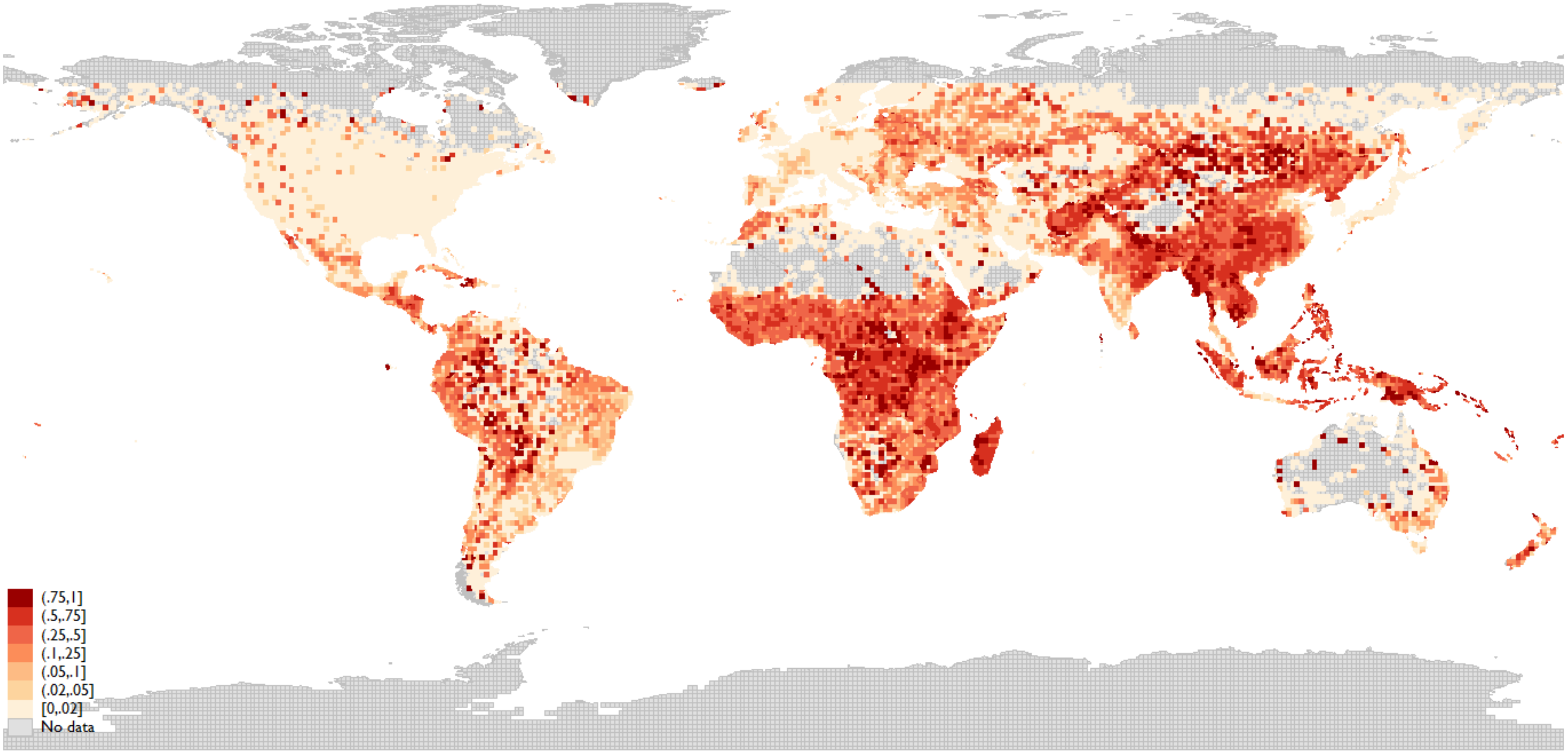

Figure 10: Proportion unlit population by 1-degree x 1-degree cell, 2003
Darker cells have a higher proportion of the population living in unlit areas

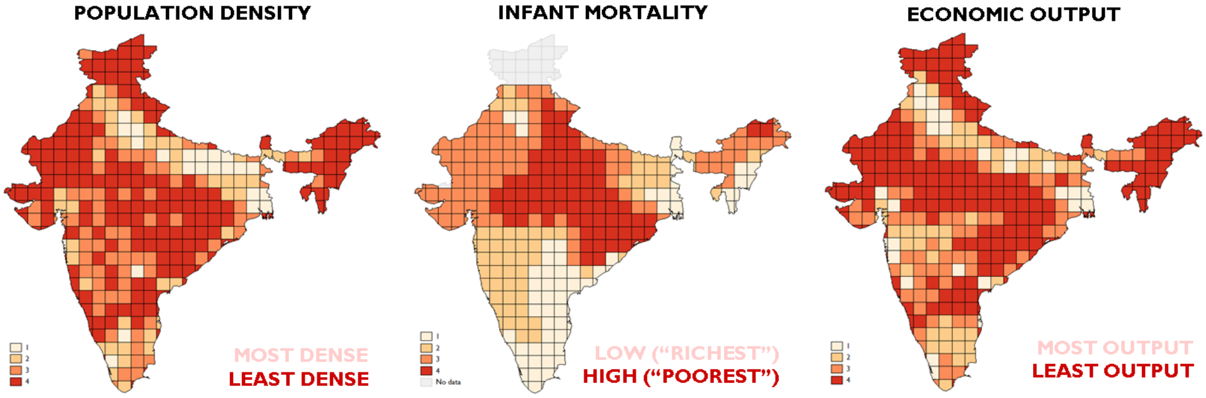

Figure 11: Distribution of population quartiles in India
Sources: LandScan 2005, Global Subnational Infant Mortality Rates Project, G-Econ Project.

For each measure of infant mortality, population density, and economic activity, I overlay their distribution against the population map to identify population quartiles sorted from high to low. For example, for the infant mortality data, I locate the cells in which the quarter of the population with the highest infant mortality live, down to the quarter of the population living in areas with the lowest infant mortality rates. The apportioning of these population quartiles are illustrated for India in Figure 11. Having identified the cells that make up each quartile, I then construct kernel density plots that show the distribution of the "proportion unlit per cell" variable within each quartile. Finally, I compare the density plot distributions between democratic and autocratic countries.

The analysis here suggests only small differences in the distribution of electrification across democratic and autocratic regimes among those living in the poorest, most remote, and economically weak areas of a country. In the distributional plots in Figures 12–14, four lines show the distribution of proportion unlit for all population quartiles. To interpret the shape of the density plots, high peaks to the left mean that many cells have full electrification while a large peak towards the right suggest that many cells have high proportions of unlit populations. To facilitate presentation, I depart from the democratic history variable used above and compare all current autocracies versus all current democracies.

Figure 12 shows the distribution of electrification for quartiles of population density. The "most densely populated" quartile contains the 25% of the population living in the most high population counts in a country. This will include the largest metropolitan areas in a country and may contain only a few cells. The "least densely populated" quartiles will contain a large number of low-density rural areas. For example, in India, a quarter of India's population lives in the 23 most densely populated cells while those in the least densely populated quartile is spread out across 217 cells. The panels of Figure 12 suggest that governments differ only slightly in the distribution of electrification between those in very dense and less dense areas. The differences

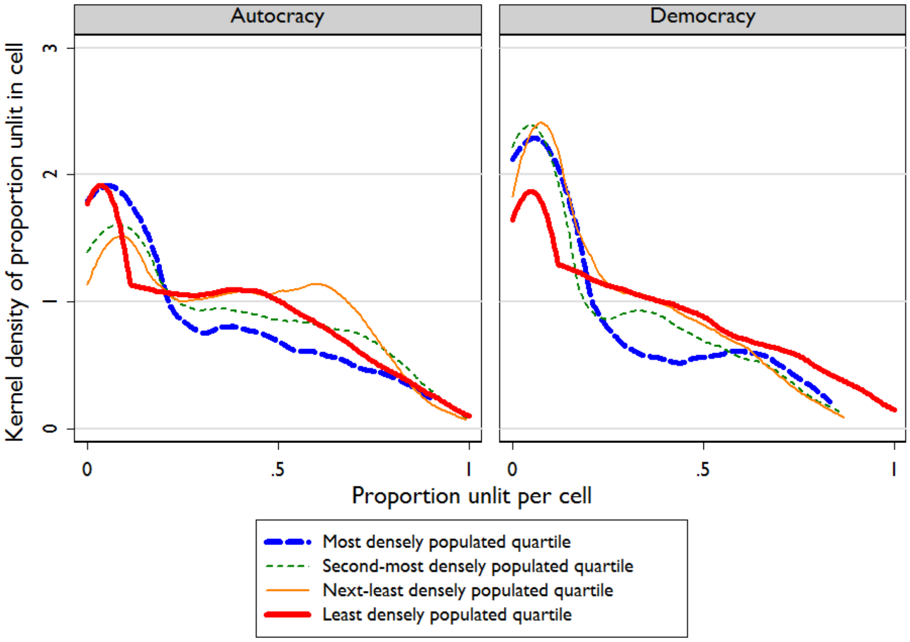

Figure 12: Distribution of electrification within most and least populated quartiles

between autocracies and democracies appear relatively minor, though in autocracies, many of the least densely populated areas are just as electrified as the most dense areas. This may be consistent with patterns of ethno-regional favoritism in which dictators direct patronage and state resources to their home regions, or with the embellishment of newly crowned capital cities like Gbadolite by Mobutu Sese Seko in Zaire.

Figure 13 shows the distribution of electrification for quartiles of infant mortality. The first quartile contains the quarter of a country's population living in areas with the lowest infant mortality rates, while the bottom quartile live in parts of the country with the highest relative rates of infant death. In India, the "lowest infant mortality quartile" is composed of the quarter of the population living in 72 cells while the "highest infant mortality quartile" is spread across 79 cells. Many scholars, including Ross (2006), argue that infant mortality rates are the best measure of poverty, given its consistent measurement and its high correlation with many other conditions of impoverishment. In comparing the panels of Figure 13, the quartile with the highest infant mortality rates appear to have only a slightly better likelihood of being electrified in democracies than in autocracies, where a large concentration of cells have about a 50% unlit rate.

Figure 14 shows the distribution of electrification for each quartile of economic intensity. The "highest economic output" quartile contains the 25% of the population living in cells with the highest gross cell products. This may include large metropolitan areas but also sites of substantial natural resource extraction. The "lowest economic output" quartile contains areas of a country with the lowest levels of economic output. In India, the

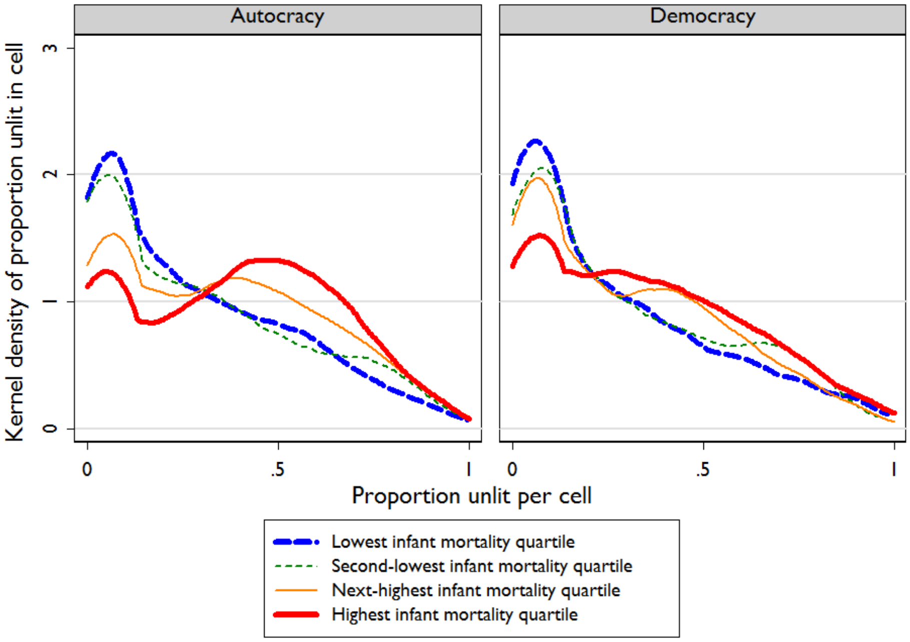

Figure 13: Distribution of electrification within lowest and highest infant mortality quartiles

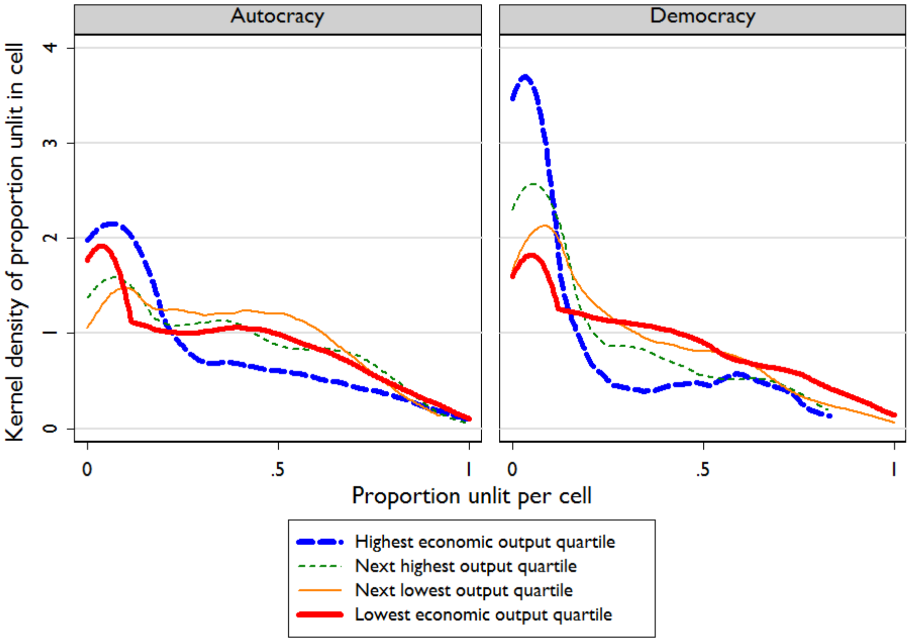

Figure 14: Distribution of electrification within strongest and weakest economic quartiles

most economically strong quartile includes the quarter of the population living in 28 highly productive cells, including the large cities of Delhi, Kolkata, Mumbai. The most economically weak quartiles is made up of 210 cells. There are some striking differences in the distribution of electrification across regimes, especially for the top quartile. The majority of the most strong economic quartile appear highly electrified in democracies and less so in autocracies. Within autocracies, the distribution of electricity among the most economically strong quartiles do not appear very different from that of the economically weak quartiles, while in democracies the difference is large. In comparing the density plots for the weakest quartile, the two regime types appear very similar, suggesting that democracies do no better in providing electricity to the least industrialized parts of their countries than do autocracies.

These descriptive results suggest that the distributional differences between democracies and autocracies are not large for those who live in the most economically weak, the most remote, and the most impoverished regions of a country. However, these results represent the distributions of groups of cells aggregated across many different sized countries. Moreover, the measures of relative deprivation captured by these quartile categories may not be the most appropriate way of identifying the poor and needy within a country. For example, countries with very high levels of absolute inequality will look similar to countries with very low inequality when calculating quartiles as I do here. Additional statistical analysis will also account for the nested nature of the cell-level observations, controlling for the fact that some large countries like Russia and China are overrepresented in these distributional plots.

6 Conclusion

Evaluating the effectiveness of different regimes in providing local public goods to their populations is difficult with traditional country-level data. Government reports and official statistics provide aggregate measures of government expenditures but cannot tell us how efficiently the money is spent, how it is distributed, and who benefits from such investments. Moreover, the quality of such data is likely to be correlated with the bureaucratic capacity and honesty of the governments providing the data. Thus despite a generation of cross-national research, we still lack consensus on whether democracies are better at providing basic public services to their citizens than autocracies. This paper demonstrates the use of satellite imagery as a promising indicator of how governments provide rural electrification around the world. By deriving objective estimates whose reliability and validity are not sensitive to endogeneity with the political institutions we want to explore, 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 but that these higher levels of investment do not appear to be targeted to the most poor or isolated regions of a country. For those living in the most vulnerable regions of a country, regime type seems to make little difference to the likelihood of receiving electrification.

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Appendix A

Fractional Logit Analysis of Unlit Populations in Poor Countries (GDP/capita¡$5,000)

Dependent variable is share of country population in unlit areas, 2003

	Partially unlit countries only			All countries		
Democratic history, 1946–2002	-0.0252**	-0.0123*	-0.0149*	-0.0192*	-0.0054	-0.0091
	(0.0080)	(0.0059)	(0.0063)	(0.0079)	(0.0066)	(0.0068)
ln (Population density), 2002		0.4470**	0.4223**		0.4453**	0.4240**
		(0.0734)	(0.0683)		(0.0773)	(0.0681)
ln (GDP/capita), 2002		-0.9454**	-1.0288**		-1.1415**	-1.1830**
		(0.1113)	(0.1241)		(0.1239)	(0.1331)
Civil armed conflicts, 1946–2002			0.0660			0.0450
			(0.0437)			(0.0478)
Ethno-linguistic fractionalization			-0.2472			0.0143
			(0.3231)			(0.3322)
ln (Mountainous terrain)			0.1247*			0.1643**
			(0.0505)			(0.0520)
Oil production per capita, 2002			0.0600			-0.1183
			(0.1087)			(0.1825)
Constant	-0.6621**	3.2674**	3.7624**	-0.8578**	4.5545**	4.5844**
	(0.1344)	(0.7919)	(0.9805)	(0.1433)	(0.8589)	(1.0150)
Observations	70	70	69	78	78	77

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

Appendix B

Satellite-derived estimates of unlit populations, 2003

Rank	Country	Unlit Population	Total Population	Proportion Unlit
1	Burundi	6,720,200	7,936,150	84.68%
2	Rwanda	6,736,820	8,498,590	79.27%
3	Cambodia	9,220,890	13,581,600	67.89%
4	Uganda	18,201,700	27,387,100	66.46%
5	Haiti	4,985,210	7,602,740	65.57%
6	Nepal	16,896,500	27,831,100	60.71%
7	Ethiopia	44,250,100	73,105,000	60.53%
8	Myanmar	27,502,500	46,323,600	59.37%
9	Bhutan	1,227,960	2,125,250	57.78%
10	Malawi	7,114,040	12,712,500	55.96%
11	Timor Leste	565,683	1,029,300	54.96%
12	Kenya	17,642,800	33,819,400	52.17%
13	Afghanistan	15,040,800	29,955,000	50.21%
14	Madagascar	8,521,940	17,864,900	47.70%
15	Laos	2,917,770	6,194,320	47.10%
16	Papua New Guinea	2,386,720	5,087,580	46.91%
17	Korea, North	10,535,900	22,739,400	46.33%
18	Eritrea	1,984,150	4,592,260	43.21%
19	Congo, DRC	26,082,000	60,495,900	43.11%
20	Guinea Bissau	547,445	1,389,530	39.40%
21	Bangladesh	54,828,000	143,327,000	38.25%
22	Sierra Leone	2,200,130	5,822,840	37.78%
23	Burkina Faso	5,082,180	13,450,600	37.78%
24	Tanzania	12,894,900	36,544,900	35.29%
25	Benin	2,672,280	7,695,130	34.73%
26	The Gambia	527,023	1,554,600	33.90%
27	Togo	1,797,340	5,380,960	33.40%
28	Nigeria	40,779,200	128,139,000	31.82%
29	Guinea	2,905,380	9,173,740	31.67%
30	Cameroon	5,316,040	16,939,500	31.38%
31	Yemen	6,437,630	20,556,300	31.32%
32	Liberia	848,300	2,795,780	30.34%
33	Niger	3,628,350	12,116,400	29.95%
34	Swaziland	310,639	1,130,320	27.48%
35	Mozambique	5,243,330	19,241,900	27.25%
36	Lesotho	542,731	2,035,590	26.66%
37	Ghana	5,800,210	21,841,900	26.56%
38	Chad	2,549,590	9,684,900	26.33%
39	China	341,869,000	1,322,150,000	25.86%
40	Senegal	2,939,000	11,609,400	25.32%
41	Central African Republic	992,113	4,171,180	23.78%
42	Congo	840,291	3,611,900	23.26%
43	India	249,281,000	1,077,590,000	23.13%
44	Honduras	1,629,130	7,064,040	23.06%
45	Philippines	19,301,500	83,780,100	23.04%
46	Cote d'Ivoire	3,735,380	16,451,700	22.71%
47	Nicaragua	1,149,680	5,427,590	21.18%
48	Thailand	12,435,000	63,774,300	19.50%
49	Mali	2,155,700	11,447,800	18.83%
50	Angola	2,228,790	11,838,600	18.83%
51	Sudan	7,333,440	40,161,100	18.26%
52	Georgia	810,520	4,613,410	17.57%
53	Somalia	1,476,440	8,470,990	17.43%
54	Vietnam	14,207,300	82,123,500	17.30%
55	Moldova	732,965	4,427,830	16.55%
56	Guatemala	1,952,230	12,011,500	16.25%
57	Indonesia	34,178,600	235,342,000	14.52%
58	Namibia	283,750	2,027,850	13.99%
59	Morocco	4,421,800	32,133,800	13.76%
60	Zimbabwe	1,578,020	12,142,200	13.00%
61	Zambia	1,233,230	11,366,400	10.85%

continued. . .

Rank	Country	Unlit Population	Total Population	Proportion Unlit
62	Lithuania	376,942	3,598,410	10.48%
63	Latvia	222,091	2,221,850	10.00%
64	Albania	322,966	3,486,930	9.26%
65	Peru	2,548,400	27,740,700	9.19%
66	Sri Lanka	1,780,120	19,741,400	9.02%
67	South Africa	3,969,540	44,139,800	8.99%
68	Armenia	263,346	2,979,870	8.84%
69	Gabon	117,123	1,348,720	8.68%
70	Mongolia	234,313	2,778,940	8.43%
71	Ecuador	1,056,070	12,879,000	8.20%
72	Cuba	917,292	11,226,500	8.17%
73	Panama	248,252	3,095,810	8.02%
74	Colombia	3,205,550	42,623,100	7.52%
75	Bolivia	661,591	8,862,800	7.46%
76	Ukraine	3,401,660	46,767,700	7.27%
77	El Salvador	482,952	6,657,670	7.25%
78	Azerbaijan	540,635	7,908,030	6.84%
79	Belarus	692,652	10,310,600	6.72%
80	Botswana	109,365	1,638,120	6.68%
81	Mauritania	203,891	3,063,830	6.65%
82	Kazakhstan	1,001,030	15,209,100	6.58%
83	Tajikistan	435,798	7,169,200	6.08%
84	Bosnia & Herzegovina	253,036	4,405,710	5.74%
85	Romania	1,219,200	22,304,700	5.47%
86	Kyrgyzstan	274,559	5,162,820	5.32%
87	Pakistan	7,627,120	162,141,000	4.70%
88	Dominican Republic	404,342	8,867,360	4.56%
89	Estonia	49,799	1,287,040	3.87%
90	New Zealand	143,913	3,767,720	3.82%
91	Bulgaria	261,711	7,443,570	3.52%
92	Turkey	2,376,460	67,973,500	3.50%
93	Costa Rica	135,619	4,016,540	3.38%
94	Turkmenistan	158,399	4,980,930	3.18%
95	Malaysia	708,951	22,724,700	3.12%
96	Paraguay	185,568	6,336,940	2.93%
97	Serbia & Montenegro	311,921	10,782,600	2.89%
98	Brazil	4,577,040	182,872,000	2.50%
99	Algeria	741,601	32,213,600	2.30%
100	Russia	3,218,480	143,054,000	2.25%
101	Iraq	565,988	26,121,400	2.17%
102	Chile	331,058	15,591,800	2.12%
103	Tunisia	196,448	9,595,320	2.05%
104	Uzbekistan	492,847	26,804,900	1.84%
105	Mexico	1,628,750	105,404,000	1.55%
106	Argentina	601,162	39,404,100	1.53%
107	Macedonia	30,703	2,050,150	1.50%
108	Slovenia	27,105	2,023,830	1.34%
109	Australia	258,419	19,522,400	1.32%
110	Croatia	54,786	4,269,240	1.28%
111	Syria	233,376	18,386,500	1.27%
112	Portugal	126,357	10,314,400	1.23%
113	Poland	357,564	38,517,000	0.93%
114	Venezuela	230,262	24,824,100	0.93%
115	Ireland	35,258	3,877,150	0.91%
116	Iran	570,223	67,485,700	0.84%
117	France	489,883	59,411,700	0.82%
118	Hungary	79,108	10,014,300	0.79%
119	Slovakia	38,699	5,436,770	0.71%
120	Oman	18,275	2,853,770	0.64%
121	Spain	230,040	39,454,500	0.58%
122	Germany	382,572	82,344,600	0.46%
123	Uruguay	13,689	3,407,320	0.40%
124	Jordan	22,425	5,755,160	0.39%
125	Greece	38,285	10,161,500	0.38%
126	Libya	21,446	5,700,280	0.38%

continued. . .

Rank	Country	Unlit Population	Total Population	Proportion Unlit
127	Norway	11,676	4,152,900	0.28%
128	United Kingdom	119,455	59,121,400	0.20%
129	Denmark	9,602	5,120,060	0.19%
130	Austria	13,456	8,160,360	0.16%
131	Japan	201,738	122,791,000	0.16%
132	Lebanon	5,400	3,619,990	0.15%
133	Canada	46,514	32,297,800	0.14%
134	Sweden	8,644	8,433,960	0.10%
135	Saudi Arabia	19,431	25,892,800	0.08%
136	Italy	26,180	56,633,700	0.05%
137	United States	112,266	290,342,000	0.04%
138	Finland	1,601	5,101,730	0.03%
139	Switzerland	1,512	7,536,000	0.02%
140	Egypt	14,266	77,026,400	0.02%
141	Jamaica	375	2,661,670	0.01%
142	Czech Republic	1,019	10,239,800	0.01%
143	Israel	431	6,098,570	0.01%
144	Korea, South	846	47,155,800	0.00%
145	Netherlands	123	16,281,300	0.00%
146	Mauritius	0	1,218,210	0.00%
147	Kuwait	0	1,898,590	0.00%
148	United Arab Emirates	0	2,447,990	0.00%
149	Singapore	0	4,137,220	0.00%
150	Belgium	0	10,401,000	0.00%