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Abstract

Most of the medium-run growth in energy demand is forecast to come from the developing world, which consumed more total units of energy than the developed world in 2007. We argue that the main driver of the growth is likely to be increased incomes among the poor and near-poor. We document that as households come out of poverty and join the middle class, they acquire appliances, such as refrigerators, and vehicles for the first time. These new goods require energy to use and energy to manufacture. The current forecasts for energy demand in the developing world may be understated because they do not accurately capture the dramatic increase in demand associated with poverty reduction.

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Over the next 25 to 30 years, nearly all of the growth in energy demand, fossil fuel use, associated local pollution, and greenhouse gas emissions is forecast to come from the developing world. The Energy Information Administration (2010a, Table 1) reports that energy consumption in OECD and non-OECD countries was roughly equal in 2007, but from 2007 to 2035, they forecast energy consumption in OECD countries to grow by 14 percent, and energy consumption in non-OECD countries to grow by 84 percent.

This paper argues that the world's poor and near-poor will play a major role in driving medium-run growth in energy consumption. As the world economy expands and poor households' incomes rise, they are likely to get connected to the electricity grid, gain access to good roads, and purchase energy-using assets like appliances and vehicles for the first time. The energy needed to manufacture and use these new assets is likely to constitute a large portion of the growth in the demand for energy in the medium term. Also, vehicles and most appliances, such as refrigerators, are long-lived durable goods, so increases along the extensive margin driven by first-time purchases of these assets will have substantial consequences for energy consumption and greenhouse gas emissions for some time.

More broadly, the relationship between economic growth and energy consumption in the developing world has been, and is likely to continue to be, heavily influenced by the extent to which that growth is "pro-poor" – that is, by the extent to which growth improves the economic condition of those previously living in poverty. Further, we argue that the current forecasts for energy demand in the developing world, such as those reported in the first paragraph, may be understated because they do not accurately capture increased demand along the extensive margin.

Trends in Energy Use in Developing Countries

Figure 1 plots total energy use in the developed and developing worlds, using actual numbers from 1980 to 2008 and Energy Information Administration projections out to 2035. Total energy includes consumption from the residential, industrial, commercial, and transportation sectors from different primary sources, including petroleum, natural gas, and coal, and electricity generated from the same fossil fuels, nuclear, hydro, geothermal, solar, wind, and biomass. The solid lines, plotting the actual numbers, demonstrate that energy consumption in the developing world overtook the developed world recently. In part this reflects accelerating growth in developing world energy consumption in the most recent ten to fifteen years.

The squares and triangles plot the Energy Information Administration's forecasts for how energy use will evolve, demonstrating that much of the growth is expected to be in the developing world. By 2035 developing world demand will be almost two times as high as developed world demand. Other organizations offer similar forecasts. The International Energy Agency (2010, Table 2.3) projects compound annual growth in non-OECD countries' energy demand of 2.0 percent through 2030, compared with the Energy Information Administration's (2010a, Table 1) projected compound annual growth of 2.2 percent through 2035.

Macro-level energy-demand forecasts are difficult to develop and inherently uncertain, but they are also critical for future planning by energy producers, firms that rely on energy as an input, and scientists and others interested in understanding the possible range of increased greenhouse gases in the atmosphere.

Underestimates can lead to underinvestment in energy production capacity, shortages and price spikes and misunderstandings about both total future greenhouse gas emissions as well as country-specific emissions trajectories.

It is worth considering several benchmarks for the Energy Information Administration's projections. The dashed lines in Figure 1 provide one reference point. They represent extrapolations of the linear trends from 2002 to 2008 in the developing and developed worlds. These indicate that the Energy Information Administration projects the developed world will follow the linear trend while the developing world will grow more slowly than it has recently.

As a second reference point, consider a very crude forecasting exercise. Dividing 2008 energy consumption, as reflected in Figure 1, by total population, the developed world consumed 202 million BTU per person and the developing world consumed 47. If every person in the developing world increased energy use to the 2008 level of the developed world, developing world energy use would quadruple. Though this calculation is substantially higher than the Energy Information Administration's forecast, it could underestimate the potential growth in energy demand for several reasons. For one, it ignores population growth. It also likely understates the current gap between energy use in the developed and developing worlds, because a certain share of the energy currently used in the developing world is to produce goods for export to developed world consumers. There are certainly reasons why this exercise could over-estimate energy use as it is highly unlikely that every single person in the developing world will achieve the level of consumption of the average person in the developed world by 2035. Also, it is possible that future energy use will be more efficient than it is currently.

As this projection suggests, however, understanding the growth in energy demand involves understanding the process by which developing world consumers evolve into developed world consumers, which we turn to next.[1]

Household-Level Energy Use

The economics profession has recognized for some time that household energy demand is driven as much by ownership of energy-using assets such as refrigerators and vehicles as by their usage (Dubin and McFadden 1984). Developing countries have recently experienced tremendous growth in sales of these energy-using assets. For example, in India there were 600,000 new vehicles sold in 2003, compared to 2,300,000 new vehicles sold in 2010 (Chugh, 2011). Similarly, in urban China there were 8 air conditioning units for every 100 households in 1995, and by 2009, there were 106 units for every 100 households (Auffhammer, 2011). This seems to mirror a general trend seen throughout the developing world: as households come out of poverty and enter the middle class, they purchase new assets, many of which use substantial amounts of energy.

Household appliance and vehicle holdings by income level: cross-sectional evidence

[1] Several papers have used country-level data and time series models to test for convergence in CO_2 emissions (see, e.g., Strazicich and List, 2003; Aldy, 2006; and Barassi, Cole and Elliot, 2011). Results are mixed, but generally suggest some convergence in emission rates among OECD countries but not worldwide.

To document this trend, we have assembled household-level survey data on appliance and vehicle ownership in several large developing countries, including China, India, Brazil, Indonesia, Mexico, and most of sub-Saharan Africa. The data are described more fully in the online Data Appendix. As a generic category, appliances can include fans, air conditioners, washing machines, water heaters, blenders, irons, televisions, and more. Vehicles can include scooters, motorcycles, cars and trucks. Our analysis focuses on refrigerators and cars, which are the two assets most consistently included in household-level surveys. Also, refrigerators are one of the first assets, after a television that a typical low-income household acquires. Moreover, the basic household decision-making that drives refrigerator and vehicle purchases applies to a range of other expensive, durable, energy-using assets. Finally, refrigerators and vehicles account for a significant share of developing world residential energy consumption. For example, refrigerators in China account for nearly 30 percent of residential electricity demand, or 15 percent of total residential energy demand.[2]

For most countries, we also use the surveys to measure each household's annual consumption expenditures as a measure of its overall well-being. We use household expenditures and not income for two reasons. First, data on expenditures are more reliable than data on income, particularly for households at the low end of the distribution who may have substantial informal and nonmonetary income sources. Second, if consumers smooth consumption either over their lifetime or across households (within extended families, for example), expenditures provide a better representation of household well-being. For Brazil, we use household income, because that country's survey does not include a comprehensive measure of consumption.

As an example, Figure 2 plots the relationship between annual household expenditures and refrigerator and vehicle ownership in Mexico in 2000.[3] The distinctive S-shaped pattern that emerges is pervasive across our datasets and has been identified by others plotting country-level vehicle ownership against GDP (Dargay, Gately and Sommer, 2007; Dargay and Gately, 1999). For the approximately 10 percent of the Mexican households that consume less than 8,000 pesos per person per year, refrigerator and especially vehicle ownership are uncommon. Also, the relatively flat slope of both the refrigerator and the vehicle lines on the left quarter of the figure suggest that there are not large differences in refrigerator or vehicle holdings even for low-income households whose total expenditures differ by a factor of two or more. Both curves reach an inflection point and become much more steeply sloped at the middle of the expenditure distribution. At the high end, the curves flatten out, suggesting that above a certain threshold, cross-household differences in expenditures, measuring lifetime income, do not drive refrigerator or vehicle purchase decisions. Refrigerators in Mexico in particular appear to reach a saturation point. The main focus of our analysis is the inflection point to the left of the graph. While the

[2] Household refrigerators in China consumed approximately 145 TWh of electricity in 2009 (Zhou et al., 2011; personal communication) while total residential electricity was 490 TWh (National Bureau of Statistics, 2010). Electricity comprises 50 percent of residential energy consumption (Ni, 2009).

[3] Data from 1992 to 2008 show similar patterns, although there has been rapid growth in refrigerator ownership at the low end of the income distribution, particularly for refrigerators, so the S-shape is slightly more compressed in recent years.

data in Figure 2 are cross-sectional and should not be interpreted as causal, they do suggest that as households rise out of poverty, many of them become first-time purchasers of energy-using assets.

Conceptual framework

Early work such as Farrell (1954) *assumed* an S-shaped relationship between income and share of households with an asset in a model based on a log-normal distribution of "acquisition thresholds." Gertler, Shelef, Wolfram and Fuchs (2011) derive the S-shaped curve by modeling the appliance or vehicle acquisition decision and adding features that we argue are especially relevant in the developing world. The basic logic is straightforward. Households face a choice between consuming a divisible good with decreasing marginal utility (such as food) and an indivisible appliance that provides a fixed utility. As household income increases, the utility from increased consumption of the divisible good declines and, the probability that the household's utility from the appliance exceeds the utility from forgone food increases. Under reasonable assumptions on the distribution of appliance or vehicle valuations, this generates an S-shaped ownership curve.

Further, most energy-using assets are expensive and most low-income households in the developing world are credit-constrained.[4] As a result, a household does not make a period-by-period choice of whether to own an asset effectively by renting it, as is assumed in much of the developed-market literature. Instead, the household must save to acquire the asset, which delays the asset acquisition to a higher income than would be suggested by the rental model. Because lower-income households are less able to self-finance, this delay is bigger at lower income level and the resulting S-curve becomes steeper. Also, if households are self-financing through savings, we show that growth in income, and not just current income, will affect asset acquisition (Gertler, Shelef, Wolfram and Fuchs, 2011).

Household appliance holdings by income level: evidence over time

Though an S-shaped ownership curve is reflected in the cross-section and consistent with theory, it is possible that there are other relevant variables that are correlated with both income and a household's value for a refrigerator or vehicle, which would suggest the simple plots like Figure 2 are misleading. One obvious candidate is access to electricity or roads. Electrification rates in Mexico are about 98 percent, so that is unlikely to explain the refrigerator patterns. Still, the inflection point could reflect households from different regions, with the ones on the very left of the curve from cultures that place low value on refrigerated food or where communal assets are often shared. However, several additional facts suggest that such explanations play a relatively minor role compared to income.

One piece of evidence against the omitted variable hypothesis comes from our own work in Mexico. We use the income variation created by the conditional cash transfer program Oportunidades to examine appliance acquisition patterns (Gertler, Shelef, Wolfram and Fuchs, 2011). Each household's transfer

[4] A number of papers have noted the credit constraints on low-income households in the developing world, including Banerjee and Newman (1993), Aghion and Bolton (1997), Lindh and Ohlsson (1998), Lloyd-Ellis and Bernhardt (2000), Banerjee (2004), and de Mel, McKenzie, and Woodruff (2008).

payment was set according to a nonlinear function of the age and gender of children. Also, villages were randomly assigned to either the treatment or control group, and households in treated villages began receiving transfers 18 months before households in the control villages. We argue that the resulting cross- and within-household variation in transfers is exogenous to other factors likely to determine appliance acquisitions. In that paper, we develop three predictions on asset acquisition that follow from the interplay between decreasing marginal utility from other goods and credit constraints and find evidence consistent with each of them.

To confirm that the relationship we found among poor Mexicans matches a broader swath of the developing world, we use data from household expenditure surveys from several large developing countries. We use what Deaton (1986) calls a "pseudo-panel data approach," in which we analyze households at the same quartile of the income distribution over time. This approach controls for any time-invariant omitted variables that are correlated with both asset valuations and location in the income distribution. For simplicity, in Table 1 we group the middle two quartiles. For each country, the "Annual Acquisitions" column reports the share of households that acquired refrigerators or vehicles between the baseline and final year, based on a linear interpolation. In other words, by 2009, 84 percent of the households in the bottom expenditure quartile in Brazil owned refrigerators, reflecting a 44 percentage point increase over the 17-year period. The data reported in the table reflect almost 4 billion people, a sizeable share of the developing world.

The first three rows of Table 1 clearly suggest that in Brazil, Mexico, and urban China, growth in refrigerator ownership at the lower end of the income distribution was faster than growth at the higher end, which is consistent with the S-shaped pattern. The next row, for rural China, depicts slower growth at the low end of the income distribution. Poor households in rural China, however, were much poorer than their counterparts in Brazil, Mexico or urban China and began in the 1990s with many fewer refrigerators per household. This suggests that most poor rural Chinese households were to the left of the inflection point in the S-curve. Households in the middle and upper parts of the distribution acquired refrigerators more rapidly, consistent with being located on the middle of the S-curve. Refrigerator acquisitions in India and Indonesia follow the same pattern as rural China, as do vehicle acquisitions in Mexico, urban China, India and Indonesia.

The data we have for Africa come from Demographic and Health Surveys (DHS) performed by the U.S. AID, which do not include data on household income or consumption, so we cannot break out the ownership rates by income quartile. We aggregate baseline ownership and growth rates for every country in sub-Saharan Africa with more than one DHS survey that identifies asset ownership. In all, the sub-Saharan Africa data cover approximately 500 million people. The numbers suggest that very few households in the region own refrigerators or vehicles, and growth in ownership has been languid. The big step toward ownership of these assets is yet to arrive in most of sub-Saharan Africa.

Household energy expenditures by income level

The patterns for appliances and vehicles strongly suggest that energy use will grow more quickly for households coming out of poverty than for households further up the income distribution. To verify this interpretation, we examined patterns in household energy expenditures by consumption quartile. Unfortunately, very few of the household expenditure surveys other than Mexico consistently ask households about electricity or other forms of energy expenditures. However, the data for Mexico clearly shows that per capita electricity expenditures grew much more quickly for the average household in the lowest income quartile than for the average household in the middle or top quartile. Between 1996 and 2008, electricity expenditures doubled for households at the low end and only grew by 50 percent for households with higher expenditures.

These results are not driven by changes in the number of household members across quartile: similar patterns emerge if we look at expenditures per household. In addition, these trends do not appear driven by changes in relative prices. Over the early part of the sample, through 2002, prices did rise more slowly for high-volume users than for low-volume users and use is correlated with income. In the later part of the sample, however, prices rose more slowly for low-volume users, and this is the period when expenditures deviated most dramatically between the two groups. This suggests that the differences across quartiles in the later part of the sample if anything understate different growth rates in consumption.

Electrification

While the household-level data suggest the potential for rapid adoption of energy-using assets as incomes rise in the developing world, several important decisions are out of households' control. The utility a household derives from a car or refrigerator depend heavily – in the case of a refrigerator almost entirely – on whether the household has access to good roads or a reliable electricity source. This section will focus on electrification rates across countries, although it would be interesting to perform a similar analysis for roads or other components of the energy infrastructure, including natural gas pipelines and gasoline refueling stations.

More than one in five people worldwide—approximately 1.5 billion people— live without electricity in their homes. Understanding where these people are, and the process by which they gain access to modern energy, is crucial to understanding the growth in energy consumption in the developing world.

Table 2 documents the ten countries where the largest numbers of people live without electricity. Though methodologies for determining electrification vary by country, they appear to capture all households with access to electricity whether or not they pay for it. Sub-Saharan Africa is relatively underrepresented in this ranking because it is divided into many smaller countries. Across the region, the majority of the people (71 percent) live without electricity. This is certainly related to the low refrigerator penetration we discussed above. It is also notable that Brazil and China are *not* listed in Table 2. Brazil, despite its large population and vast territory has only 8 million people living without electricity, and China has only 11 million living without electricity even though it has seven times the population of Brazil.

Both the Chinese and Brazilian governments have overseen significant electrification efforts. For example, Brazil's rural electrification program *Luz para Todos*, is on track to connect 10 million individuals through approximately $7 billion in grid expansion, at a cost of $3,500 per connection. Brazil relies on large hydroelectric power stations to provide more than 70 percent of the country's electricity and it currently has excess generating capacity. As a result, its expansion has been relatively inexpensive (Niez, 2010). Except in the most remote locations, electrification requires only extension of and connection to the integrated power grid.

China, in contrast, spent approximately $50 billion on its recent electricity grid development in addition to unspecified loans through state-controlled banks. An estimated 300 million people were connected to the grid as a result. In order to provide additional people with electricity, China needed to develop both additional power generation—primarily coal and distributed small hydroelectric generation—as well as build the corresponding electrical grid. On the other hand, the long history of electrification efforts (since at least 1949) had left many in China with some access to power, although the grid was unreliable, unsafe, and inefficient. Indeed, as access is nearly universal, China's recent efforts have focused on quality improvements (Niez, 2010). It is worth noting that Elvidge et al. (2011) use satellite images of night lighting to estimate that only about 80 percent of Chinese households use lights that are visible outdoors. They posit that one possibility for the discrepancy between their finding and official statistics is overestimation of the official electrification rate. However, on the ground studies (for example, UN-Energy, 2003) estimate higher electrification rates in exactly the regions where Elvidge et al. find the least electrification. It is possible that satellite images do not pick up light from the poor, who have low electricity quality and limited, dim light sources.

Cross-country correlates with electrification

Contrast China's high electrification rate of nearly 100 percent with India's comparatively low rate of about 65 percent. China does have higher per capita GDP than India, but this does not explain the difference. In fact, among the countries with close to complete electrification, China has nearly the lowest GDP per capita. One conjecture is that the strong authoritarian government in China has facilitated infrastructure roll-out, whereas more democratic India has been less successful devoting resources to electrification. Indeed, the International Energy Administration notes that the success of both Brazil and China's electrification programs result from strong political will and sufficient funding (Niez, 2010).

To explore the patterns across the developing world, Table 3 describes the relationship between electrification rates and a series of variables. Each row reports results from a separate linear regression that we estimated on a set of developing countries. The dependent variable is the country's electrification rate.[5] In each regression, per capita GDP is one explanatory variable, and then in all rows except the first one, we add a second explanatory variable. While we certainly will not interpret the coefficients in these simple cross-sectional regressions as causal, they help identify factors consistently correlated with electrification across countries.

[5] Results are very similar if we use a log-odds ratio as the dependent variable or if we estimate each specification on the set of 44 countries for which we have all 10 explanatory variables.

Table 3 reflects several interesting relationships. As expected, per capita GDP is highly correlated with electrification rates in all of the specifications. Contrary to what the China-India comparison might suggest, however, governance does not appear correlated with electrification rates: neither the coefficient on a government's Polity rating (a measure of governance ranging from hereditary monarchy at one end to consolidated democracy at the other end) nor the corruption measure from World Bank (using survey data) are statistically significant. Other factors one might have thought important are also insignificant, including natural resource endowments and urbanization. Financial openness has the opposite sign from what we would expect—that is, greater openness is correlated with a lower rate of electrification. However, this finding is not robust across various alternative specifications, and could reflect that this measure captures countries with large natural resource rents that are not invested in infrastructure. (Eight of the ten countries with the highest financial openness have significant oil revenues, much of which they may have invested abroad.)

However, one factor that appears important is the income distribution within a country. While the coefficient on the Gini coefficient is not statistically significant, the coefficient on change in poverty gap is significantly negative, suggesting that recent reductions in poverty levels are also correlated with electrification. The poverty gap measures the amount of money that would be required to lift the income of households below the poverty line to the poverty line. So, for two countries with the same per capita GDP, the one with a higher poverty gap has lower electrification. These results suggest that the share of the population moving up and out of poverty is, together with high incomes, the most important correlate with electrification. Although poverty is correlated with less electrification, causality may run in both directions: not only does a lower level of income reduce demand for electricity, but researchers like Lipscomb, Mobarak and Barhan (2011) suggest that electrification may help reduce poverty.

Micro Foundations of Macro Energy Trends

We have focused thus far on understanding household-level energy use, but can the household-level patterns in asset adoption and electrification help explain the recent growth in energy consumption in the developing world? We suspect they do, based on both deductive and empirical insights.

As a starting point, Table 4 summarizes energy use by sector for developing and developed countries, along with some additional perspective from the U.S. economy. The residential sector accounts for over 20 percent of all energy used in the United States, but only about 15 percent in the developing world. There are several potential explanations for this pattern. One possibility, for example, is that industry in the developing world is supplying U.S. and other developed world consumers. However, the proportions of energy used by households are certainly consistent with the hypothesis that economic growth will lead to large gains in residential sector energy use as households coming out of poverty purchase energy using assets. The share of energy consumed in the transport sector is also higher in the developed world, and personal vehicles account for a large part of this consumption. For example cars account for 48 percent of the energy used in transportation, in the European Union (ADEME /IEEA, Bosseboeuf, Lapillonne, Eichhammer, Boonekamp , 2007). Again, the share of households with vehicles is likely to rise quickly as poverty falls in low-income countries.

Still, the residential sector accounts for less than a quarter of total energy demand, even in the U.S., so, on its face, it may seem implausible to attempt to explain total energy demand with residential consumption. But, while we have focused on refrigerators and vehicles as convenient devices to describe a consistent adoption pattern across countries, the basic principles we have identified likely apply to other durable assets. And, at some level, nearly all commercial and industrial processes are at least indirectly supplying consumer demand. So, as more consumers buy refrigerators and air conditioners as well as cell phones and other electronics, local industry will use more energy to produce at least part of the value-chain and the commercial sector will grow to supply them.

A growing literature within environmental engineering measures the life-cycle energy and greenhouse gas emissions from different consumer actions. One approach is to use an input-output model to describe the industries that supply, for instance, appliance manufacturers and then look at the energy intensity of the sum of the inputs. Evidence from this literature suggests that about ten percent of the energy used by a refrigerator over its lifetime is used in manufacturing. Since the same estimates assume that refrigerators last for fifteen years, in the period when a large number of people are *acquiring* refrigerators for the first time, the energy from manufacturing the refrigerator, as well as from making the steel, plastic and refrigerants that it contains, will represent a substantial portion of the refrigerator's energy use.

One environmental engineering paper documents the relationship between household income and life-cycle greenhouse gas emissions associated with U.S. households' consumption (Jones and Kammen, 2011). While they consider greenhouse gas emissions and not energy use, their analysis indicates an S-shaped relationship between income and induced greenhouse gas emissions, meaning that at the low end of the income distribution, greenhouse gas emissions rise slowly with income, rise quickly at middle incomes and rise slowly again at high incomes. We suspect this relationship would be even more pronounced for consumers in the developing world where the consumption bundles differ more between the poor and the wealthy, but this remains to be explored.

Empirically, our previous work demonstrates that the relationship between a country's energy demand and income varies substantially across the developing world. We have estimated the relationship between the log of per capita energy consumption (total consumption, across all sectors) and log of GDP per capita using a panel data set with 37 developing countries over a 27-year period from 1980-2006 (Gertler, Shelef, Wolfram, and Fuchs, 2011). We include country fixed effects to control for any differences in the cost of producing energy or fixed differences in the demand for energy--for instance, those driven by weather. We also estimate year fixed effects to control for common price or technological shocks. We show that the coefficient on the log of GDP is considerably larger for countries with pro-poor growth. Our estimates suggest that energy demand in a country at the 75th percentile of pro-poor growth grows faster than per capita income, while energy demand in country at the 25th percentile rises only about half as quickly as per capita income. Because our specifications do not control for other factors that could influence demand, we would not interpret the coefficients on log of per capita energy demand as true income elasticities. However, the results do suggest large differences in the relationship between income growth and energy use across countries, depending on which households benefit from growth.

Rethinking Macro Energy Forecasts

Unfortunately, we suspect that the forecasts of energy use in the developing world that we cited at the beginning of the paper do not account for the differences in growth along the extensive and intensive margins. As a result, they may seriously underestimate the likely near-term growth in energy demand.

What leads us to believe that Energy Information Administration might be wrong and how might this be linked to asset acquisition by households coming out of poverty? For one, as we documented in Figure 1, they are projecting that the *linear* trend in energy demand growth will slow down in the developing world. This seems implausible given the large number of people in the developing world who have yet to acquire even the most basic energy-using assets (Table 1), and given the expected population growth in the developing world.

More systematically, it appears that the Energy Information Administration's past forecasts have consistently under-estimated energy demand in regions that have experienced pro-poor growth. We have compared their *2000 International Energy Outlook* forecast for each region's energy demand in 2005 with actual energy demand in 2005. Adjusting for errors in forecast GDP growth, China and Brazil, had, respectively, approximately 15 and 10 percent higher energy consumption in 2005 than the Energy Information Administration had predicted in the 2000 report.

Both Brazil and China had pro-poor economic growth over this period. Brazil, for instance, launched the large and aggressive conditional cash transfer program, *Bolsa Família*, in 2003. The program, which currently benefits over 12 million households, has been credited with lifting 20 million people out of poverty (World Bank, 2010). While China has not had an explicit anti-poverty program, it has had notable success reducing poverty since the early 1980s (for example, Ravallion and Chen, 2007). In contrast, the Energy Information Administration over-estimated the growth in energy demand in the rest of Central and South America, where the share of people living in poverty has recently increased (World Bank 2011).

The forecasting model of the Energy Information Administration is complex, but thoroughly documented. The most recent documentation available suggests that the model does not fully account for potential differences in acquisition of home appliances and other assets across developing countries. For example, Energy Information Administration (2010b) reports the specific income elasticities used as inputs to the residential energy demand component of the model. The elasticity estimates are slightly higher in the developing world than the developed, but there are no differences across the developing world. Our hypothesis suggests that countries where many households are coming out of poverty (like Brazil in recent years) should have much higher income elasticities of demand for energy than countries where growth favors households at the higher end of the income distribution (like most of the rest of South America in recent years).

There are several different approaches to forecasting energy demand, an endeavor people have been engaged in for decades. The Energy Information Administration uses what would be characterized as a "top-down" model, which relies on estimates of GDP growth and energy income elasticities. In the late 1970s, in the face of declining demand, which they suspected was related to saturation of appliance holdings, the adoption of natural gas heating, and energy efficiency standards, California policymakers pioneered the application of end-use modeling, which describes residential-sector demand as the sum of demand across different uses (Blumstein, et al., 1979). While it might make sense for the Energy Information Administration to make country-by-country adjustments to income elasticities, it will also be valuable to develop end-use models to reflect rapid increase in the middle class within the developing world. For example, McNeil and Letschert (2010) model residential appliance uptake, although their specification is based on cross-country S-curves and do not reflect income distribution within a country.

Conclusions

Energy growth along the extensive margin, as low-income households buy their first durable appliances and vehicles, will be an important driver of the demand for energy in the near future. Within a country, the adoption of energy-using assets typically follows an S-shaped pattern: among the very poor we see little increase in the number of households owning refrigerators, vehicles, air conditioners and other assets as incomes go up, above a first threshold income level, we see rapid increases of ownership with income, and above a second threshold, increases in ownership level off. Some countries have already experienced these transitions, while many others are likely to in the coming years. The large share of the world's population that has yet to go through the first transition suggests that there is likely to be a large increase in the demand for energy in the near future.

Current energy forecasts appear to understate the degree to which the distribution of economic growth affects energy demand. Energy forecasts have implications for the appropriate scale of investment in the energy infrastructure. Underestimates of demand may lead to underinvestment in energy production implying shortages and price spikes. Energy demand also has important implications for understanding the likely path of pollution, including both local pollutants and greenhouse gas emissions.

It is important to remember, however, that increases in the demand for energy associated with poverty reduction result from increases in household welfare. With a refrigerator, people may spend less time walking to stores or less time cooking. Refrigeration may affect nutrition patterns and improve health outcomes. Similarly, the switch from burning wood to using electric stoves for cooking may not only improve indoor air quality, but reduce greenhouse gas emissions because solid-fuel stoves are inefficient and gathering wood for cooking can lead to deforestation (Bruce, Rehfuess and Smith, 2011). While there is little direct evidence on the consequences of energy-using asset accumulation, Dinkelman (forthcoming) cleverly uses plausibly exogenous variation in the cost of laying electricity distribution lines in South Africa to show that village-level electrification leads to increased female labor force participation. Lipscomb, Mobarak and Barham (2011) use an engineering model of hydroelectric dam placement to predict county-by-county electrification in Brazil and find wide-ranging benefits of electrification from increased employment and income to poverty reduction. Understanding the mechanisms underlying these development trends and expanding the set of outcomes analyzed remain important areas for future research.

The growth in energy demand along the extensive margin will also create some intriguing opportunities for energy policy. First, while it is an obvious point, poverty reduction is unambiguously good and keeping families in poverty is not a way to reduce energy demand. Second, to avoid shortages, price increases, and unexpected environmental impacts, each country needs to account for how poverty reduction and economic growth are likely to shape future demand for energy and make informed investments in energy infrastructure. Third, the pervasive governmental subsidies of energy prices in the developing world do not send the right signals for taking energy conservation or environmental externalities into account. Moreover, there is evidence from high-income countries that even if households face appropriate prices, they may make decisions about energy-using goods that are myopic. Finally, there is a chance to improve the energy efficiency of assets purchased by the large numbers of households about to come out of poverty through energy efficiency standards, subsidized distribution of efficient and environmentally friendly models, subsidized research on energy efficient technologies, and other market interventions. This could be very important, as most energy-using durables are long-lived.

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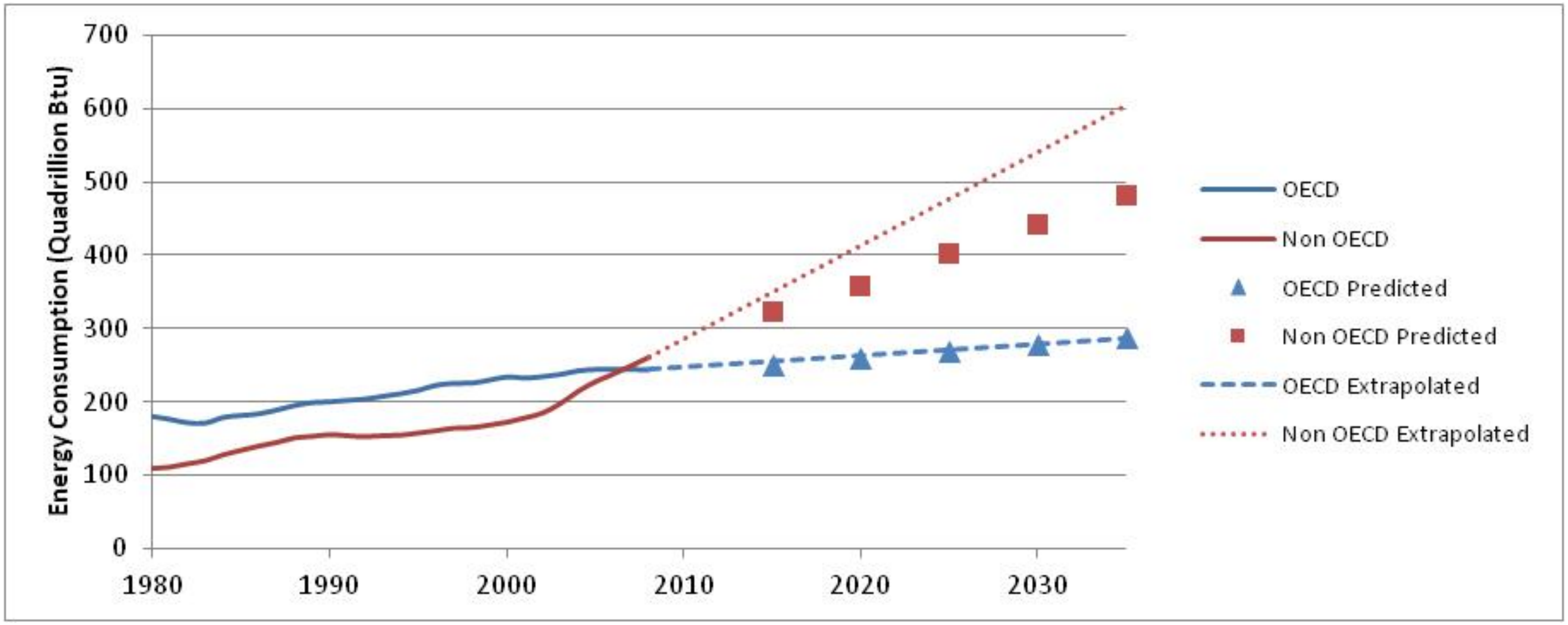
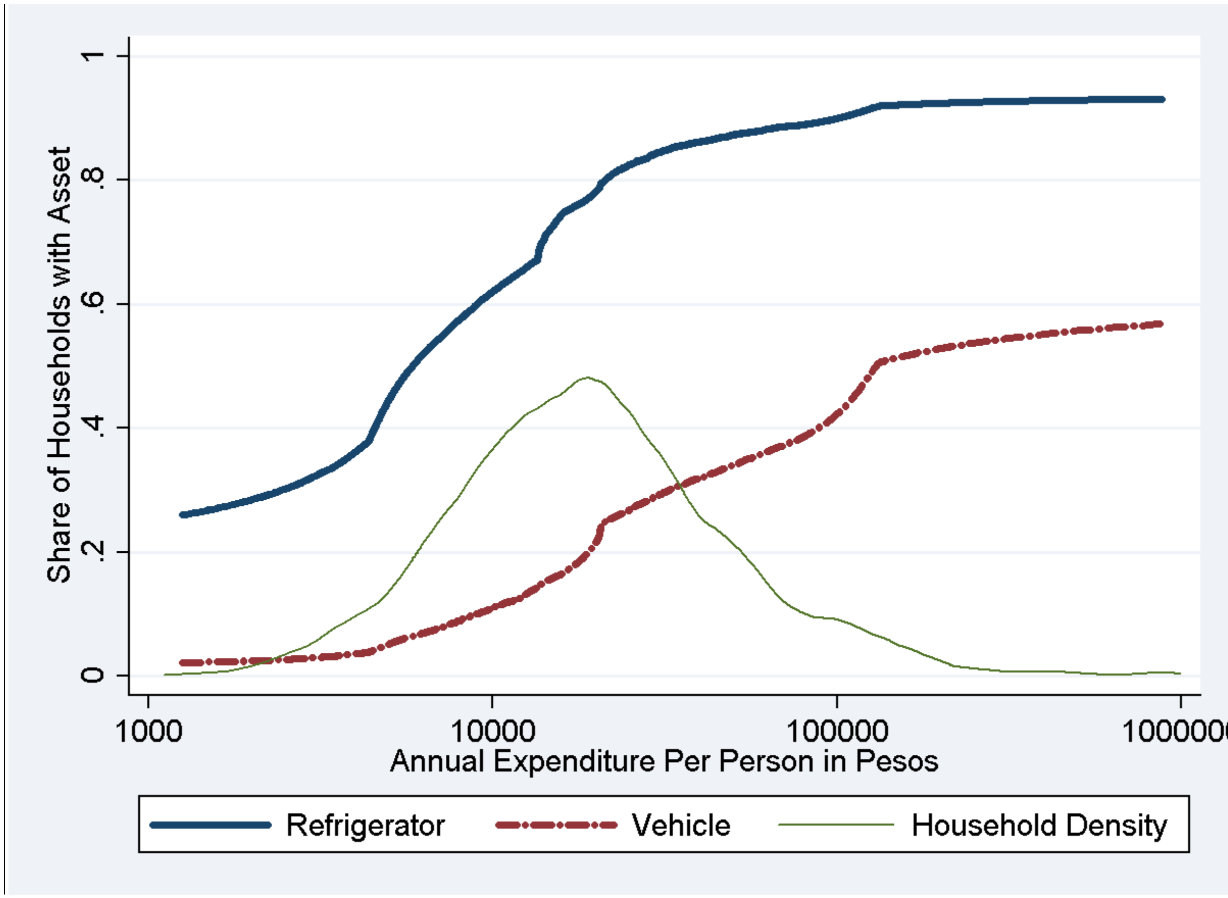
Figure 1: Energy Consumption in the Developing and Developed Worlds:
Actual and forecast



Source: Energy Information Administration, *International Energy Annual* (2008) and *International Energy Outlook* (2011).

Figure 2: Appliance Ownership Rates by Consumption Level:
Mexican refrigerators and vehicles, 2000



Source: 2000 Mexico *Encuesta Nacional de Ingreso y Gasto de los Hogares.* See data appendix for details.

Table 1: Growth in Appliance and Vehicle Ownership by Income Quartile

	Bottom Quartile		Middle Quartiles		Top Quartile	
	Baseline Ownership	Annual Acquisitions	Baseline Ownership	Annual Acquisitions	Baseline Ownership	Annual Acquisitions
Refrigerators						
Brazil (1992 – 2009)	40%	2.6%	76%	1.1%	96%	0.2%
Mexico (1996 – 2008)	32%	2.9%	70%	1.4%	91%	0.4%
China - Urban (1995 – 2002)	41%	2.9%	55%	3.0%	87%	0.6%
China - Rural (1995 – 2002)	1%	1.1%	4%	1.8%	15%	2.5%
India (2000 – 2007)	1%	0.2%	7%	0.6%	23%	1.0%
Indonesia (1999-2004)	2%	<0.05%	9%	0.3%	40%	2.6%
Sub Saharan Africa (1994-2005)	-	-	8%	0.3%	-	-
Vehicles						
Mexico (1996 – 2008)	2%	0.5%	16%	0.9%	49%	0.3%
China - Urban (1995 – 2002)	<0.5%	<0.05%	<0.5%	<0.05%	<0.5%	0.2%
India (2000 – 2007)	<0.5%	<0.05%	1%	0.1%	4%	0.2%
Indonesia (1999-2004)	1%	<0.05%	3%	0.1%	14%	0.7%
Sub Saharan Africa (1994-2005)	-	-	4%	0.1%	-	-

Notes: Standard errors suggested by the number of observations in each survey are reported in the online data appendix, which also reports other details. Quartiles, other than Brazil, are based on total surveyed consumption. Brazil uses stated income instead of consumption. Sub Saharan Africa is not divided by quartile and all households are aggregated in the middle columns.

Table 2: In Which Countries Do the Most People Live Without Electricity?

Top-ten countries by population

	Electrification Rate	*Number of People Without Electricity (Millions)*
India	65%	404.5
Bangladesh	41%	94.9
Indonesia	65%	81.1
Nigeria	47%	80.6
Pakistan	58%	70.4
Ethiopia	15%	68.7
Democratic Republic of Congo	11%	57.0
Myanmar	13%	42.8
Tanzania	12%	36.8

Source: Electrification rates from International Energy Agency, *World Economic Outlook 2009.*See data appendix for details. Note that the *World Economic Outlook 2011* lists higher electrification rates for several of these countries. The most dramatic change is for India, with a 75% electrification rate and 288 million people without electricity. The difference appears to be due to a new data collection methodology and highlights the uncertainty surrounding energy use in the developing world.

Table 3: Electrification Rates

	Log Per Capita GDP		*Additional Explanatory Variable*		*N*
Baseline	22.887***	[1.806]			81
Polity^	22.930***	[1.731]	0.296	[0.372]	81
Corruption^	24.737***	[2.529]	-4.795	[4.555]	81
Annual growth in GDP	23.064***	[2.024]	-7.803	[36.721]	78
Gini coefficient^	25.908***	[3.162]	-0.044	[0.324]	64
Poverty gap ^	15.540***	[4.280]	-0.980***	[0.220]	62
Change in poverty gap ^^	29.929***	[2.976]	0.429*	[0.240]	49
Financial openness^	23.818***	[2.021]	-1.596**	[0.789]	75
Share of population living in urban areas^	19.429***	[2.695]	0.223	[0.138]	81
Share of GDP from Natural resource rents^	23.899***	[1.985]	-0.210	[0.187]	81

^Average reported level in 2000 or later.

^^ Average reported level in 1980-1994 minus average reported level in 1994 and later.

Note: Every row reports coefficient estimates from a separate cross-country specification where the dependent variable is the country's electrification rate as a percentage as of 2008

Sources: Electrification rates from International Energy Agency, *World Economic Outlook.* Gini, Poverty Gap, Share of Population living in Urban Areas and Share of GDP from natural resource rents from World Bank, *World Development Indicators.* Polity from Polity2 measure from Polity IV Project. Corruption from World Bank, *Worldwide Governance Indicators.* Financial Openness per Lane and Milesi-Ferretti is the sum of external assets and liabilities divided by GDP; data from the web appendix to "The External Wealth of Nations Mark II: Revised and Extended Estimates of Foreign Assets and Liabilities, 1970-2004."

Table 4: Energy Use by Sector

	Developing World	*Developed World*	*U.S.*
Residential (%)	15	20	22
Commercial (%)	7	16	19
Industrial (%)	62	40	32
Transport (%)	15	25	28

Source: Energy Information Administration, *International Energy Outlook* 2011.