American Economic Review: Papers & Proceedings 2014, 104(5): 575–580
http://dx.doi.org/10.1257/aer.104.5.575

ENERGY IN THE DEVELOPING WORLD[‡]

Powering up China: Income Distributions and Residential Electricity Consumption[†]

By Maximilian Auffhammer and Catherine D. Wolfram*

Energy demand in China has grown at an alarming rate over the past 15 years. In 1995, the Chinese economy consumed 33 quadrillion BTUs of energy, and by 2011, that number had more than tripled to 110 quadrillion BTUs (US Energy Information Administration (EIA) 2013). China emitted more greenhouse gases than the United States beginning in 2006 and consumed more total energy than the United States beginning in 2009. Though forecasts vary about how quickly China's energy demand will grow in the future, even at half of the recent rate, China's energy use would double in 18 years.

Existing forecasting models appear to have underestimated China's recent growth in energy demand. For example, in its 2000 International Energy Outlook, the Energy Information Administration of the US Department of Energy predicted that China would consume 55 quadrillion BTUs of energy in 2005, just five years later. China's actual consumption was nearly 25 percent higher, at 68 quadrillion BTUs. Similarly, some academics have noted that one factor contributing to the spike in oil prices in 2008 was higher than expected demand for oil from China (Hamilton 2013).

It is important to understand factors that drive energy demand in China in order to improve forecasts and to evaluate policies that might alter the path of energy consumption. Given the level of central planning in the country, a first-order question is how well neoclassical models of household- or firm-level energy consumption apply to China.

In this paper, we focus on residential energy consumption and investigate how income growth—particularly among households close to the bottom of the income distribution—affects adoption of energy-using consumer durables. Consumers in urban China have recently acquired energy-using assets at an alarming rate. For example, there were 8 air conditioning units for every 100 households in 1995, and by 2009, there were 106 units for every 100 households (Auffhammer 2014). Similarly, vehicle ownership in urban China has risen at almost 40 percent per year between 2000 and 2010, helping fuel China's rapid growth in oil consumption (see online Data Appendix).

A previous literature has documented an S-shaped relationship between household income or expenditure level and ownership of appliances, cars and other energy-using assets (e.g., McNeil and Letschert 2010). The S-shape is consistent with decision-making in which households at very low levels of income do not allocate additional income to acquire energy-using assets, but past a certain threshold, households become much more likely to use income gains to acquire refrigerators, cars, or electric water heaters (Gertler et al. 2013).

This paper explores behavior consistent with the S-shape in China. We combine province-level data on rural appliance penetration between 1998 and 2009 with province-level data on income distributions over the same time period. We use across- and within-province variation to investigate the relationship between poverty rates and

[‡]*Discussant:* Shanjun Li, Cornell University.

*Auffhammer: University of California–Berkeley, 207 Giannini Hall, Berkeley, CA 94720-3310 and NBER (e-mail: auffhammer@berkeley.edu); Wolfram: University of California–Berkeley, Haas School of Business, Berkeley, CA 94720-1900 and NBER (e-mail: wolfram@haas.berkeley.edu). We thank Joshua Blonz for valuable research assistance and Shanjun Li for helpful comments.

[†] Go to http://dx.doi.org/10.1257/aer.104.5.575 to visit the article page for additional materials and author disclosure statement(s).

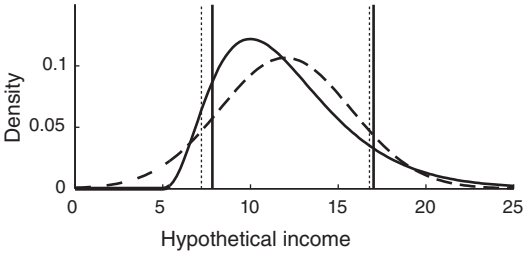

FIGURE 1. SKEWNESS OF INCOME DISTRIBUTIONS

Notes: The figure above displays a χ^2 (solid) and normal (dashed) distribution with equivalent means and variances. The vertical lines indicate the tenth and ninetieth percentiles for each distribution.

residential energy consumption, controlling for the average consumption expenditure.[1] In spite of tremendous overall reductions, China's poverty alleviation has been uneven, so we observe reasonable variation in income distributions across provinces and over time.

We find that, controlling for mean per capita consumption expenditure, in provinces with a higher fraction of the population with incomes above 3,000 RMB per year, the number of appliances per household is higher. In other words, consider two hypothetical income distributions such as the χ^2 and normal distributions drawn in Figure 1. Both have the same mean and variance, but the χ^2 distribution represents fewer people living in extreme poverty, for example below a hypothetical income level of 7.5. Our findings suggest that a province with the χ^2 distribution will have a greater share of households that own basic energy-using appliances, such as refrigerators. Our suggestive results are large in magnitude, indicating that increasing the share of the population living above 3,000 RMB per year by one standard deviation has as large an impact, in most specifications, as increasing province-level mean per capita consumption expenditure by one standard deviation.

[1] Our empirical estimates use average expenditures instead of average income as it more accurately captures household-level well-being. We will use both expenditure and income interchangeably in the conceptual discussion. The online Data Appendix reports comparable estimates using average income.

Our findings have implications for understanding future growth in appliance ownership in China. While appliance adoption has been rapid in urban China, many more urban and rural households are poised to enter the middle class and begin acquiring energy-using assets. Also, other developing countries are similarly bringing households out of poverty and into the middle class.

While home appliances are a small part of overall energy demand, they are representative of the step-change in energy use that households experience as they enter middle-class life and, for instance, use well-lighted, paved roads, pumped water, and other government services, plus purchase processed food and other manufactured consumer goods. Existing energy forecasts generally model economic growth as an important driver, but do not reflect income distributions. While more work is clearly necessary, our findings suggest that this could be an important omission.

I. Related Literature

As noted above, China's energy use has soared recently. Industry is by far the largest sector, accounting for 55 percent of overall demand in 2010. Transportation is the fastest growing sector and in 2010 accounted for 15 percent of demand, up from 8 percent in 1995. Non-transportation residential consumption accounts for 12 percent of total demand and commercial, agricultural, and other sectors account for the remaining 18 percent.[2]

Chinese consumers are driving a large share of the industrial consumption. Specifically, several papers derive estimates of the embodied energy and CO_2 in exports from China. Yunfeng and Laike (2010) use input-output tables combined with information on both the energy and CO_2 intensity of different sectors and information on export shares of different goods to estimate the CO_2 emissions embodied in China's exports. Their estimates suggest that in 2007 nearly one quarter of China's emissions were associated with goods that were eventually exported. While high, the figure also suggests that over

[2] See http://www.iea.org/statistics/statisticssearch/report/?country=CHINA&product=balances (accessed December 31, 2013).

three-quarters of China's emissions are driven by home consumption.

There is an extensive literature analyzing China's energy consumption. Zhao, Li, and Ma (2012) provide a thorough and recent review. Many of the studies focus on the industrial sector, and those that examine the residential sector are primarily case studies. At least one other paper emphasizes the role of income in explaining the growth in rural commercial energy consumption (Yao, Chen, and Li 2012), although the paper only considers average per capita income.

Several papers have described the S-shape using micro data from outside China. Gertler et al. (2013) develop a simple, two-period model that demonstrates how the presence of credit constraints accentuates the nonlinear relationship implied by the S-shape. They also use exogenous shifts in household income from the Mexican conditional cash transfer program, Oportunidades, to confirm that the patterns consistent with the S-shape appear in micro data.

While the S-shape suggests that energy demand growth may be different depending on which households in the income distributions are the beneficiaries of growth, most existing forecast models appear to ignore income distributions. Our own discussions with leading energy modelers suggest that, while there are some early plans to incorporate within-country income distributions into some large-scale models, current models rely on average incomes at best broken out by urban versus rural consumers.

Our paper is also related to the sizeable macroeconomic literature that relates economic growth to income inequality. Researchers have noted that income distributions are usually skewed, but that the degree of skewness has varied across countries and over time. The early literature on the Kuznets curve tried to dissect some of that variation, finding that up to a certain point, growth leads to increased income inequality, but continued growth leads to lower levels of income inequality. As long as the compression in the income distribution involves changes at the bottom (and not only changes at the top), our results suggest that the relationship between energy use and growth in per capita GDP will vary as a function of where the country lies relative to the Kuznets curve.

II. Descriptive Statistics

A. *Data*

The Chinese National Bureau of Statistics conducts an annual rural and urban household survey. One section of the survey collects information on households' asset holdings. We therefore observe asset holdings by households for 30 province-level entities from 1998 to 2009. (Further details are in the online Data Appendix.) We do not have access to the actual survey data, which would allow for a much richer econometric study. Statistical yearbooks report the share of households that own a number of different durable consumer goods, many of which use energy, such as automobiles, motorcycles, and dishwashers. We focus our analysis on refrigerators, air conditioners, washing machines, and televisions. All four appliances are reported consistently across years and provinces, although without information on the model types. Also, ownership rates of more expensive assets, like automobiles and motorcycles, remain low in some provinces, particularly among the rural population, which makes analyzing different adoption rates more sensitive to outliers or small differences. The survey asks about the number of appliances of each type for a given household. This allows penetration rates that can be greater than 1 if a household has multiple devices of a given type.

Our analysis also requires province-level data on the shape of income distributions, as well as data on average per capita consumption expenditure. Information on average per capita income and consumption expenditure is available every year for both rural and urban households. However, the statistical yearbooks report data on income distributions differently for urban and rural residents. For rural residents, the yearbooks report the share of the population within various income ranges. We were able to construct the share of the rural population with incomes below 3,000 RMB per year for 17 provinces across all years. 3,000 RMB per year corresponds to approximately $1.35 per day. The World Bank uses a poverty threshold of $1.25 per day and reports that 12 percent of Chinese lived below this level in 2009.[3] As we discuss

[3] See http://povertydata.worldbank.org/poverty/country/CHN (accessed December 31, 2013).

further below, there is considerable variation across provinces. For urban areas, the yearbooks report the average income within different percentile ranges, and frequently, the lowest range was too high to detect cross-province variation in the share of the population living in poverty.

B. *Patterns in Appliance Ownership*

Figure 2 plots the appliance ownership rates by average province level per capita consumption expenditure, aggregating the data across all years and all provinces. The histograms display the empirical distribution of province by year-consumption expenditure for rural (gray) and urban (white with black outlines) households. The figure suggests that households at low incomes are most likely to own a television and least likely to own an air conditioner. The data also depict the top of the S-curve for refrigerators, washing machines, and televisions, as appliances per household asymptote to 1 for refrigerators and washing machines and approximately 1.5 for televisions. Both refrigerators and air conditioners depict the inflection point at the bottom of the S-curve, where ownership first rises slowly with income and then increases more quickly. The histograms suggest that the average rural consumption expenditure, not the average urban consumption expenditure, corresponds to levels where rapid adoption takes place. For that reason, we will focus the rest of the analysis on the rural population.

C. *Income Distributions*

Our analysis relies on cross-province and over-time variation in the shape of the income distribution. In other words, if every province had normally distributed incomes with the same variance, average per capita income would be a sufficient statistic for the province and we could not separately identify the impact of the share of people living above 3,000 RMB from the impact of differences in average income. The data suggest that provinces do have different income distributions. For example, in 2008, there were 4 provinces with mean per capita consumption between 3,100 and 3,350 RMB. The share of the population living below 3,000 RMB varied from 17 to 55.

Over time the share of households below our defined poverty threshold has declined by

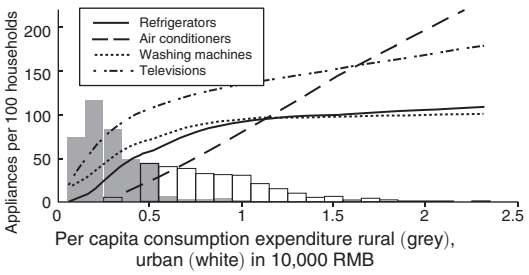

FIGURE 2. ADOPTION OF APPLIANCES BY TYPE VERSUS CONSUMPTION EXPENDITURE

Notes: The solid, dashed, dotted, and dash-dotted lines display smoothed penetration of appliances per household against per capita consumption expenditure. They were estimated using a Lowess smoothing spline with bandwidth 0.8 on the complete rural and urban appliance data for the 17 provinces in the sample.

5 percentage points per year, which is consistent with the well-documented transition out of poverty by Chinese rural households. The average per capita incomes have grown by 290 RMB per year, which is a 10 percent increase per year relative to the sample mean.

III. Econometric Model and Results

To investigate the relationship between income distributions and appliance ownership, we estimate several versions of a basic logistic diffusion curve. For each of the four appliances, we specify:

$$\ln\left(\frac{\alpha}{Diff_{it}} - 1\right) = Inc_{it}\,\beta_1 + Ineq_{it}\,\beta_2 + \varepsilon_{it},$$

where $Diff_{it}$ is the number of appliances per household in province i in year t; α is a constant set equal to 1 for refrigerators and washing machines and 2.5 for televisions and air conditioners; Inc_{it} is the average per capita consumption expenditure in province i in year t; $Ineq_{it}$ is the share of the population in province i in year t with incomes below 3,000 RMB per year; and ε_{it} is an error term, which contains either province ($\varepsilon_{it} = \phi_i + \eta_{it}$) or year specific fixed effects ($\varepsilon_{it} = \psi_t + \iota_{it}$). Year fixed effects, which control for shocks unobservable to the econometrician, capture changes in prices of the capital goods, electricity prices, and inflation at the country

Table 1—Regression Results

	AC	TV	Fridge	Washer	AC	TV	Fridge	Washer
Inc	−0.548**	−0.157**	−0.591***	−0.398	−0.305**	−0.247***	−0.309***	−0.267***
	(0.196)	(0.057)	(0.140)	(0.284)	(0.124)	(0.030)	(0.034)	(0.063)
Ineq	0.047***	0.009**	0.021**	0.007	0.044***	0.016***	0.027***	0.017***
	(0.015)	(0.004)	(0.009)	(0.017)	(0.011)	(0.003)	(0.003)	(0.004)
Fixed effects	Year	Year	Year	Year	Prov.	Prov.	Prov.	Prov.
Observations	138	173	173	173	138	173	173	173
R^2	0.671	0.835	0.847	0.347	0.718	0.782	0.870	0.808

Note: Standard errors are clustered at the province level.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

level. Province fixed effects control for unobservables that are time invariant by province but common to all provinces.

The first four columns of Table 1 report results that include year fixed effects for the four types of devices considered in this paper and the second four columns report results that include province fixed effects. The results are qualitatively robust to the type of fixed effect included in the regressions. The coefficients on income are negative and significant in all but one regression. Due to the nature of the logistic specification, the negative coefficients imply positive income elasticities. The coefficients on the inequality/poverty measure are also all positive, as expected, and significant in all regressions except for one. Across the board these regressions indicate that higher average consumption expenditures and lower shares of poor households are consistent with a higher share of adopted appliances. In terms of magnitude one has to be careful when interpreting the coefficients separately. For the specification using TVs as the dependent variable, a one within-province standard deviation increase in either variable corresponds to a 15 percent increase in adopted share. For refrigerators, a one standard deviation increase in household consumption expenditure corresponds to a 60 percent increase in adoption while a one standard deviation decrease in poor households corresponds to a 35 percent increase in adoption. It is of course important to note that changes in the income distribution would affect both variables and the nature of the shift in the distribution determines the overall effect.

An ideal specification would exploit the panel nature of the data while controlling for year-specific shocks and allowing for province-level heterogeneity ($\varepsilon_{it} = \phi_i + \psi_t + \gamma_{it}$). With aggregate data over a relatively short time span, however, we are left with insufficient variation to estimate that specification precisely. We estimated specifications similar to those in the four right columns in Table 1 and included a variable measuring the average inflation rate indexed to 1998. All four coefficients on *Ineq* remain positive and two of the four remain statistically significant.

IV. Conclusion

Existing projections suggest that the vast majority of the growth in energy demand will come from the developing world and that China will play a major part in this growth. This paper presents suggestive evidence that the shape of the income distribution, which is typically omitted from forecasting models, plays a major role in driving household acquisition of energy-using durable goods in rural Chinese provinces. The findings are consistent with previous work documenting an S-shaped relationship between household income and appliance acquisitions. While more work is necessary to link these findings to macro-level trends in energy consumption, the magnitude of our effects suggest that this is an important area for future research.

REFERENCES

Auffhammer, Maximilian. 2014. "Cooling China: The Weather Dependence of Air Conditioner Adoption." *Frontiers of Economics in China* 9 (1).

Gertler, Paul, Orie Shelef, Catherine Wolfram, and Alan Fuchs. 2013. "The Demand for Energy-Using Assets among the World's Rising Middle Classes." Unpublished.

Hamilton, James D. 2013. "Historical Oil Shocks." In *Routledge Handbook of Major Events in Economic History*, edited by Randall E. Parker and Robert Whaples, 239–65. New York: Routledge.

McNeil, Michael A., and Virginie E. Letschert. 2010. "Modeling Diffusion of Electrical Appliances in the Residential Sector." *Energy and Buildings* 42 (6): 783–90.

US Energy Information Administration. 2013. "Country Analysis Brief: China." http://www.eia.gov/countries/country-data.cfm?fips=CH.

Yao, Chunsheng, Chongying Chen, and Ming Li. 2012. "Analysis of Rural Residential Energy Consumption and Corresponding Carbon Emissions in China." *Energy Policy* 41 (1): 445–50.

Yunfeng, Yan, and Yang Laike. 2010. "China's Foreign Trade and Climate Change: A Case Study of CO_2 Emissions." *Energy Policy* 38 (1): 350–56.

Zhao, Xiaoli, Na Li, and Chunbo Ma. 2012. "Residential Energy Consumption in Urban China: A Decomposition Analysis." *Energy Policy* 41 (1): 644–53.