Energy Leapfrogging

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(1) Overview

Today's less-developed countries (LDCs) have access to energy technologies that did not exist when today's richer countries were at similar stages of development. Do LDCs therefore consume less energy per capita than rich countries in the past? And is their economic growth associated with a lower growth in energy consumption? This paper aims to answer these two questions. I use data on energy consumption, prices and GDP for 76 countries to estimate the income elasticity of energy demand for both current LDCs and industrialized countries in the past. I find that LDCs neither consume less energy than rich countries in the past nor have a lower income elasticity. I conclude that any energy savings from access to more efficient technologies have been offset by other trends, such as a shift towards a more energy-intensive consumption bundle or industrial outsourcing. This conclusion has important implications for projections of future energy consumption and carbon emissions.

(2) Introduction and Methods

There is an active debate among energy experts and policy advisors about how to forecast energy consumption and its associated carbon emissions in LDCs, as their economic growth continues. Should we extrapolate what happened in richer countries in the past? Or is it justified to assume significant "energy leapfrogging" instead? Leapfrogging is commonly referred to as the idea that today's developing countries have access to a set of technologies that was not available to rich countries in the past, when they had similar per capita income levels. The idea also frequently features in the energy debate, based on the assumption that developing countries today have access to efficient energy technologies that did not exist when rich countries were at similar stages of economic development.

Many people have inferred from this that "energy leapfrogging" should have occurred: developing countries today should either consume less energy per capita than did the rich countries at similar income levels (comparison in levels of energy consumption), and/or experience the same one percent economic growth with a lower associated growth in energy consumption than rich countries did in the past (comparison in the income elasticity of energy demand). This paper aims to test both these hypotheses. I consider a group of less developed countries (LDCs) today and a group of industrialized countries (ICs) in periods when their income was comparable to that of LDCs today, and compare both levels of energy consumption (at the same income level) and the income elasticity of energy consumption (at the same income level).[1] The first hypothesis is straightforward to test, but the interpretation is complicated by geographic, climatic, social and political differences between countries. The main focus of this paper will therefore be on testing the second hypothesis: controlling for the level of income per capita, the income elasticity of energy demand is lower for today's LDCs than for ICs in the past.

The question if and how much energy leapfrogging has occurred has important implications for the climate change debate. An informed estimate of the magnitude of energy leapfrogging is instrumental to construct a reasonable long-run "business-as-usual" (BAU) projection of energy consumption and carbon emissions (i.e., a prediction of energy consumption given projections for future GDP and energy prices). If leapfrogging occurs without policy intervention, it should be part of BAU projections. Many influential energy and emissions scenarios make implicit or explicit assumptions about leapfrogging, sometimes called "technology transfer". BAU projections are critical for three reasons. First, emissions are a key input in climate change impact models. Second, BAU emissions are critical elements in any negotiation process that aims to include LDCs in an international climate agreement. Underprediction of emissions might lead to LDCs opting out of such an agreement, while overprediction leads to "hot air". Third, many governments and energy companies base their planning decisions on these projections, and forecast errors can be costly.

The paper will answer the main question in two steps. First, I will estimate the income elasticity of energy demand at various levels of income. Second, I will test the main hypothesis: controlling for the income level, the income elasticity of energy demand is lower for LDCs today than for ICs in the past.

Research in energy economics has shown that the income elasticity of energy demand varies with the income level. Typically, economic growth in poor agricultural economies is not associated with rapid growth in energy use. Then, as economic growth continues, a phase of industrialization coincides with high energy consumption growth. Finally, growth in energy use slows down as the economy becomes more services oriented and more energy saving technology is employed. This generate an S-shaped relationship between per capita energy consumption and GDP. More specifically, previous papers have found that the income elasticity of energy demand peaks at a certain level of GDP per

[1] The paper explains in detail that the income elasticity estimates come from cross-sectional (country and sector) and time variation in energy consumption, GDP and energy prices. The resulting estimates are not "clean" elasticities, and should be interpreted as the *statistical relationship* between growth in energy consumption and growth in income. Fortunately, this interpretation is the relevant one for *forecasting*, the focus of this paper. I will still refer to these estimates as "elasticities".

capita, and potentially becomes negative for high income levels. The main hypothesis implies that if energy leapfrogging were to occur, this S-shaped curve should tilt downwards over time.

In the first step, I provide econometric evidence consistent with previous findings that the income elasticity of energy demand varies with income, but using a data set with larger scope and detail than in previous literature. I analyze a panel data set on energy consumption, prices and GDP for 76 countries and 8 sectors, covering the period 1960–2006.

In the second step, the main hypothesis will be tested. I focus on the income region relevant for LDCs today (up to $10,000 per capita) and for which I have historical data for ICs ($3,500 per capita and higher). Instead of estimating a single income elasticity for this income range, I will allow for the two groups to have differentiated income elasticities. To determine if energy leapfrogging has occurred, I then test if the income elasticity for LDCs is significantly lower than that of ICs in the past when these countries had similar incomes levels.

(3) Results

One key result is summarized by Table 1 below. The full paper provides many numerical and graphical results and is downloadable from http://bepp.wharton.upenn.edu/profile/21174/research. The table shows the long-run income elasticities of energy demand for various income bands, and for developing countries (LDCs) today versus rich countries (ICs) at similar income levels in the past. Leapfrogging would be consistent with finding a *lower* income elasticity of energy demand for LDCs than for ICs, in the income band in which these countries overlap.

			(1)	(2)	(3)	(4)	(5)
Dependent variable: $\ln(tfc_{ijt})$	Income band	Country group					
$\ln(gdp_{it})$	\$0 - \$3,500	*LDC*	0.83 **	0.85 **	0.80 **	0.80 **	0.90 **
			(0.10)	(0.11)	(0.11)	(0.11)	(0.10)
	\$3,500 - \$10,000	*LDC*	0.67 **	0.67 **	1.02 **	1.02 **	0.73 **
			(0.10)	(0.10)	(0.26)	(0.26)	(0.10)
		IC	0.24	0.22	0.70 *	0.87 **	0.63 **
			(0.23)	(0.26)	(0.31)	(0.31)	(0.18)
	\$10,000 - \$20,000	*IC*	0.17	0.16	0.38	0.42 *	0.50 **
			(0.19)	(0.22)	(0.21)	(0.21)	(0.15)
	\$20,000 - \$30,000	*IC*	0.15	0.14	-0.15	-0.12	0.44 **
			(0.15)	(0.17)	(0.22)	(0.22)	(0.10)
	> \$30,000	*IC*	0.04	0.06	0.13	0.14	0.33 *
			(0.17)	(0.19)	(0.45)	(0.46)	(0.14)
time fixed effects			λ_t	$\lambda_t * \{LDC, IC\}$	$\lambda_t * B_n$	$\lambda_t * B_n * \{LDC, IC\}$	none
p-value F-test: "income elasticity LDC = IC"			0.066	0.104	0.439	0.706	0.641
p-value F-test: "time trend LDC = IC"				0.001		0.001	

HAC-robust standard errors in parentheses. Regression contains 16,541 observations. * $p < 0.05$; ** $p < 0.10$. Table reports the implied long-run elasticities.

Table 1: Estimation by income band and by country group, using various time fixed effects specifications.

Table 1 shows that, regardless of the specification of the time fixed effects, the implied long-run income elasticity is *higher* for group LDC than for group IC over the relevant income band. Obviously, I cannot reject H_0 ("elasticities are the same") in this one-sided test. I also fail to reject H_0 against the alternative that the income elasticity in today's developing countries is higher than that in industrialized countries in the past. However, specification (1) with non-differentiated time fixed effects rejects H_0 against this alternative at the 10 percent level (p-value = 0.066).

(4) Conclusions

This paper finds that, in line with previous literature, the income elasticity of energy demand varies with income. However, I also find that the main hypothesis is not supported by the data. Within the relevant income range, the income elasticity estimated for LDCs is, if anything, higher (but not statistically significantly so) than for ICs in the past. The results in this paper lead to the conclusion that, while energy leapfrogging may have occurred, it has been offset by other trends. The combined effect is that we neither observe a difference in the levels of energy consumption between LDCs today and ICs in the past, nor a difference in their income elasticity of energy demand.

The most likely offsetting trends include a shift towards a more energy-intensive consumption bundle or industrial outsourcing to LDCs. Using a similar analysis on the sector level, I find that industrial outsourcing is unable to fully explain the lack of leapfrogging. I do find suggestive evidence that over time, consumption bundles have become more energy intensiev at the same income level. This study has established a basic, and perhaps unexpected, reference point for the discussion about how much energy leapfrogging has occurred (and will occur) in developing countries. The paper shows that energy and carbon emissions projections must be cautious about the common assumption that economic growth in developing countries will be less energy-intensive than in rich countries in the past.