Economics of Energy Demand

Lecture 8
Image of sea-level rise of Bangladesh removed due to copyright restrictions.
FIGURE 2.4 Climate forcing due to both human activities and natural processes, expressed in Watts per square meter (energy per unit area). Positive forcing corresponds to a warming effect. See Chapter 6 for further details. SOURCE: Forster et al. (2007).
Today’s Topics

• Energy demand as a derived demand
• Short-run v. long-run demand functions
• Estimating demand functions: problems & results
• Demand function instability
• Two puzzles: the McKinsey curve and the Prius
Derived Demand

• Gasoline is nasty – why do you buy it?

• The demand for energy (gasoline) is derived from the demand for energy services (transportation), e.g.
  - Food preparation, heating, lighting, cooling, loud music…

• The technology of producing any particular energy service can be summarized in a production function:
  \[ Q = F(K, L, E, M) \]
  - Capital is important in the production of most energy services
  - Some studies find that capital and (particularly electric) energy are complements: increasing the price of one decreases demand for both (coffee & cream)

• Historically there has been enormous progress in technologies for energy services
Recent estimate: auto technology advanced 2.6%/year, 1980-2006 ⇒

If weight, horsepower, & torque at 1980 levels, mileage ↑ 50% by 2006
Short Run Energy Demand: capital fixed

- Begin with two fundamental functions:
  - Demand function for some energy service:
    \[ ES = D(ES\text{cost}, Ps, \text{income} \mid Ks, \text{"tastes"}) \]
    \[ E\text{Scost} = \text{per-unit cost of the service (e.g., lighting)} \]
    \[ Ks = \text{capital stocks & tastes are fixed in the short run} \]
  - Production function for that energy service:
    \[ ES = F(E, Ms, Ls \mid Ks, \text{technology}) \]
    \[ Ms = \text{materials of various sorts} \]

- Given all prices, including \( P_E \), solve for \( E \) demand by
  - Finding least-cost inputs to produce \( ES \): \( E^*(ES, Ps,...) \), \( E\text{Scost}^* (ES, P’ s,...) \)
  - Then substituting into \( ES \) demand function, get \( E^*(Ps, ...) \)
Consider Electricity for Lighting

- Start with the two basic functions:
  - *Demand* for lighting (lumen-hours): \( L = a(L_{cost})^{-b} \), \( a \) and \( b \) positive constants, \( L_{cost} \) is cost per lumen-hour
  - \( b = - \frac{dL}{dL_{cost}} \left( \frac{L_{cost}}{L} \right) \) = price elasticity of demand for lighting, the limiting ratio of percentage changes
  - In the SR bulbs in the house are fixed, so *production function* is just \( L = eE \), \( e \) is a positive constant, \( E \) is electricity

- Given price of electricity, \( P_{E}(\$/kwh) \), solve for \$/lumen, then substitute in demand function (check units!)
  - \( L(\text{lumens}) = e(\text{lumens/kwh})E(\text{kwh}) \)
  - \( L_{cost}*(\$/\text{lumen}) = P_{E}(\$/\text{kwh})/e(\text{lumen/kwh}) \)
  - Substitute & solve: \( L = eE = a(P_{E}/e)^{-b} \); \( E = a(P_{E})^{-b}(e)^{b-1} \)
SR Demand: Some Remarks

• Here the elasticity of demand for electricity to produce lighting equals the elasticity of demand for lighting; this is not a general property of derived demand
  ➢ Derived demand for an input (electricity) can be more or less elastic than the demand for the output (lighting) from which it is derived

• Note that if \( b > 0 \), making lighting more efficient (raising \( e \)) would raise the demand for lighting – by lowering the cost
  ➢ Making cars more efficient makes driving cheaper, all else equal, and should increase driving – the “rebound effect” of CAFE

• If \( b > 1 \), so demand for lighting is price-elastic, making lighting more efficient raises the demand for electricity
  ➢ Might be plausible in this case…?
  ➢ Some have argued that CAFE standards increase the demand for gasoline this way, but it seems \( b < 1 \) in fact; small rebound
Income Also Affects Demand:
Passenger Kilometers Traveled/ Capita


Sub-Saharan Africa
Latin America
Middle East & North Africa
Other Pacific Asia
South Asia
Sub-Saharan Africa


Industrialized Regions:
- North America
- Pacific OECD
- Western Europe

Reforming Economies:
- Eastern Europe
- Former Soviet Union

Developing Regions:
- Centrally Planned Asia
- Latin America
- Middle East & North Africa
- Other Pacific Asia
- South Asia
- Sub-Saharan Africa
Derived Demand: Longer Run

• Consider my demand for gasoline
  - In the SR, with my car given, I can only respond to price or income changes by changing driving: the output effect
  - In the LR, if changes persist, I can change my car, changing the relation between gasoline demand and driving: the substitution effect

• Basic principle (Samuelson): Expect higher LR price or income elasticity than SR since more flexibility \( \Rightarrow \) greater ability to respond \( \Rightarrow \) greater response

• Most energy-transforming and energy-using capital is very long-lived: houses, cars, etc.
  - Past investment decisions shape future costs & options
  - Cost of rapid cuts in CO\(_2\): either drastically cut energy services or scrap & replace existing assets prematurely
Demand Estimation: Identification

- Early demand studies for agricultural products found demand curves sloped up
  How could this happen?

- The classic identification problem: shifts in demand traced out the supply curve

- Teaching note works out a simple example with linear supply & demand curves:
  - Not possible *in principle* to estimate demand without data on some variable that shifts the supply curve
  - Similarly, need demand shifters to estimate the supply curve
  - Generally use special techniques to get “good” estimates
Demand Estimation: Dynamics

• “Partial adjustment” models let SR response (to temporary Δ) & LR response (to permanent Δ) differ

  ➢ $E(t) - E(t-1) = \lambda [E^*(Ps, Y, tastes, \ldots) - E(t-1)], \ 0 < \lambda < 1$
  
  E* is a model of *long-run* equilibrium demand; gives demand in the limit if Ps, Y constant for a long time

  ➢ Put $E(t-1)$ on the right, find coeffs that “best fit” data:

  $E(t) = \lambda E^*(Ps, Y, tastes, \ldots) + (1- \lambda)E(t-1)$

  Response to temporary change in Ps = \lambda response to permanent change

  Coefficient of lagged demand gives \lambda, can then get E*

• Other approaches are also used

  ➢ E.g., Huntington (see teaching note) decomposes oil P into $P_{max}$, $[P - P_{max}]$, finds $P_{max}$ has larger effect

• Very durable assets (esp. structures, cities) in energy ⇒ full response to changes in price, income, … can take a LONG time
Demand Estimation: Results

- Estimated LR price & income elasticities for energy generally much larger than SR elasticities (small $\lambda$)
- SR income & price elasticities generally < 0.5 – limited ability to respond with fixed capital assets
- Gasoline & electricity are the most studied; ranges for rich countries from teaching note:

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Elasticity</td>
<td>Short-Run</td>
<td>Short-Run</td>
</tr>
<tr>
<td></td>
<td>.15 – .25</td>
<td>.20 – .40</td>
</tr>
<tr>
<td>Income Elasticity</td>
<td>Short-Run</td>
<td>.30 – .50</td>
</tr>
<tr>
<td></td>
<td>Long-Run</td>
<td>.60 – 1.10</td>
</tr>
</tbody>
</table>
Demand functions are NOT constants of nature!

- 1970 electricity wisdom: income $e > 1$, price $e \approx 0.1$; Res. = 33%, Comm. = 25%, Ind. = 41% of end use

Let’s try to “forecast” long-term changes in demand

<table>
<thead>
<tr>
<th>Period</th>
<th>GR GDP</th>
<th>GR Real $P_E$</th>
<th>GR Elect Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950-60</td>
<td>3.50</td>
<td>-2.40</td>
<td>10.61</td>
</tr>
<tr>
<td>1960-70</td>
<td>4.20</td>
<td>-3.22</td>
<td>7.30</td>
</tr>
<tr>
<td>1970-80</td>
<td>3.18</td>
<td>3.45</td>
<td>4.17</td>
</tr>
<tr>
<td>1980-90</td>
<td>3.24</td>
<td>-0.77</td>
<td>3.08</td>
</tr>
<tr>
<td>1990-00</td>
<td>3.40</td>
<td>-1.66</td>
<td>2.39</td>
</tr>
<tr>
<td>2000-07</td>
<td>2.40</td>
<td>1.62</td>
<td>1.27</td>
</tr>
</tbody>
</table>

- What happened?
And Demanders (People!) Sometimes Don’t Optimize!

- McKinsey uses the so-called “engineering approach”: calculate what energy technology should be used
- They & others (e.g., Amory Lovins) find lots of $$-saving (NPV > 0) investments in energy efficiency that aren’t made
- This “$$ on the sidewalk” is the “efficiency paradox”

Why is this low-hanging efficiency fruit not picked?

- Easy first answer, 1970s: “engineering” assumptions too optimistic, esp. about old structures. Yes, but lots of clear examples of $$ on the sidewalk.

- Second “answer”: Hausman and Joskow cite studies showing consumers act in this setting as if VERY high discount rates: 20-30%. But why? What about commercial & industrial demand?

- Imperfect information, riskiness of future savings probably play a role, but no simple story…

- But there is more…
Some folks overinvest in efficiency!

• Consider the Toyota Prius:
  - >3 Million sold, >1 Million in the US
  - ≈ A Corolla + 50mpg v. 28mpg

• Did all those consumers make a good investment?
  - C = cost difference, S = annual savings, r = interest, T = breakeven time:
    r=0, T = C/S; r>0, solve C = (S/r)(1 – e^{-rT}) \Rightarrow T = (-1/r)\ln[1-(rC/S)] if rC < S
  - Average Prius cost premium C = $7,450; assume = maintenance
  - Cars average 12k miles per year; if $3/gallon, cost/year:
    Prius: (12000/50)x3 = $720, Corolla: (12000/28)x3 = $1,286; S = $566
  - At r = 0, breakeven in 7450/566 = 13.2 years
  - At 5.0% breakeven in 21.6 years; > 7.6% ⇒ rC>S, forever is not long enough
  - Initial subsidies, higher gas prices make Prius more attractive, but…

• Hard to reconcile this with high discount rates in other settings … unless this (economic) model is missing something important!