Conventional versus Innovative Technologies in the Transportation Sector: External Costs and Benefits

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Framing the Issue

- According to the IEA, global crude oil consumption increased at an annual average rate of 1.3% from 1971-2000, with oil consumption in developing countries increasing at an average annual rate of 4.6%.

- Growth in developing Asian countries has been exceedingly high.
  - For example: China (6.0%), India (5.5%), Indonesia (6.6%), South Korea (8.2%)

- The IEA projects global crude oil demand growth to reach 1.7% per annum between now and 2030. This growth is expected to be highest in developing countries (at 2.8% per annum).

- Largest projected source of growth in crude oil demand… transportation.
  - Global: 2.1% per annum to 2030
  - Developing countries: 3.6% per annum to 2030
Framing the Issue (continued)

- 1 million tons of crude oil consumption in the transportation sector results in roughly 2.75 metric tons of CO₂ emissions.

- In 2000, global crude oil consumption in the transportation sector accounted for 4,666 million tons of CO₂. This is approximately 51% of global emissions from crude oil consumption, and 20% of total global CO₂ emissions from fossil fuel consumption.
The derived demand for motor fuel

Motor fuel is demanded to facilitate transportation services. As such, the decision to consume motor fuel is the result of a simultaneous set of decisions about
- Motor vehicle ownership
- Motor vehicle utilization
- Motor vehicle fuel efficiency

We can relate these variables to the demand for motor fuel by the following identity

$$\text{gallons} = \frac{\text{miles per vehicle}}{\text{miles per gallon}} \cdot \text{vehicles}$$

… or more compactly

$$e \equiv \frac{d}{\varepsilon} \cdot v$$
The derived demand for motor fuel (continued)

- Medlock and Soligo (2002) develop a model that shows the demand for motor vehicle stocks can be written as
  \[ v^* = v(\mu_v, W) \]
  - where \( W \) = consumer wealth and \( \mu_v \) = the user cost of motor vehicles
  \[ \mu_v = p_e \frac{d^*}{\varepsilon} + p_a - p_{a+1} \frac{(1 - \delta)}{(1 + r)} \]

- ...and the demand for motor vehicle services can be written as
  \[ d^* = d(\mu_v, W) \]

- By substitution into the above identity, we then have
  \[ e^* = e(\mu_v, \varepsilon, W) \]
Motor vehicle ownership in 100 countries (1995).

Source: World Development Indicators; World Motor Vehicle Data Book
Motor Vehicle Stocks… an “average” country

- Medlock and Soligo (2002) estimated the demand for motor vehicles given a non-linear income-vehicle stock relationship, which captures the notion that vehicle stocks reach a point of saturation, such that growth matches population growth, i.e.-the marginal value (service) provided by an additional motor vehicle to each household diminishes as vehicle stocks rise.

- The relation for $v_j$, for the Within-2SLS estimator, is specified as follows

$$
\ln v_j = \beta_{0,j} + \beta_1 \ln p_j + \beta_2 \ln y_j + \beta_3 (\ln y_j)^2 + \beta_4 \ln v_{j-1}
$$

- Using the parameter estimates for $\beta_1, \beta_2, \beta_3, \beta_4$, we can simulate motor vehicle stocks for the “average” country by calculating the intercept term ($\beta_{0,i}$) in the above equation to match the “average” country.
  - Averages:
    - GDP per capita (2000 PPP $) - $19,686
    - Vehicle stock per thousand people – 398
    - Motor fuel price ($/gallon) – US$4.10 (or about US$1.08/liter)

- Individual countries can be simulated directly by using the estimated country-specific effect ($\beta_{0,i}$).
Motor Vehicle Stocks and Per Capita Income

Simulated data for 28 countries assuming constant price and using the country-specific effect (see Medlock and Soligo (2002)).
Motor Vehicle Stocks Simulated…
An “average” country and a “US-type” country

![Graph showing the relationship between GDP per capita and vehicles per thousand people for an "average" country and a "US-type" country. The graph plots GDP per capita on the x-axis and vehicles per thousand people on the y-axis. The data is represented by two lines, one for the US-type and one for the average country. The x-axis ranges from $-10,000 to $30,000 in 2000 PPP$, and the y-axis ranges from 0 to 1,000.]
Motor Vehicle Utilization

According to Medlock and Soligo (2002), at the household level, motor vehicle utilization is a function of income and user cost

\[ d = d(\mu, W) \]

Johansson and Schipper (1997)

- Panel data for 12 countries to estimate each component of the identity \( Q = S \cdot I \cdot D \) where \( Q \) = demand for car fuel per capita, \( S \) = car stock per capita, \( I \) = fuel intensity, and \( D \) = driving distance per car.
- Use a recursive approach… estimate \( S \) and \( I \) separately, then \( D \) as a function of \( S \), \( I \) and other variables.
- Then, plug results into identity to get estimates of long run elasticity of motor fuel demand with respect to income, price and other variables.
- The relation for \( D \), for the Within-2SLS estimator is specified as follows

\[
\ln D_i = \gamma_{0,i} + \gamma_1 \ln D_{i,-1} + \gamma_2 \ln P_i + \gamma_3 \ln Y_i + \gamma_4 \ln S_i
\]

Using the parameter estimates for \( \gamma_1, \gamma_2, \gamma_3, \gamma_4 \), we simulate motor vehicle utilization by calculating the intercept term (\( \gamma_{0,i} \)) to match 2000 published data for various countries. We also simulate the “average” country described above.
Motor Vehicle Utilization Simulated…
An “average” country and a “US-type” country
Motor Fuel Demand…putting it all together

- The demand for motor fuel is a derived demand.

- As noted before, we can identify the demand for motor fuel as

\[ e \equiv \frac{d}{\varepsilon} \cdot v \]

- Thus, we can substitute the simulation results for motor vehicle stocks \((v)\) and motor vehicle utilization \((d)\), and assume some motor vehicle efficiency to obtain motor fuel consumption.

- Note, we can determine the growth rate of motor fuel demand as follows

\[ \%\Delta e = \%\Delta d + \%\Delta v - \%\Delta \varepsilon \]

- Thus, we would expect motor fuel demand to rise more rapidly in developing countries than in developed countries... growth in motor vehicle stocks is diminishing due to saturation effects, i.e.- \%\Delta v \to 0 \].
Motor Fuel Demand Simulated…
An “average” country and a “US-type” country
Current US motor vehicle efficiency is reported by the US EIA to be 16.9 mpg. Thus, at 1.5 times current we have 25.4 mpg, and at 2 times current we have 33.8 mpg.
Motor Fuel Demand Simulated... an “average” country with efficiency phased in

- Efficiency improvements are assumed to be phased in at different points of the development process to illustrate the potential impacts across a range of incomes.

- Assumptions:
  - Life of a vehicle = 7 years.
  - Percent of new vehicles sold with efficiency (x2) improvements = 10%.
  - Results in complete turnover in 50 years.
An Important Caveat

Care must be taken in reviewing the simulation results. Efficiency improvements will lower motor vehicle user cost. This will increase both motor vehicle stocks and motor vehicle utilization for a given level of income. This serves to offset, to some degree, the effect of the increase in efficiency on total motor fuel consumption.

Recall,

\[ \mu_v = p_e \frac{d^*}{\varepsilon} + p_a - p_{a,+1} \frac{(1 - \delta)}{(1 + r)} \]

\[ d^* = d(\mu_v, W) \]

\[ v^* = v(\mu_v, W) \]
How important is efficiency improvement?
Evidence: US Motor Fuel Consumption – History and
What Could Have Been

“Calculated” indicates the methods outlined above were used along with historical data to simulate the referenced curve.
A Measurable Benefit

- **Energy cost and energy security benefits:**
  - Efficiency improvements in the US have resulted in a cumulative savings of almost 225 trillion barrels from 1975 to 2000, or about 2.46 million barrels per day per year. At a $20/barrel, this comes to $49.2 million per day, or $18 billion per year.
  - In 2000, the savings totaled about 4.3 million barrels per day, or about 40% of current consumption.

- **Environmental benefits:**
  - On average globally, 1 million tons of crude oil consumption in the transportation sector accounts for approximately 2.75 million tons of CO₂ emissions.
  - Applied to the energy savings estimated above for the US, this translates to a cumulative savings of about 10,444 million tons of CO₂, which is almost double the total CO₂ emissions in the US in 2000.
  - The savings for 2000 amounted to about 729 million tons of CO₂, or 13% of total emissions in the US in 2000.
Future Benefits

- ?????
- Research to come…
  - Simulate a range of countries across multiple stages of development.
  - Assess the environmental and energy savings of efficiency improvements in multiple countries given various rates of diffusion of technological improvements.
  - Account for any potential positive “feedback” to motor vehicle stocks and motor vehicle utilization resulting from efficiency improvements.