Macroeconomic rebound, Jevons' paradox, and economic development

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1 Introduction

Writing in 19th century Britain, at time when per capita GDP was equivalent to about $5,100 in 2005 dollars (Officer and Williamson, 2010), Jevons (1865) argued that increased efficiency in the industrial use of coal led to a net increase in coal use. His argument has subsequently become associated with the broader idea – most commonly in the macroeconomic context – that the rebound from efficiency measures is greater than 100%. If true, this has significant implications for understanding the carbon mitigation consequences of global energy efficiency efforts.

Broadly framed, the issue can be viewed thus: Let Y_0 be a country's GDP per capita in the absence of a marginal efficiency policy and E_0 be its energy consumption per capita. Let $E_0 - \delta E$ be its energy consumption with a marginal energy efficiency policy prior to taking into account macroeconomic feedbacks. Let dE/dY be the marginal energy intensity of the economy and δY be the economic growth associated with the efficiency policy. Then per capita energy consumption with policy is given by $E_0 - \delta E + \delta Y \times dE/dY$. If Jevons' paradox holds, $\delta Y \times dE/dY > \delta E$.

One key question is the relationship between δE and δY. Ignoring the macroeconomic effects of higher initial costs, the effects of higher efficiency (and thus reduced energy expenditures) should be somewhat analogous to the effects of a tax cut. The rather murky literature on fiscal multipliers (m) associated with tax cuts (e.g., Spilimbergo et al., 2009) indicates that estimated cumulative two-year multipliers for tax cuts in developed countries ranges at the extremes from 0.2 to 4.0. If s represents the consumer savings per unit of conserved energy, then the magnitude of rebound is given by $ms \times dE/dY$, and Jevons' paradox holds if $ms \times dE/dY > 1$.

2 Insights from cross-country comparisons

One perspective comes from looking at international data on GDP and energy consumption. There is a reasonably strong relationship between nominal GDP/capita and energy consumption per capita, which becomes quite strong when the energy embodied in trade is associated with the country of consumption rather than the country of production. Here, I rely on Davis and Caldeira (2010)'s data set, which is based on a fully-coupled multi-region input-output model covering 113 countries/regions and 57 sectors. Economic data in their analysis is for the year 2004 and comes from the GTAP database. GDP values are quoted at market exchange rates, though use of PPP would be expected to improve the quality of the fits.

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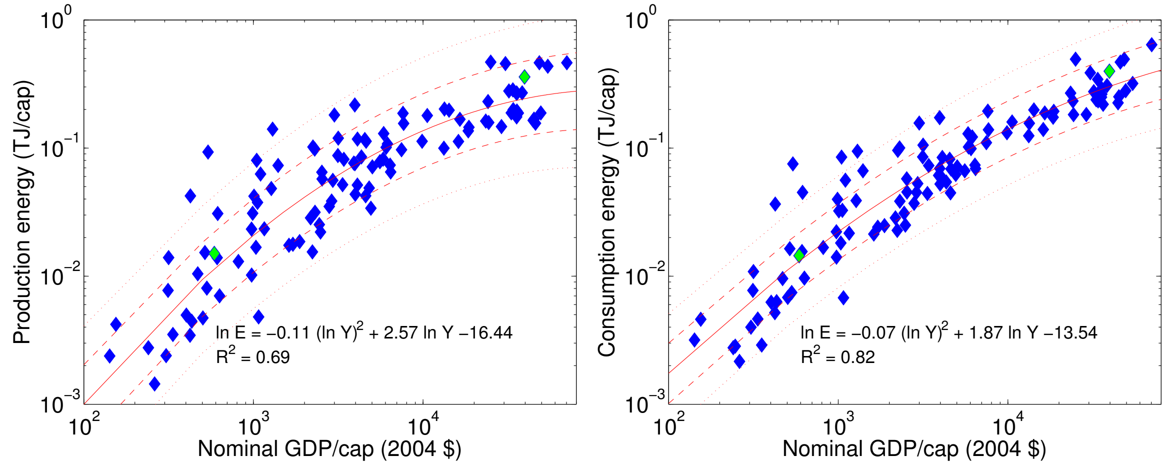

Figure 1: (Left) Per capita domestic energy consumption and (right) per capita energy consumption corrected for trade flows as a function of GDP per capita, based on Davis and Caldeira (2010). Green diamonds indicate the U.S. and India. Dashed lines show 68% confidence interval; dotted lines show 95% confidence intervals.

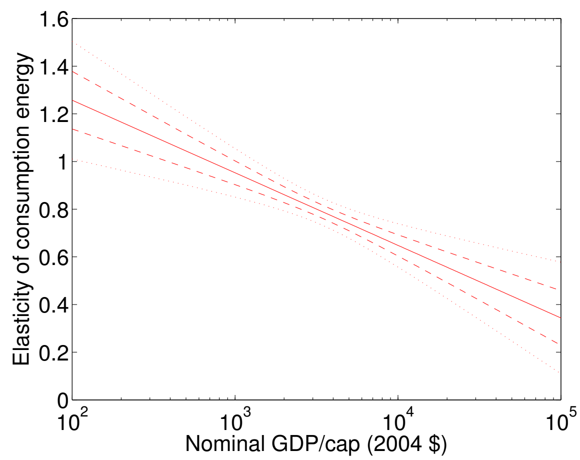

Figure 2: Elasticity of trade-adjusted per capita energy consumption as a function of GDP per capita.

The relationship between energy consumption per capita and nominal GDP per capita can be approximated by a function of the form $\ln E = a(\ln Y)^2 + b \ln Y + c$. The elasticity of energy consumption with respect to GDP per capita is therefore given by $2a \ln Y + b$. If E is in TJ/capita and Y in dollars/capita, then for domestic energy consumption per capita compared to GDP/capita, the least-squares fit is given by $a = -0.11 \pm 0.04$, $b = 2.57 \pm 0.73$, and $c = -16.44 \pm 2.90$. The R^2 value of this fit is 0.69. Presumably because of the off-shoring of industry in wealthy countries, the fit quality is higher if embodied energy is attributed to consuming economies: $a = -0.07 \pm 0.03$, $b = 1.87 \pm 0.55$, and $c = -13.54 \pm 2.21$, with $R^2 = 0.82$. (All uncertainties indicate 95% confidence intervals.)

In 2004, the U.S. had a GDP per capita of $39,700, and India had a nominal GDP per capita of $590. Thus, the projected elasticity of energy consumption per capita in these economies was about 0.47 ± 0.17 and 1.02 ± 0.13, respectively. (The comparable value for 1865 Britain is 0.74 ± 0.06.) Given per capita consumption energies of 400 and 14 GJ, respectively, these elasticities correspond to per capita marginal energy intensities of 4.7 ± 1.7 MJ/dollar and 24 ± 3 MJ/dollar, respectively. In electricity units, these values correspond to 1.3 ± 0.4 and 6.7 ± 0.9 kWh/dollar. For Jevons' paradox to hold, m times the financial savings resulting from efficiency would therefore need to equal about 80 cents/kWh in the United States and 15 cents/kWh in India. Even with $m = 4$, Jevons' paradox is therefore quite unlikely to hold in the United States, where residential electricity prices (and therefore the maximum possible financial benefits of efficiency measures) are around

10-15 cents/kWh. On the other hand, it is entirely plausible that Jevons' paradox would hold in India or other developing economies.

While some key insights can be gleaned from these sorts of international comparisons, more robust findings could be gathered by assessing time series of energy of consumption within specific countries (i.e., analogous to the work on trade-adjusted emissions by Peters et al., 2011).

3 India's electricity deficit and Chinese macroeconomic policy

One might also expect India to be a country in which the GDP growth associated with efficiency measures is sufficiently large for Jevons' paradox to hold because India suffers from regular rolling blackouts and associated economic drag. Sathaye and Gupta (2010) estimate that (in the absence of rebound) efficiency measures could eliminate India's electricity deficit in about four years. They project that, over eight years, the decreased drag associated with 81 TWh of cumulative electricity generation savings would increase cumulative GDP by about $505 billion. Given an average electricity intensity of the Indian economy of about 0.45 Wh/dollar, this GDP growth would be expected to lead to a *net increase* in electricity demand of about 150 TWh. Because this net increase would delay the elimination of the electricity deficit and thus dampen Sathaye and Gupta's projected GDP growth, it would not, howeve, be fully realized. *This first-order assessment highlights the importance of considering macroeconomic rebound when assessing the impact of efficiency policies in developing economies.*

It is worth noting that macroeconomic rebound must be considered in the context not just of other energy policies (e.g., India's coal tax) but also of broader macroeconomic policy. For example, China recently lowered its economic growth target to 7% per year. If this target is treated as a quasi-binding constraint imposed by monetary policy, then – to the extent it is enforced – it will translate the rebound effect into macroeconomic variables that are less correlated with energy use and carbon emissions than GDP.

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