NEW EVIDENCE ON THE DECOUPLING OF INCOME AND ENERGY CONSUMPTION

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Abstract:

This study explores the relationship between income and energy consumption across a sample of 17 OECD countries between 1960-2008. The main question being tackled is: “do rising incomes (crudely interpretable as income growth) still lead to rising energy consumption?” i.e. has income ‘decoupled’ from energy consumption? The results reveal clear asymmetries in the income elasticity of demand for energy, which offer a complementary perspective and understanding on the relationship between income changes and changes in energy consumption. Rising income, in some cases, no longer leads to increases in energy consumption, yet falling incomes still result in reductions in energy consumption. On the surface this would appear to be an appealing conclusion, suggesting that policy efforts in recent decades to try and decouple energy consumption from economic growth may have indeed contributed to a fundamental shift in consumer behaviours.

Key words: Decoupling; income; energy consumption; OECD 17.

Please note, the text and results contained in this draft are from an ongoing study, and should not be considered final and complete.
Introduction
The relationship between income (or transformations of income, e.g. growth) and the consumption of energy, have been the point of focus for many studies in economics and its related fields. Simple intuition and logic make it easy to understand that with economic activity, energy consumption is a must, since it motorized the vehicles that deliver raw materials and workers, power the machines that transform the goods, and also the televisions and radios of tired workers who need to relax after a days worth of productive effort.

In recent years there has however been substantial attention paid to when and how increases in economic activity, particularly in developed economies, are met by increases in energy consumption. Arguments put forward suggest that in developed economies, there is potential to increase activity while at the same time reducing energy consumption, or at the very least, not increase it. One justification is that such economies are looking to optimize their existing production, and so boost output by increasing efficiency, i.e. increasing the level of output given a constant set of inputs. Another even more compelling justification is that such economies have a tendency to shift towards the tertiary sector, having a natural consequences of reduced (marginal) energy consumption as a result of the changing industrial composition of economies.

This study provides a new assessment of the relationship between income and energy consumption for a sample of OECD countries between 1960-2008, using an energy demand function as the reference point for discussion. The main question being tackled is: “do rising incomes (crudely interpretable as income growth) still lead to rising energy consumption?” i.e. has income ‘decoupled’ from energy consumption? By virtue of the question, and the approach taken to analysis, several related questions can be answered including:

- Do income rises and income falls affect energy consumption patterns in the same way?
- When did such decoupling between rising income and energy consumption begin to occur, and will it persist?
- Is the decoupling a country specific phenomenon or something more global (in the context of the sample)?

The analysis is timely given the increased attention being given to concepts of ‘Green Growth/Productivity’ in recent months. Furthermore, the analysis is innovative, with the main innovation being in providing a new approach to modelling aggregate demand, which due to its significant flexibility is able to reveal much more information than many previous approaches.

The results reveal clear asymmetries, which offer a new perspective and understanding on the relationship between income changes and changes in energy consumption. Rising income, in some cases, no longer leads to increases in energy consumption, yet falling incomes still result in reductions in energy consumption. On the surface this would appear to be an appealing conclusion, suggesting that policy efforts in recent decades to try and decouple energy consumption from economic growth may have indeed contributed to a fundamental shift in consumer behaviours. Admittedly this is conjectural, since policy interventions are not explicitly modelled, but nonetheless not an unreasonable assertion.
This note is ordered as follows. The next section provides a discussion of some related literature, paying particular attention to the demand literature. Following this the data used in the analysis are presented. The method is then presented, discussing how asymmetric elasticities are obtained from the nonlinear demand function. Results are presented before the note is concluded.

Some related literature

Applied studies on the consumption of energy have been pervasive since the earliest known work by Hendrik S. Houthakker (1951), an understated pioneer of energy consumption modeling with several influential studies also including Houthakker (1965) and Houthakker and Taylor (1966) among others. Taylor (1975) offers a nice early review article of models used to estimated residential energy consumption, though in recent years review literature has tended to put more emphasis upon derived/estimated elasticities rather than giving clearer detail on the methods, moreover these are generally focused towards gasoline demand, see for example Brons et al (2008), Goodwin (1992), Goodwin and Dargay (2004), Graham and Glaister (2004), Dahl and Sterner (1991, 1993), Dahl (1994a, 1994b), Dahl (1995), Dahl (2012), Espey (1997,1998), and Kouris (1983).

In much of the work that followed Houthakker (1951) the importance of heterogeneity of various types has emerged as an important theme. Specifically, it has been documented that price and income elasticities may vary according to income and/or price levels with varying degrees of complexity (see for example Cargill and Meyer (1971), Chamberlain (1992), Hausman and Newey (1995), Schmalensee and Stoker (1999), Yatchew and No (2001), Chang and Martinez-Chombo (2003), Zarnikou (2003), Das (2005), Storchman (2005), Hughes (2006), Park and Zhao (2010), Wadud and Noland (2010), Lewbel and Pendakur (2012) and Karimu and Brannlund (2013) among many others), with numerous studies considering asymmetry in price responses as a specific type of heterogeneity (Dargay and Gately (1997), Gately and Huntington (2002), Ryan and Plourde (2002), Adeyemi and Hunt (2007), Griffin and Schulman (2005)). There has also been some interesting debate as to whether or not asymmetric prices may be a substitute for trends in energy demand, see for example Huntington (2006) and Adeyemi et al. (2010). in particular the possible 'imperfect reversibility' of demand to price rises or falls, Dargay and Gately (1995).

Further more general discussion on the use of nonparametric estimation in energy demand modeling can be found in Zarnikou (2003), with key examples including Hausman and Newey (1995), Yatchew and No (2001), Schmalensee and Stoker (1999), Karimu and Brannlund (2013) and in a time series context Park and Zhao (2010) among others. A related paper by Xiao et al. (2007) tests for the applicability of functional forms by estimating linear specifications with frequentist as well as Bayesian methods, though in this later paper nonparametric specifications are not considered.

The literature discussed above relates primarily. There is a wide and related literature on the issues of causality. Given the methodological stance of the present study, and the work-in-progress status of this study, these are not directly discussed. In short these studies generally put forward a-theoretic approaches to analysis that reveal some sense of causal dynamics between growth and changes in energy consumption. Vector auto-regressions and structural vector auto-regressions are the dominant approach using various forms of identification and variance decompositions to evaluate the direction and strength of causality. Many important results are provided by these studies.
Data

The data used in analysis are taken from the International Energy Agency (IEA) on-line database of Energy Statistics (available at www.iea.org) and cover the "OECD 17" countries, a widely studied subset of the wider OECD membership. These are the same countries used by for example Adetyemi et al. (2010) and Karimu and Brannlund (2013) but are extended to cover the period 1960-2008, with other studies on OECD member countries including Baltagi and Griffin (1983), Prosser (1985), Gately and Huntington (2002), Griffin and Schulman (2005) and Filippini and Hunt (2011) among others. For many years this group of countries has been considered a stable benchmark for understanding the dynamics of energy consumption and informing policy discussion at the international level. The variables needed for analysis include energy consumption, a measure of energy prices, and a measure of income. Energy demand is defined as the consumption of all types of energy (converted into thousand tons of oil equivalent or ktoe) across all sectors, therefore making no distinction between residential, industrial or commercial sectors. To proxy income, real GDP in per-capita terms is used, measured in US$ per-capita adjusted for purchasing power parity.

The index of real energy prices $P$ is also taken from the IEA database, but is only available for the period 1978-2006. Consequently this is spliced with an aggregate real price index for each country derived from data in Baade (1981); calculated by weighting gas in households and industry, coal in households and industry, electricity in households and industry, gasoline, diesel fuel and kerosene by their fuel consumption shares. This produces a real aggregate energy price index for each country in 1972 prices (1972=100) over the period 1960 to 1980. The two series (1960-1980; 1972=100) and (1978-2006; 2000=100) are subsequently spliced using the ratio from the overlap year 1978 to obtain the real energy price index, denoted by $P$. Both price and income are deflated to a base year of 2000.

The main analysis will be done using log transformed variables for consistency with the majority of previous related studies. Upper case letters are used to denote these transformations so that $Q_i$ is the natural logarithm of per-capita energy consumption, $P_i$ is the natural logarithm of price, and $Y_i$ is the natural logarithm of GDP per-capita, $i$ denotes the country and $t$ denotes the year. The descriptive statistics for these data are given in Table (1).

<table>
<thead>
<tr>
<th></th>
<th>Price</th>
<th>Income</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>Growth</td>
<td>min</td>
</tr>
<tr>
<td>Full sample</td>
<td>4.41</td>
<td>0.07</td>
<td>3.59</td>
</tr>
<tr>
<td>Austria</td>
<td>4.52</td>
<td>0.03</td>
<td>4.29</td>
</tr>
<tr>
<td>Belgium</td>
<td>4.37</td>
<td>0.09</td>
<td>4.10</td>
</tr>
<tr>
<td>Canada</td>
<td>4.13</td>
<td>0.22</td>
<td>3.59</td>
</tr>
<tr>
<td>Denmark</td>
<td>4.27</td>
<td>0.12</td>
<td>3.73</td>
</tr>
<tr>
<td>France</td>
<td>4.54</td>
<td>0.01</td>
<td>4.36</td>
</tr>
<tr>
<td>Greece</td>
<td>4.65</td>
<td>-0.02</td>
<td>4.30</td>
</tr>
<tr>
<td>Ireland</td>
<td>4.45</td>
<td>0.07</td>
<td>4.04</td>
</tr>
<tr>
<td>Italy</td>
<td>4.34</td>
<td>0.07</td>
<td>3.86</td>
</tr>
<tr>
<td>Japan</td>
<td>4.63</td>
<td>-0.01</td>
<td>4.29</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4.27</td>
<td>0.11</td>
<td>3.74</td>
</tr>
<tr>
<td>Norway</td>
<td>4.22</td>
<td>0.19</td>
<td>3.73</td>
</tr>
<tr>
<td>Portugal</td>
<td>4.56</td>
<td>0.02</td>
<td>4.04</td>
</tr>
<tr>
<td>Spain</td>
<td>4.53</td>
<td>0.03</td>
<td>4.08</td>
</tr>
<tr>
<td>Sweden</td>
<td>4.12</td>
<td>0.18</td>
<td>3.63</td>
</tr>
<tr>
<td>Switzerland</td>
<td>4.58</td>
<td>0.00</td>
<td>4.39</td>
</tr>
<tr>
<td>UK</td>
<td>4.47</td>
<td>0.08</td>
<td>4.25</td>
</tr>
<tr>
<td>USA</td>
<td>4.35</td>
<td>0.13</td>
<td>4.02</td>
</tr>
</tbody>
</table>

Table 1: Descriptive statistics for the estimation dataset.
Referring to Table (1), the average price in log-terms is 4.41 ranging from 4.12 (in Sweden) to 4.65 (in Greece). For most counties, energy price’s experienced positive growth over the sample period excepted in Greece and Japan. Sweden has the largest range for price (3.63-4.78), while France has the lowest (4.36-4.78). The average per-capita income is 19.48 in log-terms and ranges widely across the countries from 10.94 in Portugal to 26.46 in Switzerland. Interestingly, Switzerland has the lowest growth in income over the sample period with an average growth rate of 1.19%. The minimum, maximum and standard deviation values vary markedly across the countries, exemplifying the large heterogeneity between them in terms of income.

The demand for energy within the OECD 17, in per-capita terms, shows wide variation. The heaviest consumers by some margin are Canada and the USA, 5.57 and 5.38 respectively. Greece, Portugal and Spain are the lowest consumers with 1.14, 1.06 and 1.37 on average. These latter three countries also exhibit the largest average growth in per-capita energy consumption. The lowest growth was in the UK (0.10) followed closely by the USA (0.12) and Sweden (0.38).

Methods

The data used for analysis include per-capita total energy consumption for the OECD 17 (Austria, Belgium, Canada, Denmark, France, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK and USA), an index of real energy prices, and per-capita GDP. Energy prices are taken from the IEA, while the other variables are from the EIA databanks. For estimation, the variables are expressed in natural logarithms, primarily for the purpose of simplifying model interpretation as elasticities. The data cover the period 1960-2008.

The estimated model is semi-parametric and takes the following form:

\[ Q_t = \alpha_t(P_t) + m_1(P_{it}, Y_{it}) + m_2(Q_{it-1}) \]  \hspace{1cm} (1)

Given that price and income enter into the nonparametric term \( m_1() \), then their derived elasticities can be non-linear, and hence asymmetric in size to a unit increase or decrease. The functional form in (1) is somewhat different from most empirical demand specifications. It is in essence a Gorman-form, chosen for the purpose of allowing aggregation of elasticities from the country specific elasticities, which will be uniquely defined for each country and each year of the sample, up to a common group elasticity.

A note on parameter estimation

Eqn. (1) is estimated using nonparametric methods, specifically a thin-plate regression spline technique. Details of the estimator can be found in Wood (2003, 2006), along with wider discussion on the use of nonparametric methods in statistics. The non-parametric components of the model are the unknown functions \( m_1() \) and \( m_2() \), which is to say that the model is non-parametric in terms of both price and income as well as lagged-dependent effects, but additional parametric terms in price exist too. Hence the estimated model can in fact be considered a semi-parametric specification. Given more data it would be desirable to allow further model components to be nonparametric too, but the semi-parametric specification was a necessary trade-off in this regard since the consistency of non-parametric models is known to have slow convergence, and adding in this case an additional 17 non-parametric functions (for the country specific price terms) did not seem justifiable.
Calculation of model elasticities from a nonparametric model is a largely empirical process. Whilst in principle it would be possible to write out in full the nonparametric function, and take its derivative, this is highly impractical when using the thin plate regression spline approach, which essentially takes a weighted average across many different surface functions. The empirical approach taken here delivers easy-to-interpret point estimates rather than more intricate, and difficult to interpret mathematical expressions. To calculate the short-run elasticities the fitted empirical model must be evaluated at different values and the changes recorded. More specifically, to understand how changes in price (income) affect demand, the model is first fitted at some value of price (income), then holding all other variables constant the model is re-fit at a level of price (income) perhaps 1% higher than the original value and the new fitted values for demand are recorded. Hence, *ceteris paribus* the change in demand given a 1% change in income can be calculated from the two fitted values.

**A note on obtaining asymmetric elasticities**

The role of prices and in particular the possible `imperfect reversibility' (Dargay and Gately, 1995) of demand to price changes has been the focus of a number of studies by including asymmetric price response functions into empirical models. Some related studies include: Dargaay and Gately (1997), Gately and Huntington (2002), Ryan and Plourde (2002), Adeyemi and Hunt (2007) and Griffin and Shehulman (2005). There has been some debate as to whether or not asymmetric prices may be a substitute for modeling trends in energy demand, see for example Huntington (2006). Adeyemi et al. (2010) take a somewhat pragmatic perspective on this debate by specifying a general test procedure for use in applied studies. Since the proposed function is non-linear, it is not guaranteed that the elasticity is symmetric to price (or income) increases and decreases thus making it possible to asymmetry in elasticities to price rises and price falls (or income rises and falls), though it should be noted that this type of asymmetry is not perfectly analogous to a `rockets-feathers' type. Therefore in addition to calculating the elasticities described above, hereafter referred to as `positive' elasticities, additional `negative' elasticities will also be calculated simply subtracting a unit of the variable from the observed values, rather than adding a unit.

Since the change used to calculate the elasticity is negative, the expected signs if the elasticities will be reversed e.g. a price reduction will lead to an increase in demand, while an income reduction will lead to a reduction in demand, or at least that would be an appropriate *a priori* expectation. To clarify, since the price and income data vary over time, the calculated elasticities also vary over time, though this time variation is actually a by-product of the scale-dependency of the model rather than the model being a formal function of time.

To calculate the long-run elasticities from Eqn. (1) for any given individual/country, the standard long-run multiplier assumptions/transformations are applied leading to the usual long-run elasticity transformations.

**Results**

Table (2) provides the main estimation results used in the study. Several robustness checks are applied to these results, but not reported here given space constraints. All parts of the estimated demand function are significant, providing evidence of a sort that the assumed functional form may at least have some merit.
The goodness of fit of the model is somewhat high by conventional panel data standards, but (i) all appropriate model checking that has been done so far gives no obvious reason be suspicious of this and (ii) this is in fact a little lower than the values found in Karimu and Brannlund (2013), or put another way, not the only study to find such high values for this particular sample of countries.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>0.1902</td>
<td>0.0012</td>
<td>158.64</td>
<td>***</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.2047</td>
<td>0.0014</td>
<td>149.17</td>
<td>***</td>
</tr>
<tr>
<td>Canada</td>
<td>0.2178</td>
<td>0.0033</td>
<td>65.88</td>
<td>***</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.1937</td>
<td>0.0013</td>
<td>149.82</td>
<td>***</td>
</tr>
<tr>
<td>France</td>
<td>0.1961</td>
<td>0.0013</td>
<td>153.73</td>
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<tr>
<td>Greece</td>
<td>0.1840</td>
<td>0.0020</td>
<td>93.55</td>
<td>***</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.1949</td>
<td>0.0014</td>
<td>138.51</td>
<td>***</td>
</tr>
<tr>
<td>Italy</td>
<td>0.1852</td>
<td>0.0016</td>
<td>119.09</td>
<td>***</td>
</tr>
<tr>
<td>Japan</td>
<td>0.1971</td>
<td>0.0013</td>
<td>147.93</td>
<td>***</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.2018</td>
<td>0.0013</td>
<td>152.85</td>
<td>***</td>
</tr>
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<td>Norway</td>
<td>0.2055</td>
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<td>128.35</td>
<td>***</td>
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<td>Portugal</td>
<td>0.1856</td>
<td>0.0017</td>
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<td>0.0014</td>
<td>140.59</td>
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<tr>
<td>USA</td>
<td>0.2155</td>
<td>0.0028</td>
<td>77.93</td>
<td>***</td>
</tr>
</tbody>
</table>

Approximate significance of nonparametric terms

\[ m_1(P_{t}, Y_{t}) \]

\[ m_2(Q_{D,t-1}) \]

Additional model diagnostics

| n  | 819 |
| A² | 0.9960 |
| Deviance explained | 99.9% |
| GCV Score | 0.0012 |
| Scale estimate | 0.0012 |
| Serial correlation test | P(ass) |

Estimated model:

\[ Q_{D,t} = a_{1}(P_{t}) + m_{1}(P_{t}, Y_{t}) + m_{2}(Q_{D,t-1}) \]

Additional notes:

(i) Signif. codes: *** 0.001%, ** 0.01%, * 0.05%.

(ii) Approximate significance of nonparametric terms determined based on F-tests.

Table 2: Summary estimation output

Table (3) presents the average elasticities for the sample. Given the lag-term, both long run and short run elasticities are obtained. The average (across all countries/periods) long run income elasticity of demand for a 1% rise in income is a little over half the size of the same elasticity given a 1% decrease in income. Country specific results, not reported here, reveal that generally speaking similar patterns exist, and that in some cases, not only is the positive income elasticity smaller than its negative counterpart, it has even (statistically) vanished. This includes for example Greece and the UK.
<table>
<thead>
<tr>
<th></th>
<th>Short run</th>
<th></th>
<th>Long run</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rise</td>
<td>Fall</td>
<td>Rise</td>
<td>Fall</td>
</tr>
<tr>
<td>Income</td>
<td>0.0538</td>
<td>-0.0852</td>
<td>0.3788</td>
<td>-0.6602</td>
</tr>
<tr>
<td>(standard error)</td>
<td>0.018</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>-0.0981</td>
<td>0.0704</td>
<td>-0.6794</td>
<td>0.5456</td>
</tr>
<tr>
<td>(standard error)</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Average short-run and long-run income and price elasticities given price rises and price falls. Long run effects are calculated using standard impact multiplier calculations, and are only reported when (i) the short run elasticity is significant and (ii) the lag-multiplier is significant.

It is interesting to note that the timing of these changes loosely coincides with the increased public and media awareness of environmental sustainability that ensued following the Brundtland report. There are also hints that the energy crisis of the 1970's may have been in part a precursor to the changes which occurred in the subsequent decades.

**Figure 1: Box-plot of the estimated long-run elasticities of demand for energy across the OECD 17.**

From Figure 1 it can be seen that the average long-run elasticity of income across the sample countries has converged, showing lower variability towards the end of the sample, and also has become much lower in magnitude by the end of the sample. This plot does not however correct for insignificant short-run income elasticities. Figure 2 plots the short run income elasticities of demand and their respective 95% confidence intervals.
From Figure 2 it can be seen that the income elasticity tends to be decreasing over time for any given country. This is evidence that the relationship between income is firstly changing, and secondly becoming weaker. As income rises, the tendency to increase energy income is smaller than it was in 1960. There are several patterns of elasticities seen, suggesting that the results are not overly imposed by the estimated model.

Figure 3, for completeness, plots the short-run price elasticities of demand, which show a generally opposite trend to the income effects insofar as the elasticity is getting larger over time. The trends and elasticities vary from one country to the next, again supporting that the model is flexible enough to capture country specific behaviors.
Figure 3: Country specific short-run price elasticities of demand.

Preliminary conclusions
This study provides new evidence on the relationship between income changes and energy consumption. For many years, and particularly in recent years following the 2008 global financial crisis, there has been an observable shift among researchers and policy makers to better understand the relationship between these two measures. There is an obvious and inevitable policy conflict between objectives of maximizing economic output and minimizing energy consumption. An idealistic scenario would allow these objectives not only to co-exist, but in time complement each other e.g. allowing rising incomes with reducing energy consumption.

The analysis reported here provides a retrospective assessment of the relationship between income and energy consumption, using a model of total energy consumption as the reference point for assessment, offering signals of a fundamental decoupling of income from energy consumption, at least with respect to rising income. This is an appealing conclusion. Although the analysis is not cast in terms of a growth model, it does imply that economic growth (rising income) could well be possible across the OECD 17 member countries without leading to additional environmental damage.
Selected references and related readings.

(Please note that some of the references listed below may not yet be cited in the above text, but are relevant reading to this study)


