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Understanding the energy-GDP elasticity: A sectoral approach

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ABSTRACT

This paper uses per capita data for 132 countries over 1960–2010 to estimate elasticities of sectoral energy use with respect to national gross domestic product (GDP). We estimate models in both levels and growth rates and use our estimates to sectorally decompose the aggregate energy-GDP elasticity. Our estimates show that residential energy use is very inelastic to GDP if primary solid biofuels are counted in energy use tallies, especially at low income levels. Residential use of electricity is more tightly linked to GDP, as is energy use by the transportation, industrial, and services sectors. Agriculture typically accounts for a small share of energy use and has a modest energy-GDP elasticity. The aggregate energy-GDP elasticity tends to be higher for countries at higher income levels, in large part because traditional use of primary solid biofuels is less important. Gasoline prices, winter temperature, population, and land area are among other factors influencing sectoral energy use.

1. Introduction

There has been longstanding interest in the energy-GDP elasticity — the % change in energy use associated with a 1% change in gross domestic product (GDP). In early work this parameter was called the "energy elasticity" (Adams and Miovic, 1968) or the "energy coefficient" (Brookes, 1972; Ang, 1991). Other names are the income elasticity of energy use and the energy intensity of income growth (van Benthem, 2015). Using cross-sectional data, Csereklyei et al. (2016) recently reported that the mean long-run energy-GDP elasticity is around 0.7, and that this has been quite stable over time.

In this paper we use per capita data for 132 countries to estimate elasticities of sectoral energy use with respect to GDP and use these to decompose the aggregate energy-GDP elasticity into sectoral contributions. While it is known that the sectoral composition of energy use evolves as economies develop (e.g. Nakićenović et al., 1998; Judson et al., 1999; Smil, 2000; Medlock and Soligo, 2001; Schäfer, 2005; Lescaroux, 2011; Arseneau, 2012), the contributions of end-use sectors to the aggregate energy-GDP elasticity are less well understood. Our estimates are potentially useful for energy planning and forecasting, particularly in rapidly-growing economies.

Our approach involves studying final energy use by five sectors – residences, agriculture (including fishing), transport, industry, and services – as well as other energy use not allocated to final energy use by these five sectors. We estimate both a levels model and a model in 10-year growth rates. In addition to energy-GDP elasticities we also present electricity-GDP elasticities by sector; if economic growth induces a relative shift toward electricity, electricity-GDP elasticities should exceed the energy-GDP elasticities. Our models will allow GDP elasticities to vary according to GDP per capita level.

Fig. 1 shows International Energy Agency (2016) data on per capita energy use by residences and the transport sector, plotted against GDP per capita. The data are for the 132 countries in our sample over the 51 years 1960–2010, with the Organisation for Economic Co-operation and Development (OECD23) shown separately.[1] The energy use data include traditional energy forms such as primary solid biofuels.[2] Quadratic best fits have been added. Because the figure is in log–log space, the slopes are the unconditional mean energy-GDP elasticities evaluated at each GDP per capita level. The Figure reveals that at low and middle income levels, energy use by residences tends to fall and then slowly rise again as higher GDP per capita levels are reached. At high income levels, residential energy use is more closely tied to GDP. Energy use

[1] We use OECD membership at the end of 1971, which covers 23 countries ("OECD23"), to avoid self-selection into the OECD based on economic performance over the later decades of the period.

[2] We use "traditional" to refer principally to primary solid biofuels, and "commercial" to refer to transitional and modern energy forms such as oil, coal, natural gas, and electricity. We recognize that divergences from these definitions exist. For example, solid biofuels can be traded commercially.

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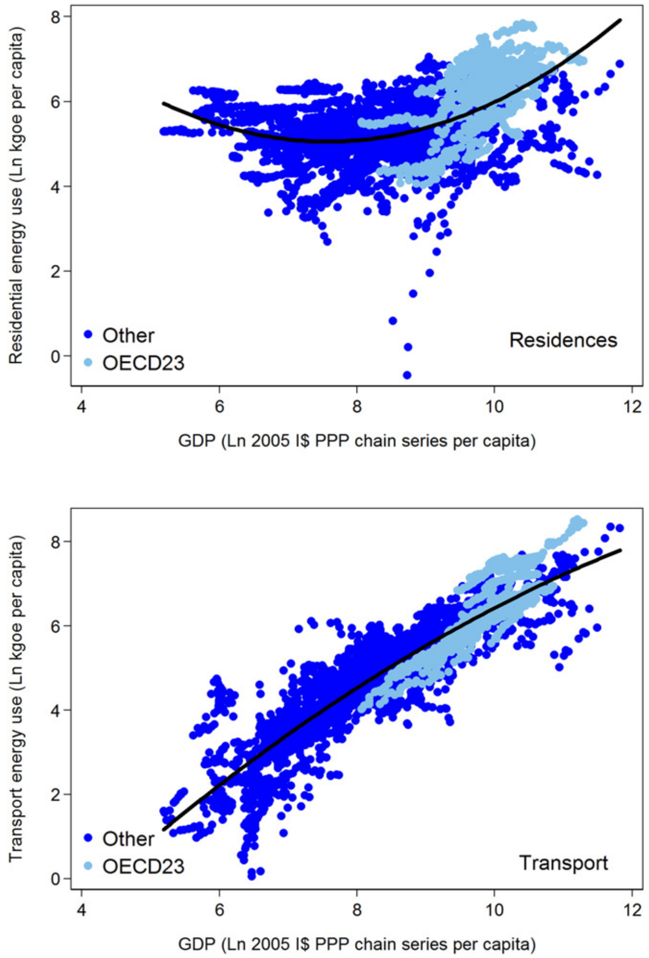

Fig. 1. Per capita final energy use for (a) residential purposes and (b) transport, by GDP per capita. Quadratic best fits have been added. Each dot is one of 4840 annual observations from 132 countries over 1960–2010.
Sources: Heston et al. (2012), International Energy Agency (IEA, 2016).

for transport is positively linked to GDP in quite a stable way across the income spectrum.

It makes sense that the GDP elasticity of residential energy use is relatively low – and even negative – at low income levels. Households in low-income countries tend to depend on traditional energy sources such as primary solid biofuels, which are inefficient sources of energy. Household demand for traditional fuels might well have a negative income elasticity on account of their inferior status vis-à-vis transition and modern fuels. There may also be supply-side constraints on the use of traditional fuels. Residential use of commercial fuels is likely to have a higher GDP elasticity, and these fuels offer energy efficiency gains. Economic growth in countries with low incomes might thus not induce sizeable increases in residential energy use measured in energy content terms, even if increases in the value of residential energy services are achieved (Adams and Miovic, 1968).

The evolution of sectoral energy use as economies develop is closely related to the evolution of sectoral output itself, early documentations of which were provided by Kuznets (1971) and Chenery and Syrquin (1975). Economic development typically sees economies transition from being dominated by agriculture, to becoming increasingly industrial, and then finally services-oriented. This pattern is to some extent reflected in energy use data also, although rather than agriculture it is residential energy use that dominates low-income energy profiles.

Among recent contributions, Jakob et al. (2012) estimated sectoral energy-GDP elasticities for 5-yearly growth rate panels of 21 OECD and 30 non-OECD countries, concluding that the effect of GDP growth on energy use may be smaller in OECD countries. For our large sample we instead find that energy-GDP elasticities actually tend to be *higher* at higher income levels, principally because traditional fuels play a smaller role in the energy mix. We obtain larger point estimates for the energy-GDP elasticity for OECD23 countries than for the non-OECD. That the energy-GDP elasticity is higher at higher GDP per capita has also been observed by, for example, van Benthem and Romani (2009) and Csereklyei and Stern (2015).

Among other recent work, Burke et al. (2015) report short-run sectoral and aggregate energy-GDP elasticities, finding that the aggregate same-year elasticity is 0.4, with a two-year elasticity of 0.5. They report a higher same-year energy-GDP elasticity for OECD countries (0.6) than for non-OECD countries (0.4), but do not explore longer-term effects. Csereklyei and Stern (2015) and Csereklyei et al. (2016) report long-run elasticities that exceed the short-run effects estimated by Burke et al., but do not explore effects at the sectoral level. van Benthem (2015) presents sectoral energy-GDP elasticities for a sub-sample of countries, reporting a low elasticity for residential energy use for lighting, heating, and cooking.

Prior work has also examined how the fuel mix varies as economies develop, finding that countries typically transition from primary solid biomass to fossil fuels and then increasingly to nuclear power and/or modern renewables (Tahvonen and Salo, 2001; Burke, 2010, 2013). There are studies that examine energy use in a single sector or a group of sub-sectors (Miketa and Mulder, 2005; Adeyemi and Hunt, 2007, 2014; Lescaroux, 2013; Mulder et al., 2014; Gao et al., 2015). Previous research also documents energy intensity convergence among countries (e.g. Liddle, 2010; Herrerias, 2012; Mulder and de Groot, 2007, 2012). Our growth rates model will allow for sector-by-sector beta convergence in per capita energy use.

Our main contribution is to provide rigorous, up-to-date estimates of long-run and 10-year sectoral energy-GDP elasticities and demonstrate how these help to understand the aggregate energy-GDP elasticity. Our study uses a long time dimension (1960–2010), broad geographical coverage (132 countries), and a broad definition of energy. While there are measurement issues for traditional fuels, it is important for these fuels to be considered given the large contribution they make to the energy mixes of many developing economies and our desire for broad geographical coverage. We will investigate the role of primary solid biofuels in explaining our results. The paper also explores potential heterogeneity among regions and country groupings.

Section 2 explains our approach. Section 3 provides the results. Section 4 concludes.

2. Models and data

We disaggregate the IEA's (2016) primary energy use data into six categories: final energy use by (a) residences, (b) agriculture, (c) transport, (d) industry, and (e) services; as well as (f) all other energy use, a category that includes primary energy lost in transformation (e.g. the generation of electricity) and distribution; primary energy used by the energy industry; other final energy use not allocated to one of the above sectors; use of non-biomass fuels for non-energy purposes; and transfers and statistical differences. Using E and E^F for primary and final energy use per capita, the following applies:

$$E = E_R^F + E_A^F + E_T^F + E_I^F + E_S^F + E_O \quad (1)$$

where R is residences, A is agriculture, T is transport, I is industry, S is services, and O is other. The data allow a greater level of disaggregation if one wishes. For example, industry could be disaggregated into subsectors. Further disaggregation would, however, reduce our country coverage due to instances of ln(0). Data uncertainties are also often exacerbated at finer levels of disaggregation.

Year-2010 data for Eq. (1) are presented in Fig. 2 for low-, middle-, and high-income countries. The data show substantial inequality: per