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Economic modelling of energy services: Rectifying misspecified energy demand functions

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ABSTRACT

Although it is well known that energy demand is derived, since energy is required not for its own sake but for the energy services it produces – such as heating, lighting, and motive power – energy demand models, both theoretical and empirical, often fail to take account of this feature. In this paper, we highlight the misspecification that results from ignoring this aspect, and its empirical implications – biased estimates of price elasticities and other measures – and provide a relatively simple and empirically practicable way to rectify it, which has a strong theoretical grounding. To do so, we develop an explicit model of consumer behaviour in which utility derives from consumption of energy services rather than from the energy sources that are used to produce them. As we discuss, this approach opens up the possibility of examining many aspects of energy demand in a theoretically sound way that have not previously been considered on a widespread basis, although some existing empirical work could be interpreted as being consistent with this type of specification. While this formulation yields demand equations for energy services rather than for energy or particular energy sources, these are shown to be readily converted, without added complexity, into the standard type of energy demand equation(s) that is (are) typically estimated. The additional terms that the resulting energy demand equations include, compared to those that are typically estimated, highlight the misspecification that is implicit when typical energy demand equations are estimated. A simple solution for dealing with an apparent drawback of this formulation for empirical purposes, namely that information is required on typically unobserved energy efficiency, indicates how energy efficiency can be captured in the model, such as by including exogenous trends and/or including its possible dependence on past energy prices. The approach is illustrated using an empirical example that involves estimation of an aggregate energy demand function for the UK with data over the period 1960–2011.

1. Introduction

Energy practitioners often emphasize that energy is desired not for its own sake, but for the services that it produces, such as space and water heating, cooling, lighting, and cooking.[2] Nevertheless, in empirical energy demand work this feature is often overlooked, with researchers tending to focus on modelling demand for aggregate energy, or for particular energy sources, such as natural gas, electricity, and oil products (see, for example, Bentzen and Engsted, 1993; Huntington, 2010).[3] However, as we demonstrate in this paper, there are potentially important, and in many cases useful, implications that arise from explicit consideration of energy as a derived demand, and ignoring such consideration results in energy demand models that are typically misspecified and from which resulting empirical estimates are likely to be misleading. Further, we show that accounting for this feature requires only minor modifications to the types of energy demand equations that are typically estimated, and does not necessitate extensive additional data requirements.

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[2] Early references identifying this feature include Goldemberg et al. (1985), Dubin et al. (1986), and Quigley (1984), although the latter focuses more on using energy as an input to produce housing services.

[3] An early exception is Dubin et al. (1986) who, noting the detailed data requirements (which in part resulted from a unique utility experiment) and computational complexity of their approach, estimate a conditional energy demand model using service prices for residential heating and cooling that are constructed using data on consumption of energy that is specific to one or other of these objectives.

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This tendency for empirical demand studies to focus on energy rather than energy services is likely to be largely data driven, since information is often available on aggregate or even individual consumption of particular energy sources, but it is rarely available at either of these two levels on consumption of particular energy services such as heating or lighting. Some notable exceptions to this are Fouquet and Pearson (2012) and Fouquet (2014), who painstakingly construct lengthy annual data series on consumption of energy services, such as lighting and heating, utilizing information on energy prices and consumption along with energy efficiency estimates and models of technical diffusion, and use these data to obtain estimates of price and income elasticities over time of these energy services. Nonetheless, such detailed data on consumption and prices of energy services for such a long period are rare and energy economists normally have to resort to modelling energy demand rather than services directly. However, we demonstrate here that empirical analysis can, and should, still focus on the demand for energy services even when data on the consumption and prices of these services are not readily available.

Another contributing factor to the focus on energy rather than energy services could pertain to interest in determining measures of price and income responsiveness (elasticities). Since neither the price nor the quantity consumed of, for example, heating services, is generally observed, there might be less interest in estimates of the own-price elasticity of demand for heating, especially since various policy instruments – such as taxes – would be difficult to impose on heating as opposed to being applied to various fuels used for heating. Thus, there is a need for estimates of the own-price elasticity of demand for natural gas when, for example, policy makers are considering various strategies that aim to reduce dependence on natural gas (and other fossil fuels). As we demonstrate in this paper, models that use energy rather than energy services as the basis for deriving the energy demand specification that is estimated might well result in misleading estimates of price and income elasticities of energy demand. This potentially also has implications for other areas of energy economics research, one key area being the rebound effect; however, to avoid becoming unwieldy this paper focuses solely on the impact of modelling energy demand and energy services.[4]

In this paper we demonstrate that a more conducive environment for analysis of many aspects of energy economics is provided by returning to the idea that energy is demanded for the services it provides rather than for any intrinsic reasons. To this end, we develop a model of consumer behaviour in which utility is derived from consumption of these services rather than from the energy sources that are used to produce them. A particular advantage of this framework is its demonstration of the direct role for energy efficiency in determining energy demand, even if energy efficiency may be predetermined at the time that current-period energy demand decisions are made. While this formulation yields demand equations for energy services rather than for energy or for particular energy sources, we demonstrate that the resulting equations can be readily converted into the standard type of energy demand equation(s) that is (are) typically estimated, although the resulting equations do involve some additional terms. This approach therefore highlights the misspecification that is implicit when typical energy demand equations are estimated, and shows how it can be readily rectified. For empirical purposes, an apparent drawback of this formulation is that information is required on energy efficiency, and this is typically not directly observed. In previous work, some authors (such as Beenstock and Willcocks, 1981; Dimitropoulos et al., 2005) have used a deterministic or a stochastic trend to proxy energy efficiency. Other authors (such as Haas and Schipper, 1998; Walker and Wirl, 1993) have attempted to construct summary measures of energy efficiency, and in some specific applications, energy efficiency can be observed (see, for example, Schleich et al., 2014). These approaches, implicitly assume that the impact of energy efficiency is exogenous, and neglect the ideas of some authors (such as Kouris, 1983) that energy efficiency (technical progress) should be considered endogenous, determined by energy price movements. In contrast, the approach we develop here encompasses both approaches, allowing energy efficiency to be endogenous and thus dependent on past prices as well as other (exogenous) factors.

To summarize, the energy demand equations that we derive from, and which are consistent with, the idea that demand is for energy services rather than energy itself, are no more complex than those that are typically estimated. Yet, they avoid a common misspecification problem without requiring data on variables that are unlikely to be generally available, and allow for the endogeneity of energy efficiency. In addition, the energy services approach opens up the possibility of examining many aspects of energy economics in a way that has not been previously possible.

The remainder of the paper is organized as follows. Section 2 provides background in terms of the few previous papers that have formally considered utility as being derived from energy services rather than energy itself. However, the full implications of this approach and the development of estimating equations that account for all the features described above are not fully considered in this earlier work, which has often been focused more narrowly on trying to capture the irreversibility of energy efficiency improvements. Section 3 introduces a new approach based on a theoretical model of utility maximization conditional on energy services. Initially the case of an aggregate energy source and aggregate energy service is considered. This is subsequently extended to the case of multiple energy sources and energy services where each energy source provides only one energy service. Finally, this model is generalized to allow for particular energy sources providing multiple energy services (such as natural gas providing space heating as well as cooking services), and for specific energy services being provided by multiple energy sources (such as space heating being provided by natural gas and/or electricity). Section 4 addresses issues of empirical implementation of the models of energy services, while different approaches to modelling unobserved energy efficiency are considered in Section 5. Section 6 provides an empirical illustration, with a brief summary and conclusion presented in Section 7.

2. Background

The starting point for our approach is the observation that particular energy sources – such as electricity, natural gas, and oil products – are not of intrinsic value to consumers. Rather, energy is used in conjunction with certain types of capital equipment (some of it energy-using, such as furnaces (or boilers), air conditioners, motors; and some of it in the nature of a substitute, such as attic/loft and/or cavity-wall insulation) to provide energy-related services (such as hot or cold air for space heating or cooling, hot water, distance travelled), and it is these services that are valued by consumers. In this regard, three particular characteristics of energy-using equipment are of relevance: much of it is long-lived — once installed it may have a useful life that spans decades; much of it is fuel(s)-specific; and its technical characteristics tend to be fixed, requiring a given level of energy use per unit of services produced.

There are a variety of factors that may induce consumers to change the stock of energy-using capital (for example by purchasing more energy-efficient appliances) and to substitute capital for energy (for example by installing insulation), such as a sustained period of high energy prices. This would also encourage manufacturers to improve the energy efficiency of capital equipment, thereby reducing the quantity of energy needed to produce a given level of energy-related services. In such circumstances, one might also expect governments to act and modify building codes and standards applied to energy-using

[4] Hunt and Ryan (2014) utilize the framework developed here to examine the impact it has on modelling and estimating the rebound effect. A similar type of framework is used by Chan and Gillingham (2015) in their theoretical analysis of the rebound effect and its welfare implications.