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Opinion paper

Efficiency snakes and energy ladders: A (meta-)frontier demand analysis of electricity consumption efficiency in Chinese households

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HIGHLIGHTS

- Frontier demand functions are estimated for a sample of 7102 Chinese households.
- Metafrontier methods capture heterogeneity arising from urban form (e.g. cities, towns and villages).
- Wealthier houses have higher efficiency potential, but are in fact less efficient in their consumption of electricity.
- From the above, a refined view of the household energy ladder concept is discussed.

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ABSTRACT

Policy makers presently lack access to quantified estimates – and hence an explicit understanding – of energy consumption efficiency within households, creating a potential gap between true efficiency levels and the necessarily assumed efficiency levels that policy makers adopt in designing and implementing energy policy. This paper attempts to fill this information gap by empirically quantifying electricity consumption efficiency for a sample of more than 7,000 households. Adopting the recently introduced 'frontier demand function' due to Filippini and Hunt (2011) but extending it into the metafrontier context – to control for structural heterogeneity arising from location type – it is shown that consumption efficiency is little more than 60% on average. This implies huge potential for energy reduction via the expansion of schemes to promote energy efficiency. City households, which are the wealthiest in the sample, are shown to define the metafrontier demand function (and hence have the potential to be the most efficient households), but at the same time exhibit the largest inefficiencies. These facts together allow for a potential refinement on the household energy ladder concept, suggesting that wealth affords access to the best technologies thereby increasing potential energy efficiency (the 'traditional view of the household energy ladder), but complementary to this these same households are most inefficient. This has implications for numerous areas of policy, including for example the design of energy assistance schemes, identification of energy education needs/priorities as well more refined setting of subsidies/tax-credit policies.

1. Introduction

A carefully obtained empirical snapshot of energy consumption efficiency at the level of individual households has the potential to inform numerous areas of policy, including for example the design of energy assistance schemes, identification of energy education needs/priorities and a framework for more informed allocation of energy subsidy and tax-credit policies. However to date, as far as is known, such a picture has not been obtained for households. Two reasons can be offered as to why this is so: first is that the methods and techniques used to acquire such information (namely frontier demand functions) were only set out very recently in Filippini and Hunt (2011, 2012, 2013); second is that household level datasets, for various legitimate reasons, often fail to collect sufficiently rich information on energy as well as a wide enough range of socio-economic variables to describe consumption patterns using economic concepts and theories. Notwithstanding a general absence of household level data, hypotheses have been presented regarding a concept referred to as the 'household energy ladder' (see for example Hosier and Dowd, 1987 or more recently van der Kroon et al., 2013), which suggests wealthier households have greater

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efficiency potential via their ability to purchase newer and more energy efficient home appliances.

When analyzing households there are often important sources of structural heterogeneities that can help inform the empirical framework for analysis. Differences in urban form, such as the differences among cities, towns and villages, are commonly associated with different lifestyle opportunities due among other things to the various agglomeration economies, and increased access to public goods, that can occur in larger populations. Numerous studies have alluded towards the implications of such features on the consumption of energy, see for example Chen and Song (2008), Peters et al. (2007), Hubacek et al. (2009) and more recently Yan (2015) in the case of China. Thus in seeking to provide an empirical benchmark on the level of household energy consumption efficiency, households from cities, towns and villages should not be immediately compared with each-other, and instead the efficiency in each location type should in the first instance only be compared to other households in similar location types.

It is however conceivable that a more general comparison may still be possible, encapsulating a notion of comparison that embeds spillover effects, and is independent of urban form. This will be explicitly handled in the empirical phase of the work by utilizing meta-frontier methods described by Battese and Rao (2002), described in more detail in the literature review and methodology sections. In brief, the metafrontier methodology can be thought of as a natural extension to traditional frontier methods, which would in the present case impose the underlying assumption that all consumers adopt an identical demand function – e.g. a single function which a single associated frontier. In the real world it is more likely that consumers are more heterogeneous than this, giving rise to the possibility that facets of consumer behavior such as price and income elasticities might reasonably be expected to vary across sub-groups of society, and accordingly that a separate frontier exists for each sub-group. This paper therefore uses the metafrontier method to address this issue, allowing for each group to adopt its own demand function and associated frontier but additionally providing a means to make higher-level comparisons across each of the sub-groups.

The empirical context for the study is cast in terms of a sample of Chinese households (for the year 2012). It is contended that this is an ideal dataset to propagate baseline understandings of energy consumption efficiency relevant to many parts of the world. For example, although it is true that there are many unique features of a Chinese lifestyle that do not easily transfer to other economic contexts, the country presently has what is arguably the most complete representation of household types compared to any other market context. The most affluent households in China are among the most affluent in the world, and the more developed cities including for example Beijing and Shanghai have characteristics common to any international city. At the other end of the spectrum, rural life in China is in cases akin to the same concepts of poverty and deprivation witnessed in many far less developed economies. In between these two extremes is a population which ranges across varying income and educational levels, with differing balances of household structure etc. Accordingly insights can be derived that have some possible resonance in almost any other market context.

The main contributions of the study derive from several important departures from existing works and can be summarized as follows: first is that the concept of the 'frontier demand function' is applied to household level data, making this as far as is known the first study to attempt this; second is the extension into the metafrontier context, allowing for important structural heterogeneity accruing to urban form effects to be explicitly modeled; third is that an error-component stochastic frontier model is utilized to help ensure accurate identification of efficiency levels. It is found that the average Chinese household operates at about 63% efficiency, and only around 7% of households achieve an efficiency level of 80% or higher. Thus there exist clear opportunities to implement household efficiency management policies and have a major impact on energy consumption levels across China. Regarding the 'champions' of efficiency, among the top 5% of the most efficient households, only 22% are from the city, the remaining being from towns (20.6%) and villages (57.4%).

The results are rich and among other things allow for an enhanced understanding of an empirical phenomenon known as the 'household energy ladder'. The conventional wisdom behind the energy ladder argues that higher income households will be able to access more efficient technologies, and is a phenomenon that has found empirical support, as for instance discussed in Hosier and Dowd (1987), Leach (1992), Kirk et al. (1994) and more recently Hiemstra-Van der Horst and Hovorka (2008) and van der Kroon et al. (2013). The results contained in the present paper do not challenge the existence of the energy ladder, but offer an enhanced perspective by illustrating that the consumption efficiency of the relatively richer city households is in fact much lower than in poorer households within towns and villages. Thus efficiency gains that may arise from 'climbing the energy ladder' may be negated by lower efficiency in consumption behavior – e.g. purchasing energy efficient light bulbs but taking less care to turn them off when they are not needed. This has clear implications for policy design.

The paper is structured as follows: Section 2 discusses the related literature; in Section 3 the data used in the analysis – the Chinese Family Panel Survey – is described; the empirical framework and econometric methodology are presented in Section 4; Section 5 provides a general discussion of the results; lastly Section 6 concludes the paper.

2. Literature review

Empirical economic (econometric) models of energy consumption first appeared in the academic literature in Houthakker (1965),[1] and were followed by high profile studies including Halvorsen (1975) among others. In these early studies, unsurprisingly, the emphasis was on obtaining informative (both economically and statistically) estimates of price and income elasticities. The notion of efficiency of energy consumption did not seem to make its first appearance until Hartman (1975) who openly discusses the importance of energy efficiency, but did not try to empirically quantify it.

There has been a dramatic growth in empirical literature discussing, and more importantly quantifying various dimensions of efficiency, predominantly in the context of a production function, since Aigner et al. (1977) outlined statistical procedures to capture such information, namely the stochastic frontier analysis method.[2] Typically these types of study concentrate on modeling a definition of total factor productivity with a view to answering questions of the type 'is a firm creating the best level of output given the resources it is using'.[3] If this is not the case a firm is regarded as being inefficient.

Energy and resource economists quickly picked up on the idea

[1] To the best of our knowledge there were no published studies prior to this.

[2] In addition to stochastic frontier methods (SFA) which emerged during the 1980s; there also exist widely used non-parametric Data Envelopment Analysis (DEA) techniques. SFA has proved popular, since in addition to measuring efficiency it also allows for explicit estimation and characterization of the frontier itself, which DEA does not.

[3] This is the notion of output efficiency, a related concept of cost efficiency ask 'if a firm is creating the current level of output at the lowest cost'.

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