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Energy demand, substitution and environmental taxation: An econometric analysis of eight subsectors of the Danish economy

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ABSTRACT

This research contains an econometric analysis of energy demand in trade and industry which allows for substitution between electricity and other energy carriers when relative prices change. The presence of substitution suggests that taxation can be a means of changing the energy input mix in a more environmental-friendly direction. For eight subsectors of the Danish economy, time series (1966–2011) are modeled by means of partial Cointegrated VARs. Long-run demand relations are identified for all subsectors and robust price elasticities are supported in five cases. The results are used in a small impulse–response experiment which suggests a potential for taxation to induce substitution of electricity for fossil-based energy.

1. Introduction

In many European countries energy systems are in a state of flux, transitioning away from fossil-based energy towards renewable-based systems. The developments are comprehensive and concern the way in which energy is both produced and consumed. On the supply side, electricity production based on renewable energy (RE) sources, like wind, solar, wave, geothermal and tidal, is making substantial progress, and for more than a decade, massive investments in RE generation capacity have already been undertaken in many EU countries.[1] In particular, from 2009 onwards, production capacity in the EU has increased markedly, primarily as a result of investments in renewables as opposed to conventional technologies. On the demand side, new opportunities also arise, such as heat pumps for the heating demand of households, and electrical vehicles which can potentially cover most personal transport. However, many industrial processes may also hide a large potential for "greening" production with the use of electricity and an important question is how policy makers can prompt industry to rely on electrical solutions to a larger extent and become less dependent on fossil-based energy sources. Besides direct regulation, one approach is to attempt to influence the economic incentives of firms for substituting electricity for other energy carriers: If industrial consumers react in the long run to changes in the relative price of electricity to other energy, substitution in energy consumption of environmentally friendly electricity for fossil-based energy, may be induced, for example by increasing taxes on the consumption of the latter, or reducing taxes on electricity.

This research offers an empirical investigation of industrial long-run energy demand with a focus on the propensity to substitute between electricity and other energy inputs. Using historical time series, covering 1966–2011, the paper presents an econometric analysis of the demand for electricity and *other energy* in eight different *subsectors* of the Danish economy. Here, other energy is an aggregate which comprises liquid fuels, non-liquid (coal and coke), gas (natural and gas works gas), district heating and biomass. Together, the subsectors account for the bulk of total industrial energy consumption and aggregate economic activity, and represent the primary-, secondary- and tertiary sectors. The Danish data are known to be of high quality and wide coverage by international standards, and

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[1] See http://ec.europa.eu/economy_finance/publications/.

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hence, provide a unique opportunity for gaining detailed insights into the dynamics of energy substitution at the subsector level.

For each of the eight subsectors, electricity consumption is assumed to be jointly determined with labor, capital, material and other energy. Under simplifying assumptions this is shown to imply that long-run electricity consumption depends on the price of electricity and other energy, both relative to the prices of the remaining inputs. The same holds for other energy. Combining this with the statistical assumption that the time series data are non-stationary of the integrated type, naturally suggests a Cointegrated VAR approach (see e.g. Johansen, 1996). In particular, the present analysis is based on a *partial* Cointegrated VAR (conditional on heating degree days) for electricity, other energy, as well as their respective prices.[2] The null hypothesis or *working hypothesis* tested in this, is the composite hypothesis consisting of demand relations for electricity and other energy, parameterized as two cointegrating relations, and the exogeneity of prices.

The literature of studies of energy demand more broadly, which use cointegration techniques, is vast as witnessed, for example, by the survey in Suganthi and Samuel (2012). Nevertheless, as pointed out in Bernstein and Madlener (2015), there are surprisingly few analyses concerning the estimation of electricity demand elasticities for industrial consumers. This is particularly true when it comes to analyses of industrial subsector demand, which allow for substitution between electricity and other energy. Most of the related econometric analyses with several types of energy (in addition to electricity) are either based on macro- or aggregate industrial data (see e.g. Nasr et al., 2000; Lee and Chang, 2005; Erdogdu, 2007; Polemis, 2007; Yuan et al., 2008). On the other hand, disaggregate or subsector analyses of industrial electricity consumption, also based on cointegration, have been adopted in Fouquet et al. (1997), Galindo (2005), Zachariadis and Pashourtidou (2007) and Bernstein and Madlener (2015). However, these studies do not focus on substitution as such, and therefore do not have to model electricity jointly with the demand for other energy inputs.[3] Finally, with respect to analyzing Danish time series data, and indeed also based on a Cointegrated VAR, Bentzen and Engsted (1993) should be mentioned. However, their focus is on macro level data and one energy aggregate. Altogether, in spite of a vast related literature, there is plenty of scope for contributing valuable insights into energy demand and substitution, when basing the analysis on a Cointegrated VAR for subsector data.

The present analysis shows that it is possible to empirically identify simple partial Cointegrated VARs, with two cointegrating relations, for all eight subsectors. These CVARs have cointegrating coefficient estimates which are interpretable in light of the working hypothesis. The results are obtained in reasonably well-specified models, with constant parameters (conditional on a limited number of breaks). For five large subsectors, referred to as, Agriculture, Machine- and vehicle manufacturing, Construction, Trade and Other services, the results are in general robust towards sample changes and the presence of a third cointegrating relation between relative prices. For these five sectors the estimation supports significant own-price and/or cross-price effects. An impulse–response experiment is therefore carried out for these sectors, in order to analyze the potential for environmental taxation to induce substitution of electricity for other energy. The experiment resembles a simple tax reform and describes the combined long-run effect from raising the price of other energy with 25% while at the same time lower the price of electricity, also with 25%. The experiment is discussed in light of the recent Danish debate on the abolition of the Public Service Obligation (PSO) tariff. The overall policy implication of the experiment is that substitution from other energy towards electricity may be induced by taxation when targeted at these sectors.

Since energy demand behavior exhibits substantial heterogeneity across the different sectors of society, a subsectorial approach, based on more homogenous groups, seems preferable relative to more aggregate analyses, which may often hide interesting mechanisms.[4,5] A priori, heterogeneity across the Danish trades and industries seems likely, and can, for example, be explained by large differences in energy intensities. The eight subsectors under study have therefore been formed as aggregates of national accounts industries, which can be assumed to be *relatively* similar with respect to energy consumption behavior.[6] A subsector approach is essential for the present analysis for which one purpose is to uncover which sectors hide a potential for energy substitution and which do not. However, there are at least two other important arguments in favor of this approach: For example, suppose that the goal is a long-term projection of the effect on *aggregate* industrial electricity consumption, from a change in the price of other energy. If this is based on estimated elasticities based on historical *data for the aggregate* industry (as opposed to subsector data), it is likely to be highly unreliable. This is a result of two facts. Firstly, electricity (own- and cross-price) elasticities are likely to be very different across subsectors (cf. the above and also confirmed by the empirical analysis below). Secondly, given different (but time independent) elasticities, for the aggregate approach to work well, the respective consumption shares of the different subsectors of the aggregate industry have to remain unchanged over the projection horizon. Such an assumption is obviously unrealistic, in particular for longer time periods. Historically, in most industrialized countries, the general macroeconomic evolution and the international division of labor, as determined by comparative advantages, have implied substantial changes in the national industry structures with respect to subsector composition.[7] The general trend has been a growing tertiary sector and a declining primary sector. As a result, one must take such sectorial changes into account when assessing the expected long-term future course of energy demand and substitution. Another argument in favor of disaggregate analyses is that policy recommendations can be made more precise. In particular, when it comes to optimal taxation of firms, for example with respect to minimizing the overall deadweight loss associated with taxing a large group of firms, it is essential to know whether there are differences in elasticities and if so, how large they can be assumed to be. Clearly, such valuable information is bound to be hidden in analyses of aggregate data.

The next section outlines the econometric framework by first introducing the data, then sketching the basic working hypothesis, and finally presenting the statistical model which makes it possible to confront hypothesis and data. Section 3 covers the estimation of the CVARs for each of the eight subsectors and includes an analysis of the robustness of the results towards sample changes and

2 See Johansen (1992) and Chapter 8 in Johansen (1996).

3 To some extent, Zachariadis and Pashourtidou (2007) is an exception, in that, they initially seem to have considered cross-price effects. However, they find insignificance and therefore do not focus on this in the remainder of their paper.

4 This has been pointed out previously. See e.g. Pesaran et al. (1998), and more recently Bernstein and Madlener (2015).

5 An immense number of analyses of energy consumption at the more aggregate (macro) level, have accumulated over the years. See e.g. the surveys, Payne (2010) and Ozturk (2010). However, for the most part this literature is concerned with the interdependence between total energy consumption and aggregate economic activity (GDP), and not substitution between energy types.

6 For this purpose, work has already been done in connection with the Danish macroeconometric model, EMMA, and I therefore build on this, Møller Andersen et al. (1998).

7 For an empirical analysis of the impact of changing foreign trade patterns on the energy consumption of the Danish manufacturing industries, see Klinge Jacobsen (2000).