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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.

Key words: Industrial energy demand, Energy substitution, Cointegrated VAR, Environmental taxes, PSO tariff, Impulse-response analysis.

JEL: codes: C3, H2, Q4.

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,

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

21 covering 1966-2011, the paper presents an econometric analysis of the demand for electricity and *other*
22 *energy* in eight different *subsectors* of the Danish economy. Here, other energy is an aggregate which
23 comprises liquid fuels, non-liquid (coal and coke), gas (natural and gas works gas), district heating and
24 biomass. Together, the subsectors account for the bulk of total industrial energy consumption and
25 aggregate economic activity, and represent the primary -, secondary - and tertiary sectors. The Danish
26 data are known to be of high quality and wide coverage by international standards, and hence, provide a
27 unique opportunity for gaining detailed insights into the dynamics of energy substitution at the subsector
28 level.

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

39 The literature of studies of energy demand more broadly, which use cointegration techniques, is vast
40 as witnessed, for example, by the survey in Suganthi and Samuel (2012). Nevertheless, as pointed
41 out in Bernstein and Madlener (2015), there are surprisingly few analyses concerning the estimation of
42 electricity demand elasticities for industrial consumers. This is particularly true when it comes to analyses
43 of industrial subsector demand, which allow for substitution between electricity and other energy. Most of
44 the related econometric analyses with several types of energy (in addition to electricity) are either based
45 on macro- or aggregate industrial data (see e.g. Nasr et al., 2000; Lee and Chang, 2005; Erdogdu, 2007;
46 Polemis, 2007; Yuan et al., 2008). On the other hand, disaggregate or subsector analyses of industrial
47 electricity consumption, also based on cointegration, have been adopted in Fouquet et al. (1997), Galindo
48 (2005), Zachariadis and Pashourtidou (2007) and Bernstein and Madlener (2015). However, these studies
49 do not focus on substitution as such, and therefore do not have to model electricity jointly with the
50 demand for other energy inputs.³ Finally, with respect to analyzing Danish time series data, and indeed
51 also based on a Cointegrated VAR, Bentzen and Engsted (1993) should be mentioned. However, their
52 focus is on macro level data and one energy aggregate. Altogether, in spite of a vast related literature,
53 there is plenty of scope for contributing valuable insights into energy demand and substitution, when
54 basing the analysis on a Cointegrated VAR for subsector data.

55 The present analysis shows that it is possible to empirically identify simple partial Cointegrated VARs,
56 with two cointegrating relations, for all eight subsectors. These CVARs have cointegrating coefficient
57 estimates which are interpretable in light of the working hypothesis. The results are obtained in reasonably
58 well-specified models, with constant parameters (conditional on a limited number of breaks). For five
59 large subsectors, referred to as, Agriculture, Machine- and vehicle manufacturing, Construction, Trade
60 and Other services, the results are in general robust towards sample changes and the presence of a third
61 cointegrating relation between relative prices. For these five sectors the estimation supports significant
62 own-price and/or cross-price effects. An impulse-response experiment is therefore carried out for these
63 sectors, in order to analyze the potential for environmental taxation to induce substitution of electricity

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

³To some extent Zachariadis and Pashourtidou (2007) is an exception, in that, in 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.

64 for other energy. The experiment resembles a simple tax reform and describes the combined long-run
65 effect from raising the price of other energy with 25% while at the same time lower the price of electricity,
66 also with 25%. The experiment is discussed in light of the recent Danish debate on the abolition of
67 the Public Service Obligation (PSO) tariff. The overall policy implication of the experiment is that
68 substitution from other energy towards electricity may be induced by taxation when targeted at these
69 sectors.

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

97 The next section outlines the econometric framework by first introducing the data, then sketching the
98 basic working hypothesis, and finally presenting the statistical model which makes it possible to confront
99 hypothesis and data. Section 3 covers the estimation of the CVARs for each of the eight subsectors
100 and includes an analysis of the robustness of the results towards sample changes and the inclusion of
101 an additional cointegrating relation. Based on the estimations, Section 4 considers the impulse-response
102 experiment. Finally, Section 5 concludes the analysis and ends by outlining the scope for related future

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

⁵An 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.

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

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

103 research.

104 **2. The Econometric framework**

105 *2.1. Data*

106 This section contains a brief introduction of the data. For a more elaborate description the reader is
 107 referred to Appendix A. The data consist of annual time series 1966-2011 from eight different subsectors
 108 of the Danish economy.⁸ Together these account for the bulk of total industrial energy consumption and
 109 economic activity, and represent the primary -, secondary - and tertiary sectors (see the appendix). Each
 110 of the eight subsectors are aggregates of national accounts industries. As mentioned, these aggregations
 111 attempt to group the national accounts industry categories into relatively energy homogenous industries.
 112 Table 1 shows which particular national account industries are included in each of the eight subsectors.

Table 1: National accounts industries comprised in each of the eight subsectors.

Agriculture	Food Manufacturing	Chemical Manufacturing	Machine/Vehicle Manufacturing	Other Manufacturing
Agriculture and horticulture	Production of meat	Manufacture of basic chemicals	Manufact. of fabricated metal	Manufacture of textiles
Forestry	Processing of fish	Manufact. of paints, soap etc.	Manufact. of computers, etc.	Manufacture of wearing apparel
	Manufacture of dairy products	Pharmaceuticals	Manufact. of other electronics	Manufacture of footwear etc.
	Manufacture of bakery products	Manufacture of rubber etc.	Manufacture of motors, etc.	Manufacture of wood etc.
	Other manufacture of food		Manufacture of wires, cables	Manufacture of paper etc.
	Manufacture of beverages		Manuf. of household appl. etc.	Printing etc.
	Manufact. of tobacco products		Manufacture of engines etc.	Manufacture of concrete etc.
			Manufacture of other machinery	Manufacture of furniture
			Manuf. of motor vehicles etc.	Manufact. of med. instruments
			Mf. of ships, transport equip.	Manufacture of toys, etc.
				Repair, inst. of machinery etc.
Construction	Trade	Other services	Other services (cont.)	
Construction of new buildings	Sale of motor vehicles	Sewerage	Rental and leasing activities	
Civil engineering	Repair etc. of motor veh. etc.	Waste and materials	Employment activities	
Professional repair and maint.	Wholesale	Publishing	Travel agent activities	
Own-account repair and maint.	Retail sale	Publishing, computer games etc.	Security and investigation	
		Motion picture, tv and sound	Services to buildings, cleaning	
		Radio, television broadcasting	Other business services	
		Telecommunications	Rescue service ect. (market)	
		Information technology service	Adult, other education (market)	
		Information service activities	Medical and dental practice	
		Buying, selling of real estate	Theatres, concerts, and arts	
		Renting, non-resid. Buildings	Libraries, museums (market)	
		Legal activities	Gambling and betting	
		Accounting and bookkeeping	Sports activities (market)	
		Business consultancy	Amusement and recreation	
		Architecture and engineering	Activities of membership org.	
		Research and developm. (market)	Repair of personal goods	
		Advertising, market research	Other personal services	
		Other technical business serv.	Households as employers	
		Veterinary activities		

113 The subsector representing the primary sector is referred to as *Agriculture* and includes horticulture
 114 and forestry in addition to agriculture. The energy intensity is high in this subsector which accounts for
 115 almost all energy consumption of the primary sector. The subsectors of the secondary sector comprise,
 116 *Food manufacturing, Chemical manufacturing, Machine- and vehicle manufacturing, Other manufacturing*
 117 and *Construction*. Together these subsectors account for about 80% of all energy consumption in the
 118 secondary sector. The service sector of the economy is represented by two subsectors, referred to as *Trade*
 119 and *Other services*, of which the latter comprises a wide range of services (see Table 1). Together, Trade
 120 and Other services account for around 60% of all energy consumption in the tertiary sector.

121 For each subsector, the variables of interest are the following (the particular selection of variables is
 122 motivated in the next section):⁹ *Electricity intensity*, or electricity consumption per unit of output, $\frac{E_t}{Y_t}$,
 123 where E_t is electricity consumption in gigajoule (GJ) and Y_t is real Gross Output (Y_t). The *intensity*
 124 *of other energy*, denoted, $\frac{O_t}{Y_t}$, which is defined analogously. The prices of electricity and other energy,

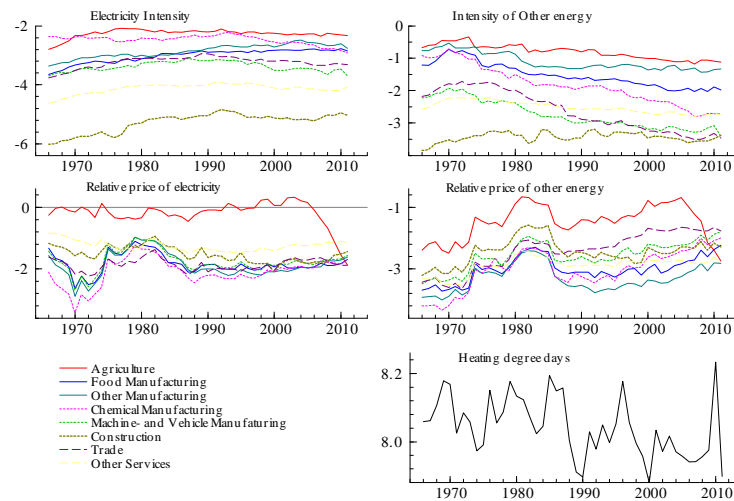
⁸The sample stops in 2011 as subsequently Statistics Denmark redefined some of the industry groups.

⁹The exact definitions of the variables are found in Appendix A.

125 P_t^E and P_t^O , respectively, stated in Danish kroner per GJ and both deflated by the GDP deflator, P_t .
 126 Heating degree days, i.e. the exogenous weather-related variable to be conditioned on.

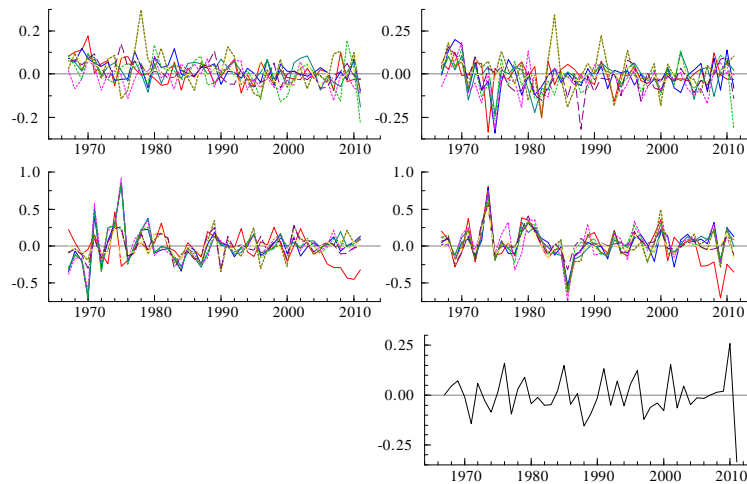
127 Each of the first four panels of Figure 1 shows the time series plots for the variables in logarithms, for
 128 all eight subsectors. The sixth panel shows heating degree days (common for all subsectors) in logarithms.
 129 Figure 2 shows the corresponding first differences. The overall impression is that levels are drifting rather
 130 persistently around linear deterministic trends. In addition, level breaks appear. In general, this is most
 131 pronounced for the intensity of other energy (panel 4 in Figure 1), clearly a result of the two oil crises, and
 132 the compensating large drop in energy prices around the mid-1980s. However, level shifts and "spikes"
 133 appear also for the other variables for the various industries. These are addressed individually below.
 134 Compared to the levels in Figure 1, the first differences in Figure 2 are more stable, fluctuating around
 135 fairly constant levels, with spikes here and there, reflecting the level shifts.

Figure 1: The annual time series of the logarithmic transformed levels for all eight subsectors.



Source: Statistics Denmark and Elværksstatistikken (for heating degree days).

Figure 2: The first differences of the logarithmic transformed variables from Figure 1.



136 The indication of drifting levels with first differences being more stable suggests that these series can
 137 be econometrically modeled as realizations of an I(1) Cointegrated VAR process (see Section 2.3).

138 2.2. A behavioral working hypothesis for the long-run dynamics

139 The purpose is now to briefly sketch a *working hypothesis* which states how the variables are expected
 140 to relate in a steady state. In short, this simply consists of two demand relations, one for electricity
 141 and one for other energy, and the assumption that prices are exogenous to the individual subsector. As
 142 explained below, having a working hypothesis provides a point of departure for imposing just-identifying
 143 restrictions in the initial part of the estimation, thereby facilitating the identification of the actual long-
 144 run dynamics of the data.

145 As pointed out in Berndt and Wood (1975) energy demand is a *derived* input demand in a similar
 146 fashion as the demand for intermediate material, labour and capital. Assuming that firms minimize
 147 costs, given their level of output and the prices of all inputs, the demand relations for electricity and
 148 other energy can be viewed as the solutions of the corresponding sufficient first order conditions. The form
 149 of this equation system and hence the properties of its solutions will depend on the functional form of the
 150 underlying production function. As a simple and tractable approximation, assume, for (subsector) Gross
 151 Output, a nested constant-elasticity-of-substitution (CES) production function with constant returns to
 152 scale (CRS) and with inputs, capital, labor, material, electricity and other energy.¹⁰ If this is coupled
 153 with the approximation that there is no substitution towards material, it follows that the demand for
 154 both electricity and other energy, per output unit, will depend on their relative prices, relative to a
 155 price CES-aggregate with respect to capital, labour and energy. In the data analysis below, the latter is
 156 approximated by the Gross Domestic Product deflator at *factor cost*, P_t .¹¹

157 In addition to energy demand as arising from the production process, in order to increase estimation
 158 efficiency and avoid potential omitted variable biases, it is necessary to control for other influences. In
 159 particular, for energy demand heating degree days could be important. Apriori this is expected to hold
 160 primarily for other energy and not electricity. However, as one can simply test whether or not the latter
 161 could be the case, heating degree days are allowed to enter the electricity relation as well.

162 Assuming a steady state for the (trend-adjusted) energy variables *given* the price variables (and
 163 heating degree days) one can make a log-linear approximation of such a conditional system (around the
 164 steady state), to obtain long-run demand relations in logarithms. This leads to the *long-run equations*,

$$165 \quad ey_t = \theta_{e,t} + \gamma_e pr_t^e + \delta_e pr_t^o + \eta_e h_t, \quad (1)$$

$$166 \quad oy_t = \theta_{o,t} + \gamma_o pr_t^e + \delta_o pr_t^o + \eta_o h_t, \quad (2)$$

165 where $ey_t \equiv \ln(E_t) - \ln(Y_t)$, $oy_t \equiv \ln(O_t) - \ln(Y_t)$, $pr_t^e \equiv \ln(P_t^E) - \ln(P_t)$, $pr_t^o \equiv \ln(P_t^O) - \ln(P_t)$ and
 166 $h_t \equiv \ln(H_t)$, H_t being heating degree days.¹² Although in the estimation below, the parameters of (1)
 167 and (2) vary unrestricted, a reasonable working hypothesis suggests that own-price coefficients, γ_e and δ_o ,

¹⁰Such production function seems reasonable as a working hypothesis when analyzing time series such as the Danish. In particular, it has been used in the large-scale macroeconomic model ADAM of the Danish economy (Knudsen and Smidt, 1994). With regard to CRS, also note that in the context of several inputs considered, i.e. material, energy, capital and labor, the assumption of CRS seems reasonable. This is relative to more stylized or text book-like production functions which typically have only two inputs, capital and labor. Finally, an output elasticity of unity (as is implied by CRS) has been found previously in the literature. Although dated, see Bentzen and Engsted (1993) and references therein.

¹¹See Knudsen and Smidt (1994) (in Danish), and note also that the variable for economic activity is Gross Output (e.g. analyzed in Berndt and Wood, 1975) whereas it is the deflator with respect to Gross Domestic Product at factor cost, P_t , that is used in the expression for the relative prices of electricity and other energy.

¹²Acknowledging the presence of the other (non-energy) inputs and adhering to the above assumptions, the equations (1) and (2) should, strictly speaking, be accompanied by a third equation for an aggregate for capital, labor and total energy. However, it can be shown that due to Slutsky symmetry and price homogeneity, which follow from the above cost minimization problem, *and* the fact that the share of energy of total costs is rather limited for most industries, this equation can in practice be ignored in the estimation without any significant loss of information.

168 are negative, whereas cross-price coefficients, δ_e and γ_o , are positive. The $\theta_{.,t}$ are deterministic functions
169 of time, and include constants, trend terms and dummy variables. Trend terms describe the underlying
170 smooth component of the evolution of energy intensities. If negative this supposedly reflects long-term
171 energy savings resulting from technological progress and economies of scale. Dummy variables, on the
172 other hand, are more likely to proxy the influence from exogenous extraordinary factors, e.g. energy
173 crises and economic policy interventions etc. (see below).

174 To sum up, the working hypothesis consists of the two long-run relations (1) and (2), together with
175 the hypotheses of negative own-price coefficients, positive cross-price coefficients, and exogenous relative
176 input prices. In Section 2.3, when the statistical model has been introduced, it is explained what this
177 hypothesis implies in terms of testable restrictions.

178 2.3. The statistical model

179 In the statistical model it is assumed that the variables, pr_t^e, pr_t^o, ey_t , and oy_t are determined jointly
180 in a system of equations. That is, they are treated as endogenous from the outset. Heating degree days,
181 h_t , is treated as exogenous, i.e. influences this system but is itself determined by factors outside this
182 system. As mentioned, the working hypothesis imposes further exogeneity, so that in addition to h_t one
183 could also condition on pr_t^e and pr_t^o . However, the exogeneity of these variables is not as obvious as that
184 of h_t , and as a result it is preferred to *test* this in the partial model of pr_t^e, pr_t^o, ey_t , and oy_t , conditional
185 on h_t . The statistical model, in which the long-run relations (1) and (2), can be tested as parametric
186 restrictions, is therefore a *partial or conditional* CVAR model for $(pr_t^e, pr_t^o, ey_t, oy_t)$, which conditions on
187 h_t . The formal statistical argument for applying this, is that exogeneity, in the above sense, implies that
188 h_t is (strongly and thus) *weakly exogenous* for the cointegrating matrix (i.e. β below), which includes the
189 main parameters of interest (see e.g. Johansen, 1992). As shown *ibid*, it follows that efficient estimation
190 of β can then be obtained based on the partial model, which is more parsimonious.

Before stating the partial model, denote the full variable vector as $x_t' = (pr_t^e, pr_t^o, ey_t, oy_t, h_t)$, and
partition this into $x_t' = (z_t', h_t)$ where $z_t' \equiv (pr_t^e, pr_t^o, ey_t, oy_t)$. Assume that, conditional on the past, x_t
has a joint Gaussian distribution, *i.i.* $N_5(0, \Omega)$, with Ω positive definite. Further, suppose that the process
of x_t given the past has the VAR(2) representation,¹³

$$\Delta x_t = \Pi x_{t-1} + \Gamma_1 \Delta x_{t-1} + \Phi \mathcal{D}_t + \varepsilon_t, \quad (3)$$

for $t = 1, 2, \dots, T$, and which has been written in the Error-Correction-Mechanism (ECM) form and where
 $\varepsilon_t \sim i.i. N_5(0, \Omega)$ and \mathcal{D}_t is a $d \times 1$ vector of deterministic components (dummy variables, trend, constant).
It is assumed that the characteristic roots, $\lambda \in \mathbb{C}$, always obey either $\lambda = 1$ or $|\lambda| > 1$, where $|\cdot|$ denotes
the modulus. Thus, if there are no roots at 1, or equivalently, $\det(\Pi) \neq 0$, then x_t is stationary.¹⁴ In
contrast, if at least one real-valued unit root exists (i.e. $\lambda = 1$) or equivalently $\det(\Pi) = 0$, then x_t
is non-stationary. In other words, Π has reduced rank, $r < 5$, which is parameterized as a non-linear
restriction on Π in (3), that is,

$$\Pi = \alpha \beta', \quad (4)$$

191 where the matrices α and β are $5 \times r$ of rank r . If furthermore, $\det(\alpha'_\perp (I - \Gamma_1) \beta_\perp) \neq 0$, where α_\perp and
192 β_\perp (both $5 \times 5 - r$) denote the orthogonal complements of α and β , it follows from Theorem 4.2 in
193 Johansen (1996) that x_t is I(1) and follows a CVAR which, for $0 < r \leq 5$, has r cointegration relations
194 given by the columns in β . This is assumed for the present analysis, meaning that only I(1) cointegration

¹³For all VAR models estimated in Section 3, two lags were sufficient.

¹⁴I.e. "asymptotically stationary" in the sense that it can be made stationary by a suitable choice of initial values see (see Johansen, 1996, p. 15, for example).

195 is considered.¹⁵

Using the above partitioning, $(z'_t, h'_t)'$, and an corresponding partitioning of the parameters, equation (3), with (4) imposed, can be written as,

$$\begin{pmatrix} \Delta z_t \\ \Delta h_t \end{pmatrix} = \begin{pmatrix} \alpha_z \\ \alpha_h \end{pmatrix} \beta' x_{t-1} + \begin{pmatrix} \Gamma_{z,1} \\ \Gamma_{h,1} \end{pmatrix} \Delta x_{t-1} + \begin{pmatrix} \Phi_z \\ \Phi_h \end{pmatrix} \mathcal{D}_t + \begin{pmatrix} \varepsilon_{z,t} \\ \varepsilon_{h,t} \end{pmatrix}, \quad (5)$$

where α_z is $4 \times r$, α_h is $1 \times r$, $\Gamma_{z,1}$ is 4×5 , $\Gamma_{h,1}$ is 1×5 , Φ_z is $4 \times d$, Φ_h is $1 \times d$ and with the covariance matrix decomposed as, $\Omega = (\Omega_{i,j})$ for $i = z, h$ and $j = z, h$ where Ω_{zz} is 4×4 , Ω_{hz} is 1×4 , Ω_{zh} is 4×1 , Ω_{hh} is 1×1 . As mentioned, imposing weak exogeneity of h_t , implying $\alpha_h = 0$, efficient inference about β may then be conducted based on the conditional model of Δz_t given Δh_t and *the past*, given by,

$$\Delta z_t = \theta \Delta h_t + \alpha_z \beta' x_{t-1} + \Theta_z \Delta x_{t-1} + \Psi_z \mathcal{D}_t + e_{z,t}, \quad (6)$$

196 where $\theta \equiv \Omega_{zh} \Omega_{hh}^{-1}$, $\Theta_z \equiv \Gamma_{z,1} - \theta \Gamma_{h,1}$, $\Psi_z \equiv \Phi_z - \theta \Phi_h$, $e_{z,t} \equiv \varepsilon_{z,t} - \theta \varepsilon_{h,t}$ where $e_{z,t} \sim i.i.N_4(0, \Omega_z)$ with
 197 $\Omega_z \equiv \Omega_{zz} + \Omega_{zh} \Omega_{hh}^{-1} \Omega_{hz}$ and uncorrelated with $\varepsilon_{h,t}$.

198 In terms of (6), the working hypothesis implies, *two* cointegrating relations (β is 5×2 of rank 2),
 199 which are restricted and normalized corresponding to (1) and (2), for which the signs of the estimated
 200 cointegration coefficients are as expected, and that the two first rows of α_z , corresponding to pr_t^e and
 201 pr_t^o , contain zeros only. The working hypothesis thus amounts to a submodel of (6) and is tested as such.

202 For reliable statistical inference on this submodel, a *well-specified* or statistically adequate *unrestricted*
 203 partial VAR is first formulated. This is simply a partial VAR model like (6) including the above error
 204 term assumptions but where no restrictions have been imposed, in particular, whether the matrix in
 205 front of x_{t-1} equals $\alpha_z \beta'$. That the model is well-specified implies here that constant parameters can
 206 be assumed and that, based on the residual analysis, it is reasonable to assume that the errors do
 207 not exhibit auto-correlation, non-normality or heteroscedasticity. Statistical adequacy is assessed by
 208 residual-based multivariate misspecification tests (see below). The most important assumption is that of
 209 no autocorrelation since the presence of correlated errors implies inconsistent estimators. Once statistical
 210 adequacy of the unrestricted partial VAR has been established, one can proceed to test the hypothesis of
 211 $r = 2$ based on the *trace test* (multivariate unit root test) and other criteria, as described below. Given
 212 this, α_z and β , under the working hypothesis, can be estimated as described in Doornik (1995).

213 Estimation requires identification and the working hypothesis imposes a single zero restriction on each
 214 of the two cointegrating relations, which fulfill the rank conditions for generic identification, see Chapter
 215 5 in Johansen (1996). Hence, r times $r - 1$ just identifying restrictions are imposed on the cointegrating
 216 space, implying that it is possible to estimate the two long-run relations and obtain standard errors for the
 217 long-run coefficients. The latter can then be used to assess the significance of (or lack of) the cointegrating
 218 coefficients and thus reduce the model accordingly by excluding insignificant coefficients. In this way the
 219 present econometric approach is a compromise between a priori information, the working hypothesis, and
 220 data-led analysis (well-specified unrestricted VAR and model reductions based on insignificance).

221 In practice, obtaining a well-specified model requires taking account of influential events that the model
 222 is not intended to explain and that may obscure and bias the estimation of the structural relations. This is
 223 usually done by introducing level shift dummies and/or exclude extraordinary time periods. Here, it was
 224 necessary to include level shift dummies, i.e. with the form $(0, \dots, 0, 0, 1, 1, 1, 1, 1, \dots, 1)$. The coefficients
 225 of the levels of these shift dummies are restricted such that breaks in the level of the variables are allowed
 226 not to cancel in the cointegrating relations and at the same time do not cumulate into broken linear

¹⁵If $\det(\alpha'_\perp (I - \Gamma_1) \beta_\perp) = 0$ and a further full rank condition holds (see Johansen, 1996, p. 58), x_t is I(2).

227 trends. *If* the breaks cancel, which is assessed by *testing* a zero restriction on the respective cointegration
 228 coefficient, the shift dummy is excluded from the cointegration relations, and an unrestricted impulse
 229 dummy, i.e. with the form $(0, \dots, 0, 0, 1, 0, 0, 0, 0, 0, \dots, 0)$, is included instead (see e.g. Juselius, 2006).
 230 When including the level of a shift dummy (with the restriction on its coefficients, cf. the above) its first
 231 difference (from lag 0 to $k - 1$) enters unrestricted.¹⁶ Trends (linear deterministic) enter the model in
 232 the same fashion. Hence, trends are allowed in the variables, and may not cancel in the cointegrating
 233 relations, and at the same time these trends are restricted such that quadratic trends are avoided. Finally,
 234 to take account of more temporary outliers, dummies with the form $(0, \dots, 0, 0, 1, -1, 0, 0, 0, 0, \dots, 0)$ were
 235 included.

236 3. Estimation results for the eight subsectors

237 With the working hypothesis as the point of departure, the purpose is now to estimate cointegrating
 238 relations between the variables, ey_t, oy_t, pr_t^e , and pr_t^o , given h_t , for each of the eight subsectors.

239 The specifications of the unrestricted partial VAR models for each subsector are given in Table 2.
 240 The table lists the lag length (either 1 or 2) and the years for the various dummy variables, which were
 241 necessary to obtain a well-specified unrestricted model with constant parameters for each subsector. It
 242 appears from the table that in most cases the years for the breaks coincide with major exogenous events.
 243 For example, breaks were needed for 1973-74 and 1978-79 to take account of the two major energy
 244 crises, and the large drop in energy prices and contractionary fiscal policy around 1985-86, also had to
 245 be conditioned on. Note the different timing across the eight subsectors, associated with some of the
 246 breaks, which may reflect that a given shock impacts on the different industries in a staggered way. The
 247 estimation results with respect to these breaks and trends constitute an interesting by-product of the
 248 analysis and they are further described in Appendix C.

249 The multivariate misspecification tests for statistical adequacy are reported in Appendix B. It appears
 250 that the hypothesis of no autocorrelation in the errors is accepted at the 5% level for all subsectors and
 251 in most cases with a relatively high p-value (reported in the square bracket). The test for normality
 252 and heteroscedasticity are reported in the next two lines. In five out of the eight cases normality can
 253 be accepted at the 1% level. In the cases of rejection, what drives the test away from normality is
 254 excess kurtosis, but otherwise the residual distributions were relatively symmetrical. As a result non-
 255 normality seems not to be critical here. In six out of the eight cases it was possible to compute the
 256 misspecification test for heteroscedasticity. Again the absence of heteroscedasticity was accepted at the
 257 1% level in all six cases. Note that, for Chemical- and Other manufacturing, the model has 2 lags and
 258 three breaks plus a transitory dummy, making the number of parameters relative to observations relatively
 259 large thereby prohibiting the computation. In any case, the existence of (moderate) heteroscedasticity is
 260 usually not crucial for the long-run estimates. In addition to the error term assumptions, as assessed by
 261 these misspecification tests, the assumption of constant parameters was also assessed in connection with
 262 specifying the models cf. Table 2, and constancy could be accepted for the unrestricted partial VARs.
 263 This assumption is further assessed, by recursive estimation, for the cointegrated models below.

¹⁶By treating the level like this, *similarity* in the trace test is obtained, as the effect on the variables from this deterministic term is the same under the null and the alternative (see Nielsen and Rahbek, 2000).

Table 2: Specification information for the partial unrestricted VARs for each industry. Lag length and years for breaks, impulse- and transitory dummies.

	Lags (k)	Dummy variables	
		Shifts:	Impulse and transitory:
Agriculture	1	1969, 1978, 1986	
Manufacturing:			
Food	2	1969, 1979	
Chemical	2	1975, 1978, 1989	Transitory in 1970
Machine- and vehicle	1	1969, 1986, 2010	
Other	2	1974, 1985, 2009	Transitory in 1970
Construction	1	1995, 2000	Impulses in 1969, 1987
Services:			
Trade	1	1974	Impulse in 1988
Other	1	1970, 1974, 1979, 2009	

264 Altogether, given the misspecification tests in Appendix B, all models seem reasonably well-specified.
265 Given this one can turn to the cointegrating analysis, that is the statistical inference about the cointe-
266 grating rank. Even though the working hypothesis implies $r = 2$, it should be checked that this restriction
267 is not completely contradicting the evidence based on the unrestricted estimation. The results from ap-
268 plying the top-down testing procedure for the trace test, as described in Johansen (1996), are given in
269 Table 3. The table shows the value of the rank, r , as suggested by the trace test. Unless this is clear-cut,
270 in the (loose) sense that the associated p-values are far from 5% the outcome is given as an interval to
271 indicate the uncertainty explicitly. It occurs more often than not that the results from the trace test
272 are not sufficiently clear-cut in the sense of pointing towards one particular value of r . As discussed in
273 Juselius (2006), since the choice of cointegration rank usually has influence on the subsequent inference
274 (e.g. about the long-run relations), it is therefore important to supplement the results from the trace test
275 and use as much other information as possible. This approach is also adopted here: In particular, based
276 on the unrestricted model ($r = 4$) and the model with $r = 3$ imposed, the modulus of the eigenvalues
277 of the companion matrix (inverse characteristic roots), the graphs of the cointegrating relations, $\hat{\beta}'x_t$,
278 and the significance of individual adjustment coefficients in $\hat{\alpha}_z$, were all inspected. The results from
279 considering all these pieces of information for all industries are summarized in Table 3.

Table 3: Summarizing information on the inference on the Cointegration Rank. The numbers refer to the cointegrating rank.

	Model aspect			
	Trace test	α signif.	Eigenval.	Graph, $\beta'x_t$
Agriculture	2-3	2-3	2	2
Manufacturing:				
Food	2-3	2-3	2	2-3
Chemical	3	3-4	1-2	2-3
Machine- and vehicle	2	3	2	2-3
Other	1-2	2-3	1-2	2-3
Construction	0	2	2-3	2-3
Services:				
Trade	2	2-3	1-2	2-3
Other	2-3	2-3	2	2

Notes: In the presence of variables the asymptotic distributions of the trace test statistic are simulated in CATS in RATS.

280 As is often the case, the table first of all suggests that there is some uncertainty associated with

281 the choice of rank. On the other hand, $r = 2$ seems in general to be a reasonable point of departure,
 282 consistent with the working hypothesis. However, it is also the impression that in most cases a third
 283 cointegrating relation may exist. Therefore, as a robustness check of the cointegration estimates given
 284 $r = 2$, Section 3.2 identifies and adds a third relation to assess whether the estimates of the two first
 285 relations are sensitive to this.

286 3.1. Estimation results by subsector

287 Having established that the models are reasonably well-specified and that the choice of two cointe-
 288 grating relations is clearly consistent with the evidence, this section describes the estimation results for
 289 α_z and β given $r = 2$. In the initial estimations the restrictions implied by the working hypothesis are
 290 imposed. That is, as described above, the zero rows in α_z and the just-identifying restrictions on β as im-
 291 plied by (1) and (2). Subsequently, insignificant regressors are removed from the long-run relations. The
 292 p-value below corresponds to the resulting restricted partial CVAR against a partial CVAR with $r = 2$,
 293 as the only restriction imposed. Henceforth, this is referred to as *the p-value of the overall restriction*.
 294 Since the method is the same for all eight subsectors most space for explanations has been devoted in
 295 connection with describing the first subsector, Agriculture.

296 **Agriculture:** The estimates of the restricted versions of α_z and β in (6) are given in the first part
 297 of Table 4. Note that the $\widehat{\beta}$ matrix (or its two columns transposed, $\widehat{\beta}'_1$ and $\widehat{\beta}'_2$) has been augmented
 298 with the deterministic components. The estimates of the deterministic components for all subsectors are
 299 analyzed in Section C in the appendix. It is noted from the table that the overall restriction imposed by
 300 the working hypothesis is accepted with relatively high p-value, 0.43. The signs and significance of the
 301 own and cross-price coefficients are as expected, recalling that the cointegration relation by convention
 302 is written in the deviation form, so that the sign is reversed compared to (1) and (2). The estimates in
 303 $\widehat{\beta}'_1$, corresponding to electricity demand, thus suggest that the long-run own-price coefficient is 0.15 (or
 304 15%), whereas the cross-price coefficient is about the same magnitude 0.18, both significant with absolute
 305 t-values, 2.68 and 3.85, respectively. For the demand relation for other energy the own-price coefficient
 306 is also significant and of similar magnitude (0.14), whereas the cross-price coefficient is somewhat lower,
 307 0.06, and with a relatively low t-value (-1.51). In fact the latter could be restricted to zero, but since this
 308 did not change any of the obtained conclusions and since the sign is as expected, it was chosen to let pr_t^e
 309 remain in the demand relation for other energy.

310 Note that, the term, "coefficient" as opposed to "long-run elasticity" or even "long-run effect", is
 311 used. This is to stress that in general the cointegrating coefficients cannot be interpreted as such.¹⁷
 312 Instead, the notions of long-run elasticities and long-run effects are defined explicitly in the context of
 313 the impulse-response experiment in Section 4.

314 The heating degree days estimate suggests that more heating degree days in a year will increase
 315 electricity demand. Note that, this is borderline insignificant ($t = -1.69$) and can be removed although
 316 this does not change the obtained conclusions. Since the sign is as expected, it was chosen to let h_t
 317 remain in the electricity relation.

318 Turning to the adjustment matrix, $\widehat{\alpha}_z$, the last two rows show that both ey_t and oy_t adjust towards
 319 equilibrium whenever pushed away from this. In particular, electricity consumption adjusts downwards if
 320 above the long-run demand (and vice versa), cf. the negative adjustment coefficient, -0.44 , which is highly
 321 significant ($t=-8.41$). For other energy the corresponding numbers are, -0.87 and -6.38 , respectively.
 322 Finally, note that the first two rows of the adjustment matrix, α_z , contain zeros only consistent with the
 323 exogeneity of the relative input prices as implied by the working hypothesis.

¹⁷See Johansen (2005).

324 **Food manufacturing:** The estimation results for this subsector are given the second part of Table 4.
325 The p-value for the overall restriction is 25%. Exogeneity of the relative input prices and significant error
326 correction of both energy intensities are also supported. However, with the exception of the cross-price
327 coefficient with respect to electricity in the second relation, the cointegrating coefficients corresponding to
328 the relative input prices were all insignificant and could be restricted to zero, suggesting that substitution
329 in this subsector is negligible. The estimated cross-price coefficient with respect to electricity in the second
330 relation, i.e. γ_o in terms of (2) is 0.26 but has the opposite sign of what is expected. Finally, note that
331 heating degree days could be excluded from both long-run relations.

332 **Chemical manufacturing:** For this subsector the p-value for the overall restriction is as high as
333 64%. As with food manufacturing exogeneity of the relative input prices and significant error correction
334 of both energy intensities were supported, whereas the only price coefficient that is significant is the own-
335 price coefficient of electricity, which has the expected sign. The significant positive estimate of heating
336 degree days in the second relation reflects that the heating demand.

337 **Machine- and vehicle manufacturing:** The p-value for the overall restriction is 35% and there
338 is evidence consistent with cross-price effects. However, although the both intensities error correct when
339 their respective levels deviate from their long-run values only the relative price of other energy can be
340 assumed to be exogenous. In other words, there seems to be some adjustment in the relative price of
341 electricity to deviations in both intensities from their long-run relations. This adjustment may reflect
342 general equilibrium effects between the two prices, and/or that the price-taking assumption is not suf-
343 ficiently realistic. The heating degree days estimates in $\hat{\beta}$ suggests that more heating degree days in a
344 year will increase electricity demand.

345 **Other manufacturing:** For this subsector the p-value for the overall restriction is 14%. The cross-
346 price effects are insignificant for this subsector but own-price coefficients for both electricity and other
347 energy are significant and have the expected signs. Exogeneity of the relative input prices and significant
348 error correction of both energy intensities are also supported. As expected, the heating degree days
349 coefficient is significant and positive in the second relation.

350 **Construction:** For Construction the p-value for the overall restriction is as high as 95%. With the
351 exception of some significant adjustment of the relative electricity price when electricity consumption per
352 unit of output is above its long-run value the working hypothesis as a whole is supported. In particular,
353 in addition to the own-price coefficients, cross-price coefficients, with the expected sign and of some
354 magnitude, suggest that changes in relative energy prices induce energy substitution for this subsector.
355 Finally, note that heating degree days could be excluded from both long-run relations.

356 **Trade:** The p-value for the overall restriction imposed by the working hypothesis is 37%. Exogeneity
357 of the relative input prices and significant error correction of both energy intensities are also supported.
358 With the exception of a zero cross-price coefficient in the electricity relation the remaining price coefficients
359 are significant and have the expected signs. With respect to heating degree days, note that the borderline
360 insignificance in the first relation could be restricted to zero without affecting the conclusions and that
361 the positive coefficient in the relation for other energy most likely reflect heating demand.

362 **Other services:** For this large aggregate of service industries the p-value for the overall restriction is
363 as high as 81%. The estimation results suggest exogeneity of the relative input prices and significant error
364 correction and for electricity the cointegrating coefficients are in accordance with the working hypothesis,
365 i.e. a negative own-price coefficient and a positive cross-price coefficient, both significant. The relation
366 for other energy seems to be a simple heating demand relations with no price effects.¹⁸

¹⁸The borderline insignificant adjustment coefficient in $\hat{\alpha}_z$ (0.15, t=-1.39) could be restricted to zero but this did not change the long-run relations significantly.

Table 4: Testing the working hypothesis: The table reports the estimates of the restricted α_z and β , given $r = 2$. The restrictions implied by the working hypothesis were first imposed and then insignificant regressors were removed from the relations. If the initial restrictions are rejected they have been relaxed. The p -value corresponds to the resulting restricted partial CVAR against a partial CVAR with $r = 2$, as the only restriction imposed.

Agriculture			p-value = 0.43									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D69_t$	$D78_t$	$D86_t$
Δpr_t^e	0.00	0.00	$\tilde{\beta}'_1$	0.15 [2.68]	-0.18 [-3.85]	1.00	0.00	-0.35 [-1.69]	0.01 [5.07]	-0.42 [-7.78]	0.13 [2.27]	-0.26 [-4.09]
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	-0.06 [-1.51]	0.14 [4.43]	0.00	1.00	0.00	0.02 [16.83]	-0.19 [-3.81]	-0.15 [-3.60]	0.00
Δey_t	-0.44 [-8.41]	-0.21 [-2.45]										
Δoy_t	0.00	-0.87 [-6.38]										
Food Manufacturing			p-value = 0.25									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D69_t$	$D79_t$	
Δpr_t^e	0.00	0.00	$\tilde{\beta}'_1$	0.00	0.00	1.00	0.00	0.00	-0.004 [-3.31]	-0.39 [-9.04]	-0.19 [-5.38]	
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	0.26 [5.70]	0.00	0.00	1.00	0.00	0.02 [8.19]	0.00	0.19 [2.91]	
Δey_t	-0.71 [-5.34]	-0.28 [-3.48]										
Δoy_t	-0.72 [-2.61]	-0.79 [-4.65]										
Chemical Manufacturing			p-value = 0.64									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D75_t$	$D78_t$	$D89_t$
Δpr_t^e	0.00	0.00	$\tilde{\beta}'_1$	0.32 [7.93]	0.00	1.00	0.00	0.00	0.02 [10.11]	-0.28 [-4.29]	-0.39 [-5.74]	-0.16 [-2.87]
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	0.00	0.00	0.00	1.00	-0.99 [-3.44]	0.04 [12.40]	0.00	0.43 [6.46]	-0.37 [-5.11]
Δey_t	-0.61 [-4.89]	0.00										
Δoy_t	-0.89 [-5.80]	-0.60 [-6.78]										
Machine/Vehicle Manufacturing			p-value = 0.35									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D69_t$	$D86_t$	$D10_t$
Δpr_t^e	0.56 [2.75]	1.27 [3.14]	$\tilde{\beta}'_1$	0.00	-0.41 [-3.89]	1.00	0.00	-1.72 [-4.35]	0.03 [4.19]	0.00	-0.52 [-4.12]	0.98 [4.50]
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	0.00	0.54 [14.58]	0.00	1.00	0.00	0.00	-0.22 [-3.68]	0.52 [17.24]	-0.33 [2.95]
Δey_t	-0.27 [-7.49]	0.00										
Δoy_t	-0.27 [-5.75]	-0.65 [-7.07]										
Other Manufacturing			p-value = 0.14									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D74_t$	$D85_t$	$D09_t$
Δpr_t^e	0.00	0.00	$\tilde{\beta}'_1$	0.19 [3.46]	0.00	1.00	0.00	0.00	-0.01 [-4.89]	-0.23 [-2.81]	0.00	0.50 [4.06]
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	0.00	0.45 [8.65]	0.00	1.00	-0.61 [-2.23]	-0.01 [-1.95]	0.00	0.65 [7.76]	-0.27 [-2.30]
Δey_t	-0.47 [-5.43]	0.00										
Δoy_t	0.00	-0.57 [-5.55]										
Construction			p-value = 0.95									
	$\hat{\alpha}_1$	$\hat{\alpha}_2$		pr_t^e	pr_t^o	ey_t	oy_t	h_t	<i>Trend</i>	$D95_t$	$D00_t$	
Δpr_t^e	-0.27 [-5.79]	0.00	$\tilde{\beta}'_1$	2.34 [7.39]	-1.10 [-6.48]	1.00	0.00	0.00	0.00	0.41 [3.42]	0.00	
Δpr_t^o	0.00	0.00	$\tilde{\beta}'_2$	-2.85 [-5.72]	1.21 [4.50]	0.00	1.00	0.00	-0.05 [-7.08]	0.00	0.75 [4.74]	
Δey_t	-0.26 [-3.19]	-0.18 [-3.03]										
Δoy_t	-0.33 [-2.82]	-0.27 [-3.23]										

Table 4 (continued)

Trade			p-value = 0.37										
	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\widehat{\beta}'_1$	pr_t^e	pr_t^o	ey_t	oy_t	h_t	$Trend$	$D74_t$			
Δpr_t^e	0.00	0.00	$\widehat{\beta}'_1$	0.33 [3.44]	0.00	1.00	0.00	0.47 [1.65]	0.01 [6.09]	-0.53 [-8.23]			
Δpr_t^o	0.00	0.00	$\widehat{\beta}'_2$	-0.57 [-2.12]	0.82 [8.83]	0.00	1.00	-1.88 [-2.57]	0.00	0.00			
Δey_t	-0.26 [-7.81]	0.00											
Δoy_t	-0.21 [-3.77]	-0.15 [-5.82]											
Other services			p-value = 0.81										
	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\widehat{\beta}'_1$	pr_t^e	pr_t^o	ey_t	oy_t	h_t	$Trend$	$D70_t$	$D79_t$	$D86_t$	$D09_t$
Δpr_t^e	0.00	0.00	$\widehat{\beta}'_1$	0.53 [4.38]	-0.33 [-4.87]	1.00	0.00	0.00	0.01 [3.91]	-0.17 [-1.70]	0.00	-0.13 [-1.91]	-0.37 [-3.55]
Δpr_t^o	0.00	0.00	$\widehat{\beta}'_2$	0.00	0.00	0.00	1.00	-0.43 [-2.89]	0.01 [8.38]	-0.20 [-3.52]	0.11 [3.23]	0.00	-0.21 [-3.03]
Δey_t	-0.18 [-2.20]	-0.15 [-1.39]											
Δoy_t	0.28 [-4.37]	-0.58 [-7.03]											

Note: The brackets contain t-ratios and the $\widehat{\beta}$ matrix is augmented with deterministic components

367 In general, although not *all* restrictions as implied by the working hypothesis are accepted for all
368 subsectors, the estimated models are generally well-behaved in the sense of being simple and economically
369 interpretable.

370 3.2. Assessing robustness: sample changes and cointegration rank

371 In spite of reasonable statistical adequacy, economically interpretable estimation results, it remains
372 to assess whether conclusions are robust towards changes in the choice of sample and whether the model
373 assumption of constant parameters is reasonable. Moreover, the "empirically best" choice of the coin-
374 tegration rank is often uncertain and can be crucial for the inference on cointegration relations and
375 adjustment parameters. These aspects are investigated in detail in Appendix D and here the findings are
376 summarized.

377 To assess parameter constancy and the robustness of test conclusions, i.e. with respect to the sign
378 and significance of cointegrating estimates and the p-value of the overall restriction, towards sample
379 changes, *forward recursive* estimation of CVAR models restricted as in Table 4, was performed for each
380 subsector. As discussed in the appendix, taking into account the anticipated variability in the beginning
381 of the forward recursive graphs (due to *short-sample uncertainty*), the analysis suggests that parameter
382 constancy seems reasonable and that the overall/joint restrictions are accepted for the vast majority of
383 subsamples. In addition, the conclusions from Table 4, with respect to significance of individual price
384 coefficients, are rather robust. As the forward recursive analysis cannot say anything about the influence
385 from early observations, this was complemented by an assessment of the robustness towards the exclusion
386 of the first part of the sample. This exercise is meant only to give an rough indication and, as argued in the
387 appendix, the full sample estimation is preferred over this. With this in mind, this exercise nevertheless
388 suggests reasonable robustness for five out of eight subsectors, namely Agriculture, Machine- and vehicle
389 manufacturing, Constructions, Trade and Other services.

390 Table 3 suggests that although two cointegrating relations is a reasonable choice for each subsector,
391 consistent with the working hypothesis, there is some indication of an additional cointegrating relation.
392 In Appendix D it is therefore attempted to identify an additional relation jointly with the existing
393 restrictions on the two first cointegrating relations. The purpose is to assess the robustness of the
394 estimates of the two existing cointegration relations towards adding a third relation and not the latter
395 as such. Nevertheless, as argued in Appendix D this third relation can be interpreted as capturing the

396 co-movement of electricity prices and the price level of other energy. This co-movement most likely results
397 since some of the components of Other energy, primarily coal but also oil, in particular, have been used as
398 inputs into electricity production. Hence, the third relation is common for all eight subsectors. Table D.1
399 in Appendix D summarizes the estimates of the price coefficients from the first two cointegrating relations
400 (the existing ones from Table 4), when the third relation is added. In comparison to Table 4, the table
401 shows that in five out of the eight cases the estimated own and cross-price coefficients in the first two
402 cointegrating relations are approximately unchanged with respect to sign, significance and magnitude.
403 The most important exception, which relates to the electricity relation, is that for Agriculture, for which
404 both own and cross-price coefficients become insignificant (and are therefore restricted to zero). Also, for
405 Machine- and vehicle manufacturing there is some change in magnitudes, in that the estimated cross-price
406 coefficient changes from 0.41 to 1.73, albeit sign and significance are robust. For Construction the lack of
407 robustness concerns the relation for other energy. Hence, also in this respect the overall picture clearly
408 supports the robustness of the obtained results.

409 4. The potential for environmental taxation - impulse-response analysis

410 As it appears from Section 3.2, the analysis in Appendix D suggests that the estimation results for
411 Agriculture, Machine- and vehicle manufacturing, Construction, Trade and Other services are robust.
412 This is with respect to sample changes and, with the exception of Agriculture, towards the presence of
413 a third cointegrating relation. Moreover, for these subsectors own-price and/or cross-price coefficients
414 suggest that, in the long run, the input mix of electricity and other energy will change in response to a
415 change in their relative price. For these five subsectors the purpose is now to throw light on the long-
416 run potential for taxation to move energy consumption away from other energy and towards the more
417 environmental friendly electricity. This can be done by using the estimated CVAR models from Section
418 3 to conduct a hypothetical experiment based on *impulse-response* functions. In general, these functions
419 provide a complete characterization of the full dynamic adjustment (i.e. both short- and long-run effects)
420 for all variables in the system when changing some variables.

421 In the recent years there has been an active debate on the Danish energy and environmental tax pol-
422 icy. In particular, in connection with the Growth Package 2014, it was suggested that the Public Service
423 Obligation (PSO) tariff (on electricity use) paid by Danish enterprises should be lowered, in order to
424 improve their international competitiveness. The PSO is a tariff on the electricity consumption by busi-
425 nesses and households and it is used to finance the support of initiatives within renewable energy. More
426 recently, in the spring 2016 the Danish government proposed to abolish the PSO tax altogether, based
427 on the same arguments.¹⁹ In spite of being a simplified analysis the impulse-response experiment below
428 can to some extent throw some light on the potential consequences for industrial energy consumption
429 (and thus tax revenues) of removing the PSO and increasing taxes on the consumption of other energy
430 to compensate the lost revenues.

431 The impulse-response experiment illustrates the long-run effects on the demand for electricity and
432 other energy from raising the price of other energy by 25% while at the same time lowering the price
433 of electricity, by 25% in the long run.²⁰ The experiment can thus be regarded as describing the long-
434 run effects on the energy consumption mix of a simple tax reform which implies lower electricity taxes
435 while increased taxation of other energy. The assumption of a 25% reduction in electricity prices is

¹⁹The PSO was introduced in 1998 in connection with the liberalization of electricity markets and has had its current form since 2005. It is set quarterly by the state-owned Danish national TSO, Energinet.dk, and is primarily used for ensuring a minimum price to producers of renewable electricity and to small CHPs. See e.g. www.energinet.dk.

²⁰As usual, since all variables are in logarithmic form, all percentage changes both the impulses ($\pm 25\%$) and the responses are approximations.

436 inspired by the abolition of the PSO tariff, but it should be emphasized that the experiment primarily
 437 serves as a "benchmark analysis" quantifying the dynamic responses (in particular the long run effects)
 438 of taxation.²¹ This may nevertheless serve as a point of departure for more realistic and applicable
 439 analyses, which preferably should split up other energy into its subcomponents and accordingly apply
 440 different tax rates for each of these. Moreover, budget balancing could be imposed, so that the revenues
 441 lost from removing taxation on electricity are matched by those collected from the extra tax on other
 442 energy. In addition legislative aspects, other governmental budget restrictions and political constraints,
 443 tax incidence across the subsectors etc. would have to be taken into account, complicating the analysis.
 444 This is therefore best left for a separate paper which may use the present work as a building block.

445 Although one could consider the impulse-response analysis for the model with three cointegration
 446 relations, it makes more sense to base the computations on the models from Table 4, with $r = 2$. This
 447 is because the third relation is a relation for the level of electricity prices, which, together with the
 448 exogeneity of pr^o , shows how this is driven by the price of other energy, supposedly reflecting that higher
 449 prices of coal (and oil for the earlier part of the sample) imply higher costs for power plants (cf. the
 450 discussion above). Since the purpose of taxation in the present context is to induce substitution from the
 451 use of other energy towards electricity in the industries, the relevant type of tax, should preferably be
 452 levied on the consumption of industries and not on power plants. Hence, by basing the impulse-response
 453 experiment on the models as estimated in Table 4 which have $r = 2$, the relevant picture of the dynamic
 454 effects of taxation is obtained.

455 The computations of the impulse-response functions are based on the estimated CVAR models which
 456 are in their *reduced form*. This is possible because the reduced form errors can reasonably be assumed to
 457 be uncorrelated, with the exception of one correlation between the two price errors for Agriculture. In
 458 particular, correlations between residuals were in general low, and the *moderate* significance (compared
 459 to their approximate critical values $\pm 2/\sqrt{T} = 0.3$) of some correlations was driven by only one or two
 460 observations, corresponding to well-known extraordinary events, i.e. in the years 1973-74, 1978-79, 1986,
 461 2009.

462 Since the price of other energy is exogenous, an impulse of 25% at t_0 will raise this price by 25%, for
 463 $t_0 + 1$, $t_0 + 2$, $t_0 + 3$ etc., resembling a tax increase. However, for the five subsectors analyzed in this
 464 section, electricity prices are only exogenous for Agriculture, Trade and Other services. For Construction
 465 and Machine- and vehicle manufacturing this is not the case and this implies that a 25% negative impulse
 466 at t_0 to electricity prices will not imply a long-run (permanent) decrease of 25%, due to the feedback from
 467 the other variables on electricity prices. It is therefore more reasonable to *normalize* the impulse so that
 468 it produces a decrease of 25% in the long run in electricity prices and then look at the long-run effects on
 469 the intensities. This can be done by using the equations $C\delta = h$, where C is the long-run impact matrix,
 470 δ is the impulse (unknown and to be solved for, for electricity prices) and h includes the chosen long-run
 471 effects. See e.g. Møller (2008) for an example of this normalization, and Johansen (2005) for the general
 472 case.

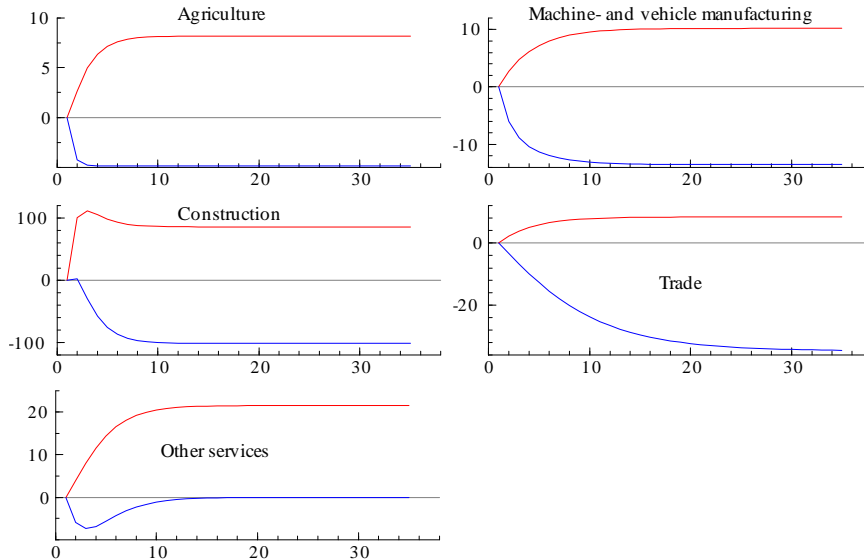
473 The graphs of the impulse-response functions for the energy intensities are given in Figure 3. The
 474 red and blue graphs correspond to electricity and other energy, respectively. The percentage change
 475 is shown on the vertical axis and the horizon is 35 years, since within this period all long-run values
 476 have been reached *approximately* (the horizontal axis). For the interpretation of the impulse-response
 477 graphs, define the *long-run effect* as the difference between the long-run value (i.e. the asymptote) and

²¹Recently, it has been estimated by the government that removing the PSO tariff and instead finance the support to renewable energy via the fiscal budget will imply a 25% reduction of the electricity bill for the average industrial end-user (see e.g. the home page of the Danish Ministry of Business and Growth). However, it remains unclear what the time horizon is, whether substitution has been allowed for and in general what assumptions are made about the future spot prices and thus the PSO payments to be financed.

478 the starting point ($= 0$). Since this is the result of a 25% change, in the present experiments, one could
 479 accordingly define a *long-run elasticity* as the being 1/25 of the long-run effect. Again it should be
 480 underscored that, in general, a long-run elasticity is not equal to a cointegrating coefficient (such as those
 481 from Table 4), since the former will generally depend on other parameters of the model. Nevertheless, in
 482 the simple CVAR models with one lag and exogeneity restrictions cointegrating coefficients coincide with
 483 the long-run elasticities, so that the long-run values in the impulse-response graphs are in fact equal to
 484 25 times the cointegration estimates from Table 4. In particular, as explained below this is the case for
 485 Agriculture, Machine- and vehicle manufacturing, Trade and Other services.

486 Starting with Machine- and vehicle manufacturing, the long-run effect is a 10.20% increase in electricity
 487 and a 13.52% drop in other energy. These effects are driven only by the change in the price of other
 488 energy. This is due to the fact that, although the level of electricity prices adjusts to both relations, since
 489 it does not enter the cointegrating relations and since $k = 1$, it has no short-run or long-run effect on the
 490 intensities. For Agriculture, Trade and Other services, where exogeneity holds for both pr^e and pr^o , the
 491 interpretation is also rather straightforward, in that the long-run effect is simply the sum of own- and
 492 cross-price elasticities, multiplied by 25.²² Hence, the intensities of electricity in Agriculture, Trade and
 493 Other services increase by 8.19%, 8.37% respectively, and 21.47%. For these three subsectors the intensity
 494 of other energy drops by respectively, 4.85%, 34.68% and 0%. Note that the latter zero (long-run) effect
 495 reflects the zero (price) coefficients in $\hat{\beta}_2$ in Table 4. However, note also that these zero restrictions are
 496 merely statistical approximations. That is, these coefficients were insignificant and thus restricted to
 497 zero, but they had the expected signs. In other words the zero long-run effect on other energy for Other
 498 services (fifth panel, Figure 3), should be viewed as an approximation to an insignificant but negative
 499 effect.

Figure 3: Impulse response analysis showing the dynamic effects (in percentage) on the intensities of electricity (red) and other energy (blue) from a 25 percent permanent increase in the price of other energy and a long-run decrease of 25 percent in electricity prices.



500 For Construction the impulse-response analysis is slightly more complicated due to more involved
 501 adjustment dynamics of the system, which is reflected in the non-zero adjustment coefficient in the first
 502 entry of $\hat{\alpha}_z$. However, concerning the long-run effects (of the 25% long-run changes in both prices), the

²²Note that, due to the above-mentioned error-correlation for Agriculture, the results for this subsector are more uncertain compared to the remaining. They may nevertheless give an overall impression.

503 results suggest that for this sector a tax reform could be highly effective. In particular, in the long run the
504 intensity of electricity rises by 85.85% while the intensity of other energy drops by as much as 101.50%.

505 Finally, note that most of the long-run effect is reached within a decade for all five sectors, but also
506 that there are differences in the adjustment process. For example, for Agriculture the long-run effect on
507 other energy is already reached (roughly) after three years, whereas for Other services, the effect after
508 three years is quite different from the corresponding long-run effect, which is reached after roughly 20
509 years.

510 To sum up, the impulse-response results are well-behaved and although there are differences in magni-
511 tudes across the subsectors, they suggest that changing relative prices by imposing taxes, can be a means
512 of inducing substitution.

513 **5. Concluding remarks**

514 For each of eight subsectors of the Danish economy, together accounting for the bulk of aggregate
515 industrial energy consumption and economic activity, this research has identified long-run demand rela-
516 tions for electricity and other energy (an aggregate of liquid fuels, coal, coke, gas, district heating and
517 biomass). Conditional on a limited number of extraordinary events (oil crises, fiscal policy etc.) it was
518 possible to obtain reasonably well-specified statistical models (partial CVARs) with constant parameters
519 for the most part. Moreover, the estimation results obtained from the full sample covering 1966-2011
520 were, in general, reasonably robust. In particular, for five large subsectors, Agriculture, Machine- and
521 vehicle manufacturing, Construction, Trade and Other services, the results seemed robust towards sample
522 changes and the presence of a third cointegrating relation between relative prices (common to all subsec-
523 tors). For these five subsectors, for which significant own-price and/or cross-price effects were found, an
524 impulse-response experiment was carried out in order to investigate the potential for taxation to induce
525 substitution of electricity for other energy and thus for greening industrial energy consumption. The
526 experiment, which resembled a simple tax reform, described the combined long-run effect from raising
527 the price of other energy with 25% while at the same time lowering the price of electricity by 25% (in the
528 long run). The overall policy implication is that substitution from other energy towards electricity may
529 be induced by taxation, when targeted towards these sectors. The experiment may throw some light on
530 the potential consequences for industrial energy consumption (and thus tax revenues) of removing the
531 Danish PSO tariff, which has recently been suggested for strengthening the competitiveness of the trade
532 exposed industries, and increasing taxation on fossil-based energy as a means of financing this. Com-
533 pared to financing by increasing the bottom-bracket taxes, as has been suggested in the Danish political
534 debate, such a tax reform is of course likely to impact differently in terms of competitiveness but would
535 presumably contribute more effectively to the green transition.

536 The disaggregate or subsectorial approach revealed large behavioural differences across the subsectors.
537 For internationally integrated economies, such as the Danish, this insight contributes valuable information
538 with respect to long-term forecasting of aggregate energy demand and substitution, since over longer time
539 horizons, the subsector composition is bound to change substantially, for example as a result of increasing
540 international trade.

541 The study contributes new insights to the literature on energy demand and substitution, which in spite
542 of being vast contains very few econometric analyses which consider electricity demand and substitution
543 at the subsector level.

544 A number of possible extensions and paths for future research to follow suggest themselves. For exam-
545 ple, it could be fruitful to apply the present analysis to time series data from other countries. Obviously
546 the other Scandinavian economies for which detailed high-quality data are also available, could be con-
547 sidered. However, also for developing countries, for which the subsector composition is likely to undergo

548 large changes in the future, a disaggregate approach seems promising for improving long-term energy
549 forecasting. Secondly, as mentioned the impulse-response experiment conducted here is to some extent
550 stylized, and hence, could be augmented in order to consider more complex and realistic tax policies.
551 From an econometric point of view there are also a number of extensions which could be interesting to
552 consider. For example, as it appears from the time plots of the intensities these graphs are rather smooth.
553 This suggests that, as an alternative to the present approach, which models ratio-transformed variables
554 by an I(1) CVAR with trends and level shifts, one could consider an I(2) approximation, supposedly
555 for the original variables. Another possibility is that the data are better modelled by including some
556 non-linearity in the form of thresholds in the adjustment to the long-run equilibrium deviations (see e.g.
557 Bec and Rahbek, 2004). For example, it seems reasonable that, an increase in the price of other energy
558 has to be of some magnitude, in order for the consumer to react, in the sense of undertaking long-term
559 investments in new electricity intensive capital.

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613 Appendices (supplementary material)

614 A. Description of the data

615 The data consist of annual time series 1966-2011 from eight different subsectors of the Danish economy.
616 Together these make up the bulk of total industrial energy consumption and economic activity, and
617 represent the primary -, secondary - and tertiary sectors. To get an idea of magnitudes, note that with
618 respect to aggregate industrial energy consumption (excluding transport energy), these eight industries
619 accounted for 67% in 2005.²³ Each of the eight subsectors are aggregates of national accounts industries.
620 These aggregations attempt to group the national accounts industry categories into relatively energy
621 homogenous industries. Table 1 in Section 2.1 shows which particular national account industries are
622 included in the eight subsectors.

623 The subsector representing the primary sector is referred to as *Agriculture* and includes horticulture
624 and forestry in addition to agriculture. The energy intensity is high in this subsector, which, by 2005
625 terajoule (TJ) numbers, accounted for as much as 14% of the total industrial non-transport energy con-
626 sumption. Agriculture, horticulture and forestry together account for almost all energy consumption
627 of the primary sector. In general, energy is used for heating, operating of machines (electricity) and
628 transportation related to fieldwork. In horticulture energy is used for heating greenhouses, and in partic-
629 ular, electricity is used for controlling and lighting. The distribution of all non-transport energy in this
630 industry between electricity and other energy is 20% versus 80%, suggesting a considerable potential for
631 substitution.

632 The subsectors of the secondary sector comprise, *Food manufacturing*, *Chemical manufacturing*,
633 *Machine- and vehicle manufacturing*, *Other manufacturing* and *Construction*. Together these subsectors
634 account for about 80% of all energy consumption of the secondary sector.²⁴ By 2005 TJ numbers, the
635 food manufacturing subsector was as energy consuming as agriculture and hence accounted for as much
636 as 13% of the total industrial non-transport energy consumption. The distribution of all non-transport
637 energy in this industry between electricity and other energy is 25% versus 75%. Chemical manufacturing
638 accounted for 6% of the total industrial non-transport energy consumption, using the 2005 numbers. Of
639 this, electricity accounted for 43% and other energy for 57%. With respect to energy consumption and
640 its distribution between electricity and other energy the machine and vehicle subsector mirrors chemi-
641 cal manufacturing. Other manufacturing accounted for 9% of the total industrial non-transport energy
642 consumption, using the 2005 numbers. Of this, electricity accounted for 27% and other energy for 73%.
643 Considering the particular industries included in these subsectors (cf. Table 1) energy is used for lighting,
644 refrigerating, cooling and heating, and for operating of machines (electricity). Finally, for Construction
645 the corresponding number are 3% of the total industrial non-transport energy consumption, of which
646 electricity accounted for 16% only.

647 The service sector of the economy is represented by two subsectors, referred to as *Trade* and *Other*
648 *services*, of which the latter comprises a wide range of services (see Table 1). Together, these two industries
649 account for around 60% of all energy consumption of the tertiary sector.²⁵ Trade accounts for 10% of
650 the total industrial non-transport energy consumption of which half originates from electricity. Although
651 Other services is a large subsector, which by overall economic measures has been growing in size, this
652 subsector contains the industries which are not particularly heavy when it comes to energy consumption.
653 Nevertheless, together they account for 6% of the total industrial non-transport energy consumption, out
654 of which 39% comes from electricity and 61% from other energy.

²³Source: Statistics Denmark.

²⁴Using 2005 TJ numbers from Statistics Denmark.

²⁵See Footnote 24.

655 For each of the eight subsectors, the time series variables of interest are the following: *Electricity*
656 *intensity*, or electricity consumption per unit of output, $\frac{E_t}{Y_t}$, defined as the ratio of electricity consumption
657 (E_t), in gigajoule (GJ), relative to Gross Output (Y_t) in thousand Danish kroner at 2010-prices, chained
658 values. The consumption of *other energy* (also in GJ) per unit of (Gross) output, or simply the *intensity*
659 *of other energy*, is denoted as, $\frac{O_t}{Y_t}$, and is defined accordingly. Prices of electricity, P_t^E , and other energy,
660 P_t^O , stated in Danish kroner per GJ and both deflated by the Gross Domestic Product deflator at factor
661 cost, P_t , in 2010-prices, chained values. Statistics Denmark is the source of the data on these variables.
662 Finally, as the exogenous weather-related variable, on which the partial model is conditioned, heating
663 degree days are used. The heating degree data were originally obtained from Elværksstatistikken. Two
664 observations (1966-67) were reconstructed based on an older time series by use of a simple regression.

665 B. Misspecification tests

666 *Agriculture*

667 Vector AR 1-2 test: F(32,75) = 0.83540 [0.7094]
668 Vector Normality test: Chi²(8) = 17.794 [0.0228]*
669 Vector ZHetero test: F(68,84) = 0.84273 [0.7668]

670 *Food manufacturing*

671 Vector AR 1-2 test: F(32,53) = 1.3249 [0.1792]
672 Vector Normality test: Chi²(8) = 9.8425 [0.2763]
673 Vector ZHetero test: F(100,42) = 1.5291 [0.0616]

674 *Chemical manufacturing*

675 Vector AR 1-2 test: F(32,38) = 0.98288 [0.5163]
676 Vector Normality test: Chi²(8) = 17.504 [0.0253]*

677 *Machine- and vehicle manufacturing*

678 Vector AR 1-2 test: F(32,75) = 0.94376 [0.5604]
679 Vector Normality test: Chi²(8) = 28.344 [0.0004]**
680 Vector ZHetero test: F(64,84) = 1.5347 [0.0329]*

681 *Other manufacturing*

682 Vector AR 1-2 test: F(32,38) = 1.5223 [0.1071]
683 Vector Normality test: Chi²(8) = 8.0739 [0.4263]

684 *Construction*

685 Vector AR 1-2 test: F(32,75) = 1.0493 [0.4204]
686 Vector Normality test: Chi²(8) = 33.812 [0.0000]**
687 Vector ZHetero test: F(64,84) = 1.1180 [0.3137]

688 *Trade*

689 Vector AR 1-2 test: F(32,86) = 1.5019 [0.0712]
690 Vector Normality test: Chi²(8) = 11.244 [0.1882]
691 Vector ZHetero test: F(60,95) = 1.3103 [0.1185]

692 *Other services*

693 Vector AR 1-2 test: F(32,67) = 1.2303 [0.2351]
694 Vector Normality test: Chi²(8) = 22.464 [0.0041]**
695 Vector ZHetero test: F(72,77) = 1.0360 [0.4385]

696 C. Estimates of trends and structural breaks

697 Even though the main interest in this analysis eventually lies on own- and cross-price effects, the
698 estimates of the coefficients of the deterministic components, i.e. trends and level shift dummy variables,
699 in Table 4 are now briefly commented on.

700 Starting with the trend a relatively unanimous picture emerges. The trend coefficient estimates are for
701 the most part negative, with the most pronounced exceptions in Other manufacturing and Construction.
702 Taking Agriculture as an example, the negative trend estimate of 0.01 in the cointegrating relation,
703 suggests that steady state electricity demand (per unit of output) shifts to the left in a (ey, pr^e) diagram
704 at an annual rate of 1%, whereas the demand curve for other energy shifts 2% per year.²⁶ As mentioned
705 such gradual decrease in energy intensities most likely reflect energy savings resulting from gradual
706 technological progress and the gains from economies of scale (fewer but larger and more efficient farms).

707 Although different dummies were needed for different subsectors, there are some common. First of all,
708 the turn of the 60s to the 70s marks a significant shift in energy demand relative to output. In particular,
709 for four subsectors, the years 1969-1970 were associated with a long-run upward shift in energy intensities,
710 ranging from 17% (Other services) to 42% (Agriculture) for electricity and around 20% for other energy.
711 There can be several reasons for this and it must be kept in mind that it is the ratio of energy to Gross
712 Output that shifts, implying that both the numerator and the denominator could fall, but if the latter
713 decreases the most, the ratio will increase. Here, the rise in the intensities for Agriculture and Food
714 manufacturing were due to a recession in output, whereas for Machine and vehicle manufacturing and
715 Other services there was a large increase in the consumption of other energy.

716 The years 1974/75 were the wake of the first energy crisis. It appears that the manufacturing indus-
717 tries, Machine- and vehicle, Chemical and Other, experienced large increases in electricity consumption,
718 whereas there were no effect on the intensity of other energy. The increases in electricity intensity reflect
719 an output reduction, as a result of the persistent economic downturn following the crisis. Oil consumption
720 was reduced as resulting from the higher oil prices and if only partly substituted by coal, a reduction
721 in the level of other energy would occur. The evidence is consistent with the latter reduction being of
722 roughly a similar magnitude as the reduction in Gross Output, leaving the intensity of other energy unal-
723 tered. The next energy crisis in 1978/79, on the other hand, clearly reduced the intensity of other energy
724 for the Food- and Chemical manufacturing and Other services, with 20%, 43% and 11%, respectively.
725 This decrease could first of all reflect increased energy-saving investments and improved insulation in the
726 longer term. Substitution to other energy carriers could also have taken place. In particular, for Food-
727 and Chemical manufacturing there seems to have been some substitution towards electricity implying an
728 increase in the electricity intensities of the same magnitude. However, for Agriculture the reverse seems
729 to hold.

730 Finally, to some extent the periods around the years 1986 and 2009 also seem to stand out, supposedly
731 as a result of highly contractionary fiscal policy and a large drop in oil prices, respectively.

732 D. Robustness Analysis

733 D.1. Assessing robustness towards sample changes

734 For all subsectors the estimations in Section 3 have been based on the full sample, i.e. all available
735 information and are as such preferred over estimations based on subsamples. However, as a useful
736 robustness check the purpose is now to estimate the models based on subsamples to check that the
737 obtained conclusions do not depend critically on the inclusion of a smaller part of the sample.

²⁶Detailed interpretations of cointegrated VAR models in terms of simple graphical diagrams (e.g. the demand and supply cross) are found in Møller (2008) and Møller and Sharp (2014).

738 For this purpose, forward recursive estimation of the CVAR models, with the same restrictions as
739 those imposed in Table 4, is now performed for each subsector. This recursive estimation is based on
740 the idea of starting with a *baseline sample* of minimal length (given the number of parameters), in this
741 case the first 20-25 years. The model is then estimated recursively, by increasing the sample beyond the
742 baseline sample, adding one observation at a time. The resulting sequence of estimates (along with error
743 bands) and test statistics are then plotted against the endpoints of the corresponding subsamples. The
744 plots can then be used to assess whether the recursive estimates change significantly suggesting a violation
745 of the model assumption of constant parameters. Moreover, they can be used to check whether the test
746 conclusions, with respect to sign and significance of cointegrating estimates, and overall acceptance of
747 the restrictions (p-value), change markedly in comparison with the full sample results.

748 Figures D.1 through D.8 below show the graphs of the forward recursive estimations for all eight
749 subsectors. In each figure there are two types of recursive graphs, relating to cointegrating coefficients
750 and the Likelihood Ratio (LR) test for the overall restriction, respectively. All panels except the last one
751 show the recursive estimates of the most important cointegrating coefficients. That is, for both electricity
752 and other energy, the own- and cross-price coefficients, and the coefficient with respect to heating degree
753 days. The recursive graphs of the estimates are accompanied by ± 2 standard deviations, which makes
754 it possible to assess the robustness of the full-sample test conclusions towards the shorter subsamples.
755 The last panel plots the recursively calculated LR test statistic corresponding to the overall test, with
756 acceptance at the 1% level when the graph is *below* the line.

757 Before assessing the graphs it should be noted that since the baseline sample is relatively short, some
758 variability in the beginning of the graphs of both the estimates and the LR statistic is always expected.
759 Henceforth, this variability is referred to as *short-sample uncertainty*. Note also that, in the recursions
760 the short-run parameter estimates are kept fixed at their full sample values. This approach often gives a
761 more clear picture when it comes to assessing the constancy (or lack of) of the long-run parameters. This
762 is because instability or structural changes in the short-run parameters, which in the present context is of
763 less importance, will introduce more variability in the recursive graphs for the long-run estimates, even
764 though long-run parameters are constant. In addition to this, instability in the short-run parameters also
765 introduces more noise and hence variability in recursive standard deviations (error bands) which may
766 affect the test conclusions.

767 Concerning the assumption of constant parameters it is noted that, with the exception of Chemical
768 manufacturing and Construction, there are in general no pronounced *significant* changes in the graphs
769 of the estimates. For Chemical manufacturing there are some supposedly significant changes around the
770 mid-90s, whereas for Construction, this seems to be the case for other energy towards the end of the
771 sample. However, in both cases magnitudes do not seem alarming. Hence, given the expected short-
772 sample uncertainty and the fact that in practice there is always some minor variability throughout the
773 graphs, parameter constancy seems to be a reasonable assumption.

774 For the LR test of the overall restrictions imposed in Table 4, in four out of the eight cases, the
775 restrictions can be jointly accepted for *all* subsamples. For the remaining half, rejection takes place only
776 in the beginning and can supposedly be ascribed to short-sample uncertainty, at least partly.

777 Focussing on the own and cross-price coefficients, the conclusions with respect to the significance of
778 the full-sample cointegrating estimates in Table 4 are very robust. In particular, with the exceptions of
779 the estimated own-price coefficient for electricity in Agriculture and the cross-price coefficient for other
780 energy in Trade, *all* significance conclusions obtained in Table 4 hold. In addition, even for these two
781 cases the graphs are relatively stable and the change from significance to insignificance is not large.

782 To sum up, given that some variability in the beginning of the recursive graphs is always anticipated
783 due to short-sample uncertainty, the overall impression from the forward recursive analyses is that,
784 parameter constancy seems reasonable, the overall restrictions seem to be accepted for the vast majority

785 of subsamples, and finally, that the conclusions, as obtained in Table 4, with respect to significance of
 786 individual price coefficients, are rather robust towards the shorter subsamples.

787 Since the baseline sample is fixed (the first 20-25 observations) in all recursions, the forward recursive
 788 analysis cannot say anything about the influence on the estimation from the observations in the beginning
 789 of the sample. As the first 10-15 years include supposedly a structural break around 1970 and the
 790 two energy crises, robustness towards the exclusion of the first part of the sample was also assessed to
 791 complement the forward recursive estimation. However, it should be underscored that, given the limited
 792 number of observations (45), the full sample estimation, which conditions on these breaks by the use
 793 of level shifts dummies, and in particular for which it is possible to maintain statistical adequacy, is
 794 preferred over cutting off the first part of the sample. The resulting recursive plots for the overall p-value
 795 are given in Figure D.9. Note that, as opposed to before, now it is the p-value corresponding to the
 796 LR test statistic and not the statistic itself that is reported. Hence, acceptance at the 1% level occurs
 797 when the graph is *above* the blue line. Considering that the full-sample analysis takes the energy crises
 798 into account by use of the level shift dummy variables, the recursive graphs seem reasonable for five
 799 out of eight subsectors, namely Agriculture, Machine- and vehicle manufacturing, Constructions, Trade
 800 and Other services. For the latter it was however not possible for the likelihood to converge in the first
 801 part of the graph. For the three manufacturing industries (Food-, Chemical and Other), the full-sample
 802 conclusions are not robust. In particular, it seems that the first few observations could be the main driver
 803 of the obtained conclusions, although it should be reiterated that the full sample estimation conditions
 804 on the structural breaks by use of the level shift dummies.

Figure D.1: Results of forward-recursive estimations for Agriculture. The first five panels of the figure depict the respective estimated cointegrating coefficients, together with 95% confidence limits, against the end point of the recursive samples. The last panel shows the recursively calculated test statistic corresponding to the overall restriction on the α_z and β matrices, where values above the blue line indicate a rejection of the restriction at the 1% significance level.

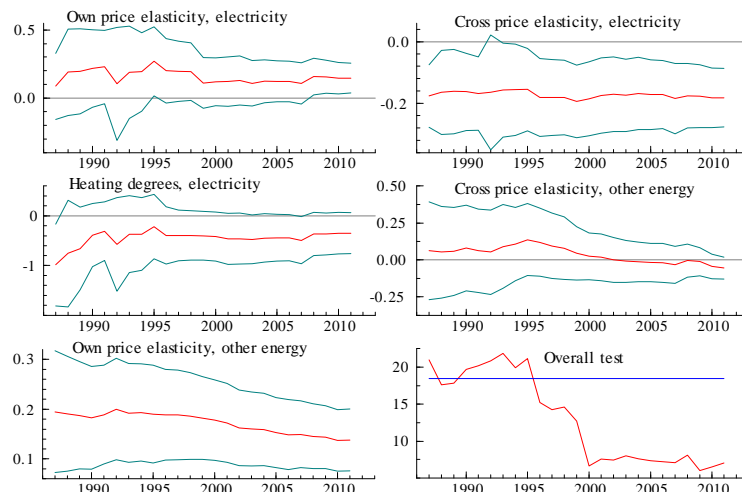


Figure D.2: Results of forward-recursive estimations for Food manufacturing. The figure is otherwise similar to Figure D.1.

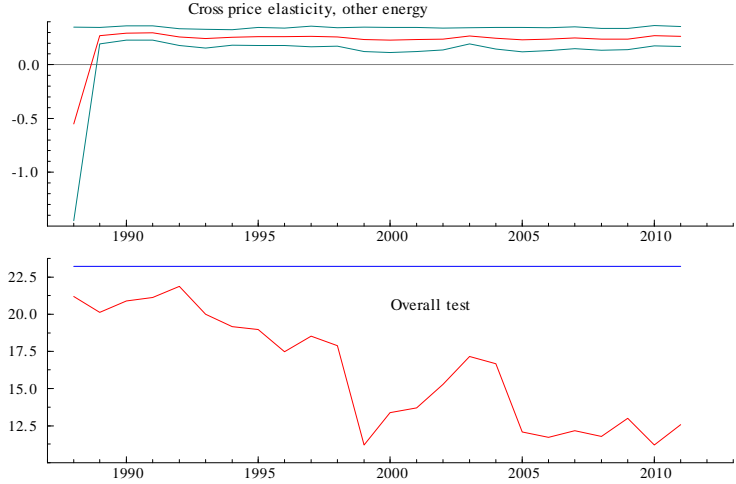


Figure D.3: Results of forward-recursive estimations for Chemical manufacturing. The figure is otherwise similar to Figure D.1.

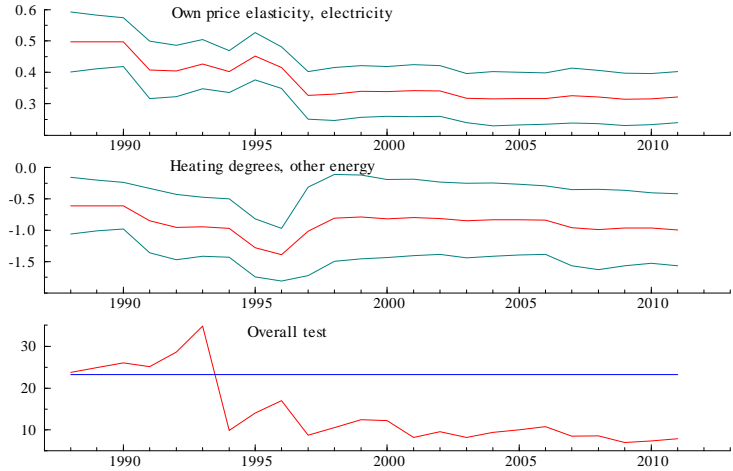


Figure D.4: Results of forward-recursive estimations for Machine- and vehicle manufacturing. The figure is otherwise similar to Figure D.1.

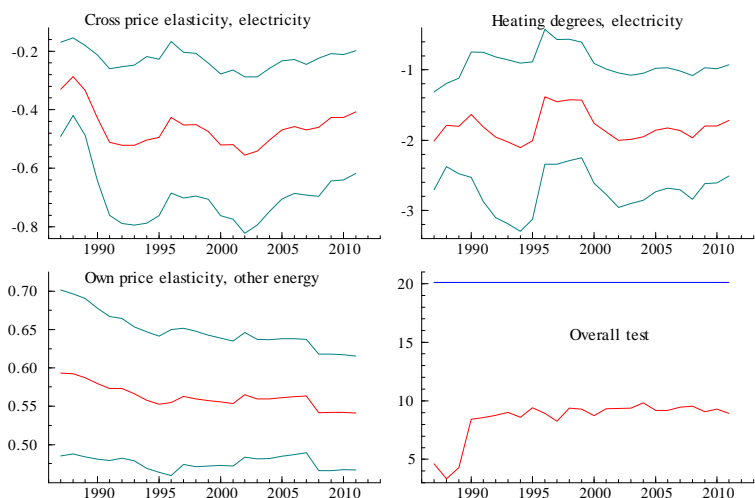


Figure D.5: Results of forward-recursive estimations for Other manufacturing. The figure is otherwise similar to Figure D.1.

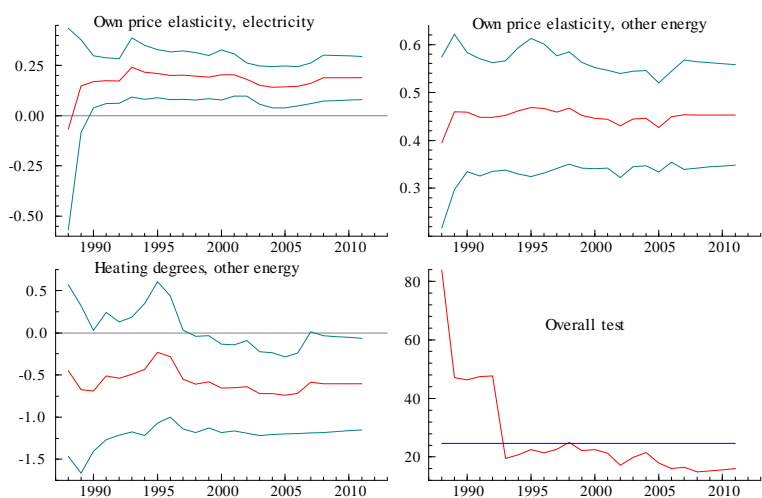


Figure D.6: Results of forward-recursive estimations for Construction. The figure is otherwise similar to Figure D.1.

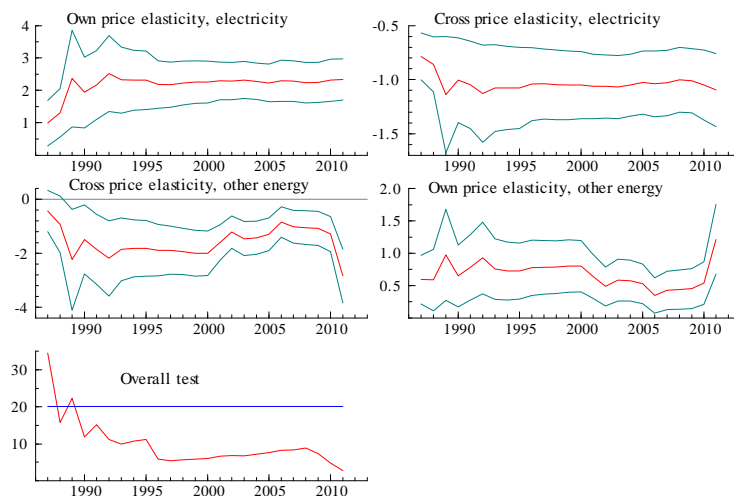


Figure D.7: Results of forward-recursive estimations for Trade. The figure is otherwise similar to Figure D.1.

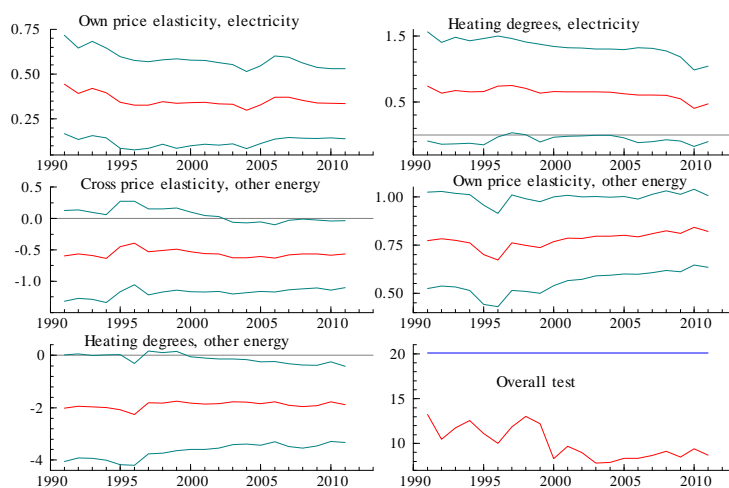


Figure D.8: Results of forward-recursive estimations for Other service. The figure is otherwise similar to Figure D.1.

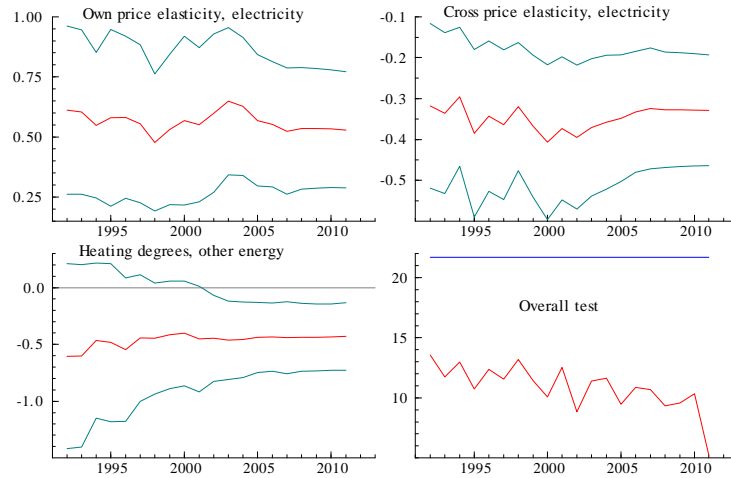
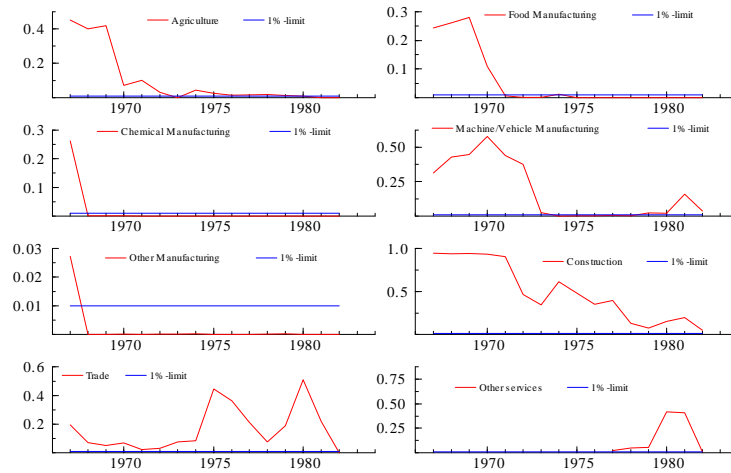


Figure D.9: P-value for the overall test for each of the eight industries. Comparison to blue 1-percentage line.



805 *D.2. Assessing robustness with respect to the cointegration rank*

806 Table 3 in Section 3 suggests that although two cointegrating relations is a reasonable choice, consistent
 807 with the working hypothesis, there is some indication of an additional cointegrating relation, although
 808 this is more relevant for some of the subsectors than others. In this appendix it is therefore attempted to
 809 identify an additional relation jointly with the existing restrictions on the two first cointegrating relations.
 810 The purpose is to assess the robustness of the estimates of the two existing cointegration relations towards
 811 adding a third relation and not the latter as such.

812 Since the number of restrictions on each cointegrating vector that are required for (just) identification
 813 equals $r - 1$, there must now be at least two restrictions on each vector, which must fulfill the rank
 814 conditions for generic identification (see Chapter 5 in Johansen, 1996).²⁷ As before, only the $r - 1$

²⁷This implies that, in case there is only one restriction on one of the existing cointegrating vectors and/or the rank condition failed, it was necessary to impose an additional restriction on the existing relation. However, this was only necessary for the electricity relation for Agriculture in Table 4, which has only one restriction.

815 restrictions on β needed for just identification were imposed on the new relation initially and then
816 insignificant variables were removed from the cointegrating relations.

817 A third relation is to some extent expected. In particular, for each subsector bivariate plots of the
818 relative input prices suggested that these two variables cointegrate (conditional on the breaks). Since
819 some of the components, primarily coal but also oil, in particular, are inputs into electricity production,
820 it is expected that the price level of these inputs will influence electricity prices in the longer term. Hence,
821 the third relation is common for all eight subsectors. The price of these components (of other energy)
822 should reasonably be exogenous to the Danish economy. Therefore, when augmenting with another
823 cointegrating relation, it was an obvious approach to retain the assumption that the price of other energy
824 was exogenous, i.e. a zero row in the α_z matrix. However, as this is a testable restriction this was tested
825 and accepted in all cases except for Agriculture. On the other hand one would expect significant error
826 correcting adjustment of the relative electricity price to the new relation. Therefore, for α_z , only the first
827 two adjustment coefficients in the row corresponding to the relative electricity price, were restricted to
828 zero as before (when $r = 2$). Finally, both intensities were initially allowed to adjust to the new relation
829 and if insignificantly, the adjustment coefficients were set to zero.

830 Table D.1 below summarizes the estimates of the price coefficients from the first two cointegrating
831 relations (the existing ones from Table 4), when the third relation is added. As the latter does not
832 contain any parameters of interest for the given purpose, the estimates from this bivariate cointegration
833 relationship between pr_t^e and pr_t^o are not reported. Likewise, the estimates from the adjustment matrix
834 are also not reported, as these in general were unaltered and reflected significant error correction. The
835 last column shows the p-value corresponding to the overall test of the new restricted cointegration model,
836 i.e. with the two existing cointegrating vectors and the new one, against the unrestricted partial CVAR
837 with $r = 3$ as the only restriction. In comparison to Table 4 in Section 3, the table shows that in five out
838 of the eight cases the estimated own and cross-price coefficients in the first two cointegrating relations
839 are approximately unchanged with respect to sign, significance and magnitude.

Table D.1: Robustness of the previous cointegrating estimates towards the presence of a third cointegrating vector (between relative input prices).

	$\hat{\beta}_{11} = -\hat{\gamma}_e$	$\hat{\beta}_{21} = -\hat{\delta}_e$	$\hat{\beta}_{12} = -\hat{\gamma}_o$	$\hat{\beta}_{22} = -\hat{\delta}_o$	p-value
Agriculture	0.00	0.00	-0.06 [-1.65]	0.14 [4.57]	0.03
Food Manufct.	0.00	0.00	0.26 [6.41]	0.00	0.33
Chemical Manufct.	0.37 [9.31]	0.00	0.00	0.00	0.36
Mach./Vehcl Manufct.	0.00	-1.73 [-3.22]	0.00	0.50 [10.22]	0.17
Other Manufct.	0.17 [3.09]	0.00	0.00	0.46 [8.47]	0.31
Construction	2.21 [13.43]	-1.02 [-6.14]	0.00	0.00	0.87
Trade	0.35 [3.49]	0.00	-0.57 [-2.10]	0.81 [8.66]	0.16
Other services	0.63 [6.42]	-0.25 [-3.41]	0.00	0.00	0.14

840 The most important exception, relating to the electricity relation, is that for Agriculture, for which
841 both own and cross-price coefficients become insignificant (and are therefore set to zero). Also, for
842 Machine- and vehicle manufacturing there is some change in magnitudes, as the estimated cross-price
843 coefficient changes from 0.41 to 1.73, albeit sign and significance are robust. For Construction the lack
844 of robustness concerns the relation for other energy. Hence, the results seem generally relatively robust.