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RESEARCH ARTICLE

Modelling energy demand under discontinuities from an energy economic point-of-view

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Abstract

The major motivation for this paper is the need for the identification of policies required in principle for heading toward sustainable energy systems in any region world-wide. In particular, this work emphasizes modelling the demand side of energy systems and identifies interactions with energy policy measures. The core objective of this paper is to carry out a review of econometric energy demand modelling approaches over time. In this context, special attention is paid to lessons learned from modelling historical discontinuities and structural breaks in order to better understand issues of disruption. Our analysis builds on econometric analyses using standard estimation approach for modelling energy demand by means of a production function, depending on price and income. We start with ordinary least-squares (OLS) and extend the approach to autoregressive distributed lag (ARDL)model. We identify long-term as well as short-term elasticities. Finally, we analyze whether elasticities are constant over time and whether structural breaks exist.
The major conclusions of our analyses are that approaches assuming constant elasticities over time are no longer useful. The magnitude of the impact made by economic parameters such as prices and income elasticities over time has been decreasing due to our analyses. This has an impact on energy policies, namely taxes and standard. The effect of taxes in an energy system is that they increase prices and reduce energy demand depending on the price elasticities. Yet, the smaller price elasticities are, the lower the impact of new taxes is. This leads to the conclusion that there is still a higher need for increased standards and technological innovations. The major useful policy suggestion based on this research is that technical measures for increasing energy efficiency are very important as a measure accompanying energy taxes.

Keywords

Energy demand, econometrics, dynamic elasticities, discontinuities

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Introduction

Currently, one of the major targets of governments and policy makers world-wide is the reduction of the greenhouse gas (GHG) emissions worldwide to meet the Paris climate targets to curtail the further temperature increase to 1.5° up to 2050[1]. The use of energy globally contributes by about 75% to the total GHG emissions. Hence, one of highest priorities, in order to reduce GHG emissions, is to implement appropriate policy measures in the energy sector as immediately as possible. To reduce energy consumption, the most effective and suitable policies and measures to assist in meeting the limiting temperature increases targets up to 2050 and heading toward sustainable energy systems have to be identified. An additional motivation for the research conducted in this paper is to identify the impact of so-called discontinuities.

Reliable modelling of an energy system, including development of different scenarios, is of core relevance to identify possible pathways for decarbonisation of any energy system in any geographical area world-wide. Regarding modelling of energy systems, the logic is simply as follows: first, future energy demand has to be modelled and then, secondly, the supply side because if there is no demand, there is also no need for modelling a supply side of the system providing energy for the consumers in the different sectors. On the supply-side it will be modelled how the estimated energy demand can be provided in an optimal way, e.g. with lowest possible costs. Energy demand needs to be modelled depending on the impacts of policies, in static as well as in dynamic models. The supply side of the energy systems is to be modelled usually by means of optimization and simulation approaches.

An important category that has recently gained importance according to this HORIZON project and that can be considered qualitative as well as quantitative is open-source modelling. Especially, in the field of supply side analysis of energy systems open-source modelling has become increasingly established, including all aggregation levels of the supply side and various optimisations as well as simulation model approaches see *e.g.,* Despres *et al.*[2] and Prataviera *et al.*[3]. The major advantage of open-source modelling is the transparency of approaches and data used. It can be described based on the FAIR principles (Findable, Accessible, Interoperable, Reusable).

The FAIR Data Principles (**F**indable, **A**ccessible, **I**nteroperable, and **R**eusable), published in Scientific Data in 2016, are a set of guiding principles proposed by a consortium of scientists and organizations to support the reusability of digital assets. These principles have since been adopted by research institutions worldwide. The guidelines are timely as we see the unprecedented volume, complexity, and speed in creation of data.

The core objective of this paper is to carry out a review of econometric energy demand modelling approaches in a historical context over the past about 50 years to better understand its status quo. Of specific interest is to analyse what has changed over time regarding statistical approaches used. In addition, we have investigated how the results for price and income elasticities have changed, especially, whether static approaches are still useful or dynamic ones are preferable. Finally, the consequences for energy policy are discussed.

In this context, special attention is paid to lessons learned from modelling historical discontinuities and structural breaks in order to better understand the recent developments related to COVID19. That is to say, not the effects of the pandemic itself are investigated but how to consider discontinuities, disruptions and structural breaks due to "unexpected influences from outside" in principle. We consider whether these unexpected short-term disruptions really require new or additional modelling elements, or whether they can simply be represented by well-known influence parameters, such as income, consumer spending or economic output (*i.e.,* Gross domestic product (GDP)) or short-term behavioural changes associated with longer-term reversion to habitual patterns of energy consumption. The final objective is to identify the key consequences for policymakers by defining the most effective types of policies for curbing carbon emissions in the energy sector and straightforwardly mitigating global warming.

In principle, this paper combines a mixture between a historical review paper with some exemplary analyses presenting a technical paper. The main novelty of this paper is, that – to the best of our knowledge – it is the first to analyse and document the following three issues simultaneously: (i) the historical development of econometric energy demand modelling approaches providing exemplary results for the example of oil demand in selected regions in a systematic way, (ii) exemplifying how the dynamics of elasticities developed over time and (iii) emphasis and analyses of the effect of discontinuities and structural breaks.

The paper is organized as follows: after presenting and acknowledging the historical literature and, subsequently, exploring the different approaches of energy demand modelling in the following sections. Our methodological approach is explained after the brief history. It starts with the basics and definitions of "energy modelling" to understand the connections and relations between modelling of energy systems, energy demand, energy supply and energy policies. We then examine the role of (irreversible) efficiency improvements and the historical maximum prices are described and analysed for the specific example. The subsequent section focusses on the dynamics of elasticities and depicts the specific developments in the chosen example of oil demand in three world regions as described in section "methods". The impacts of structural breaks and disruptions are investigated, and the final section presents our analysis of which major energy policy instruments exist to interfere. Conclusions complete the work.

A brief review of the history of energy demand modelling

In the last five decades different approaches for econometric modelling of energy demand were developed but in principle all were based on modelling energy demand depending on

income and price elasticities. Moreover, scenarios for future energy demand are derived considering assumptions regarding the future development of the most important economic parameters such as energy prices or GDP, see *e.g.,* Pindyck/Rubinfeld[4], and Ryan/Plourde[5].

Since the 1970s different stages of modelling energy demand are observed and can be divided into two categories:

1. Qualitative discussion:
   new parameters entering the modelling scene step by step, *e.g.,* price, historical maximum price, error-correction-term; some parameters were disappearing, *e.g.,* the symmetric koyck lag, yet from our point-of-view most important is the question whether approaches assuming constant elasticities over time are or time-dependent elasticities are used.

2. Quantitative development (not necessarily improvement) of mathematic statistical tools, *e.g.* Cointegration, Autoregressive Distributed Lag (ARDL)). This issue is linked to significant improvements in computer capacities over time.

The story starts in the early 1970s. After the member countries of the Organization for Economic Co-operation and Development (OECD) experienced considerable increases in energy demand during the decade 1960–1970, the consequences led to the first oil crises in 1973/74. After 1973, energy consumption has been growing much more moderately, likely caused by a slowdown in economic growth rates and an increase in real energy prices. To mark this moment, in 1972, Meadows[6] published his seminal contribution on "The Limits to Growth", announcing resource shortages and increasing prices.

While before 1973 energy demand was simply modelled as a linear function of income, a more differentiated development took place afterwards. It started with including prices in the former solely income dependent models. The turbulences in the world oil price in the 1970s led to the emergence of a new culture in modelling energy demand. Pindyck/Rubinfeld[4] provided the first comprehensive work on the structure and analysis of world energy demand. Pindyck[7] conducted one of the first and most comprehensive analyses on price and income elasticities by fuel type. Kouris[8] published the paper "Elasticities - Science or Fiction?" in 1981. He argued that there are some severe problems presented by using constant elasticities only. Madlener[9] was one of the first to provide a systematic approach, analysing the strengths and weaknesses of various demand approaches - considering the bottom-up as well as the aggregated dimensions. Already in in 1996, he pointed towards the problem of missing ex ante approaches for energy demand modelling.

After the drop in oil prices in the mid-1980s discussions focused on irreversible technological efficiency improvements leading to asymmetric demand reactions, and studies focusing on the impact of historical maximum prices were conducted by Gately[10,11] and Dargayand[12]. Walker and Wirl[13] analysed the transport sector and concluded that irreversible efficiency improvements such as cars with lower specific gas consumption were the major reason for the moderate rebound in oil demand after 1985. For a more recent work on the oil issue see Gallo[14]. Haas and Schipper[15] found significant evidence that technical efficiency is an important parameter for describing the evolution of residential energy demand.

Regarding the method over a long period of time, Ordinary Least Square (OLS) estimates were the dominating approach at least until about 1993. Engsted and Bentzen[16] were among the first suggesting unit root tests for testing the stationarity of the depending variables, *e.g.,* prices, in time series analyses and applying cointegration approaches for energy demand modelling. In the following years, a series of new approaches started considering step-by step asymmetries, lags, dynamics and finally structural breaks and disruptions. Ryan and Plourde[5] provided one of the last comprehensive surveys on energy demand analyses in general, Ajanovic *et al.*[17] for transport specifically. An extension of the basic approaches consisted of adding some form of dynamic adjustment mechanisms. Yet, it has proven difficult to extend the theoretically more rigorous approaches to include dynamic adjustment processes. For a further discussion of this issue with respect to transport see 18. Studies for different fuels in the residential sector were conducted in 19 and 20. For an application of energy demand modelling with respect to natural gas demand see 21 for modelling price relationships see 22. Some applications of energy demand modelling with respect to the German "Energiewende" can be found in 23 and 24.

Hanna and Gross[25] provide a very comprehensive literature review on structural breaks and disruption in modelling energy demand. They explore, in their review, how different energy system models and scenarios explicitly represent and assess potential disruptions and discontinuities following definitions of disruptions and discontinuity set out by Burt[26] which should help to distinguish between the two concepts and are consistent with Ayres' expanded criteria for discontinuity[27]; for a meta-analysis of scenarios see Densing *et al.*[28].

Finally, regarding the the COVID19 pandemic, the following references deal with the short-term observations (especially in terms of energy/electricity demand and CO2 evolution) There are review papers such as Krarti[29] or Navon[30], country-specific studies such as Malliet *et al.*[31] and others, Dawud and Kemfert[32], Jiang *et al.*[33] and Cheshmehzangi[34]). However, they all can hardly contribute to a better understanding of longer-term impacts of energy demand patterns after an unexpected event. Corresponding empirical studies on quantitative effects can only be conducted in the future.

Methods

Despite being very often used, the term "energy modelling" is very imprecise, notwithstanding Albert Einstein's formula $E=mc^2$. A more precise formulation for "energy modelling" is at least "energy system modelling" or, more strongly, from an energy economics perspective, "energy market modelling" or "energy policies modelling". If the modelling of energy systems is specified more precisely, the models are split in energy supply and energy demand models (see Figure 1). At first, demand needs to be modelled then supply. The reason is

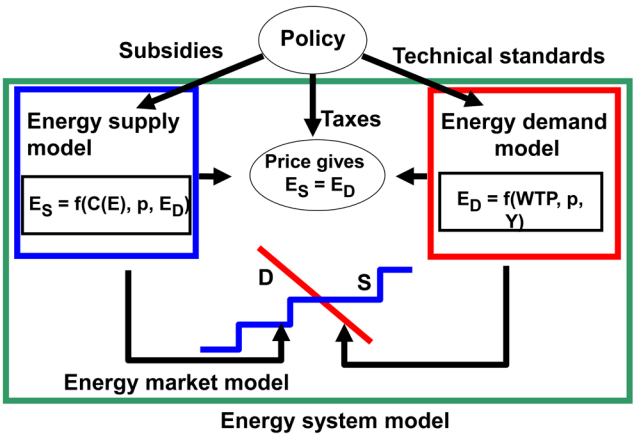


Figure 1. Basics of energy system modelling and the impact of price and income as well as different policy instruments such as subsidies, taxes and technical standards.

simply, that if there is no determination of demand, there is no need to model the supply side. However, energy demand cannot be treated in isolation. The most important interactions with the supply side and energy policy within the energy system must be considered too.

Figure 1 depicts the components of an energy system model. The model for energy demand 'E_D' depends on consumers' willingness to pay 'WTP' as well as on the price of energy 'p' and the income 'Y'. The model for energy supply 'E_S' depends on the marginal production costs of energy 'C(E)', from the market price 'p' and on overall energy demand. Demand and supply model provide in their intersection of demand and supply the market price 'p' and the corresponding energy market equilibrium. In addition, different types of policies (*e.g.,* subsides, taxes, technical standards) may interfere within the overall energy system model on the demand or supply side or as taxes on the price.

The method used in the following is based on econometric analyses. Econometric approaches are widely used for analyzing energy demand. We have conducted a thorough review of the peer-reviewed literature which is documented in the course of this chapter. The major reason behind choosing this approach is that it provides an insight on the magnitude of impact of different parameters such as income and energy prices as well as the analysis of possible structural breaks.

We reviewed how the econometric modelling approaches developed over time, and the most important corresponding equations are illustrated by applying it to an own example. The example is on modelling historical oil demand for the EU, the USA and the OECD. This example is chosen mainly due to the availability of empirical data, but also to the need to phase-out oil in order to decarbonise energy systems as quickly as possible. However, the methods and modelling approaches used in this paper can be applied equally to any energy carrier or sector *e.g.,* electricity demand or transport/industrial sectors that are of particular interest for achieving the European 2030 (EU Green Deal) or 2050 climate neutrality targets. The formal analyses documented in this paper are mainly conducted for pedagogic reasons to exemplify how such analyses could be conducted. It is not our goal to conduct in-depth econometric analyses *per se.* but to provide some examples to illustrate the theory.

The inclusion and exclusion criteria for including the models/methods are that we have selected econometric approaches applied so far in the peer-reviewed literature and we have excluded all other approaches. The objective was to conduct assessments which of these econometric methods provide useful results and which do not.

Consequently, the documentation starts with the early purely symmetric approaches which emerged in the 1970s, looking next at asymmetries and irreversible efficiency improvements, as well as lags and disruptions/structural breaks. We also consider the development of widely used mathematical approaches over time such as cointegration. We end with two well-known and understood analytical approaches to identify disruptions and structural breaks in energy demand modelling in the past; the so-called "Dummy variables" and the "Chow-Test". In the following exemplary analysis, the programme MICROFIT 5.5 created at Oxford university - which can be downloaded for free from the internet is used. With MICROFIT 5.5 we applied regression analyses choosing UNIVARIATE/single regression menu from the main page of the programme and choosing ordinary least-squares (OLS) approach. It was applied using the Equation (1) to Equation (6) documented in the following and leading to the results documented in Table 1.

The basic standard estimation approach for modeling energy demand by means of a production function, depending on price and income, is presented in equation one. This approach is also called a partial demand model (Pindyck/Rubinfeld[4]) because overall interactions of an economy are not considered. The equations used in the following are taken from Pindyck/Rubinfeld[4], Walker/Wirl[13], Ryan/Plourde[5] and Ajanovic/Haas[18]. In the basic Equation (1), the dependent variable is energy demand Et, the explanatory variables are the energy price Pt with the price elasticity a and income Yt with the income elasticity β:

$$E_t = CP_t^{\alpha} Y_t^{\beta} \quad (1)$$

with:

C……Intercept

E_t…….. Energy demand in year t (non-climate-corrected)

P_t…..……. Real energy price (calculated by means of weighted fuel prices)

α ……....Long-term price elasticity

Y_t…..……. Real income, *e.g.* Gross Domestic Product (GDP)

β……Long-term income elasticity

Table 1. Estimates of static elasticities of long-term oil consumption over the period 1960 – 2020 using the ordinary least-squares (OLS) approach.

	EU-15		OECD		USA	
	w/o lag	w/ lag	w/o lag	w/ lag	w/o lag	w/ lag
α **(LT price elasticity)**	-0.12	-0.11	0.00	-1.00	0.00	-1.00
β **(LT income elast)**	0.38	0.22	0.40	1.25	0.30	0.50
A **(ST price elasticity)**	--	-0.01	--	-0.08	--	-0.04
B **(ST income elast)**	--	0.02	--	0.10	--	0.02
λ (lag)	--	0.91	--	0.92	--	0.96
R2_corr	0.49	0.99	0.64	0.99	0.65	0.97

In logarithmic form for making OLS estimates or other regression analyses possible is a sum such as:

$$\ln E_t = C + \alpha \ln P_t + \beta \ln Y_t + \varepsilon_t \quad (2)$$

where:

ε_t ……residual (error term)

The next question is whether lags in adaptation to changes in price and income exist. The reason is simply that consumers may respond in the short-term by means of changes in behaviour but in the long-term by means of investments *e.g.* in efficiency measures, such as building insulation or new and cleaner heating systems. This principle is depicted in Figure 2. It can be seen that there is a short-term response to price increases due to changes in behaviour *e.g.* in transport driving less and with some delay there is a more pronounced long-term effect, considering a possible change to a more efficient technology, e.g. in transport an energy-saving electric vehicle. If the appropriate decision and response period is sufficiently long, lagged explanatory variables should be included explicitly in the model. This is done in the following Equation (3) by including λ.

The basic equation in (1) is extended to:

$$E_t = C P_t^{\ A}\ Y_t^{\ B}\ E_{t\text{-}1}^{\ \lambda} \quad (3)$$

with:

λ ..... „Lag“

And in logarithmic form:

$$Ln\, E_t = C + A\, ln\, p_t + B\, ln\, Y_t + \lambda\, ln\, E_{t\text{-}1} + \varepsilon_t \quad (4)$$

where:

A= Short-term price elasticities, B= Short-term income elasticities

The lag λ is a relative delay but can be translated *e.g.* into years. If λ is 0.5, for example, it means that the lag in years is

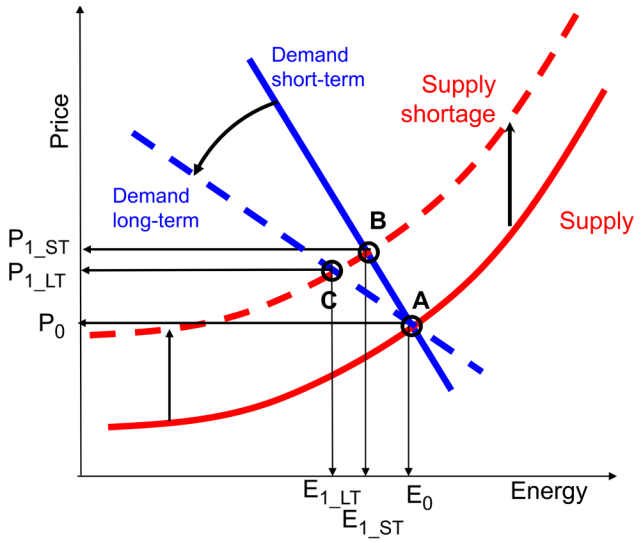


Figure 2. Short-term and long-term adaptation to changes in market prices for energy.

1/(1-0.5) = 2 years. Furthermore, it is also important to differ between long-term and short-term elasticities. While the short-term elasticities capture the immediate behavioural responses, the long-term elasticities capture the full changes over time including investments in efficiency or changes in modes in transport. This is the reason why short-term and long-term elasticities have been implemented. in the literature see e.g.Walker/Wirl (1993).The long-term elasticities are calculated by means of dividing short-term ones by (1-λ):

$$\alpha = A / (1\text{-}\lambda) \quad (5)$$

$$\beta = B / (1\text{-}\lambda) \quad (6)$$

As already mentioned in the introduction, the chosen empirical example elaborates in the analysis of the historical oil demand. Table 1 depicts the result of exemplary estimates with and without a lag for EU-15, OECD and the USA over the period 1960–2020. The rationale why for the estimates in this

paper data from 1960 to 2020 were used is that before 1960 no consistent data sets are available.

The methods used to collect the information were based on our knowledge of which organisations, institutions and companies that provide data in this context. The major sources identified for the data needed were:

BP[35],OPEC[36],

OECD[37]

World Bank[38]

Note, that no automation tools were used in this process. The reason why for Europe only EU-15 countries are considered is simply that these were the only European countries where the time series for GDP were available since 1960. In the first two lines of Table 1, the estimates of the long-term elasticities are documented. The values in the columns with lags are calculated using the Equation (5) and Equation (6). It can be seen that for OECD and USA the differences in the long-term price elasticities with lag are quite high (between (0.11) and 1) which is mainly caused by the large magnitude of the lag (> 0.9 for every country). The long-term price elasticities without lag are of low magnitude for all countries implying that, regarding the long-term income elasticities with and without lags, they are rather in the same range (in a range between 0.3 and 0.5, except for OECD, it is 1.25). Most interesting is that the lags are tremendously high and so are the R^2 (Coefficient of Determination) in the estimates with lags.

A major final address of this paper will eventually be to identify whether the approaches assuming constant elasticities over time still provide any useful results. From the results of Table 1 the situation is still ambiguous but as demonstrated in the latter sections of our paper, a dynamic effect over time is observed which strongly questions this static approach.

Note, that the specific elements of the data sources cited are based on the Equation (4) to Equation (6). The specific parameters used for the estimates presented in Table 1 are

- Oil consumption E (Source: BP[35])
- The oil price p (Source: BP[35])
- GDP Y (Source: OECD[37]).

A specific category of approach is so-called cointegration. In some papers in the 1990s (*e.g.,* Bentzen and Engsted[16]) it was argued, that so-called cointegration techniques could be an important tool for current and future analyses of energy demand and, might be a straightforward method for deriving energy policies. Cointegration means that a long-term equilibrium between the variables exists, see Malliet *et al.* (2021)[31]. For cointegration analyses different approaches exist, yet the ARDL (Autoregressive Distributed Lag) approach turned out to be most favourable, according to Pesaran&Pesaran (2015)[39] especially because cointegration analyses can be conducted regardless of whether the variables are stationary or non-stationary. In this process we firstly analyze whether the variables in Equation (3) are cointegrated and if they are, an Error-Correction-Model (ECM) is applied to investigate long-term as well as short-term elasticities and the speed of adjustment. The major advantages of ECM are that they allow us to clearly distinguish between short-term and long-term elasticities, because both total magnitude of variables and first differences are included in the model, see Lee[40]. The whole procedure consists of three equations. The first equation for the basic long-term relationship is already known: Equation (2). The second one is the following Equation (7) for the first differences:

$$\Delta Ln\, E_t = C + A\,\Delta ln\, p_t + B\,\Delta ln\, Y_t + \Delta ECM\,(K + \alpha\, ln\, p_{t-1} + \beta\, ln\, Y_{t-1} + ln\, E_{t-1}) \quad (7)$$

And the third equation for the error-correction-model (ECM-) term is:

$$ECM = Ln\, E_t + \alpha\, ln\, P_t + \beta\, ln\, Y_t + \varepsilon_t \quad (8)$$

For the following analysis, the programme MICROFIT 5.5 created at Oxford university - which can be downloaded for free from the internet, is used. The results for the exemplary estimates of the short- and long-term estimates for our example of long-term over-all oil consumption 1960–2020 are reported in Table 2 and Table 3 using the ARDL approach based on AIC (Akaike Information criteria). For details see Pesaran&Pesaran (2009)[41].

In Table 2, the results for the long-term elasticities α and β are documented along with either a trend or a constant. Note that

Table 2. Estimates of elasticities of long-term over-all oil consumption 1960–2020 using the ARDL approach based on AIC (Akaike Information criteria).

	EU-15		OECD		USA	
α (LT price elasticity)	-0.82	-0.94	-0.56	-0.64	-1.10	**-0.98**
β (LT income elast)	0.55	0*)	0.28	0	0.65	**0.48**
C (intercept)	--	5.39	--	4.87	--	**0.82**
T (time trend)	**-0.013**	--	**-0.003**	--	**-0.015**	**--**

*) N.S. = not significant at 10%

Table 3. Estimates of elasticities of ECM for over-all oil consumption 1960–2020 using the ARDL approach based on AIC.

	EU-15		OECD		USA	
ARDL order	(1,0,0)	(1,1,1)	(1,1,0)	(1,0,1)	(1,0,0)	(1,0,1)
A (ST price elasticity)	-0.11	-0.08	-0.04*)	-0.02*)	-0.07	-0.06
B (ST income elast)	0.07	0.10	0.09*)	0.05*)	0.30	0.28
ECM(-1)	-0.13	-0.09	-0.26	-0.23	-0.06	-0.11
T (time trend)	-0.002	--	-0.001*)	--	-0.009	--
R^2 korr	0.78	0.82	0.66	0.70	0.69	0.58

*) N.S. = not significant at 10%

if t and C are used simultaneously, we did not obtain significant estimates neither for t nor for C. The results for the estimates of the ECM and the short-term elasticities A and B are reported in Table 3.

The major results of the estimates of long-term elasticities of oil consumption for the selected regions from 1960 to 2020 using the ARDL approach as documented in Table 2 are:

- The long-term prices are cointegrated with energy consumption for all three regions in both cases, with a constant or a time trend with high values between (0.56) and 1.1.
- Long term income is cointegrated with energy consumption for all three regions only when using the time trend; for the constant it is only cointegrated for the case of the USA.

The major results of the estimates of corresponding short-term elasticities are (see Table 3):

- The short-term impact of prices is small, similar to Table 1, yet significant for all countries except the OECD. The price elasticities are significant for EU-15 and the USA in both cases, with trend or constant.
- income elasticities are significant for EU-15 and the USA in both cases, with trend or constant.

As already mentioned after the simple OLS estimates, a major issue of this paper is whether static approaches do still provide any useful results. Again, from the results of Table 2 and Table 3 it is still ambiguous but as shown in Kouris[8] and Haas *et al.*[42] as well as in Figure 7 of this paper ovr time a trend towards smaller absolute magnitudes of elasticities maybe observed

Note, that the specific elements of the data sources cited are based on the Equation (7) and Equation (8). The specific parameters used for the estimates presented in Table 2 and Table 3 are

- Oil consumption E (Source: BP[35])
- The oil price p (Source: BP[35])
- GDP Y (Source: OECD[37]).

There are some considerable caveats with respect to cointegration. These tests rely on the assumption that elasticities are constant over long time periods (*e.g.,* 50 to 100 years) and, as discussed below, the assumption of constant elasticities over time is among the major points of criticism according Kouris (1981)[8]. It has not yet been proven whether cointegration approaches are also useful for time periods with mixed signs in price changes, especially for periods including years after the drop in oil prices the results are at least ambiguous, see *e.g.,* Sahbi and Sakiru (2017)[43].

The role of (irreversible) efficiency improvements and the historical maximum price

After the drop in oil prices in 1985, oil demand in OECD countries did not rebound as it should have according to the economic textbooks. This insight led to the development of new concepts such as asymmetry with respect to rising and falling prices and the irreversibility of efficiency improvements see e.g. Kirchgässner[44]. For example, if fuel price increases from A to B in Figure 3a, consumers may drive less and buy smaller and more efficient vehicles in order to reduce consumption. If prices fall back down to A again, consumers are not likely to scrap their more efficient vehicles and may increase their consumption by a lesser amount than the original decrease as shown in Figure 3b, see e.g. Andersen. Examples of the interactions between prices, efficiencies, behaviour and energy demand in transport are shown in Ajanovic and Haas[18] and Haas *et al.*[45].

In the literature there are different asymmetric model specifications, taking into account differences for rising and falling prices as well as the historical maximum price, see *e.g.* 46. A dummy variable D_{prise_t} is used which is 1 if the fuel price is rising and 0 vice versa. The following basic equation is used and a simple OLS estimate is conducted:

$$Ln\,E_t = C + (\alpha_0 + \alpha_{rise} \,.\, D_{prise,t})\; ln\, p_t + \beta\, lnY_t + \varepsilon_t \qquad (9)$$

with

α_0 …… general long-term price elasticity

α_{rise} … price elasticity for rising prices

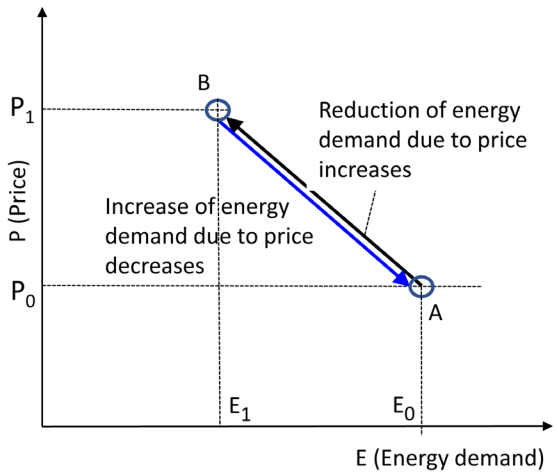


Figure 3a. Symmetric model specification.

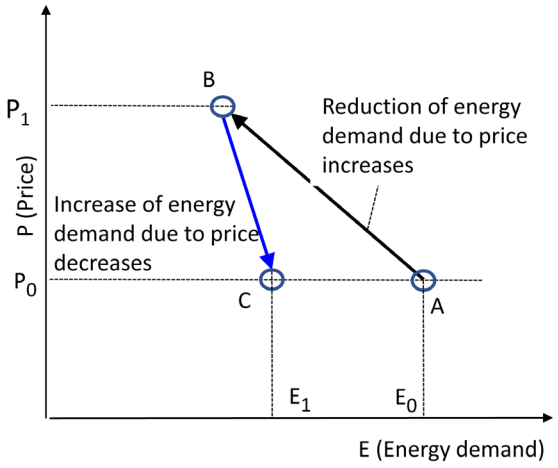


Figure 3b. Asymmetric model specification.

and

$D_{prise_t} = 1$ if $P_t > P_{t-1}$

$D_{prise_t} = 0$ if $P_t \leq P_{t-1}$

In this Equation (9), only the coefficient α_{rise} is of interest and whether it is significantly different from zero or not. If it is, this proves that asymmetry exist.

The next issue of interest is the possible impact of historical maximum price. In some seminal contributions *e.g.* 10,11 introduced the possible role of a historical maximum price on energy demand, especially with respect to the oil price. Thereby, prices are decomposed into three components: (i) historical maximum price, (ii) price recoveries, and (iii) price cuts (see Figure 4). The idea is that in addition to asymmetries, having in mind the historical maximum price might influence consumers' behaviour in a sustainable way.

Next, the price is decomposed as follows:

$$p_t = p_{max,t} + p_{rec,t} + p_{cut,t} \tag{11}$$

Note, that the specific elements of the data sources cited are based on the Equation (12) to Equation (15). The specific parameter used for the estimates presented in Figure 4 is the oil price p (Source: BP[35]), see also Table 5.

In an illustrative exercise with the oil demand data following Equation (9), (10) and (11) approaches, some new variables are defined:

$$p_{max,t} = \text{Max}\,(p_0 \ldots . p_t) \tag{12}$$

$$p_{rec,t} = \begin{matrix} p_{rec,t-1}, \text{if } p_t \bullet p_{rec,t-1} \text{ or } p_t > p_{max,t} \\ p_{rec,t-1} + (p_t - p_{t-1}) \end{matrix} \tag{13}$$

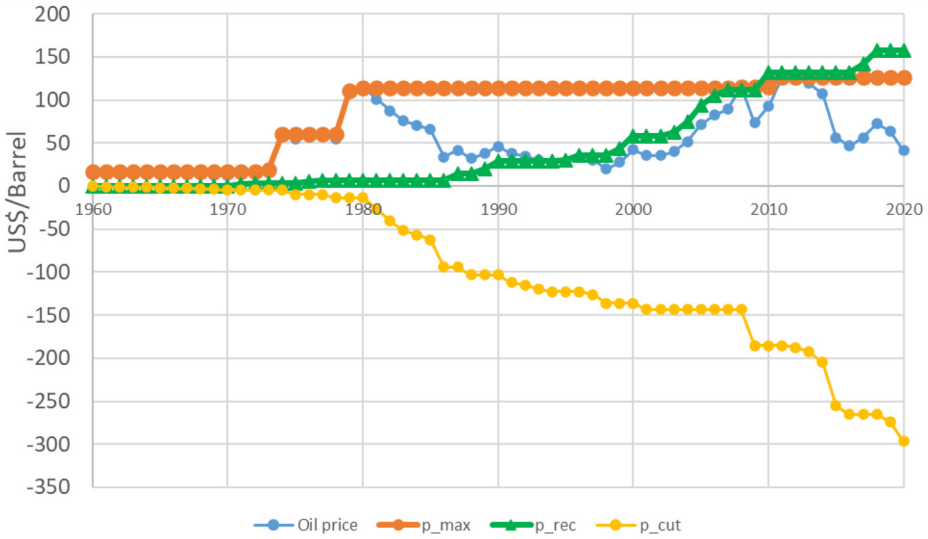


Figure 4. Principle of decomposition of the oil price in rising and falling prices as well as the historical maximum price.

$$p_{cut,t} = \begin{matrix} p_{cut,t-1}, \text{if } p_t \geq p_{t-1} \\ p_{cut,t-1} + (p_t - p_{t-1}) \end{matrix} \quad (14)$$

Substitution of these definitions into Equation (1) to decompose the price results in Equation (15):

$$Ln\, E_t = C + \alpha_{rec,t}\, ln\, p_{rec,t} + \alpha_{max,t}\, ln\, p_{max,t} + \alpha_{cut,t}\, ln\, p_{cut,t} + \beta_0\, ln\, Y_t + \varepsilon_t \quad (15)$$

Estimating Equation (15) the only interest is in the price elasticities. Figure 6 quantitatively shows the exemplary estimates for pedagogic reasons for the three long-term price elasticities α_{max}, α_{rec} and α_{cut} over different periods of time. As seen in Figure 5, the trends are clearly towards declines of price and income elasticities over time. In addition, the estimates in Figure 5 depict that α_{max} and α_{rec} has been quite significant. Only for α_{cut} no reasonable estimates were obtained. And the figures for α_{max} and α_{rec} are decreasing over time.

The results displayed in Figure 5 were obtained as follows: the year 1980 depicts the results for estimating the period 1960 to 1980, the values indicated in 2000 shows the results for estimating the period 1960 to 2000, and 2020 shows the values for the period 1960 to 2020. Note, that the specific elements of the data sources cited are based on the Equation (12) to Equation (15). The specific parameters used for the estimates presented in Figure 5 are

- Oil consumption E (Source: BP[35])
- The oil price p (Source: BP[35])
- GDP Y (Source: OECD[37])

The detailed sources for these parameters are documented in Table 5.

The dynamics of elasticities

A very important reason for the investigation of the dynamics of elasticities is that price and income elasticities may not be constant over time, (see Figure 6). As mentioned earlier in this paper, in 1981 Kouris[8] published the paper "Elasticities - Science or Fiction?" and argued that there are some severe problems with using constant elasticities. The major point of his criticism was that elasticities depend very strongly on the time periods they are estimated from.

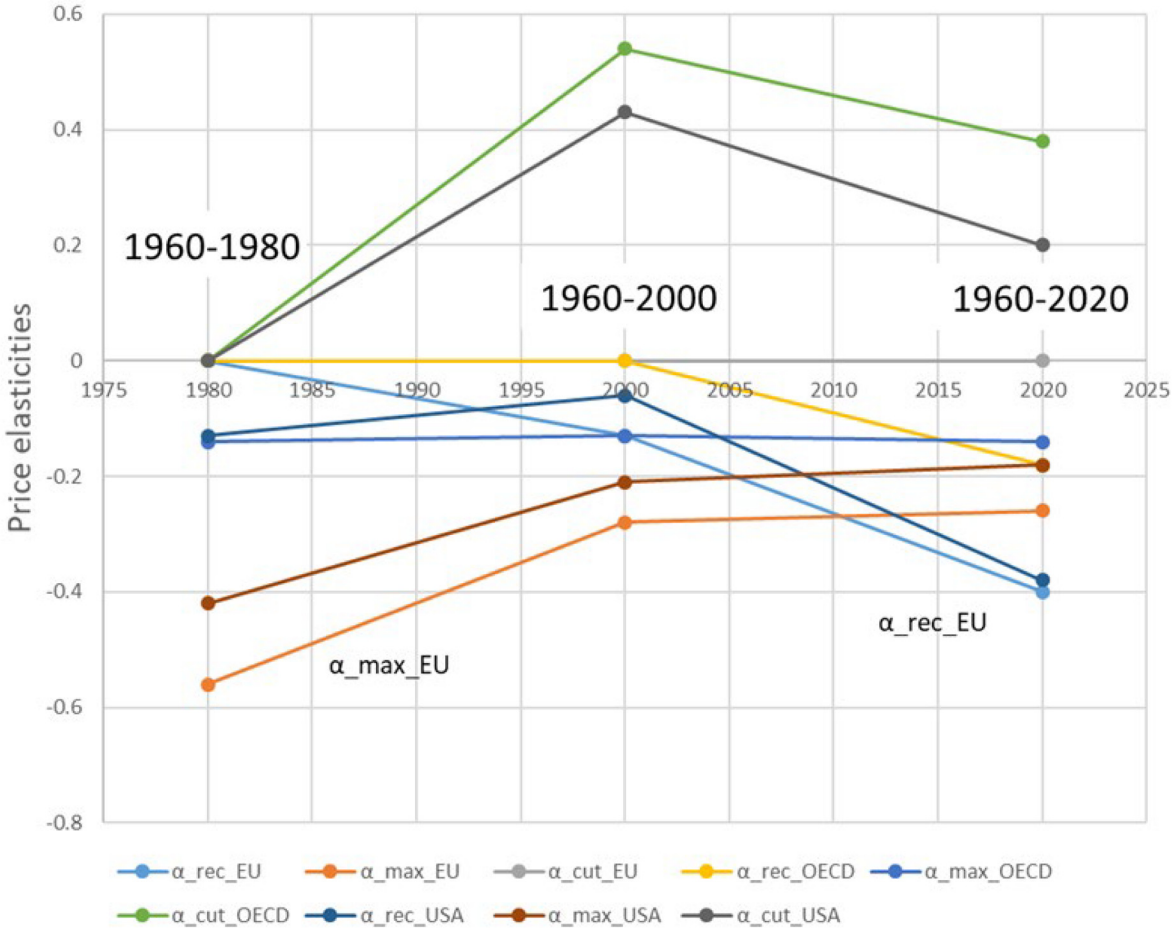


Figure 5. Estimates of the three components of price elasticities for EU-15, OECD and USA for long-term oil consumption over three periods applying the OLS approach (0 = value is not significant).

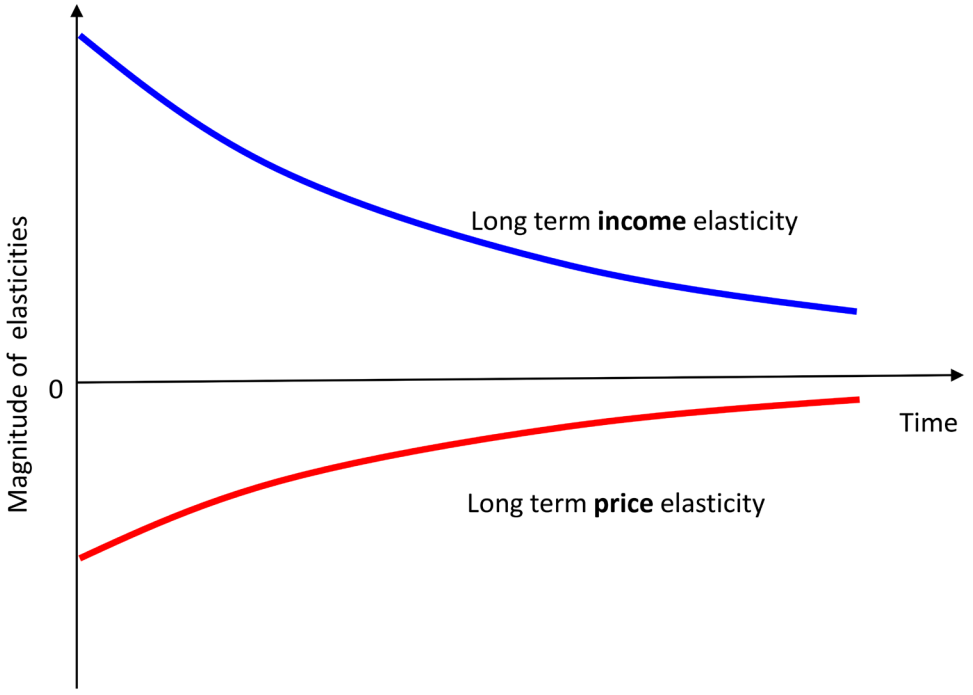


Figure 6. **The principle of our idea of continuously decreasing absolute values of long-term income and price elasticities.**

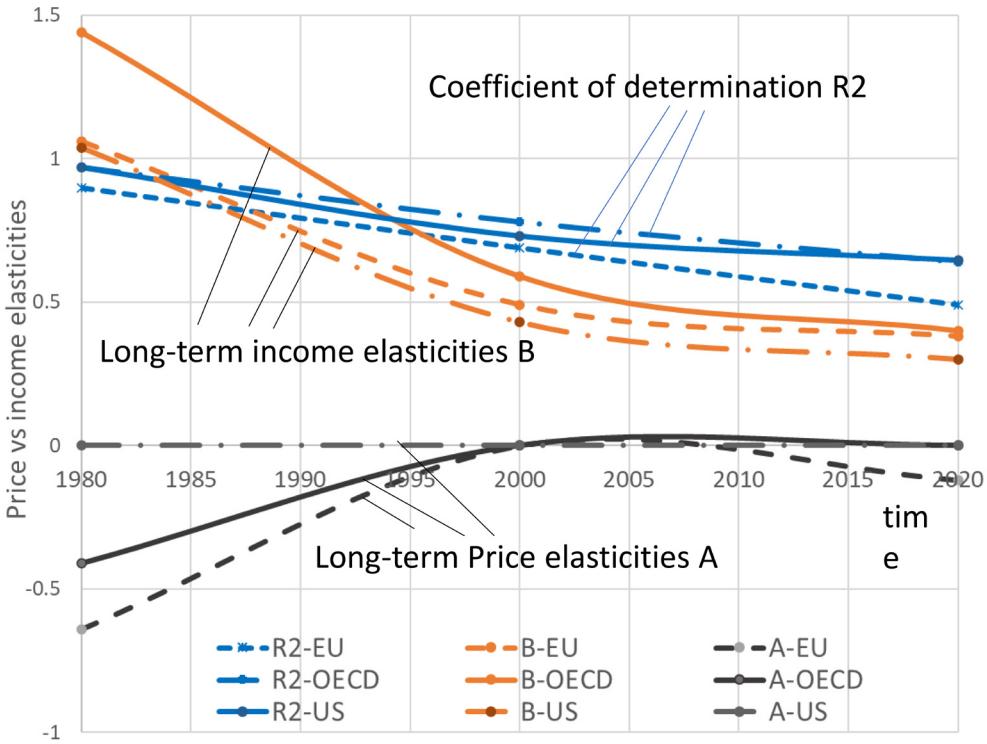


Figure 7. **The dynamics of long-term price elasticities A and long-term income elasticities B as well as of R^2 (coefficient of determination) for OECD, EU and USA.**

So far it has been assumed that elasticities are constant. Haas *et al.*[42] have shown an example for the gradually declining income elasticity in Austria's electricity demand. Figure 7 qualitatively depicts the development of declining price and income elasticities as it has been increasingly observed over time.

Figure 7 quantitatively shows exemplary estimates for long-term price elasticities α and long-term income elasticities β over different periods of time. As can easily be seen, the trends are clearly towards declines of price and income elasticities over time. In addition, the corresponding statistical parameters for the coefficient of determination (R^2) are documented in this figure and they are also declining, the longer the estimation period comes to recent years. This indicates that the coefficient of determination respectively the explanatory values of the economic parameters have decreased over time. The results displayed in Figure 7 were obtained as follows: the year 1980 shows the results for estimating the period 1960 to 1980, the values indicated in 2000 shows the results for estimating the period 1960 to 2000, and 2020 shows the values for the period 1960 to 2020.

Note, however, that for all estimates conducted in this work over different time periods the fittings of the coefficient of determination (R^2) has been decreasing over time.

Structural breaks and disruptions

So far in this paper we have assumed continuous developments without any sudden changes. However, there is the question whether sudden specific events, *e.g.* oil price shocks, wars on oil, economic crisis like those in 2008/2009 or the current COVID19 crisis need a specific attention in modelling energy demand.

In this context, there are at least two approaches which are well known to model such kind of events: using Dummy variables and the Chow-Test.

Using Dummy variables

The first approach uses Dummy variables for the years where structural breaks are suspected, see Equation (16):

$$Ln\,E_t = C + \alpha \ln p_t + \beta \ln Y_t + \gamma_1 D_{1980t} + \gamma_2 D_{1988t} + \gamma_3 D_{1998t} + \gamma_4 D_{2011t} + \varepsilon_t \quad (16)$$

where:

D_i ... Dummy variables (*e.g.,* a specific year)

$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ …Coefficients of the Dummy variables

with:

$D_{1980} = 1$ if $t \leq 1980$

$D_{1988} = 1$ if $t \leq 1988$

$D_{1998} = 1$ if $t \leq 1998$

$D_{2011} = 1$ if $t \leq 2011$

The logical reasoning and purpose of the dummies is to identify whether before and after the years indicated there is a significant difference. That is to say, in Equation (14) it is only of interest whether the coefficients γ_i are significantly different from zero or not. If they are, it proves that in these years structural breaks exist. The dummies are used for the following years and reasons: 1980 (first peak in oil prices), 1988 (first historical low in oil prices), 1998 (absolute historical low in oil prices), 2011 (last peak in world-wide oil prices).

The results of the example are documented in Table 4. As can be seen the results for the coefficients of the dummy variables indicate at a 90% level that there are several structural breaks in the investigated countries. For the EU-15 the years 1988 and 2011 indicate significant structural breaks, for the USA all years investigated show significant values for the dummies. For the OECD countries structural breaks were found for all investigated years except for 1980. Interestingly, the first year of a historical maximum in prices in 1980 shows a structural break in the USA only.

Note, that the specific elements of the data sources cited are based on the Equation (12) to Equation (16). The specific parameters used for the estimates presented in Table 4 are

- Oil consumption E (Source: BP[35])
- The oil price p (Source: BP[35])
- GDP Y (Source: OECD[37])

Using the Chow Test

The Chow test, proposed by Gregory Chow in 1960, is usually an F-test of whether the true coefficients in two periods are equal. The principle is explained in Figure 8 where for two sub-periods of a longer one it is tested, whether the numbers for developments in energy demand E E_0, E_1 and E_2 are the same.

Such analyses were conducted for the years discussed above – 1980, 1988, 1998 and 2011 – using the Chow Test function in MICROFIT 5.5 and the result was simply that the presence of a structural break could not be rejected for any

Table 4. Estimates of structural breaks in oil consumption using dummies for the years 1980 (first peak in oil prices), 1988 (first historical low in oil prices), 1998 (absolute historical low in oil prices) 2011 (last peak in oil prices), using OLS approach over the period 1960–2020.

	EU-15	OECD	USA
D1980	-0.06*)	-0.11*)	-0.23
D1988	-0.34	-0.27	-0.11
D1998	-0.05*)	-0.13	-0.16
D2011	-0.19	-0.23	-0.22

*) not significant at 10%

Table 5. Databases used for analyses.

Data	Database
World oil price	BP Statistical Review 2022
Oil demand	BP Statistical Review 2022 OPEC Annual Statistical Bulletin, 57th Edition, 2022, Table 4.7
Consumer price indices	OECD. Dataset: Consumer price indices (CPIs)
Gross domestic product	World Bank Data

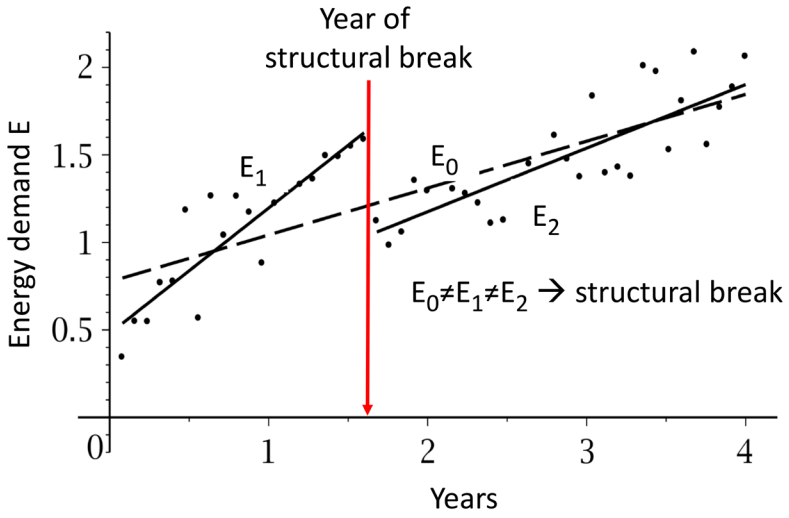


Figure 8. The Chow test for identifying structural breaks.

of these years or countries. Note, that the estimates were done for all years separately.

When wrapping up and taking into account both analysis methods discussed in this section (including the case studies calculated for the historical oil case), it is mainly to be expected that in a few years' time (when corresponding series of data are available) the analyses with these methods will also identify an effect of the COVID19 crisis for the years 2020/2021. Despite this, it is not expected to show a great difference in terms of patterns to those identified above for the case study of oil. Yet, the COVID19 crisis may give policymaking an additional boost (*e.g.* "EU Green Recovery Plan"), and perhaps motivate the implementation of intended structural changes and technology switches in the energy system much earlier than originally planned. Policy instruments play a core role in this context.

The effects of energy policy instruments

A major objective of this paper is to derive recommendations for energy policymakers from energy demand modelling lessons learned. Hanna and Gross[25] conclude that policymakers could prepare more effectively for social, economic and political disruptions by integrating multi-disciplinary insights from a wide range of sciences and finally from repurposed energy systems optimization models. In Figure 2, the major policies available for interfering in energy demand and how they work have already been indicated. These are: subsidies, taxes, technical efficiency improvements such as standards, and – maybe most important of all – money spent for research and development. While the effect of subsidies is mainly to switch to and/or increase the share of energy use from low carbon technologies, the effect of taxes and technical efficiency improvements is more sophisticated.

The effects of energy policies have been analysed and discussed in several papers. The reduction of CO2 emissions of cars in the EU by analyzing the underlying mechanisms of standards, registration taxes and fuel taxes is discussed by Ajanovic *et al.*[47]. Regarding the impact of taxes, the seminal paper of Weitzman[48] uses uncertainty to draw a wedge between price (*i.e.,* a carbon tax) and quantity (*i.e.* emission permits) instruments that are equivalent in a deterministic and static setting. Suppliers (more precisely OPEC) and consumers (EU and other industrialized countries) use quantity instruments nowadays, although Wirl[49] shows that the instrument prices dominates for both players (a supply monopoly and a consumer cartel). Karp *et al.*[50] corroborate this finding numerically. The impact

of energy policies on GHG emission reduction in passenger car mobility in the EU-15 is analysed in scenarios in Ajanovic[51].

Regarding the reduction of energy demand the two major policy instruments are taxes and standards. The effect of the implementation of a tax is achieved from the price elasticity directly. If, for example. a price elasticity of -0.44 has been estimated (as in described in Ajanovic and Haas[18] for road passenger transport) it is indicating that a 1% increase in price *e.g.* by a tax, it leads to a reduction of energy consumption of 0.44%.

Given this elasticity due to the analysis done in Ajanovic and Haas[18] if a standard of 1% efficiency improvement would be introduced, a reduction of energy demand by only 0.56% (= 1 – 0.44 = 0.56) us the price elasticity) would be achieved. The delta to 1 is the rebound effect, for example an increase in service demand km driven due to the now cheaper service price for mobility because of the better efficiency, see also Andersen *et al.*[52].

The conclusion for policy makers is twofold. On the one hand, due to the rather high rebound effect – see Ajanovic and Haas[18] – of about 44% energy savings lost because of more km driven if fuel intensity is improved – technical standards with an effect of 56% as well as taxes with an effect of 44% as single separated policy instruments will have only limited success. On the other hand, however, if introduced in a combined leads to the effect that taxes compensate for the rebound due to standards and the full savings of 100% could ideally be achieved.

Conclusions

In this paper we have reviewed empirical energy demand models in the context of their historical development. The major conclusions of these analyses are ambiguous. On the one hand, econometric modelling of energy demand has made tremendous progress over the last about 30 years, especially regarding the mathematical tools but also with respect to specific approaches such as asymmetries, lags, and short-term vs long-term considerations. On the other hand, regarding further qualitative insights, the progress was very moderate especially with respect to dynamic adjustment mechanisms.

A major general conclusion regarding economic parameters is that their magnitude has been decreasing over time and hence the dynamics of elasticities is important. The smaller price elasticities are, the lower the impact of price changes. Consequently, the lower the impact of associated new/additional taxes on CO2-emissions, the higher the need for standards and technological innovations. Hence, the major useful policy suggestion based on this research is that energy efficiency is an important complementary measure to taxes.

A synthesis of the results of historical energy demand modelling shows that there is no need for “dramatizing” terminologies such as disruptions, shocks, or structural breaks to describe short-term, unexpectedly occurring exogenous influencing factors and/or events, but that these can be described in a pragmatic view in a longer-term context using already known and proven methods and models. This also includes observable discontinuities in energy demand development during the COVID19 pandemics, which in a few years will then most likely be described by the well-known influencing factors in modelling such as income, consumer spending or economic output (*i.e.,* GDP), or short-term (voluntary or forced) behavioural changes associated with longer-term reversion to habitual patterns of energy consumption.

However, the momentum of the COVID19 pandemic can be used (and is being used, for example, in the “EU Green Deal” and “EU Green Recovery Plan”) to recognise and push for the importance of effective energy policy instruments and technological innovations. Against this background, perhaps some of the materials and methods presented in this paper are valuable for a better description of past, present and possible future energy demand developments during critical periods and its longer-term impacts. Optimistically, one may assume that the open science community will significantly contribute to further boosting energy demand modelling research in the future.

Ethics and consent

Ethical approval and consent were not required

Data availability statement

Underlying data

Table 5 shows the data used from the references documented:

Please note that no restrictions regarding the availability of data exist and that no automation tools or software codes were used in this process. Other researchers will be able to access the data in the same way as the authors and the authors do not have special access rights that others do not have.

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The manuscript has got some potential. However, the manuscript needs further improved before to be accepted for publication. I has listed some specific comments that might be helpful of the authors to further enhance the quality of the manuscript. Please consider the particular comments listed below.

1. The structure of this study could be further improved to make it in a more clear way, see the following or similar:
(1) Introduction
(2) Literature reviews
(3) Materials and Methods
(4) Results and Discussion
(5) Conclusion and policy implications

2. The abstract is good but it seems like something is missing here. The Abstract must report the aim of the study, the basic information on the sample (time span, countries analyzed), the empirical methodology used, the main findings, and the relevant policy implications.

3. The motivation and contribution need to be strengthened.

4. Literature Review: Instead of merely listing previous studies, create a narrative highlighting debates, contradictions, or gaps in the existing literature. This approach will help to establish the research gap your study aims to fill clearly. I strongly recommend the authors to add one paragraph discussing the difference between their work and the previously performed studies in literature. In other words, what is the novelty of this work? I offer the authors to revise the abstract and introduction in order to incorporate the novelty of their work.

5. The methodology section needs to be revised to provide a clearer description of the statistical methods used, including equations (especially ARDL model) and any assumptions made.

6. The authors did not show the results of unit root test in the paper, which reduce the persuasiveness of the paper because ARDL model is invalid if I(2) variable exists.

7. Why does the authors not test the long-run relationships among variables by using cointegration test?

8. In the conclusion section, discuss in detail some policy directions and policy measures. Furthermore, does this study allow for academic and practical implications? Please, try to reflect on these issues especially with regard to sustainability issues.

9. Please check the manuscript again for errors.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
I cannot comment. A qualified statistician is required.

Are all the source data underlying the results available to ensure full reproducibility?
No source data required

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental Sciences & Ecology Business & Economics Science & Technology - Other Topics Energy & Fuels Mathematical Methods In Social Sciences

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 07 May 2024

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Andre Plourde
Department of Economics, Carleton University, Ottawa, Ontario, Canada

This paper is very timely and the authors are to be commended for addressing the "policy" issues within an identified theoretical framework. It is useful for the reader to have the overall context of energy supply and demand outlined at the beginning of the paper, as the focus for much of the remainder of the paper is strictly on the demand side. The policy conclusions are interesting and timely. From a broader perspective, however, the authors do not address the matter of energy/oil production and use creating negative environmental externalities and that emissions taxes and charges are thus means of internalizing these externalities. I understand that a detailed discussion of these matters is beyond the scope of the paper, but it might be useful for the authors to acknowledge briefly this matter at the beginning of the paper (which would set the context of the analysis even more clearly).

First, the authors seem to use "energy" and "oil" interchangeably, especially as the empirical analysis proceeds. It seems to me that the empirical analysis focuses only on oil and that this point should be made clear to the reader. Addressing this issue is a matter of adding a few sentences of text and then ensuring that word usage is consistent.

Second, I find the use of "static and dynamic" confusing. Do the authors think of "static" as meaning something like "constant elasticities" and "dynamic" as meaning "time-varying elasticities"? If so, then that should be clearly articulated in the text. Either way, the meaning ascribed to these terms by the authors should be made clearer to the reader.

Third, I would strongly urge the authors to add a "data" section as a lead-in to the empirical analysis. As things stand, the same information about data sources is provided five times in the paper: pages 13, 14, 17, 23, and 27 of the version that I was able to print. And even then, some basic questions about the data are not addressed: is the same oil price used in all regressions (irrespective of geographical area)? what are the units of measurement of the variables used in the analysis? Are exchange rates used to convert the income or the price data? The authors should bring all of this information together in a short section, then edit the existing text to remove the duplication.

Fourth, on page 20, it would be important to note that it is CUMULATIVE price recoveries and CUMULATIVE price cuts that are two of the components of the decomposed price series. By extension, it would be useful to add an equation between equations (14) and (15) to emphasize the nature of the price decomposition: $P_t = P_{max,t} + P_{rec,t} + P_{cut,t}$.

Fifth, I would urge the authors to re-write one sentence on page 20 to make the text consistent with standard statistical practices. Specifically, "If it is, this proves that asymmetry exist[s]" should be replaced with something like: "If it is, then the hypothesis that asymmetry exists cannot be rejected."

Finally, three minor points:
(i) The result that the (own-price) elasticity of oil demand has been decreasing (in absolute value) over time obtained by the authors is consistent with one that a colleague and I derived in an earlier paper: Ryan and Plourde (2002) [Ref 1] "Smaller and Smaller? The Price Responsiveness of Non-transport Oil Demand", *Quarterly Review of Economics and Finance* 42(2): 285-317. This might be a useful addition to the paper's reference list.
(ii) As the authors know, a limitation of their empirical analysis is the single-fuel focus of the empirical analysis, which precludes inter-fuel substitution from being portrayed and captured. This should be briefly mentioned in the text.
(iii) I noted very few typos and the like. Two exceptions: on page 7, "Dargayand" should be "Dargay and Gately"; on page 17, "ovr" should be "over".

Thank you for giving me the opportunity to review this paper.

References

1. Ryan D, Plourde A: Smaller and smaller? The price responsiveness of nontransport oil demand. *The Quarterly Review of Economics and Finance*. 2002; **42** (2): 285-317 Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Areas of focus of my research have included empirical energy demand analysis and energy policy issues.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 07 November 2023

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William Chung
Management Sciences, City University of Hong Kong, Hong Kong, Hong Kong

General understanding: The authors reviewed the development of econometric energy demand modelling approaches: (1) general energy demand function of price and income, with and without lag effect, (2) Autoregressive Distributed Lag for having both short-term and long term elasticities, (3) the asymmetric model (for the role efficiency improvements and the historical maximum price), (4) the need of the dynamics of elasticities, and (5) the approaches of having the structural breaks and disruptions. Using the data from the Oil sector, model results were used to support the need for (1), (2), (3), and (5). Using the data from the Power sector, model results were used to support the argument of the dynamics of elasticities. Then, the effects of energy policy instruments, like tax and technical efficiency improvements (standard), were discussed in the context of elasticities.

Major contribution: The paper provides an excellent general review of the development of econometric energy demand modelling approaches with model results from the oil and power sectors. The development discussion highlights the need for dynamics of elasticities and structural breaks with numerical illustrations. This manuscript can help readers select the appropriate energy demand modelling approach in the oil sector.

Major comments and suggestions:

1. The article title is misleading, using only around 2 out of 12 pages (not including the reference list) for discussing "modelling energy demand under discontinuities."

2. In terms of academic merit, the contribution of this manuscript is thin.

3. The authors may consider to rename this article.

4. All the arguments and reviews are related to the oil sector except for the discussion of the dynamic of elasticities. Does it imply that the dynamic of elasticities is not a concern in the oil sector but the power sector?

Minor comments:

1. There are some typos in the citation in the text, like (16) on page 7, the authors' order is not consistent; p.8, Andersen; p6, Walker/Wirl (no ref number).

2. P.13, "In Figure 2, the major policies...." However, Figure 2 on page 6 does not discuss any policies.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
I cannot comment. A qualified statistician is required.

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Over 20 years in Energy system modelling; Algorithms development for solving energy systems; Energy efficiency policies analysis; Regression analysis.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 12 September 2023

https://doi.org/10.21956/openreseurope.16346.r34760

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Tahsin BAKIRTAŞ
Sakarya University, Sakarya, Sakarya, Turkey

The manuscript titled "Modeling energy demand under discontinuities from an energy economic point-of-view" is interesting and worth evaluating due to its subject. The authors created the content and format of the manuscript in scientific format and used analytical methods. In this context, when the manuscript is examined, although the manuscript has some shortcomings, it is worth evaluating. In terms of authors improving the manuscript;

a) The section in the manuscript under the title "A brief review of the history of energy demand modeling" refers to manuscripts examining energy demand. There is a very extensive literature in this field. Instead of passing over this literature with a few manuscripts, it should be presented in the form of a table and the literature review should be expanded in this context.

b) The methodology and methods used in the manuscript must be introduced from primary sources. Instead, the package program used is mostly referenced and how it works is explained.

c) Although the results in the model used are meaningful and the interpretation is quite successful, there is a need to strengthen the policy interpretation by comparing it with other manuscripts in this field.

Considering all these together, the manuscript needs to be revised.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: energy, econometric methods, economics, international economy

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.