The Economic Effects of Peak-Oil

A Sectoral Input-Output Analysis of the Economies of the Czech Republic, The United Kingdom and the United States of America

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Thesis submitted for the partial fulfillment of the degree

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Submitted to Mag. Dr. Christian Kerschner

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AFFIDAVIT

I hereby affirm that this Master's Thesis represents my own written work and that I have used no sources and aids other than those indicated. All passages quoted from publications or paraphrased from these sources are properly cited and attributed.

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ABSTRACT

A resource peak occurs when its production reaches maxima, per unit of time given external constraints. This concept is applicable to all resources that are subject to extraction from nature. That society has a limited endowment of resources then becomes the natural conclusion. The resource under investigation in this research is *oil.* It is the fuel energising our growth oriented economic systems. But like all resources, its quantity is also limited. What would happen to a world where oil suddenly became scarce and consequently more expensive? A constituent part of the answer to this complex question has been explored in this research. Specifically, this research looks at the building blocks of an economy; its sectors, to quantitatively ascertain the possible effects of the resource oil as it peaks. This phenomenon is referred to as ‘Peak-Oil’ in literature.

The building blocks of the economies of the USA, UK and Czech Republic are commercially available in the form of Input-Output tables. These tables are used throughout the world for central planning by governments. In practice, if country A for example wants to build 50,000 houses in year X, how much raw materials like oil, bricks, mortar, labour etc. would be required? These raw materials are quantities of-course, but they can also be expressed as costs, in Dollars or Euros. This research utilises monetary denominations or costs as substitutes for quantities for ease of understanding. In order to obtain the extra costs that these raw materials will incur, the tool to use is the Leontief Input-Output Price model which produces an output or requirements matrix containing the required price percentage increases that each sector involved will have to bear. Notice *oil* in this example. As the fuel of our energy intensive economic systems, oil use is found in every sector of an economy in its many different forms (kerosene, petrol, diesel etc.). If one were to raise the cost of an oil barrel from say $60 to $120, the associated costs would naturally go up for every sector. This research takes this very concept of oil price increases and applies it to the macro-economies of the USA, UK and Czech Republic such that the resultant requirements matrix represents price increases for every sector. Furthermore, it uses a second type of Input-Output model, known as the Ghosh Model to determine which sectors are the most and least important to the overall economy as a result of the price increases. The results from the Ghosh Model and the Leontief Price Model (with increased oil prices) are plotted against each other.

The resulting figures show price increases throughout the economy versus sector importance to the macro-economy for the USA, UK and Czech Republic. Substantial price increases in the most important sectors of each economy are discussed and compared. As a result of the analysis, construction and manufacturing stand out as the two most affected sectors in all economies. Other affected sectors are also discussed in detail. Finally, conclusions and future research avenues are presented.

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PREFACE

I remember a time when London would get buried in many inches of snow. Temperatures would plummet below -5^{o}C and snowmen and snowball fights would be ubiquitous. I would go out of my home and build a snowman in the driveway every year without fail. But I noticed something happening. With each passing year, the snowfall was becoming lighter which meant that the snowmen gradually shrank in size. As I grew taller, the snowmen became shorter. Until a fateful winter a decade ago when no snow befell the streets of London. It felt as though the fun was always going to be temporary and life had merely exhibited its impermanence. The real change however was that the winters were not as cold anymore either. Pondering as to why this had happened, I wondered whether this had anything to do with the greenhouse gas effect I had learned about at school. I concluded that I had been seeing it in real life over the years. The moral of the story I thought; climate change is real.

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LIST OF ABBREVIATIONS

URR – Ultimately Recoverable Resource

IHS CERA – Cambridge Energy Associates

EOR – Enhanced Oil Recovery

ERI – Energy Return on Investment

GTL – Gas to Liquid Fuel

CTL – Coal to Liquid Fuel

NTL – Natural Gas to Liquid

Mb/d – Million barrels per day

Gb/d – Giga barrels per day

NAICS – North American Industry Classification System

OPEC—Organization of Petroleum Exporting Countries

IOA—Input-Output Analysis

FWDL—Forward Linkages

DEFINITIONS [1]

Conventional Oil: Light medium oil which has migrated from its source rock to a reservoir rock with extraction done primarily through mechanical pumping or the field's own pressure.

All Oil: Conventional oil and NGLs, EOR, heavy crude and oil from kerogen.

Oil from Kerogen (shale oil): Oil shale or similar rocks containing significant amounts of the oil precursor Kerogen from which oil can be extracted by retorting.

All Liquids: Umbrella phrase, also includes GTLs and CTLs.

Ultimately Recoverable Resource (URR): Usually refers to the quantity of oil or gas that has been historically touted as likely to be extractable from a field or a region by some time in the future.

'Mid-point' Peak: Applies to conventional oil. Refers to the concept that production will peak when roughly half of the URR of oil in a region has been produced.

Resource: Total hydrocarbon deposit in one place, whether discovered or not or economically recoverable or not.

Reserve: That quantity of oil or gas that has been discovered and is assessed as likely to be recovered under current or reasonably expected technical and economic conditions.

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[1] Definitions taken from Bentley, (2016)

1 INTRODUCTION TO PEAK-OIL

1.1 Oil as a Finite Resource

A finite resource is one that “is concentrated or formed at a rate very much slower than its rate of consumption and so, for all practical purposes, is non-renewable” (“Finite resource - Oxford Reference,” 2019). Some examples of finite resources include crude oil, natural gas, coal, phosphorus and uranium. Concerning energy economics, crude oil takes center stage as the most important entity of the non-renewable resources spectrum. This is because of the heavy reliance of the world economic system on cheap and abundant oil to fulfil its energy requirements. However, any finite resource that is continuously being extracted will eventually face a production peak (Rogner, 2012).

1.2 Conventional and Non-Conventional Oil

In the pursuit of understanding the rise in oil prices in addition to the parameters of future oil supply, it is important to understand the difference between c*onventional* and *non-conventional oil.*

From the land surface to the sea-bed, oil exists in many forms. It appears in degraded form in tar pits as well as extensive areas of tar sands; as flowable oil captured in the rock where it first formed requiring hydraulic fracturing or fracking to release it; or having migrated from its original rock to a porous rock reservoir from which it can be extracted through drilling. The drillable oil—otherwise known as the *“relatively light, flowable oil in fields”*–is billed as conventional oil. Currently and historically, the great bulk of oil production has been that of this type of oil (Bentley, 2016).

Non-conventional oil types include oil from tar sands or oil obtained through fracking. Generally found in extensive regions - such as Canada’s Alberta Tar sands - non-conventional oil does not flow as well as conventional oil through a production well and has to be treated with either chemicals such as solvents or needs to be heated. Such processes reduce the oil viscosity and facilitate better flow rates through the production infrastructure. Non-conventional oil is thus very heavy (w.r.t. viscosity). Additionally, non-conventional oil can also be yielded through distillation of kerogen [a sedimentary organic matter that produces petroleum and natural gas (Vandenbroucke and Largeau, 2007)]. Yet, oil production is possible through other sources which further extends the variety available in non-conventional oil types. GTLs or Gas to Liquid fuels where the natural gas is subjected to the Fischer Tropsch (Dancuart and Steynberg, 2007) process to yield GTL, condensate natural gas liquids or NGLs and coal to liquids or CTLs or through biomass (Bentley, 2016). However, GTLs are not generally considered in non-conventional liquids.

With the many sources of oil available, it is natural to question the dominance of conventional oil. The simple answer is lower production cost of conventional oil. There are two further reasons for this; *flow rate* and *Energy return.*

1.2.1 Flow Rate

An oil field is geographically concentrated, facilitating large flow rates with ease through simple drive mechanisms including water flood, gas drive or the own pressure of the oil field (Bentley, 2016). As an additional dimension, one can also consider the actual viscous flow through ducts, i.e. oil flowing through pipes.

FIGURE 1: *VALVES AND PIPE ANGLES ON AN OIL TANK FORM. PIPE FLOWS ARE UBIQUITOUS, OFTEN OCCURRING IN GROUPS OR NETWORKS (WHITE, 2006)*

The reason for considering this dimension comes from asking an important question, i.e. what pressure drop is required to drive the flow from the pump or considering the pressure drop from the pump is known, what flow rate will follow (White, 2006). In the context of a conventional oil field, the flow rate can be enhanced using the techniques above but only up to a point as physical limits imposed by fluid dynamics take hold. Nevertheless, achieving identical flow rates with non-conventional oil sources may not be possible. Brecha (2012) also argues in agreement stating that it is improbable that the production rates (which by definition include the actual flow rates) of new unconventional resources can make up for the decline in conventional oil production (see section 1.2.2).

Flow rates have increased over the years. For example, the first commercial oil well in the USA, the Drake well produced just 20 barrels per day in 1859. Today, many large fields have generally yielded 500,000 b/d and the world's largest, the Ghawar in Saudi Arabia produces 5 million b/d.

1.2.2 Energy Return on Investment

Energy return on investment for oil and gas is defined by the ratio between the actual energy returned and the energy invested to obtain a conventional or non-conventional energy source. Guilford et al., (2011) and (Hall et al., 2008) define it by the following relation:

$$EROI = \frac{Quantity\ of\ Energy\ Supplied\ by\ the\ Produced\ Oil\ and\ Gas}{Quantity\ of\ Energy\ used\ in\ that\ activity} \tag{1}$$

Where EROI is the Energy Return on Investment.

Guilford et al. (2011) suggest that conventional oil gave an EROI of 30:1 in the 1930s which rose to 40:1 in the 1970s given the increase in scale and technology. However, there was a subsequent fall in the EROI with the advent of more difficult drilling expeditions such as deep offshore or Arctic oil. Today the average ratio of ERIO is 14:1. By contrast the, non-conventional oil gives much lower EROI. For example, tar sands oil gives roughly around 1.5 to 8:1 for EROI (Bentley, 2016).

1.2.2.1 EROI for Imported Oil

Lambert et al. (2014) have related social well-being and energy quality. They calculate that an EROI of less than 5-10:1 is when modern developed societies shall start to struggle. However, they make this point by assuming that most countries have to import their oil from the global market, and hence this EROI is that of *imported oil*. Lambert et al., (2014) conclude their paper by pointing that decreasing EROI will have the most adverse effect on developing nations. Developing nations do not have the capital or expertise of their developed counterparts, to actively invest in substitution solutions. Yet in the context of Peak-Oil, as supply from conventional sources declines further, it is difficult to imagine economic growth of an identical gradient with non-conventional sources whose *actual* EROI stand at around 1.5-8:1 in comparison to pre-and-post 1970s of 30:1 and 40:1. Thus, it is plausible to assume that reduced *actual* EROI may surely have a knock-on effect on *imported EROI* resulting in declining social well-being indicators when compared with historical levels.

1.3 Oil Reserves Data

In their paper "The End of Cheap Oil" Campbell and Laherrere (2012) pointed out that distorted reserve estimates were a critical error in forecasting how much oil is left. They went on to deduce that estimating reserves is an in-exact science. Bentley (2016) is in agreement with Campbell and Laherrere and states that poorly understood reserves data is by far the biggest factor in misunderstanding the transition from conventional to non-conventional oil. The problem lies between the differentiation of *proved* ('1P' data) oil reserves and *proved-plus-probable* (the '2P' data) reserves.

1.3.1 Proved ('1P') Oil Reserves

Generally, published data of oil reserves are of proved (1P) reserve category. Notable publishers include BP Statistical Review of Energy, the annual tables in *World Oil* or the *Oil and Gas Journal*, or on the *US Energy Information Administration (EIA)* website. In reference to *conventional oil reserves only,* these data have been extraordinarily misleading because in practice, companies and countries are often intentionally ambiguous about the prospect of the reserves they report on and publishing figures that best suit their interests. One reason for this is that an overestimation can result in a raise of an oil company's stock price. In short, companies tend to understate [which Campbell and Laherrere call P10 or probability of 10% of URR (Ultimately recoverable oil)], overstate (or P90 i.e. the probability of a 90% chance of URR) or give no updates for long periods of time to the data published (Bentley, 2016; Campbell and Laherrère, 1998).

1.3.2 Proved Plus Probable ('2P') Data

Bentley (2016), Campbell and Laherrere (1998) agree that proved and probable or 2P data is the correct way to estimate a conventional oil reserve size culminating that the errors in the 2P or P50 (probability of 50% that oil is present) cancel each other out. If 1P data are used, global reserves of 'all oil' show an apparent ever upward trend. The quota wars of the OPEC gains in a scenario where 1P data is used. The increases in reserves' size since the year 2000 however, are largely attributed to the inclusion of tar sands and Orinoco reserves and since 2010, the inclusion of US shale-oil. Since 1P data is defined as those quantities that "with reasonable certainty can be recovered in future under *existing* economic and operating conditions", it fails to backdate the global reserves data as in the case with 2P. The global 2P reserves data for conventional oil only shows a peak at 1980 and a steady decline ever since. Presently, the disparity between 1P and 2P data is in part because until the year 2000, both measures covered roughly the same category of oil. Overall, 1P data have shown a sharp upwards trend since 2002 due to the inclusion of non-conventional oil reserves. Whereas the 2P data, backdated for conventional oil only has been in decline since 1980.

In practice, estimating through a 2P system means totaling up the mean or average estimates in each oil field. These data sets are costly to obtain but are available from sources such as *Wood Mackenzie*, *PFC Energy* and *Rystad Energy.*

1.4 Peak-Oil

Peak-Oil as a concept has been explained in several publications for example by Deffeyes (2006); Aleklett (2012); Murphey (2008); Kerschner and Capellán-Pérez, (2017) and Bentley (2016). Their explanations generally agree that Peak-Oil signifies a point when oil production [be it from a field (conventional) or tar sands (unconventional)] for any region or the world as a whole reaches a maximum and then declines. Bentley (2016) states that the primary reason for this is the *resource availability limit* which Kerschner and Capellán-Pérez, (2017) describe as the available amount underground for future exploitation. Where the concept of Peak-Oil has been widely discussed by all authors, Kerschner and Capellán-Pérez, (2017) also provide an all-encompassing definition:

"Peak-Oil is the maximum possible production of petroleum fuels per unit of time given external constraints. These constraints can be geological, economic, environmental or social and determine its available quantity and quality to society" Kerschner and Capellán-Pérez, (2017).

In terms of an oil field's production, all of the above constraints apply but the application of this definition has to be clarified. Regarding resource limitation, a field can reach several maxima in its production history (Bentley, 2016). These "resources" therefore encompass the application of new technology (which may increase a field's maximum production previously not possible). For example the U.S. patent by Ellingsen, (2002) provides a solution that increases the oil production from a conventional oil reservoir. Also, a notable increase in oil prices can produce a new maxima where Ringlund et al., (2008) have assessed that in the long term, all regions experience enhanced oil rig activity when oil prices increase. However, there are physical limits to the ultimately recoverable resource (URR) and every last drop of oil cannot be physically extracted from any field as stated by Campbell and Laherrère, (1998).

Therefore, Peak-Oil does not generally mean production peaks happening as a result of 'above ground' factors such as peaking demand, limited access to oil exploitation in a country or region or imposition of constraints such as quotas. But it is worth noting that the production profile of a field before and after a peak in addition to its economic significance vary on a case by case basis, i.e. every field is different and that a given field's production cannot be extrapolated to explain Peak-Oil on a world level. Additionally, economic significance of Peak will be different when applied to conventional or non-conventional fuels only or to 'all liquids' (Bentley, 2016).

Typical Production Profiles for Conventional-Oil (Oil Fields)

Field production profiles vary depending on the location and size of the field. Figure 2 shows a schematic of production profiles for four different oil fields of varying sizes:

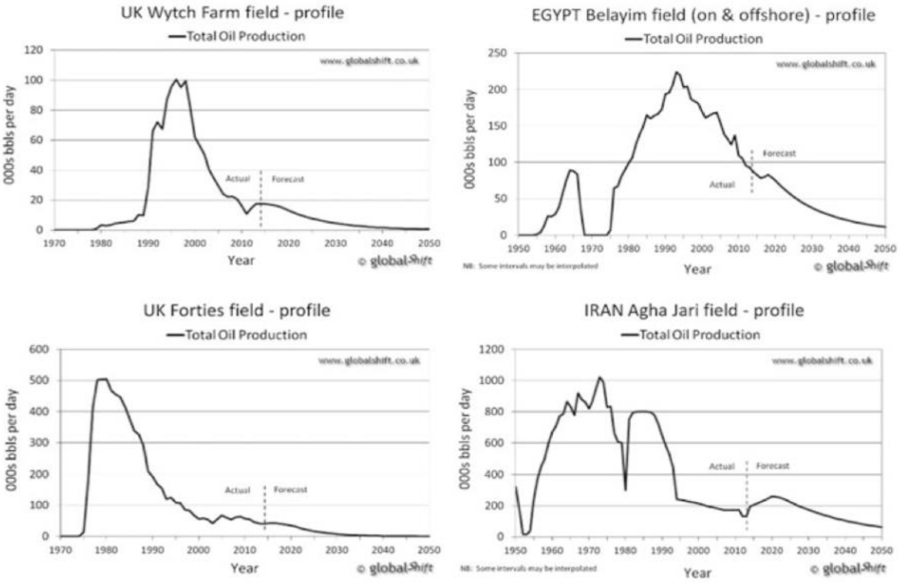

Figure 2: *Typical field production profiles(Bentley, 2016)*

Top left: The UK's largest onshore oil field Plateaued at 100,000 b/d which did not last very long, followed by a steady decline and some late recovery. The top and bottom end of the dashed line signifies the range of production forecasted. The graph represents the actual production (applies to all figures).

Top right: One of Egypt's largest oil fields with both onshore and offshore production. A maximum or peak production of roughly 230,000b/d followed by a steady decline. No production in the 1970s due to war.

Bottom left: UKs largest field with a peak production at 500,000b/d followed by a sharp decline.

Bottom right: Large Iranian oil field, suffering production declines due to political events (Iranian revolution) with a peak production of one million b/d. Production started to decline after half of the field's likely recoverable oil was produced. Note that the profile of this field is unique amongst the typical large oil fields in the middle east.

The above examples show that generally all oil fields exhibit a steep gradient toward peak production followed by a steady decline over a long period (Höök et al., 2009). It is worth noting that the production rate at peak or plateau in part reflects the size of the pipeline additional to the infrastructure transporting the oil from point A to point B.

For all types of oil fields, production inevitably declines. Physical constraints such as loss of field pressure, volume depletion in oil wells and increasing drive fluid bypass in the oil basin [the driving fluid can be naturally occurring or injected (Bentley, 2016)] compound to this end. Water flooding is the prime recovery technique used for most reservoirs because it provides the highest recovery factor and is relatively cheap particularly for offshore fields where seawater is readily available (Muggeridge et al., 2014). Techniques exist to raise the production of a declining field but these are often costly and only slow the rate of decline. Some emerging oil recovery technologies are *low-salinity water injection* and *deep reservoir flow diversion* the more details of which are outlined by Muggeridge et al., (2014).

In this research, conventional oil has so far been defined as one exclusive to non-conventional types like Tar sands but inclusive of condensate and natural gas liquids. In 2008 the World Energy Outlook (WOE) and in 2013 the International Energy Agency, (2013) explained that the approaching global peak of conventional oil production shall force the world to employ rising volumes of non-conventional energy sources to quench the increasing demand. However, as mentioned previously, non-conventional sources are expensive to produce oil from with smaller EROIs making them a temporary fix at best.

1.5 Forecasting Peak-Oil

Forecasting is a broad subject and only some of the relevant techniques have been discussed here. Bentley, (2016) outlines some of the main issues to recognize:

- Production forecasts are going to be underestimates for a given region until the rate of conventional oil discovery has peaked. Until there is scope for further substantial discovery, future discovery in terms of Peak-Oil cannot be estimated accurately.
- The use of 1P data cannot be used to know the rate of oil discovery as well as peak discovery. Instead 2P data must be used since post 2000, 1P data has included ‘all oil’ in its projections. 1P data is also not backdated to indicate historical trends. Oil industry 2P data on the other hand is backdated, furthermore keeping clear of mixing conventional oil forecasts with other forms of oil.
- Mid-point peaking, a ‘field aggregate’ method, can be utilized once discovery peak has been reached and the field is in decline.
- Where field aggregate methods rely on estimates of URR, they need to be in line with the 2P discovery trend.

Additionally, along the same line as Bentley, (2016), Sorrell et al., (2010) evaluated fourteen existing forecasts of global supply of conventional oil. They found that irrespective of the numerous modelling approaches with varying assumptions, an overlap existed along two dimensions: the shape of the future production profile and the implied ultimately recoverable resource (URR) of conventional oil.

1.5.1 A History of Forecasting Peak-Oil

Most Peak-Oil literature starts with Hubbert, who first described the phenomenon later called Peak-Oil, and is often seen as the godfather of Peak-Oil forecasting. In his 1956 paper, he explained that oil forecast must rise over time to a peak plateau and then fall away, following a bell-shaped curve. The curve shows an approximation of the rate of production of a finite resource over time. Figure 3 shows the Hubbert curve:

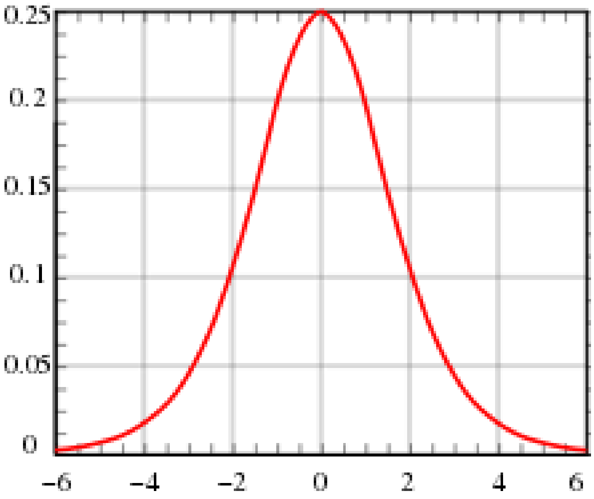

Figure 3: *Hubbert's Curve* (2019)

However, forecasts were happening prior to 1956 as well. The skeptical camp in the Peak-Oil debate have long pointed fingers at the incorrect forecasts of conventional oil production as a basis for their position in the debate. Based on the information available at the time, this view is valid to a certain extent. This is because the forecasts made prior to the East Texas field discovery in the US in 1930 as well as discovery peaks for new fields in the mid 1930s had a high probability of being underestimates, mainly because of inaccuracies of the 1P data system discussed in the earlier section. Large oil fields continued to be discovered well into the mid 1960s, for example the Ghawar field in Saudi Arabia. Once the discovery peak (the maximum number of oil fields discovered worldwide) for conventional oil fields was reached, it became relatively straightforward to forecast future production peaks, provided quality data and accurate approaches were used.

Therefore, when Hubbert predicted the US conventional oil peak to be between 1965 and 1970, the discovery of US oil in fresh basins had already been waning for 20 years. Hubbert's technically based global production peak prediction at around the year 2000 was made when global discovery of oil new fields had been in decline for a couple of decades (Bentley, 2016).

Hubbert did not get it right on the first go. In 1938, he forecasted that the US peak would happen twenty years earlier than it did. He exclaimed that *"early discoveries have already been made"* and that "*it seems doubtful that* [*the beginning of US oil decline*] *can be postponed any later than 1950 and possibly not that long."* Hubbert believed that *"11 or 12 billions of barrels"* of proved US oil reserves existed. However, the error here was that he also believed that 1P data was a useful way of measuring the discovered amount of oil. The 2P data at this time showed 5Gb of oil in East Texas alone. Hubbert corrected this error in 1956 by basing his predictions on 2P data.

The lessons learned from Hubbert's work today point us in the direction of using 2P data instead of 1P data. Additionally, the region must be defined (e.g. Hubbert's prediction was for the US Lower-48 states) as well as the type of oil. Also, the use of realistic URR estimates based on mid-point peaks. Furthermore, examining with care any data with high URR estimates.

Following the oil shock of 1973 there have been major contrasts about the global oil supply awareness to date. For example, upon the discovery of shale oil, Monbiot, (2012) claimed of there being enough oil to fry us all versus the authors mentioned earlier such as Aleklett, (2012) or Campbell and Laherrère, (1998) who advocate that Peak-Oil has either already occurred or is going to occur very soon. Some predicted only 30 years of oil remaining. Conversely, many analysts around the 1970s accepted that the global URR estimates stood at 1800Gb to 2500Gb only 240Gb of which had been produced by 1970. Using 'mid-point' forecasting was made easier with this estimate and the conclusion was that the production of conventional oil would increase until about the year 2000 before beginning its decline. For example Andrews and Udalls', (2003) presentation at *ASPO (the Association for the study of Peak-Oil)* 2003. Other examples are the *UK department of Energy* report in 1976, stating the expected date of peak in the UK around the year 2000. Ehrlich and Ehrlich, (1970) predicted the peak date around the year 2000 based on estimates of around 1900Gb of oil and Ward and Dubos, (1983) also predicted the year 2000 to be the Peak-Oil year. Additionally, in 1979, Shell, an oil giant, expected a production plateau within 25 years.

A collapse in oil prices around the year 1985 fueled by the rising production of oil from Alaska, Mexico and the North Sea, led many analysts–who previously warned of an imminent decline of oil production—to dismiss the notion that Peak-Oil would happen around the year 2000. However, Colin Campbell-a notable oil geologist-published a study of the oil prospects of Colombia and Latin America as a whole. This study was called *The Golden Century of Oil 1950-2050* (Campbell, 1991). It looked at the production of conventional oil exclusive of NGLs or oil from shale or tar sands. The data used for this study was 1P but Campbell stressed on the uncertainty of the data stating that the intention was to draw attention to the general limits of the resource base. Campbell's work provided evidence that this new impression of oil abundance was wrong and that Peak-Oil was still expected to happen around the year 2000.

Having seen Colin Campbell’s *The Golden Century of Oil*, *Petroconsultants* (an oil and gas exploration company) became interested in re-doing his work with 2P data. Around the same time, John Laherrere-another notable geologist and geophysicist-became interested in the use of lo logistic curves to model oil depletion, and came into contact with *Petroconsultants* to use his approach to model global supply. The combination of these two events resulted in a series of landmark reports estimating the global conventional oil URRs amongst other things. The results of these reports were summarized in a *Scientific American* article in March 1998: *The End of Cheap Oil* (Campbell and Laherrère, 1998), stating that the non-conventional sources such as tar sands and shale deposits would produce only 700Gb of oil over 60 years. Campbell and Laherrere’s prediction were congruous with Hubbert and were not welcome everywhere, with one oil company even trying to suppress the report (Bentley, 2016).

1.5.2 Current Forecasting Methods for Conventional Oil

The forecasting methods today comprise of two classes, namely field aggregate and bottoms up by field and are usually referred to as aggregate or bottoms up.

1.5.2.1 Field Aggregate Method

There are two approaches to the field aggregate method. The first one does not attempt to model production profiles for individual fields but instead uses generalized functions that are known and assumed to exhibit the behaviour of a large group of fields. In application, this means modelling all of the world’s fields into a single group and applying Hubbert’s curve to predict total production. The second approach provides production forecasts by adding together a series of logistic curves where each curve represents a ‘phase’ of oil production. This approach also encompasses different classes of oil such as tar sands and other non-conventional oil types. Laherrere used this method in his global model discussed earlier.

1.5.2.2 Bottoms up by Field Approach

Conversely, the bottoms up by field approach takes production of individual fields and sums them to give total output in a region (usually referred to as a country). For global output, one simply adds up regional production. The bottoms up approach is not very practical, however, there are far too many fields to accurately add together and data for many smaller fields is often not available. For example in the USA, there are more than 30,000 fields (Bentley, 2016). Where the field numbers are so gargantuan, the bottoms up approach combines the unquantified and smaller fields into clusters. These are then modelled as one large field. Yet to be found oil is modelled by pretend fields that follow a uniform size function established by the data on the real fields. The result is that the bulk of forecast volume is derived from assumed production profiles of individual fields.

Both methods have their strengths and weaknesses. The bottoms up approach uses a lot of assumptions and where yet-to-find conventional oil regions are large, it is difficult to implement. However, since most of the regions in the world today have relatively small yet-to-finds in terms of URR, the bottoms up model is fully applicable. Caution must be practised here though, since the bottoms-up approach uses a lot of assumptions and the data is difficult to check by others. Alternatively, the field aggregate model uses simple and robust assumptions. The analysts who used the field aggregate model since the global oil supply constraints that occurred in 2004, typically made the best predictions. However, in the future, both models are needed to understand what is in store for oil.

1.6 Global Production Peak

The global production peak forecasts include both authors who see this happening in the nearer future and those who predict its occurrence in a long time from now. Jackson and Smith, (2013) for example believe that given the current size of global oil resource, it is unlikely that mankind will face a physical supply shortage for up to three decades. But they also note that the demand evolution may well dictate the global supply curve. This idea of curbing energy consumerism and going back to a more subsistence based living is supported by Friedrichs, (2010) as socioeconomic adaptation and he gives Cuba in the 1990s as an example where the entire Cuban economy was devastated. Coming back to the global production peak expectants, *IHS CERA*—a consultancy for energy markets—produced figures 4 and 5 for their forecasts of conventional oil from fields and production of all liquids (NGLs, CTLs, Biofuels, Tar sands oil etc.) up to 2030 and 2070 respectively:

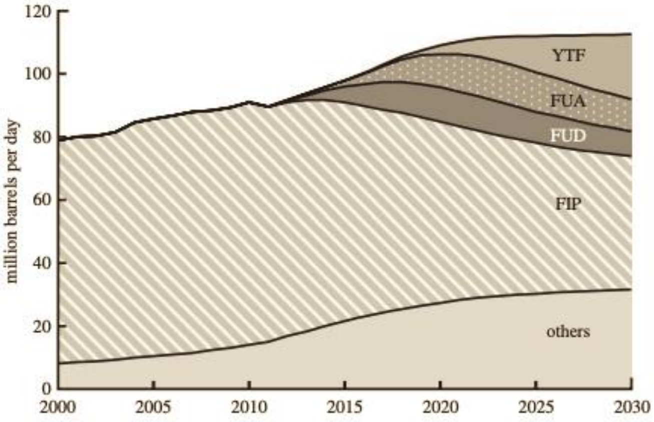

FIGURE 4*: IHS CERA GLOBAL REDESIGN OF LIQUID PRODUCTION: CONVENTIONAL OIL FROM FIELDS CURRENTLY IN PRODUCTION (FIP), FIELDS UNDER DEVELOPMENT (FUD), FIELDS UNDER APPRAISAL (FUA) AND FIELDS YET TO FIND (YFT) (JACKSON AND SMITH, 2013)*

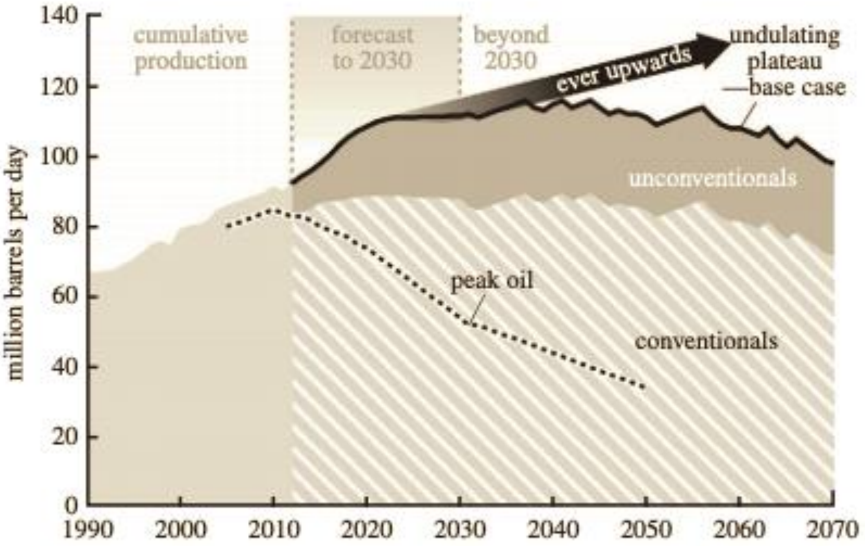

FIGURE 5: *FUTURE MODELS OF OIL PRODUCTION INDICATIONS 2030-2070 (JACKSON AND SMITH, 2013)*

Figure 4 shows no early peak but instead a negative gradient that extends all the way to 2030 and beyond at around 85Mb/d for conventional oil which starts from around 2020. For all liquids *CERA* indicates the plateau at around 115Mb/d starting at 2040 in figure 5. The Peak-Oil line refers to Colin Campbell's estimate of global URR conventional oil at a total of 1920Gb in contrast to *CERA* who predicted a full 1000Gb more for conventional oil and 700Gb more for all other oil. (Bentley, 2016; Campbell, 2015)

The plateaus in figure 4 and 5 are what Jackson and Smith, (2013) call "undulating plateaus". The total production forecast by *IHS CERA* in figure 4 shows that even for all liquids, the supply will not be able to keep up with demand beyond 2020 (keeping in mind the desired production is at the year 2000 level i.e. 80Mb/d).

Conversely, Laherrere's forecasts are of a conservative nature for which he collected data from a variety of sources. As discussed earlier, Laherrere adjusted for the industry data. Laherrere deduced an asymptotic production of 5Mb/d as shown in figure 6. Laherrere puts the global peak for all liquids at around 95Mb/d in the year 2016.

Figures 4 and 6 give a very polarised view of the forecasts. Laherrere says that Peak-Oil has already occurred and production is at 95Mb/d whereas *CERA* says that there is not a peak but there will be an all liquids plateau instead.

Figures 7, 8 and 9 show forecasts from 'mainstream' oil forecasting organisations. From figure 7 and 8, the forecasts for *BP* and *IEA* respectively, show very similar forecasts where the production of conventional oil stays flat until 2035. ExxonMobil (figure 9) also shows that global conventional oil production is forecast to remain flat until 2040.

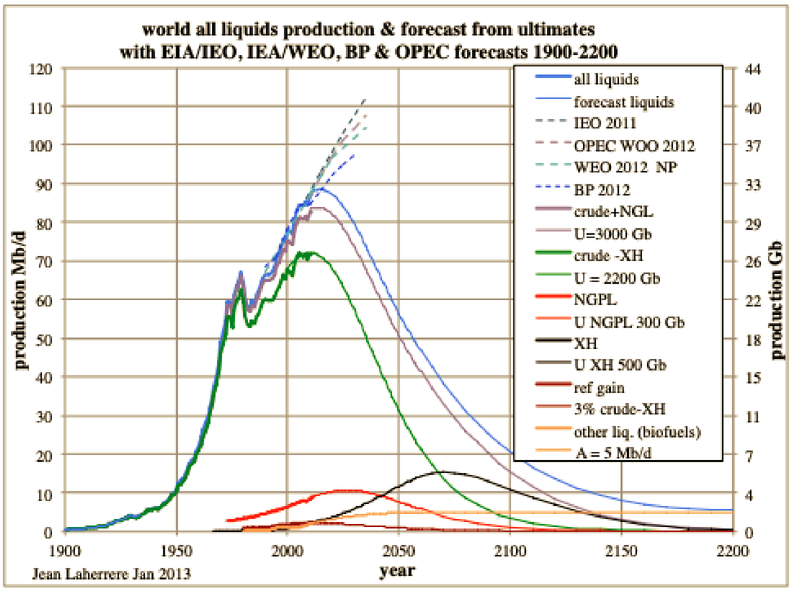

FIGURE 6*: LAHERRERE'S FORECASTS FOR GLOBAL OIL PRODUCTION*[2]

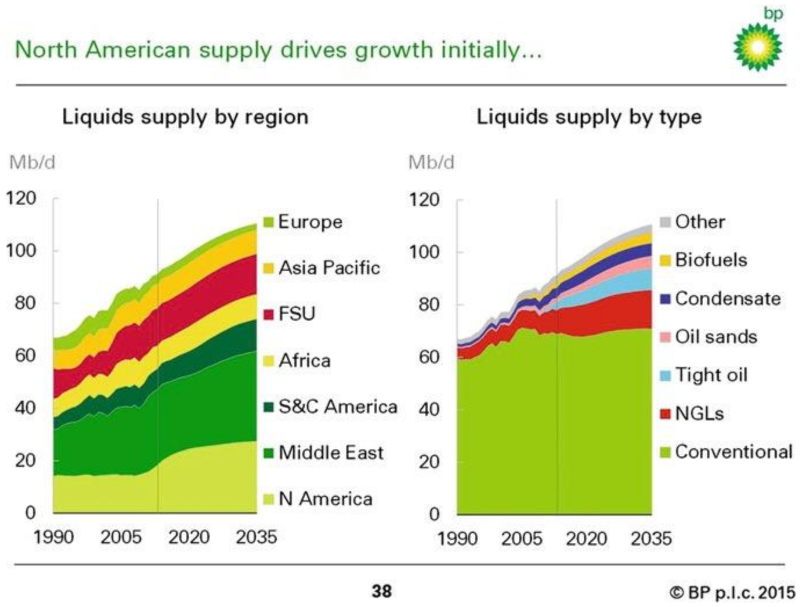

FIGURE 7*: BP'S ENERGY OUTLOOK FOR THE YEAR 2035 FOR ALL LIQUIDS*[3]

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[2] Jean Laherrere Ap 2015

[3] https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

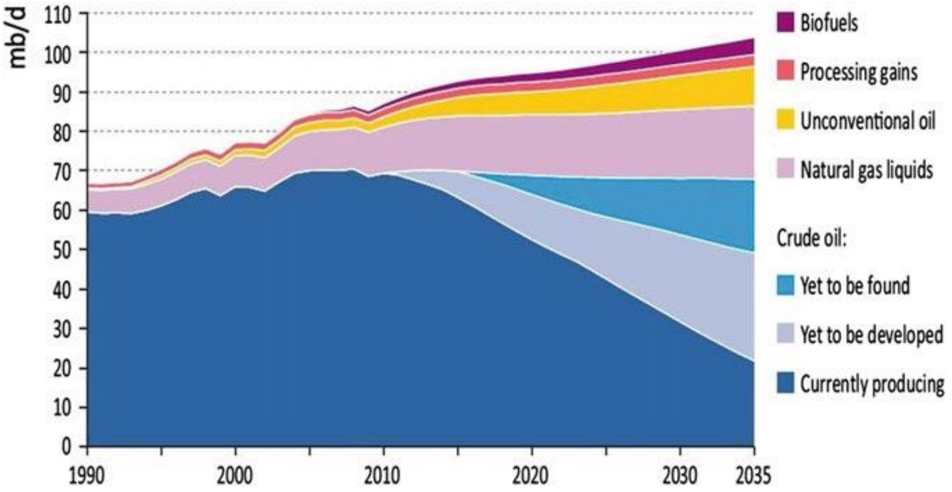

FIGURE 8: *THE IEA FORECAST FOR ALL LIQUIDS PRODUCTION UPTO THE YEAR 2035*[4]

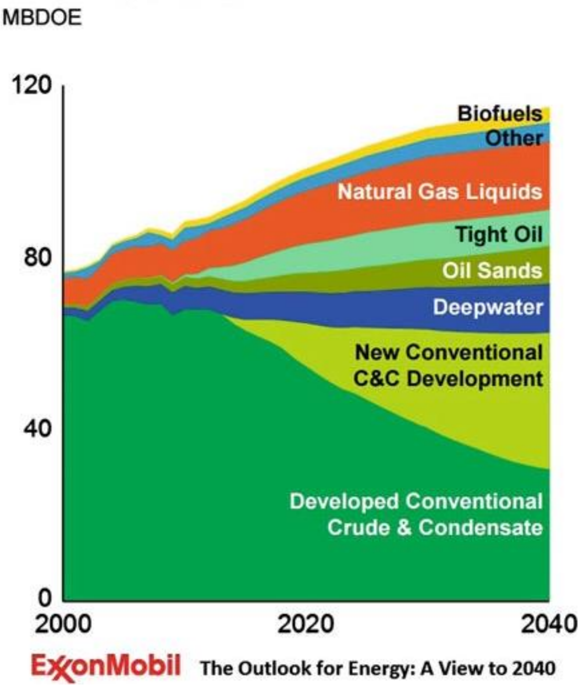

FIGURE 9: *EXXONMOBIL FORECAST UPTO 2040 FOR ALL LIQUIDS SUPPLY*[5] *(C&C=CRUDE AND CONDENSATE)*

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[4] IEA World Energy Outlook, 2011

[5] Figure taken from Bentley, (2016) who in turn got it from M. Mushalik who procured the data from ExxonMobil (http://crudeoilpeak.info)

The mainstream forecasters mentioned here do not see an 'all liquid' production peak in their forecast horizons however, they have begun to see a plateau in conventional oil production at-least. Recall section 1.2.2 on EROI and one can deduce that although mainstream forecasters do not see an 'all liquid' peak, the caveat remains that non-conventional oil does not give the same energy return on investment as conventional oil does.

Given the data above, it is fairly clear that global production peak for conventional oil as defined by Campbell and Laherrère, (1998) is already past, somewhere around 2005 (Bentley, 2016). The peak of 'all conventional' oil, has also already past with reference to the IEA data, at the time of writing this thesis. 'Below ground' factors such as resource limitation play a big part in this for example field decline. Friedrichs, (2010) outlines further *'above ground'*[6] factors as a result of Peak-Oil. He calls it "totalitarian retrenchment" whereby despots preserve privileges for themselves and their cronies in the face of adversity (Peak-Oil in this case) and "predatory militarism" such as that of Imperial Japan in 1941 from its then future forecast of energy shortages.

The peak of conventional oil production is therefore primarily due to resource limitation i.e. a limited endowment of oil to begin with (see section 1.1). A combination of factors such as flow rates and physical limits to extraction feed into the eventual peaking of a field, characterised by Hubbert's curve. From an economic point of view, higher prices will no doubt increase production, only up to a point, of conventional oil aided further by new EOR techniques. However, the resource limitation means that not much more oil will be produced. It is entirely plausible that the higher oil prices may not increase production and instead results in demand reduction, mainly from developed countries.

For "all oil" production (all liquids apart from GTLs, CTLs and biofuels), the peak is less certain but given that conventional oil production has already peaked, non-conventional oil production will go up significantly. However, whether this production will be able to offset the losses from conventional oil production is unclear. In relation to the EROI of non-conventional resources, this prospect of cutting short the losses incurred by conventional oil peak looks challenging. Should non-conventional production fail to plug the gap, the peak of all oil production would be expected to peak at around 2020.

For 'all liquids' i.e. GTLs, CTLs and biofuels, the resource base is large. For example, gas reserves to make GTLs. However, whether the costs such as low EROI, environmental concerns, carbon dioxide limits and the high conventional oil (Brent crude) prices makes for rapid increase in 'all liquids' production such that it adequately offsets conventional oil's decline is unclear.

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[6] *Above ground* in this case refers to human action as a result of Peak-Oil

All these factors need to be taken into account when forecasting, but it is plausible to conclude that the world practically and undoubtedly faces growing restrictions on 'all liquid' production, which is quite possibly a peak (Bentley, 2016).

The examination above presents an above and below ground as well as geopolitical understanding of the Peak-Oil phenomenon. When analysed this way, the fact that Peak-Oil is already here presents itself as a probable and possible proposition. However, the question one may ask themselves is: if all of this information was already available, why ambiguity has surrounded the Peak-Oil phenomenon. The final section of this chapter provides an overview of the potential explanations.

1.7 The Ambiguity Surrounding Peak-Oil

So far, this introductory chapter has approached the Peak-Oil phenomenon via explaining peak in terms of actual field production. Notable Peak-Oilists like Campbell and Laherrère, (1998); Deffeyes, (2006); and Hubbert, (1956) have all used similar explanations as baselines for their forecasts. Yet, the world as a whole has failed to grasp the concept of Peak-Oil (Bentley, 2016). For a number of years, most 'mainstream' forecasters like the *IEA*, *OPEC* and many oil consultancies have provided no warning for the high oil prices the world finds itself in today. Additionally, these organisations have gone as far as dismissing any concerns related to Peak-Oil. Notable media entities that exert huge influence such as the Economist have not contributed majorly to enhancing the debate on Peak-Oil either but given its neoliberal ideology, that is understandable (Becken, 2014). However, in this case, the focus shall remain on oil forecasters who did not entertain the warnings made by technical forecasts which ultimately meant that businesses, government and society at large did not incorporate Peak-Oil into their thinking. High oil prices around 2008 resulted in oil prices to go to the 1978 oil shock levels in real terms which helped trigger the 2008 global recession. The average high oil prices and their following high volatility caused significant economic hardship. Had the mainstream forecasters taken more responsibility in providing awareness to the world about Peak-Oil (conventional), society as a whole may have taken steps to better prepare itself for instance by consciously reducing oil consumption and downscaling economic activity

Bentley, (2016) outlines many reasons for the errors made by mainstream forecasters. Of those discussed in this thesis are:

(i) Use of 1P instead of 2P data for forecasting
(ii) The ill-attention to 'mid-point' peak when assessing future supply of conventional oil
(iii) The 'economic' argument of resource availability
(iv) Approaching 'Peak-Oil' from an analytical angle

1.7.1 The use of 1P data

The differences between 1P and 2P data have been discussed previously in sections 1.3.1 and 1.3.2 of this chapter. The point of information here is that many mainstream oil forecasters have used 1P data as the basis of making claims that a *steady rise* in global proved reserves is apparent. To name a few authors Watkins, (2006) stated that reserves were on the rise, however he was talking about 1P or proved reserves data, which has been one of the major sources of misunderstanding. Radetzki, (2010) also made the same error citing proved reserves data as the basis for his expectancy of large oil reserves.

BP and *Chevron* have echoed similar sentiments with their CEOs predicting that the world proved reserves are continually rising. *The Oil and Gas Journal* 2014 Worldwide Field Production Survey also used proved reserves data. The governing reason for using 1P data primarily seems to be that it fits the narrative of the historic average or higher expectancy in terms of oil availability in the world which is further incentivised by the fact that 2P data are difficult and expensive to access. It is small wonder then as to why many prominent forecasters have not understood and communicated it.

The reporting of 1P as opposed to 2P data matters a great deal since it is one of the primary reasons why the oil depletion debate is taking place. The conception that 1P reserves are a reasonable measure of remaining oil is debunked when for example looking back at the 1970s. Many believed then that the world would run out of oil because at the time it had 30 years of proved reserves (1P data). In 2006, the line was that 40 years of proved reserves remain. The impression one can gather from these conflicting claims is that 1P oil forecasting is unreliable (Bentley et al., 2007).

1.7.2 Consideration of 'Mid-Point' Peak in Future Supply Assessment of Conventional Oil

It is worth reiterating here that 'mid-point' peak does not refer literally to production peaking at exactly the middle point of all volume of URR estimates in a region. It is rather a concept that explains production in a region as it touches approximately half or less of the URR.

An example is that of Peter Davies, the Chief Economist of *BP*, who regularly dismissed the Peak-Oil Theory. In a House of Lords, UK committee in 2001, he expressed that the world still had 40 years of proved reserves thus arguing that peak must be far away. Perhaps BP was calculating reserves via dividing the current production by proved 1P reserves. Sorrell et al., (2010) argue that forming a judgement on the timing of peak production is indeed difficult, but possibly less important than acknowledging that it is likely and taking appropriate mitigating actions. Sorrell et al. (2009) conclude that larger estimates for global URR may be reasonable and hence the assumptions of some of the 'peaking' forecasts overly pessimistic. However, at the time of his speech, the world had already consumed roughly 1000Gb of oil out of its original URR availability estimated somewhere between 2000 to 3000Gb (excluding NGLs) with per year consumption at 30Gb. If the lower end of the URR estimate was used then this meant that the world had already used up half of its oil and the second half of production in the duration of the 40 years was going to happen at a declining rate. If the higher end of the URR estimate is taken into account, then the peak would be reached in roughly 17 years – where Sorrell et al. (2009) states that very high URR estimates do not move the peak point much further away -meaning that over half of the 40 years of proved reserves would be produced in the post-peak era. Whether Peter Davies understood this concept remains unclear but his clout in high circles remained significant in shaping the Peak-Oil discourse (Bentley, 2016).

1.7.3 The Economic Argument

The non-Peak-Oilists also subscribe to the view of traditional economics in terms of resource availability. What that means in practice is that higher prices will result in higher supply. This process has been called 'turning resources into reserves' where all classes of oil are considered including ones that are 'nearly oil' such as kerogen. In other words, this view preaches that oil reserves of all types and nearly oil should be seen as 'just inventory', waiting to be consumed. This argument has some merit since 'all oil' reserves are indeed substantial. However, the economic argument encompassing the supply/demand curve in an inverse ratio did not hold up in the case of the UK oil. Production in the UK peaked in 1999 when oil prices were $10/bbl before rocketing to $100/bbl. The higher price should have meant that production should increase but it did not(Bentley, 2016). Then there is the concept of substitutability which so far has proved not to be perfect in the case of oil i.e. no other energy source as of yet can compete with the EROI of classic conventional oil. The lesson from the UK experience is clear: conventional oil decline in the real world will not magically stop if the prices go up since there are physical and geological forces at play.

This economic view became dominant because of oil's history. Between the 1970s and 1980s the global 1P data predicted a mere 30 years of supply and that oil was to become ever scarcer. However, with the collapse of oil prices in the 1980s, this view came to the mainstream again with the presumption that it was correct leading to the views that forecasts based on a fixed quantity of available oil were grossly in error by the likes of Adelman, (1995).

1.7.4 Approaching Peak-Oil from an Analytical Angle

Throughout researching for Peak-Oil, this thesis agrees with Bentley, (2016) that a quantitative approach based introductory guide to this topic has been difficult to come by in academic literature. The impression a researcher with a technical background gathers from this is that either data driven (which encompasses not only economic data but also evidence based arguments for Peak-Oil were never popularised and given the time of day, or that somehow for reasons unexplainable, the quantitative data has been misunderstood for a very long time. When approaching the problem in the manner that this introductory chapter has outlined, it is difficult to dismiss that Peak-Oil has not or will not happen. Oil is a finite resource and no matter the economic argument, the reality is that it is not a matter of if but when it will peak depending on the definition i.e. conventional oil, all oil or all liquids.

1.8 Conclusions and the Future Outlook

With the data and explanations presented above, one would probably conclude a troubled picture of our energy future (even if good news in terms of CO2 emissions). How human ingenuity triumphs over the energy crises it faces in the short to medium term is yet to be seen. The picture will of course change if a significant new source of energy were to be discovered or invented for example. Given the vast amount of data we now have, coupled with new and emerging technology as well as the ability to accurately map the possible location of future oil fields, should new and vast fields emerge, the Peak-Oil debate may be put on hold. Should the recovery factor increase i.e. the URR of oil from conventional fields goes up, the Peak-Oil picture changes again. Currently the recovery factor by volume stands at 40% which means that 60% of oil is left unrecovered in the fields (Bentley, 2016). If the recovery factor were to change, the global oil supply would start to look much more optimistic. However, should this happen, it would spell disaster for climate change.

The overall reduction in world oil consumption due to carbon dioxide emissions fuelling climate change is another optimistic outlook. It is entirely possible that high prices and climate emergency policies force countries to reduce consumption and thus resulting in a fall in demand. Though this would be an ideal scenario and one that was discussed in the earlier sections, it does not seem likely. A recent report published by the The Economist, (2019) says that the oil majors are gearing up to expand production by 25% more in 2025 than in 2017 and for now, the worldwide demand for oil is growing at 1-2%. Whether events actually play out as planned by the oil majors is yet to be seen and everything will be quite different as expected after the corona crises.

1.9 Structure of this Thesis

There are four further chapters to this thesis. Chapter two contains the literature review. The contents include; complete derivation of the IOA the constituent parts of which are the Price Model, Ghosh Model and Forward Linkages. The chapter concludes with a summary of IO models' plausibility debate. Chapter three talks about the data and the experimental method used for price simulation. Chapter four presents the results in graphical and tabular format. These are accompanied by a detailed discussion of the results. Finally, Chapter five draws overall conclusions on the research and discusses limitations and future research avenues.

2 LITERATURE REVIEW: PEAK-OIL AND THE ECONOMY

2.1 Introduction

Chapter one of this thesis provided a technical overview as evidence that Peak-Oil, with all the information we currently have, is something that cannot be dismissed or debated down. The fact of the matter is that it is here and it will stay and will return in the aftermath of the corona crises. Finding new oil fields, raising EROIs or increased production from unconventional resources will only delay it (Hall et al., 2008). That Peak-Oil is an inevitable phenomenon-understood by way of "mid-point peak" modelling-for any and every producing field, region or world as a whole highlights its predetermined endowment. The economic argument of price rises resulting in higher production does not hold when the evidence of field production is taken into account. Instead a peculiar scenario of higher prices and falling demand becomes plausible. The falling demand can bring prices down temporarily but that will end up encouraging consumption while discouraging investment in energy conservation techniques because of high prices delaying economic adjustment and accelerating the coming of a recession (Ayres et al., 2013). The idea of perfect substitutability for oil is yet to take shape in the form of convincing EROIs i.e. substitutes cannot compete with the 'historic' EROIs of conventional oil.

In this chapter, this thesis starts to focus on the economic effects of high oil prices/energy shocks. Kerschner et al., (2013) is one comprehensive study looking at economic effects which they call a 'vulnerability' to Peak-Oil through the use of a disaggregated sector model i.e. the Input-Output Analysis (IOA).

2.2 The Reference Paper for this Research

This research is also based on Kerschner et al., (2013) who conducted a similar analysis on the US economy. In addition to using the Price Model and Forward Linkages, they also used out-degree centrality which is a technique originating from social network analysis or SNA which in-turn has its roots in sociology. To summarise the SNA sorts relations such as friendships among a given set of actors (nodes) into a square, actor by actor matrix much like the IOA which does the same for sector by sector. It has evolved over time as a "tool kit of concepts and measures for identifying important actors according to their structural position in the network of relations" (Kerschner et al., 2013)[7]. In the context of their research, out-degree centrality basically reflects the number of sectors to which a given sector *i* provides monetary inputs. So, if the

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[7] Can be found on Page 5 of Kerschner et al., (2013)

transportation sector has a high out-degree centrality, it would imply that transportation provides inputs to many other economic sectors (even if small in terms of economic value).

Even though this research has not utilized out-degree centrality, there is overlap on the basic idea of economic assessment analysis by Kerschner et al., (2013). Figure 15 shows the vulnerability map by Kerschner et al., (2013):

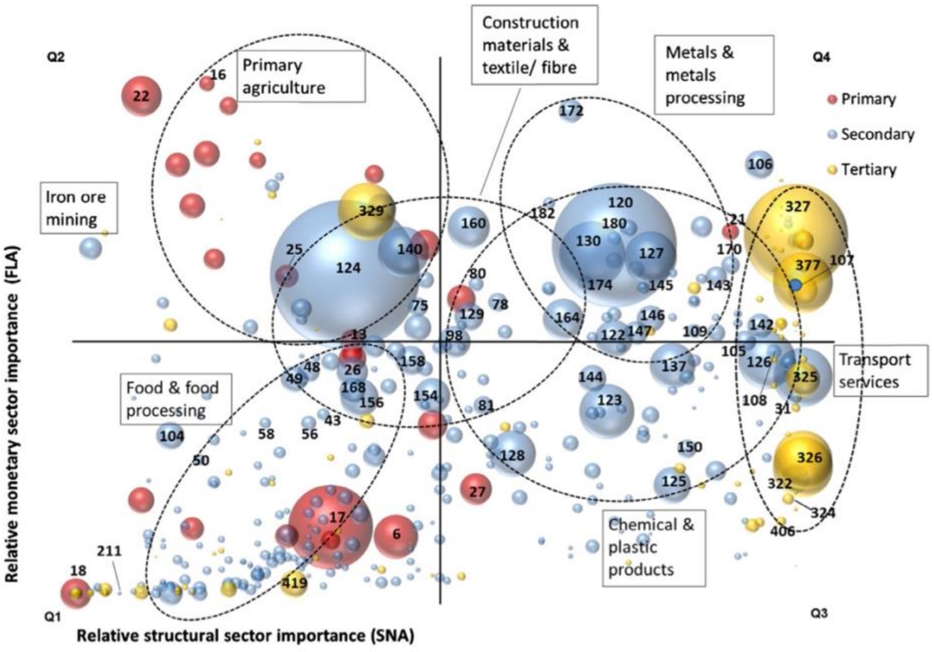

FIGURE 10*: US ECONOMY RESULTS BY KERSCHNER ET AL., (2013)*

The diagram is divided into four quadrants:

- Q1 (bottom left) identifies the least important sectors in terms of both monetary and structural contribution.
- Q2 (upper left) holds sectors with increasing monetary importance.
- Q3 (bottom right) is for structurally important sectors irrespective of their contribution to GDP
- Q4 (top right) has the most important sectors according to both monetary value and structural importance

The bubbles and numbers within represent sectors (for a list sectors refer to Kerschner et al., (2013)) The bubble sizes visualise how vulnerable a sector is. The colours represent agriculture and mining etc. (red), manufacturing (blue) and services (yellow).

There are similarities in the findings of Kerschner et al., (2013) and this research over the most affected sectors in the US economy. For example, the construction cluster in their diagram is an amalgamation of many secondary sectors and some primary sectors. This research also found that the construction sector was one of the most affected in the US economy. A third source of similar information was mentioned earlier about *BP's* assessment of the most oil intensive sectors in the US economy. Given this consensus, one can begin to converge on the suggestion that construction is prone to disruption of a higher magnitude than some other sectors in the US economy. By contrast, the transport sector does not feature in the most affected sectors for this research as it does in Kerschner et al., (2013). It is not clear why this is the case. Similar to the findings of this research, the chemicals and plastics cluster contains myriad secondary sectors that have relatively bigger bubbles than clusters such as food and food processing. Chemicals and plastics manufacturing features in the most affected sectors of this research as well. All this really tells the reader is that things have not changed much in the USA in relation to the chemicals and plastics manufacturing in the five years between Kerschner et al., (2013) and this research (data for this research comes from 2018).

Out-degree centrality certainly adds that extra dimension of structural importance of a sector to the macro-economy. Since this research has not employed out-degree centrality as it was out of scope for this work, the comparisons made here are based purely on price increases relative to forward linkages in an economy. Finally, similar studies looking at the UK and Czech Republic economies are not available in current literature which means that a similar comparative analysis cannot yet be undertaken for these economies.

2.3 Peak-Oil in Literature

Pargman et al., (2017) argue that the stories we tell ourselves about the world such as what matters and what does not, what is right and what is wrong etc. play an important role in our decision making as well as policy endorsements. In relation to Peak-Oil, they argue that speculative methods are capable of illuminating hidden biases in contemporary thinking while putting forth the proposition of alternative perspectives for action. Specifically, the speculative method they have adopted in this paper is an *"allohistorical narrative"*; a parallel universe where only half of the total oil was present. What would this world look like? The main difference between the imagined world and the real one is that coal is more abundant here. The paper primarily raises questions such as *how does the decline of oil impact transport infrastructure? How does it impact geopolitics? How does it impact food production and health, industrial design and technological innovation, sociocultural norms, practices, beliefs and narratives, the impact on climate as well as what children would read in history books?* The aim of this paper is to present a believable scenario that never happened–but could have been–by placing Peak-Oil in the past, somewhere around the 1970s and using that as a guiding light to forge events up to the present day. Though the paper asks interesting questions, it does not provide answers to them.

Chapman, (2014) discusses that until 2014, Peak-Oil was a major discussion point yet since then it has attracted lesser attention. His paper evaluates the continued relevance of Peak-Oil and criticises the commercial interests and an unproven belief in the market as well as technical solutions which have come about through a narrow paradigmatic focus. He states that critics of Peak-Oil theory have used unreliable reserves data, over optimistic assumptions about the supply of unconventional oil and unrealistic predictions for alternative energy production to discredit evidence that the resource limited peak in the world's oil production has already arrived. He states that the Peak-Oil doubters use figures and counter arguments for their own positions that tend to criticise Peak-Oil theory from three perspectives i.e. that reserve estimates show sufficient oil for decades of high output production, irrespective of inconsistencies in the data, that technological solutions will make sure that conventional fields continue to yield higher percentage of oil than was previously possible and that alternative energy will be increasingly adopted and gradually replace oil, eased by the use of gas. On the other hand, he also states that proponents of Peak-Oil may over or underreport on for example reserve sizes to justify certain arguments. Those that believe Peak-Oil has already happened tend to provide a definitive date. They also often criticise the oil industry or doubtful as to the ability of governments to think strategically. However, Chapman, (2014) concludes that rather arguing for or against, Peak-Oil should be acknowledged and accepted as part of a complex energy situation based on the realisation that cheap fuel is no longer available and that prices will increase leading to a decrease in high energy based growth. He also suggests that the role of nuclear power needs proper re-evaluation as well as the effectiveness of different renewables.

Höök et al., (2014) looked at hydrocarbon liquefaction's viability as a Peak-Oil mitigation strategy. They look at CTL (coal to liquid fuel) and GTL (gas to liquid fuel). They find that there three dominant issues with this strategy. Firstly, significant amounts of coal and gas would be needed to get anything more than a marginal production of liquids. Second, the cost of CTL plants is excessive though it is better for GTL. Even so, large scale GTL plants require a very high upfront investment. Finally, both GTL and CTL extract heavy environmental toll, ranging from increased greenhouse gases to water contamination. The paper concludes by reflecting that CTL would only work for countries with large coal reserves such as China, USA, India, Russia, Australia and South Africa. Also, financing CTL projects would be significantly difficult unless the public discourse goes in favour of it which is unlikely given its environmental impact. GTL also faces similar problems such as high capital costs, technical efficiency and reliability, oil price volatility, uncertainty of the petroleum products markets and project financing. Technological viability is an issue with GTL since only a small number of companies hold important patents to its production methods.

Kerschner et al., (2013) developed a vulnerability map of the USA economy by combining two tools used to analyse economic systems i.e. Input-Output Analysis and Social Network Analysis (not a staple of economic analysis) applied to economic data. Their approach shows the relative economic importance of sectors vulnerable to Peak-Oil furthermore, identifying strategic sectors with the highest contribution to GDP that could put the entire USA economy at risk from Peak-Oil. Kerschner et al., (2013) outlined such sectors including Iron Mills, Fertilizer Production and Air transport. Transport is a sector at one of the highest risks as it uses a great deal of fossil fuel in the form of petrol, diesel and kerosene for example.

As mentioned earlier, studies that look specifically at the macroeconomic effects of Peak-Oil are few and far in between. Logar and van den Bergh, (2013) for example, use an IOA model to examine the impact of Peak-Oil on tourism in Spain and the resulting effects on the Spanish economy. They do so by developing a number of situations where oil prices increase and analyse the estimated change in the price of tourism services in Spain, the effect of price changes on tourism services demand and what this demand change would do to the Spanish economy. Their results show that as the demand for tourism decreases, the highest falls in outputs are observed in tourism related shares of air, water, land and railway transport sectors. This is followed by the output falls in tourism agencies' activities, non-market recreational, cultural and sporting activities, restaurants and hotels. They adopted various oil price scenarios (US$115, US$150 and US$200 per barrel) to assess GDP (gross domestic product) decrease. They found that it was between -0.08% to -0.38% with the number of job losses through direct and indirect effects at 20, 000 and 100, 000.

Murray and Hansen, (2013) frame Peak-Oil as not about oil reserves or resources because neither translate into production rate. Therefore, Peak-Oil is not about running out of oil but about its peak in production. They state that "*production is the key metric because price is controlled by the balance between supply and demand*." Peak-Oil would be a myth if a reader is expecting an abrupt decrease in oil production. The case in which it is not a myth is if the reader understands that the coming about of Peak-Oil is a struggle between supply and demand which is resolved through global oil markets. Therefore, Peak-Oil can originate from economic as well as geological factors. However, Murray and Hansen, (2013) also state that since expensive unconventional sources are only short term fixes to an otherwise plateauing conventional oil production, societies face a dilemma; *"Will prices stay high enough to develop unconventional sources and, in doing so, limit economic growth? Even so, can the production rate of unconventional oil ever be enough to support the concept of an "energy revolution", much less "oil energy independence?"* (Murray and Hansen, 2013) [8]

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[8] Page 246, EOS Transactions American Geophysical Union Journal, 2013

Kerschner and Hubacek, (2009) assess the suitability of the IOA for the economic effects of Peak-Oil. Owing to its suitability to analyse the quantity dimension of Peak-Oil, they applied the supply-constrained model to the UK, Japanese and Chilean economies showing results that exhibit the differences between the net-oil importing and exporting countries in terms of final demand. Through its application on the economies listed, Kerschner and Hubacek, (2009) demonstrate that the supply-constrained model is a highly promising candidate for analysing the quantity dimension of Peak-Oil. Furthermore, they argue that since production coefficients, which represent the technological evolution of a sector (see next section 2.3), cannot be replaced instantaneously, they make possible the evaluation of *"short-run effects of supply shocks, damages through environmental events or other man-made catastrophes. Thus, IO has proven to be very valuable for risk assessments as performed in this study."* Kerschner and Hubacek, (2009)[9]

Campbell and Laherrère, (1998) remains the seminal paper on Peak-Oil in the last twenty years. In it, they asserted that the coming oil crunch would not be temporary. They based their claim on identifying three critical errors prevalent in the oil industry forecasts at the time, namely distorted estimates of reserves, the pretention that production will remain constant and lastly the assumption that every bucket drop of oil can be pumped from the ground with the same ease as when the pumping first began. They explain the concept of "mid-point peaking" in production and deduce hence that the "*economic perspective*, *when the world runs completely out of oil is thus not directly relevant: what matters is when the production begins to taper off."* They conclude the paper by advising that the world would soon have to come to grips with the end of cheap and abundant oil.

Finally, Hubbert, (1956) is where the concept of Peak-Oil began alongside the coining of the term "Peak-Oil" by M. King Hubbert. Hubbert explained that field production goes up with time, reaches a peak and then declines. He explained this by way of a bell-shaped curve (Refer to figure 3). He concluded his report with a thoughtful observation which stated that 5000 years into the future discovery, exploitation and exhaustion of the fossil fuels will be seen as just another short-lived event in the span of recorded history.

2.4 The Input-Output Analysis

2.4.1 Introduction and background

Input-Output Analysis or IOA (throughout the duration of this text, Input-Output Analysis and IOA will be used interchangeably) Wassily Leontief in the late 1930s for which he received the

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[9] Page 1667, Energy Journal, 2009

Nobel prize in 1973. His structural approach would have paved the way for the transformation of Economics into a truly empirical discipline although that has not materialised. IOA is also referred to as *interindustry analysis.* This is because the main purpose of IOA is to analyse the dependence of different sectors within the economy on each other.

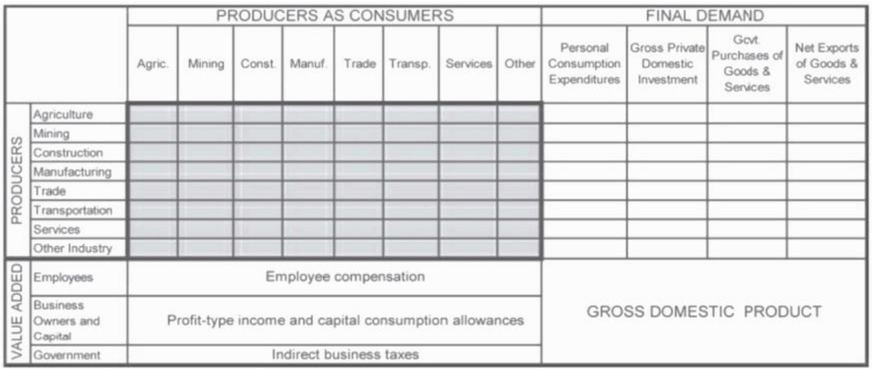
Wessily Leontief was born in 1905 in Munich to an intellectual Russian family but spent his childhood in St. Petersburg. In 1925, he moved to the University of Berlin where he began working on his doctorate assembling ideas for what he described as “the national economy as a circular process.” In 1928, he published a paper where he explained a two-sector Input-Output system that represented variables such as production, distribution and consumption characteristics of a given economy as a single integrated system of linear equations. In 1932, Joseph Schumpeter head-hunted Leontief from the National Bureau of Economic Research, New York (which he had joined in 1931 following his move to the USA) and took him to Harvard where he began work on the first IOA tables for the US Economy. Finally, in 1936 came the complete explanation of his analytical framework.

“In its most basic form, an Input-Output model consists of a system of linear equations, each one of which describes the distribution of an industry’s product throughout the economy. Most of the extensions to the basic Input-Output framework are introduced to incorporate additional detail of economic activity, such as over time or space, to accommodate limitations of available data or to connect Input-Output models to other kinds of economic analysis tools (Miller and Blair, 2009).”

The premier book for Input-Output Analysis is Miller and Blair, (2009) which provides a detailed insight into the workings of the model, for those readers interested in further understanding. Here however, the explanations have been trimmed down in relation to the perimeters of this research.

2.4.2 The Basics of IOA

The basic Leontief IO table is constructed from observed economic data. This observation can be made for a nation, state or a country etc. Specifically, the user makes their observation within the activity of a group of industries that produce goods and supply goods. In IOA language outputs and inputs are synonyms of production and supply respectively, and will be used interchangeably throughout this text. Coming back to industry observation, the information one extracts concerns the flow of products from each industrial sector to itself and to other sectors. For example, the steel industry manufactures steel that is used to develop and maintain machinery used within the steel industry itself as well as in other industries such as car making or construction. This makes the steel industry a producer and a consumer while making all other industries consumers only. However, it is also possible that consumer industries of steel provide inputs to the steel industry as well. For example, electricity production requiring inputs of steel for a grid but providing electricity as an input to the steel industry. When defining IOA like this, it is easy to see that industries are directly and indirectly linked within an economy and the tabulated form of this information is the basic IO table. Figure 10 shows an example of an IO table:



		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Govt. Purchases of Goods & Services	Net Exports of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
	Other Industry												
VALUE ADDED	Employees	Employee compensation								GROSS DOMESTIC PRODUCT			
	Business Owners and Capital	Profit-type income and capital consumption allowances											
	Government	Indirect business taxes											

FIGURE 11: *INPUT-OUTPUT TRANSACTIONS TABLE (MILLER AND BLAIR, 2009)*

The rows of this table report on the allocation of a producer's output throughout the economy (which is made up of all the sectors listed here). The columns define the inputs required by a particular industry to produce its outputs. The producers and consumers are all the industries and are shaded in grey here.

The non-shaded area of the chart stands for the *Final demand*. Final demand signifies the end user or consumer. In other words, it is you and I. For example, electricity is sold to other sectors as an input as well as to residential customers.

The bottom left part of the table labelled *value added*, accounts for non-industrial inputs necessary for production. These are labour, capital, imports and taxes.

The final section of the table; the bottom right hand part, is the total sum of everything in this table. This number is the GDP or Gross Domestic Product of the nation, country or region under observation.

2.4.3 Fundamental Relationships and the Leontief Inverse

In order to understand how an Input-Output table works, one must first go through the derivation of the fundamental relationships that result in a compact equation, which represents the Input-Output Analysis. Understanding the mathematics behind IOA requires the reader to have a foundation in matrix algebra. Miller and Blair, (2009) provides all the necessary concepts for the interested reader to get started. Furthermore, arguments between different academics over the utility of the IOA models discussed here are only summarised in this thesis. Should the reader be interested in further detail, the author recommends Kerschner, (2012) Chapter 2.

Let $x_i$be the total output/production of sector i

Let $f_i$be the final demand for sector i's product

Let j be some last sector in the economy

Let z be the product of sector i

The equation representing sector i's production is given by the following relation:

$$x_i = z_{i1} + z_{i2} + \cdots z_{in} + f_i \tag{2}$$

Alternatively, equation (2) can be written as

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{3}$$

Where z_{ij} represents the interindustry sales by sector i to sector j

Going back to equation (2), it represents the general form of an equation which represents a given sector's product and its distribution throughout the economy as inputs to other sectors. So, equation (2) for sector 1 in an economy for example will be given by:

$$x_1 = z_{11} + z_{12} + \cdots z_{1j} + f_i \tag{4}$$

Equation (2) can be extended for sector 2, 3 and so on. Simply replace the 'i' in the equation with the sector number you are looking at.

Similarly, for sector 'n' the equation is given by

$$x_n = z_{n1} + z_{n2} + \cdots z_{nj} \ldots + z_{nn} + f_i \tag{5}$$

Now, we come to representing the equations above in matrix form. The following nomenclature applies to the matrix form with everything else remaining the same as explained on page 22.

(i) Lower case bold letters represent column vectors. For example; $\boldsymbol{x}$ as opposed to x and $\boldsymbol{f}$ as opposed to f

(ii) For $\boldsymbol{x}$ and $\boldsymbol{f}, \boldsymbol{x}'$ and $\boldsymbol{f}'$ represent corresponding row vectors or the transpose matrix

(iii) Upper case bold letters represent a matrix of the order n x n; **Z** in this case for example

With this information in mind, equation (2) is written in matrix form as follows:

For sectors

$$\boldsymbol{x} = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_n \end{pmatrix}$$

For products

$$\boldsymbol{Z} = \begin{bmatrix} z_{11} & z_{1n} \\ z_{n1} & z_{nn} \end{bmatrix}$$

For final demand

$$\boldsymbol{f} = \begin{pmatrix} f_1 \\ \vdots \\ \vdots \\ f_n \end{pmatrix}$$

Now that we have established the corresponding matrix form of equation (2), we can condense equation (2) further still as

$$\boldsymbol{x} = \boldsymbol{Z}\mathbf{i} + \boldsymbol{f} \tag{6}$$

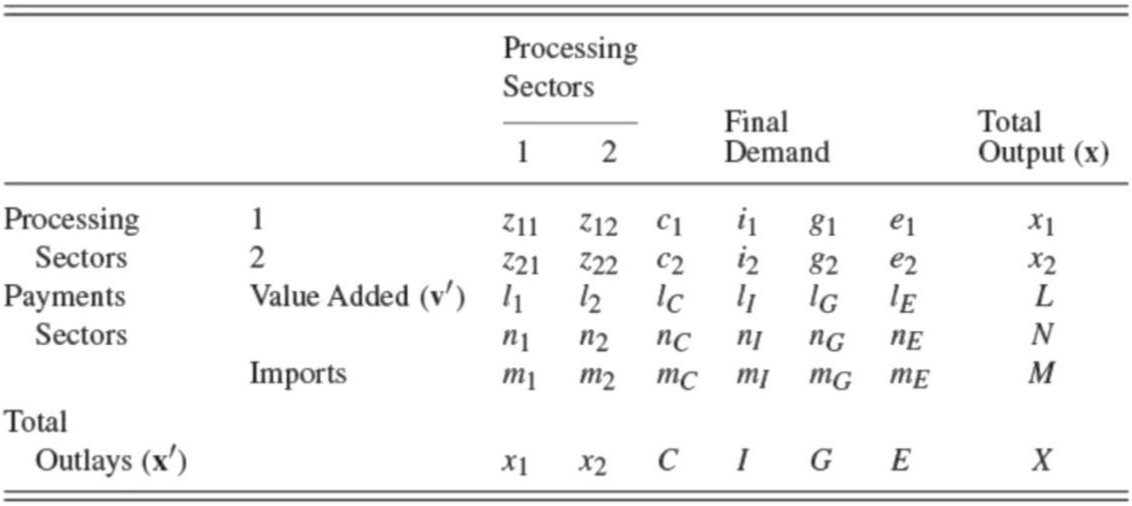
Where **i** represents the column vector of 1's depending on the column dimension of the rest of the equation. In this case it is $\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1n \end{pmatrix}$**.** This is also known as the **summation vector.**

Observation: When solving with **i** as column vector, the resulting numbers are equal to the row sums of the matrix **Z.** Alternatively for **i'** (which would become a **row summation vector**), the resulting numbers are the column sums of matrix **Z.**

Now consider the information in the jth column in equations (2), (4) and (5). When represented as a column vector it becomes:

$$\boldsymbol{x} = \begin{pmatrix} z_{1j} \\ z_{ij} \\ \vdots \\ z_{nj} \end{pmatrix}$$

This vector represents the sales to sector j OR purchases by sector j. Furthermore, this is the **source** and **magnitude** of sector j's **inputs i.e.** what sector j consumes in order to produce its own products.



		Processing Sectors 1	2	Final Demand				Total Output (x)
Processing Sectors	1	z_{11}	z_{12}	c_1	i_1	g_1	e_1	x_1
	2	z_{21}	z_{22}	c_2	i_2	g_2	e_2	x_2
Payments Sectors	Value Added ($\mathbf{v}'$)	l_1	l_2	l_C	l_I	l_G	l_E	L
		n_1	n_2	n_C	n_I	n_G	n_E	N
	Imports	m_1	m_2	m_C	m_I	m_G	m_E	M
Total Outlays ($\mathbf{x}'$)		x_1	x_2	C	I	G	E	X

Figure 10: Input-Output table for a Two Sector Economy (Miller and Blair, 2009)

Figure 10 shows an IO table for a two-sector economy. Here, labour and capital have been grouped together as **Value Added**. It is worth noting that labour and capital are primary inputs (production cannot happen without these). Furthermore, all value added/primary inputs are lumped together in the **Payments Sector.**

In figure 10, **C, I, G and E** represent **C**onsumer (household) purchases, **I**nvestment for private purchases, **G**overnment purchases and **E**xports.

In this table and generally for a given IO table, there are two components to the final demand. The first is exports and the second is domestic demand.

For sectors 1 and 2, the final demand is given by:

$$f_1 = c_1 + i_1 + g_1 + e_1 \tag{7}$$

$$f_2 = c_2 + i_2 + g_2 + e_2 \tag{8}$$

L has two component parts for sector 1 and 2 which is employee costs or labour services and represented by $\boldsymbol{l_1} and\ \boldsymbol{l_2}$. **N** represents all value-added payments and are denoted by $\boldsymbol{n_1} and\ \boldsymbol{n_2}$. This makes the value-added payments as:

$$v_1 = l_1 + n_1;\ v_2 = l_2 + n_2 \tag{9}$$

Now, let us consider z_{ij} which represents the inter-industry sales. The understanding so far suggests that if more cars are needed from sector j (the manufacturer for example), more steel will be required from the steel industry or sector i in this case. However, the caveat here is over the nature of this relationship. This is where z_{ij} needs to be expanded further. In the case of steel input to car output, z_{ij} expands to the following equation:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{10}$$

Where a_{ij} is the technical coefficient and the ratio represents the production of sector j with steel input from sector i, with respect to the total production of ***industry*** j in that year. Re-arranging the equation for z_{ij} gives:

$$a_{ij}x_j = z_{ij} \tag{11}$$

We can now substitute equation (10) into equation (5) giving a general form:

$$x_n = a_{n1}x_1 + \cdots a_{ni}x_i + \cdots a_{nn}x_n \ldots + f_n \tag{12}$$

For equation (5), we represented the matrix equation in (6). The same can be done for equation (11):

$$x = Ax + f \tag{13}$$

Where A represents the matrix of technical coefficients.

Making *f* the subject of the formula gives the following equation:

$$(I - A)x = f \tag{14}$$

Note that since equation (12) is a matrix equation, taking Ax and taking x common will give I-A instead of 1-A where I is the identity matrix. For a given set of final demands *f's*, this is a set of *n* linear equations in the *n* unknowns.

Finally, the **Leontief Inverse** or the total requirements matrix is given by making x the subject of the formula:

$$x = f(I - A)^{-1} \tag{15}$$

Matrix A is interesting because it essentially tells how well a particular section of the economy is performing in terms of its particular inputs. Furthermore, it indicates the status of technology which means that if one follows the evolution of matrix A for a given section of the economy, one would be able to quantitatively state how well it is doing in terms of technology.

Finally, the Leontief IO model is driven by exogenous demand changes therefore, making it a demand driven model.

2.4.3.1 The Price Model

The original idea behind Leontief's model was to use physical units to represent the information in an IO table. For example; bushels of wheat, yards of cloth, man-years of labour etc. Physical units therefore assumed that the technical coefficients matrix **A** was based on physical quantities. These days however, Input-Output data are generally assembled in monetary terms such as the tables used for the analysis in this thesis. With physical quantities replaced by monetary units, the Leontief model has a mathematical dual known as the price model. (Miller and Blair, 2009). Below is the derivation of the Price model:

$$x_i = \sum_{j=1}^{n} z_{ij} + v_j \tag{16}$$

Equation (15) can be expressed in transposed matrix terms as

$$x' = Z\mathrm{i}' + v' \tag{17}$$

Where v' is the total value-added expenditures by each sector

$$v' = [v_1 \dots v_n] \tag{18}$$

When equation (6) and (13) are equated as an identity

$$Ax + f \equiv Z\mathrm{i} + f \tag{19}$$

Comparing equation (19) for Z, we get

$$A\hat{x} = Z \tag{20}$$

Where $\hat{x}$ represents a diagonal matrix with the elements of the vector along the main diagonal.

Observation: Multiplying $\hat{x}$ by $\hat{x}^{-1}$ results in the identity matrix (I) which is given by

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{21}$$

Substituting equation (19) into equation (16) gives

$$x^{-1}\hat{x} = i'A\hat{x}\hat{x}^{-1} + v'\hat{x}^{-1} \tag{22}$$

We can see that the technical coefficients matrix is now in the equation. Simplifying it gives

$$i' = \mathrm{i}'\mathrm{A} + v'_c \tag{23}$$

Where $v'_c = v'\hat{x}^{-1}$ and the right-hand side of equation (22) is the cost of inputs per unit of output. **A** in this equation now is for monetary units. The technical coefficients in this matrix represent the inputs required to produce $1 worth of output for each sector. At this point, the conversion of the traditional Leontief quantity model is complete and we can now interpret this equation for base year index prices with new notations to reflect the Price Model.

$$\tilde{p} = \tilde{p}\mathrm{A} + v'_c \tag{24}$$

Rearranging this equation for $\tilde{p}$ and expressing it in terms of column vectors gives

$$\tilde{p} = (I - \mathrm{A})^{-1} v_c \tag{25}$$

Equation (23) is dependent on changes in v_c that would lead to both direct and indirect price increases throughout an economy as the sectors are connected.

2.4.3.2 Assumptions and Limitations of the Leontief IO Model

The Leontief IO model is driven by demand only. This means that it cannot be applied to situations where the analysis requires the user to change supply inputs. As expressed from equation (10) the price ratios are constant between inputs. The price elasticities are also zero in the Leontief model. Finally, since the model is demand driven, there is no accounting for forward but backward linkages (explained in the following sections) (Kerschner, 2012).

2.4.4 The Ghosh Model

So far, the Leontief model, which is driven by exogenous demand has been discussed. One of the limitations of the demand driven model is that the user cannot use it in situations where supply input change effects are the intended measurable quantities. For example, in the context of this research, when oil prices rise, what multiplier effects will be seen throughout the economy relative to the least and most oil consuming sectors cannot be revealed by the demand driven model.

In 1958, Ghosh proposed a substitute approach to the Leontief Input-Output model. The Leontief inverse in equation (15) relates the gross outputs of all sectors to the amount of the final product or final demand i.e. at the end of the process a unit of product *leaves* the interindustry system. Ghosh's interpretation does the opposite. Instead of relating sectoral gross outputs to the final product, it relates it to primary inputs i.e. a unit of value *entering* the interindustry system at the beginning of the process (Miller and Blair, 2009).

First, the mathematics underpinning Ghosh's approach require the user to "rotate" or transpose the vertical column view of the Leontief model to a horizontal view. Second, the matrix of coefficients **A** will now be denoted by **B** where instead of dividing each *column* of **Z** matrix by the gross output of the sector as in equation (10), the division is done by dividing each *row* of **Z** by the gross output of the sector associated with that row. Matrix **B** is called the *direct-output coefficients* matrix in this case.

The direct output coefficients matrix is given by the following equation. Notice that the division is done by x_i instead of x_j in this case:

$$b_{ij} = \frac{z_{ij}}{x_i} \tag{26}$$

The b_{ij}coefficient represents the distribution of sector i's outputs across sector j that purchase interindustry inputs from i. These are called *allocation* coefficients as opposed to technical coefficients.

By expressing the columns as rows or transpose, equation (17) applies i.e.

$$x' = Z\mathrm{i}' + v' \tag{27}$$

Recall that v from equation (18).

In equation (20), we replace **A** with **B**

$$B\hat{x} = Z \tag{28}$$

Substituting equation (28) into (27) for Z we get

$$x' = \mathrm{x'B} + v' \tag{29}$$

Where i'$\hat{x} = x'$

Rearranging equation (27) for x

$$x' = \mathrm{v}'(\mathrm{I} - \mathrm{B})^{-1} \tag{30}$$

Where the $G = (\mathrm{I} - \mathrm{B})^{-1}$ is the Ghosh inverse with elements g_{ij}.

Re-arranging for x, we get

$$x = \mathrm{G}'\mathrm{v} \tag{31}$$

2.4.4.1 Linkages in Input-Output Models and Forward Linkage Analysis

When one speaks about the economy and "interconnectedness" of sectors, it is natural to deduce that for example, a change of price or production in sector A shall have a direct or indirect effect on sector B, C, D…etc. and vice versa. Specifically, however, there are two types of economic effects taking place when considering this example. Let us start with sector A increasing its output. When this happens, the *demands* from sector A on other sectors (B, C or D) whose inputs it uses for its own output, goes up. Notice the word *demand* in this example. Intrinsically, when linked with an IO model the conclusion points to the demand driven model. Miller and Blair, (2009) refer to this as the "direction of causation in the usual demand-side model and the term *backward linkage* is used to indicate this kind of interconnection of a particular sector with those (“upstream”) sectors from which it purchases inputs.”

Let us view the earlier example again but from a different perspective. When output increases in sector A, one can also say that there are increased *supplies* from sector A available for all other sectors that use a part of its output as their own inputs. Notice how the focus has shifted from *demand* to *supply* when the same example is viewed from a different perspective. We have now changed the “direction of causation” to the supply side and now the term *forward linkage* is applicable to reflect this type of interconnection of sector A “to those (“downstream”) sectors to which it sells its output (Miller and Blair, 2009)”[10].

Applying the concept of forward linkages to Peak-Oil analysis would mean that high oil prices having primary direct effects on the most energy intensive sectors, sector A in our example, thus significantly raising its costs. This increase will then be directly and indirectly passed on to all the sectors that are linked to sector A, henceforth revealing a multiplier effect throughout the economy. Forward linkages will aid in understanding a sector’s economic significance to GDP. In practice, this means that if for example sector A experiences a 50% price increase, the corresponding forward linkage value represents its position within the economy. The higher this forward linkage number, the more economically significant the sector is to economy.

Forward linkage analysis is based on the Ghosh IO model where the transactions **Z** are the sum of intermediate sales by sector i as a proportion of the total value of i’s total output (x_i). To capture forward linkages, one simply takes the row sums of the Ghosh Inverse where each row sum reveals the total value of intermediate sales of sector i as a proportion of the value of i’s total output. Expressed mathematically, forward linkages are given as:

$$FL_i = \sum_{j=1}^{n} g_{ij} \tag{32}$$

Where the elements of the Ghosh Inverse are given by g_{ij}.

2.4.5 A Summary of the Plausibility of IO Models Discourse

The literature review so far has covered two types of Input-Output models i.e. the demand driven Leontief model and the supply driven Ghosh model. The idea is to use the price model to artificially inflate the oil prices such that all oil consuming sectors see their costs go up disproportionally to the inflation factor. However, why not use linkages from the Leontief model

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[10] Page 14752 of the electronic version of this book

instead of using the Ghosh model. The straightforward answer is that the demand driven nature of the Leontief model allows for *backward linkages* only whereas the supply driven nature of the Ghosh model allows for *forward linkages.* Since we are looking at energy from oil at a very high price, the Ghosh model allows one to theoretically determine the multiplier effects in a *downstream* manner throughout the economy. However, why not use the Ghosh model instead of the Leontief model for the quantity dimension of Peak-Oil

Oosterhaven, (1988) published a paper on the plausibility of the supply side model in which he asserts that the theoretical use of supply driven model to indicate forward linkage strength is justified, but all other applications are flawed. He severely criticised the supply side model for its implausible use in international comparative studies, national and regional searches for key sectors and national/regional impact studies. He cites that the Ghosh model takes demand for as being perfectly elastic. This means that final demand reacts perfectly to any supply changes and that purchases such as factories without machines etc. will continue to be made. In case of closing the model with respect to households for example, the supply driven model states that the supply of one million shirts would mean that household income would also increase by one million, which is clearly implausible. The Ghosh model therefore ignores the interdependence of products.

Oosterhavens', (1988) severe criticism of the supply driven model started a discourse with Gruver†, (1989) stating that the solutions presented by the supply driven Input-Output models are plausible and consistent with basic production theory under a very strict set of assumptions imploring that the characteristic of perfect substitutability is intrinsic in these models and should be accepted.

Rose and Allison, (1989) added a new angle to the debate by stating the production coefficients remaining perfectly fixed restricts the application potential of a supply driven Input-Output model and that given the extensive use of approximation in mathematics, economics and regional sciences.

Oosterhaven, (1996) continued the debate by stating that perfect elasticity of demand for outputs in the supply driven model is ludicrous particularly for impact studies and that it was only plausible when calculating descriptive forward linkage strength. Oosterhaven, (2012) continued the line of reasoning mentioned in Oosterhaven, (1988) that the Ghosh model was *“formulated to describe certain aspects of centrally planned economies.”* He further stated that adding supply driven consumption makes the Ghosh model ever more problematic for market economies as well primarily because the “complementarities between inputs are negated, not only for firms, but also for households.”

Dietzenbacher, (1997) took the debate further by reinterpreting the supply driven Ghosh model as the Ghosh price model. He noted that the typical interpretation of the supply driven model refers to changes in physical output caused by primary physical inputs changes and though the interpretation of the Ghosh model in terms of quantities is implausible, it becomes plausible as a price model. Dietzenbacher demonstrated this by stating that the output values of a sector change due to price changes that are caused by price changes in the primary inputs. He showed that the results obtained by standard Leontief Price model and the reinterpreted Ghosh Price model were equivalent. This price dual of the Ghosh quantity model *"allows for a meaningful interpretation of the inverse matrix in terms of multipliers."* Dietzenbacher concludes the paper by confirming that since prices are fixed the Leonteif price model–which derives the output values from exogenous final demands–and the Ghosh price model–which obtains quantity ratios for the outputs from quantity indexes for final demand– show one-to-one correspondence between output values and quantity ratios because prices are fixed. Finally, he called the price versions of the Ghosh model and the Leontief model as each other's mirror image.

The general summary of Oosterhaven, (2012, 1996, 1989, 1988), Kerschner and Hubacek, (2009) ,Kerschner, (2012) and Dietzenbacher, (1997) points to the direction of the argument that the supply driven price model is useful for theoretical forward linkage analysis within the parameters of this research. The next chapter explains the method used to perform the calculations.

3 DATA AND METHOD

3.1 Introduction

This chapter outlines the strategy utilized to represent a “Peak-Oil” scenario. Given that this thesis is a quantitative investigation, it employs the standard methodology of secondary data analysis taken from EXIOBASE; a database which provides a “global, detailed Environmentally Extended Multi-Regional Environmentally Extended Input-Output Table (EE MRIO)” (Exiobase, 2019). EE MRIO is a well-established method in the field of applied economics with the objective to analyze global value chains in addition to environmental footprints of economic activity. Many EE MRIO databases have been constructed to this end and include the OECD ICIO database and World Input-Output Database WIOD. EXIOBASE covers 44 countries and 5 Rest-of-the-world regions. Recently Croatia as a new EU member country was added (Nathani and Hellmüller, 2019). This research does not use the Environmentally Extended version of the EXIOBASE tables and instead focuses on the core Input-Output table of the economies in question.

The IO tables for the economies of the USA, UK and Czech Republic were subjected to price simulations in the “oil and gas” sectors. Furthermore, sectors with the highest oil imports were also identified for price manipulation. The general rule of thumb was to double the prices in these sectors.

When applied to the original numbers, the price model produces a requirements matrix in which each row gives a sum of 1. This practice serves as a cross check to confirm that the database had workable values and was carried out on the data of all three countries. On a plot, these values appear as a horizontal line (see figures 11, 12 and 13). Miller and Blair, (2009) call these; “base year” values. They serve as the benchmark from which the increase or decrease in a requirements matrix is gauged (In our case, the increase comes from inflating the *oil and gas* sector numbers). Once the *oil and gas* sector prices were artificially inflated, the Price Model was run on them. The rows of the new resulting requirements matrix were added together to reveal price rises throughout the economy. Finally, the Ghosh model was applied to the original numbers to obtain the forward linkage values.

3.2 EXIOBASE

EXIOBASE provides Multi-Regional Environmentally Extended Supply-Use Tables and Input-Output tables. These are abbreviated as MR-SUT and MR-IOT. The MR-IOT tables have many uses. One is to do an analysis such as this research while another is to analyse environmental impacts associated with the final consumption of product groups. This database of tables was "*developed by the European research consortium within the EU-projects EXIOPOL*[11]*, CREEA*[12] *and DESIRE*[13] *funded by the European Commission under the 6th (EXIOPOL) and 7th (CREEA and DESIRE) framework program* (Nathani and Hellmüller, 2019).[14]" The purpose of EXIOBASE is to deliver a tool that is suitable for global environmental analysis.

Apart from EXIOBASE, sources such as the "World Input-Output Database or WIOD" also provide IO tables. The primary reason for using EXIOBASE over WIOD is the availability of disaggregated imports which were necessary for this research. A significant part of the simulation strategy used in this work relied on using disaggregated import numbers, hence the choice of using EXIOBASE.

3.3 The IO table layout

The IO tables used in this research have the following features:

- All tables have 164 sectors
- Certain sectors are aggregated together under an umbrella term. For example, the construction sector in the Czech Republic IO table holds the information of 45 other sectors, all relating construction related activities
- All tables have disaggregated import and export numbers. When applying a simulation strategy that deals with oil as an exogenous element, having disaggregated import numbers for select sectors was very useful as the relevant oil importing sectors were easily singled out to artificially increase their oil and gas imports
- Disaggregated export numbers

Refer to figure 10 for a schematic of the IO table which is identical to the tables used for this analysis.

3.4 Data Procession and Simulation Strategy

The raw data tables consisted of 4 sections namely, domestic sectors, value added or sector costs, exports and final demand.

In order to apply the Leontief Inverse to a given table, the first step of the process was to sum up the individual import columns of every sector to obtain total imports per sector. Secondly,

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[11] A New Environmental Accounting Framework Using **E**xternality Data and Input-**O**utput Tools for **P**olicy **A**nalysis

[12] **C**ompiling and **R**efining **E**nvironmental and **E**conomic **A**ccounts

[13] **D**evelopment of a **S**ystem of Indicators for **R**esources **E**fficient Europe

[14] Information found on Page 3

the exports rows were summed up for each sector to reveal the total exports. This process was applied to all three countries' tables, i.e. USA, UK and Czech Republic.

Following on from this, the tables were scanned for any zero-sum sectors in its rows and columns with the intention of removing these sectors. This was done to eradicate errors from the technical coefficients matrix [Refer to equation (10)]. As such, the zero-sum sectors would have had no impact on the final numbers.

Finally, the rows were summed up followed by the summing up of the columns. IO tables are required to produce the same numbers from the sum of the rows as it does for the columns. This check confirmed that the values were correct and that the data was ready to be processed.

All three countries' tables were subjected to the process above.

3.4.1 Application of Forward Linkages

Referring to section 2.3.4.1 and equation (32), forward linkages were applied first to all three tables.

The direct outputs coefficient matrix was calculated using equation (26). This was followed by the application of equation (30) to obtain **G.** The rows of **G** were summed up for each sector to obtain the forward linkages.

This calculation was repeated for all countries.

3.4.2 Application of the Price Model and the Simulation Strategy

The next part of the data processing was to apply the mathematical dual of the Leontief Inverse, i.e. the Price Model to the data. Consistent with equations (10) to (25), all sectors in each country's IO table were subjected to technical coefficients matrix **A** calculation [Eq. (10)]. This was followed by calculating the transpose of **A,** which was then utilized to calculate the Leontief Inverse. To simulate a significant enough increase in oil prices such that it qualifies as a Peak-Oil scenario, all exogenous inputs of oil into the economy had to be identified for manipulation. Kerschner et al., (2013) have previously conducted such an experiment:

"In order to obtain a 100% price increase of the "oil and gas extraction" sector's output, we raised its production costs (factors of production) capital, labour and imports at equal shares by approximately a factor of five (495%). Secondly, we address direct oil and gas imports of all sectors by increasing the corresponding share of their total imports equally by 100%. Moreover, we take an 85% share of all sectors' direct imports of refined petroleum products, which

correspond to that sectors fraction of production costs, which is determined by crude oil (the rest are the costs of the refining process) and also raise them by 100%"(Kerschner et al., 2013)[15].

Strategy one of this research is inspired by that of Kerschner et al., (2013) but does not strictly adhere to it. Prices in the "oil and gas extraction sector" were doubled by fictitiously increasing costs (capital, labour and imports). The rationale assumed behind doing so stems from the ever-increasing difficulty of extracting oil from tricky geographical locations. Furthermore, as explained in Chapter one, as an oil field reaches peak production and starts to decline, the oil becomes ever more difficult to extract owing to the loss of field pressure for example. Such issues can easily compound resulting in mounting costs for oil extraction and increasing prices due to demand outstripping prices. Also, non-conventional oil such as that from the tar sands is costly to exploit, which would also raise oil extraction costs.

Secondly, specific sectors were marked out as oil and gas intensive sectors for price manipulation. This information was taken from The North American Industry Classification System (NAICS, 2017). Table 1 below shows a breakdown of oil and gas sectors according to the NAICS.

Petroleum refineries	Industrial gas manufacturing
Petroleum lubricating oil and grease manufacturing	Oil and gas extraction
Asphalt shingle and coating materials	Petrochemical manufacturing
Natural gas distribution	Fertilizers production
Asphalt paving mixture and block manufacturing	

Table 1*: Oil and Gas Intensive Sectors*

Some of these sectors were not explicit in the IO tables used in this research. For example, the NAICS manual puts *Asphalt shingle and coating materials* and *Asphalt paving mixture and block manufacturing* under Petroleum and Coal products sector. However, the EXIOBASE IO tables are not disaggregated to that level. Furthermore, the petrochemical manufacturing sector is not explicitly mentioned in the EXIOBASE system. Clews, (2016) unravels this problem, stating that the petrochemical industry produces products such as rubber, solvents, fertilizers, explosives and adhesives.

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[15] Page 4, Kerschner et al., (2013)

Given the lack of explicit knowledge of oil use in terms of concrete and reliable numbers in academic and commercial resources, an investigation into the “oil and gas” imports of the sectors most closely related to the above sectors in table 1 was conducted (see table 2). It was found that some the highest import numbers for these sectors were oil and gas related. A calculation was conducted to work out the oil and gas import numbers as a proportion of the total imports for each of the selected sectors. This number was on average roughly 60% ± 30% for all of the selected sectors for all economies. To create a consistent strategy for an aggressive Peak-Oil scenario, the upper quartile value of approximately 85% was selected as the proportion of oil and gas imports in the total imports of each of the selected sectors. This 85% value was calculated, doubled and added to the total import number. The following flow diagram visualizes this strategy:

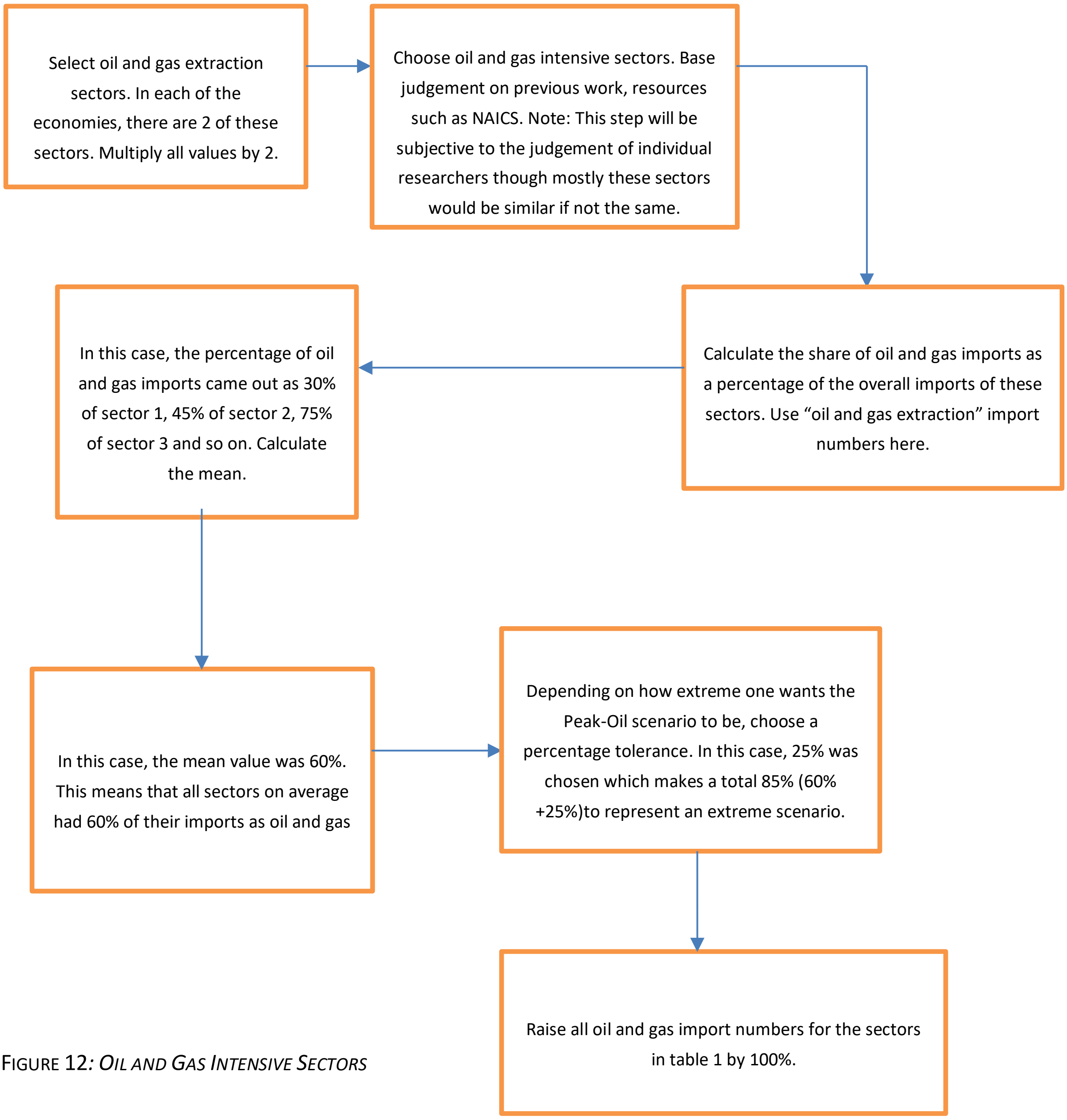

FIGURE 12*: OIL AND GAS INTENSIVE SECTORS*

Therefore, to summarize, this research adopted the following strategy of oil price simulation:

(i) Doubling oil and gas production costs
(ii) Doubling 85% of the import costs of the selected sectors in table 2

The above are the boundary conditions for this simulation. It presents one possible blueprint for accounting for most, if not all exogenous factors directly linked to oil prices exhibiting a Peak-Oil scenario. Table 2 shows the sectors this research used for oil price manipulation. The sectors in yellow are those whose production costs were increased. The orange sectors represent sectors that had their import costs raised by 85%.

Petroleum Refinery
N-fertiliser
P- and other fertilisers
Chemicals nec
Manufacture of rubber and plastic products (25)
Production of electricity by gas
Production of electricity by petroleum and other oil derivatives
Manufacture of gas; distribution of gaseous fuels through mains
Retail sale of automotive fuel

TABLE 2*: SECTORS SELECTED FOR OIL IMPORT PRICE INCREASES*

4 RESULTS AND DISCUSSION

4.1 Introduction

The Price Model with respect to the simulation strategy and Forward Linkage calculation was applied to 156 sectors in the USA and 146 sectors in the UK and the Czech Republic respectively. The following sections present the graphs obtained and discussion for each economy.

4.2 The US, UK and Czech Republic Economies' Results

The sectors in all three economies were sorted into eight clusters. These are:

(i) Manufacturing
(ii) Agriculture
(iii) Construction
(iv) Energy Production
(v) Retail and services and miscellaneous
(vi) Mining
(vii) Recycling
(viii) Transport

4.2.1 Overview of the results

There are eight scatter plots, each representing one of the eight clusters listed above. Each scatter plot contains the results for the USA, UK and Czech Republic. The plot "legend" on the right-hand side of each figure acts as a key to represent which results belong to which country. The plot points are 3-D bubbles for better illustration. Each figure is also accompanied with a table listing all sectors represented within it. This table comes with the forward linkage value alongside the corresponding price increases. Note that the sectors employed for simulation–outlined in chapter 3–have been left out of the results for clarity. The tables are sorted according to the sector *Forward Linkage or FWD Linkage* value. A colour coding scheme has been used to highlight the highest and lowest forward linkage. This goes from shades of red to yellow. The same colour scheme has been applied to the *Price Model %* column in the tables. The darkest shade of red colour represents the highest price increase in % whereas the lightest shade of yellow represents the lowest price % increase. Note that some of the *Price Model %* column values are zero. This is not because the price % increase as a result of the simulation was zero for the respected sector. Instead, the percentage increases have been represented correct to two decimal places–as percentages are generally represented–which has resulted in the rounding off to zero for some sectors. Note also that the same logic does not apply to the *FWD Linkage* value as it is not a percentage.

Manufacturing and production related activities	**Relative price change%**	**FWD Linkage**
Manufacture of coke oven products	0.00	2.8561
Re-processing of secondary aluminium into new aluminium	0.23	2.6021
Aluminium production	0.24	2.5946
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.30	2.5633
Re-processing of secondary steel into new steel	0.22	2.5531
Manufacture of bricks, tiles and construction products, in baked clay	0.33	2.4227
Casting of metals	0.19	2.3620
Manufacture of cement, lime and plaster	0.35	2.2558
Re-processing of ash into clinker	0.19	2.2554
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	0.01	2.1014
Re-processing of secondary wood material into new wood material	0.01	2.1010
Manufacture of fabricated metal products, except machinery and equipment (28)	0.40	2.0501
Copper production	0.20	2.0353
Re-processing of secondary copper into new copper	0.12	2.0353
Other non-ferrous metal production	0.00	2.0338
Paper	0.50	2.0029
Manufacture of other non-metallic mineral products n,e,c,	0.36	1.9424
Pulp	0.01	1.7792
Re-processing of secondary paper into new pulp	0.25	1.7792
Manufacture of glass and glass products	0.57	1.7735
Re-processing of secondary glass into new glass	0.29	1.7716
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	0.19	1.7289
Lead, zinc and tin production	0.00	1.6474
Re-processing of secondary lead into new lead, zinc and tin	0.00	1.6467
Re-processing of secondary preciuos metals into new preciuos metals	0.05	1.6237
Precious metals production	0.06	1.6237
Manufacture of ceramic goods	0.29	1.4633
Manufacture of electrical machinery and apparatus n,e,c, (31)	0.32	1.4431
Manufacture of radio, television and communication equipment and apparatus (32)	0.28	1.3999
Plastics, basic	4.73	1.3822
Manufacture of fish products	0.07	1.3818
Re-processing of secondary plastic into new plastic	5.36	1.3791
Manufacture of textiles (17)	1.65	1.2948
Manufacture of other transport equipment (35)	0.29	1.2661
Manufacture of motor vehicles, trailers and semi-trailers (34)	0.79	1.2605
Manufacture of machinery and equipment n,e,c, (29)	0.52	1.1403
Manufacture of medical, precision and optical instruments, watches and clocks (33)	0.49	1.1062
Manufacture of furniture; manufacturing n,e,c, (36)	0.80	1.0719
Manufacture of beverages	0.96	1.0601
Manufacture of tobacco products (16)	0.04	1.0570
Manufacture of office machinery and computers (30)	0.20	1.0383
Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.09	1.0331
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	1.46	1.0030

Table 3*: USA Manufacturing Sectors*

Manufacturing and production related activities	Relative Price change %	FWD Linkage
Wool, silk-worm cocoons	0.00	2.6058
Re-processing of ash into clinker	0.58	2.4999
Manufacture of cement, lime and plaster	0.75	2.4793
Manufacture of bricks, tiles and construction products, in baked clay	0.44	2.4189
Manufacture of fish products	0.60	2.3175
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	0.53	2.3138
Re-processing of secondary wood material into new wood material	0.57	2.3133
Manufacture of coke oven products	0.06	2.3035
Re-processing of secondary plastic into new plastic	0.19	2.2596
Plastics, basic	0.20	2.2572
Re-processing of secondary paper into new pulp	0.48	2.2102
Pulp	0.51	2.1988
Casting of metals	0.19	2.1440
Re-processing of secondary lead into new lead, zinc and tin	0.02	1.9828
Re-processing of secondary glass into new glass	0.51	1.9585
Manufacture of glass and glass products	0.63	1.9579
Lead, zinc and tin production	0.02	1.9364
Re-processing of secondary aluminium into new aluminium	0.22	1.8049
Aluminium production	0.43	1.8048
Manufacture of ceramic goods	0.38	1.6530
Manufacture of other non-metallic mineral products n,e,c,	0.83	1.5353
Paper	0.61	1.5082
Manufacture of electrical machinery and apparatus n,e,c, (31)	0.19	1.4145
Manufacture of beverages	0.97	1.4113
Copper production	0.14	1.2988
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.25	1.2958
Re-processing of secondary steel into new steel	0.44	1.2955
Manufacture of machinery and equipment n,e,c, (29)	0.42	1.2902
Manufacture of medical, precision and optical instruments, watches and clocks (33)	0.19	1.2870
Manufacture of other transport equipment (35)	0.42	1.2618
Manufacture of fabricated metal products, except machinery and equipment (28)	0.36	1.2443
Manufacture of motor vehicles, trailers and semi-trailers (34)	0.50	1.2345
Other non-ferrous metal production	0.27	1.2292
Manufacture of furniture; manufacturing n,e,c, (36)	0.58	1.2291
Precious metals production	0.05	1.2272
Manufacture of radio, television and communication equipment and apparatus (32)	0.26	1.2173
Manufacture of office machinery and computers (30)	0.28	1.1896
Manufacture of textiles (17)	1.13	1.1709
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	0.22	1.1185
Manufacture of tobacco products (16)	0.37	1.0086
Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.95	1.0023

TABLE 4: *UK MANUFACTURING SECTORS*

Manufacturing and production related activities	**Relative Price change %**	**FWD Linkage**
Casting of metals	0.88	2.4353
Re-processing of ash into clinker	0.35	2.2833
Manufacture of cement, lime and plaster	0.35	2.2815
Re-processing of secondary wood material into new wood material	1.44	2.2406
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	1.17	2.2379
Manufacture of bricks, tiles and construction products, in baked clay	0.42	2.1989
Re-processing of secondary aluminium into new aluminium	1.11	2.1538
Aluminium production	1.17	2.1518
Re-processing of secondary paper into new pulp	0.48	2.0730
Pulp	0.66	2.0714
Animal products nec	0.18	2.0267
Manufacture of glass and glass products	0.54	2.0089
Re-processing of secondary glass into new glass	0.70	2.0053
Manufacture of other non-metallic mineral products n,e,c,	0.80	1.9656
Manufacture of fabricated metal products, except machinery and equipment (28)	1.50	1.8986
Manufacture of ceramic goods	0.16	1.7650
Lead, zinc and tin production	0.11	1.7409
Re-processing of secondary lead into new lead, zinc and tin	0.09	1.7379
Wool, silk-worm cocoons	0.23	1.6554
Paper	0.58	1.6307
Manufacture of electrical machinery and apparatus n,e,c, (31)	1.38	1.5422
Manufacture of beverages	0.72	1.5264
Manufacture of textiles (17)	0.87	1.4381
Manufacture of motor vehicles, trailers and semi-trailers (34)	2.74	1.4112
Precious metals production	0.99	1.3932
Manufacture of radio, television and communication equipment and apparatus (32)	0.58	1.3695
Copper production	0.54	1.3466
Manufacture of fish products	0.70	1.2705
Manufacture of office machinery and computers (30)	0.33	1.2672
Manufacture of furniture; manufacturing n,e,c, (36)	1.74	1.1968
Manufacture of medical, precision and optical instruments, watches and clocks (33)	1.50	1.1844
Manufacture of other transport equipment (35)	3.03	1.1467
Manufacture of machinery and equipment n,e,c, (29)	0.82	1.1449
Plastics, basic	0.19	1.1421
Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.56	1.1382
Manufacture of coke oven products	0.68	1.1317
Re-processing of secondary plastic into new plastic	1.60	1.1213
Re-processing of secondary steel into new steel	0.66	1.0886
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.70	1.0854
Other non-ferrous metal production	0.73	1.0691
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	0.35	1.0374
Manufacture of tobacco products (16)	0.48	1.0000

TABLE 5: *CZECH REPUBLIC MANUFACTURING SECTORS*

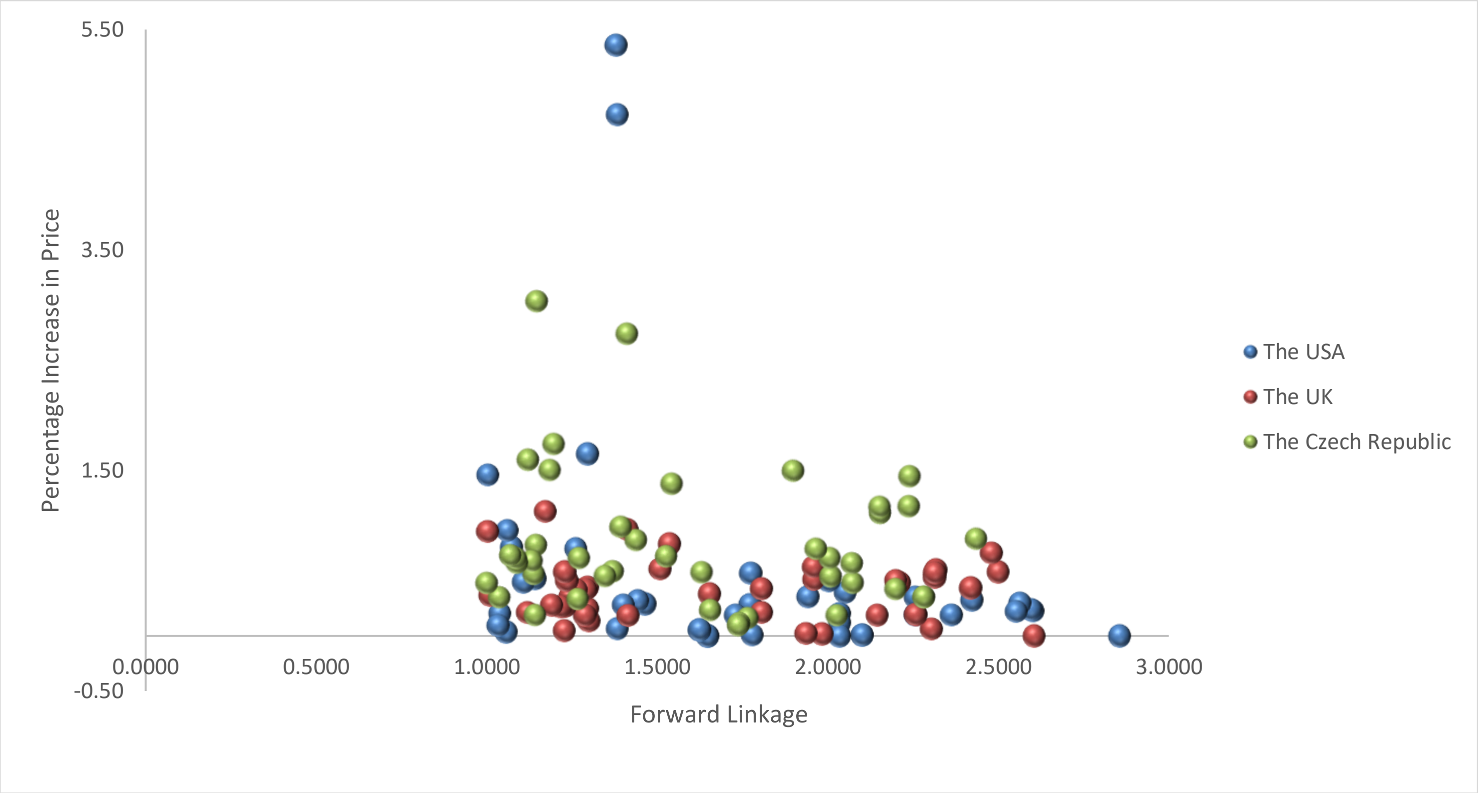

FIGURE 13: *THE USA, UK AND CZECH REPUBLICS' MANUFACTURING SECTORS*

Figure 13 shows the effects of Peak-Oil on the manufacturing sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors than both the USA and the UK in this regard.

Agriculture and food related activities	Relative Price change %	FWD Linkage
Raw milk	0.07	2.4970
Cattle farming	0.06	2.3301
Pigs farming	0.03	2.3269
Cultivation of sugar cane, sugar beet	0.06	2.2271
Poultry farming	0.11	2.1399
Cultivation of crops nec	0.09	2.1100
Cultivation of paddy rice	0.04	2.0975
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.00	2.0552
Cultivation of cereal grains nec	0.15	1.9767
Meat animals nec	0.00	1.8789
Cultivation of wheat	0.18	1.6190
Processing of dairy products	0.40	1.5129
Processing of meat pigs	0.11	1.3253
Processing of Food products nec	0.47	1.3253
Processing of meat cattle	0.07	1.3202
Cultivation of plant-based fibers	0.14	1.2579
Processing of nuclear fuel	0.00	1.2465
Processing of meat poultry	0.27	1.2092
Cultivation of oil seeds	0.10	1.1220
Processing vegetable oils and fats	0.00	1.0933
Processed rice	0.04	1.0769
Cultivation of vegetables, fruit, nuts	0.12	1.0153
Sugar refining	0.12	1.0002
Production of meat products nec	0.32	1.0000
Animal products nec	0.14	1.0000

TABLE 6: *USA AGRICULTURE SECTORS*

Agriculture and food related activities	Relative Price change %	FWD Linkage
Cultivation of sugar cane, sugar beet	0.00	2.3183
Raw milk	0.32	2.2074
Cultivation of plant-based fibers	0.00	2.0916
Pigs farming	0.62	1.8773
Cattle farming	1.12	1.8257
Animal products nec	0.00	1.7255
Cultivation of wheat	0.76	1.7022
Meat animals nec	0.24	1.5290
Cultivation of cereal grains nec	0.47	1.4951
Sugar refining	0.00	1.4938
Processed rice	0.10	1.4557
Processing of Food products nec	0.86	1.4207
Processing vegetable oils and fats	0.02	1.4110
Cultivation of vegetables, fruit, nuts	0.39	1.4070
Cultivation of oil seeds	0.24	1.3842
Processing of dairy products	0.64	1.3784
Cultivation of crops nec	0.00	1.2591
Processing of meat pigs	0.08	1.2444
Processing of meat cattle	0.82	1.2211
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.77	1.1165
Processing of nuclear fuel	0.04	1.0267
Processing of meat poultry	2.65	1.0104
Production of meat products nec	0.51	1.0012

TABLE 7: *UK AGRICULTURE SECTORS*

Agriculture and food related activities	**Relative Price change %**	**FWD Linkage**
Raw milk	0.44	2.3892
Cultivation of cereal grains nec	2.06	2.2469
Cultivation of sugar cane, sugar beet	0.02	2.2333
Pigs farming	0.41	2.1796
Cultivation of crops nec	2.37	2.1209
Cultivation of oil seeds	2.25	2.0092
Cattle farming	0.41	1.9432
Poultry farming	0.43	1.9395
Meat animals nec	0.22	1.8223
Cultivation of wheat	2.31	1.7130
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.98	1.6493
Processing of dairy products	0.45	1.5511
Processing vegetable oils and fats	0.21	1.5001
Processed rice	0.42	1.4474
Processing of meat pigs	0.38	1.4091
Cultivation of vegetables, fruit, nuts	1.49	1.3682
Processing of Food products nec	0.54	1.3537
Sugar refining	0.10	1.3323
Processing of meat cattle	1.02	1.3301
Production of meat products nec	0.04	1.3000
Processing of nuclear fuel	0.60	1.0147
Processing of meat poultry	0.30	1.0010
Cultivation of plant-based fibres	0.39	1.0001

TABLE 8: *CZECH REPUBLIC AGRICULTURE SECTORS*

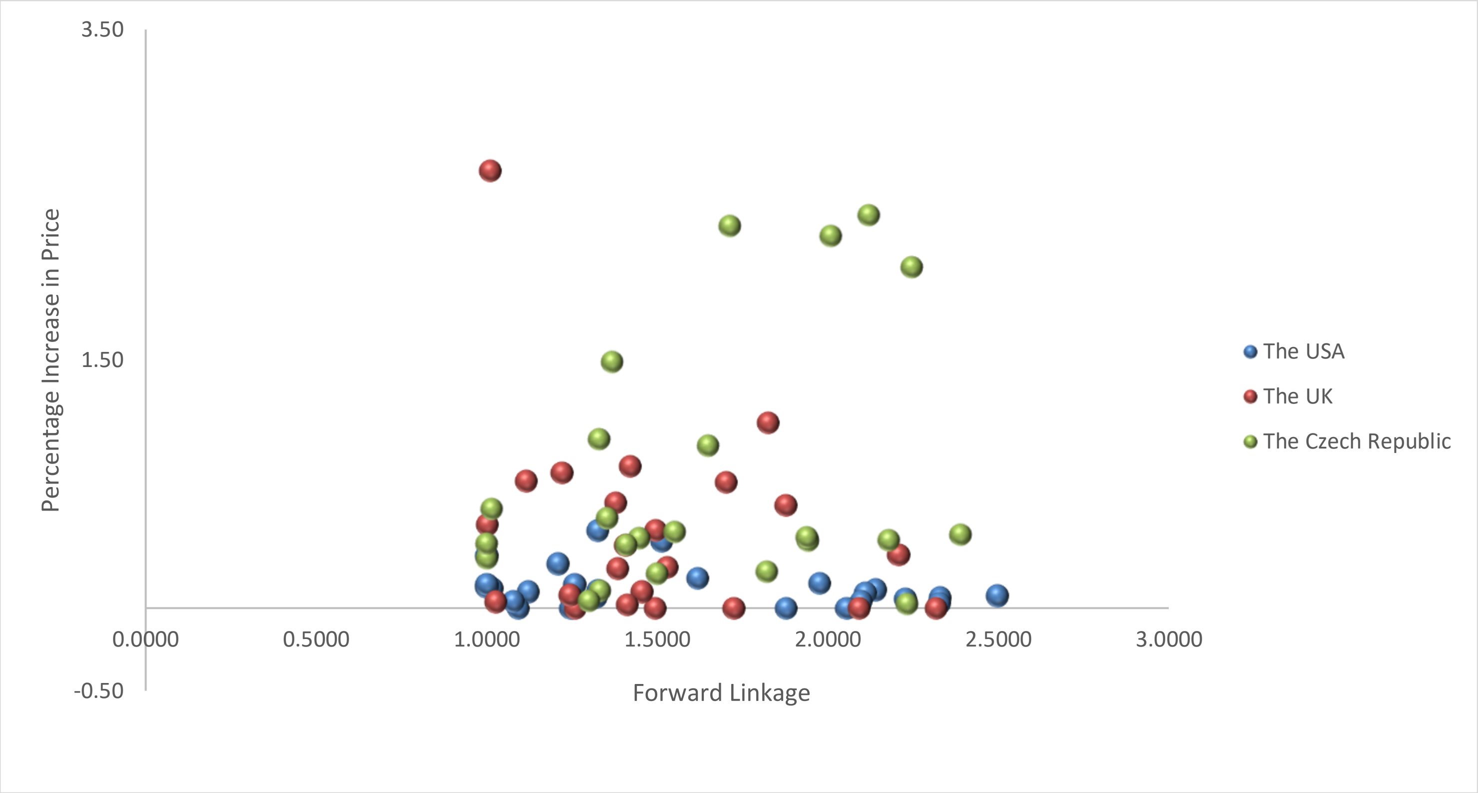

FIGURE 14*: THE USA, UK AND CZECH REPUBLICS' AGRICULTURE SECTORS*

Figure 14 shows the effects of Peak-Oil on the agriculture sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors than both the USA and the UK in this regard, though some UK sectors with FWD linkage close to 2 are affected by indirect price increases.

Construction and related activities	Relative Price change %	FWD Linkage
Real estate activities (70)	0.03	1.3296
Re-processing of secondary construction material into aggregates	0.01	1.1346
Construction (45)	0.65	1.1346

TABLE 9: *THE USA CONSTRUCTION SECTORS*

Construction and related activities	Relative Price change %	FWD Linkage
Construction (45)	0.65	1.4964
Re-processing of secondary construction material into aggregates	0.07	1.4959
Real estate activities (70)	0.17	1.0500

TABLE 10: *THE UK CONSTRUCTION SECTORS*

Construction and related activities	Relative Price change %	FWD Linkage
Re-processing of secondary construction material into aggregates	0.08	1.7798
Construction (45)	0.58	1.7794
Real estate activities (70)	0.92	1.5286

TABLE 11: *THE CZECH REPUBLIC CONSTRUCTION SECTORS*

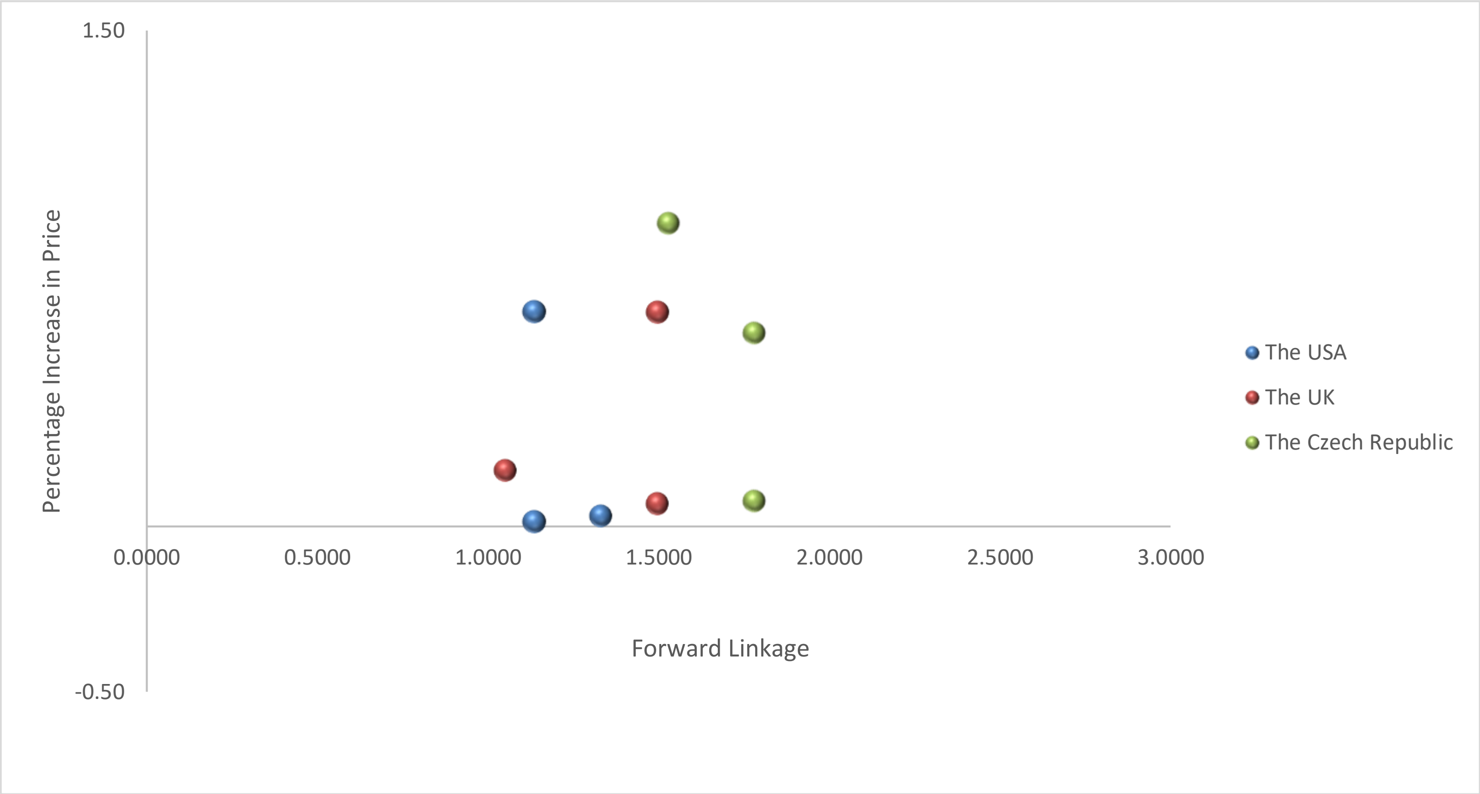

FIGURE 15*: THE USA, UK AND CZECH REPUBLICS' CONSTRUCTION SECTORS*

Figure 15 shows the effects of Peak-Oil on the construction sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 1.5–with respect to high price increases. The Czech Republic appears to have more sectors than both the USA and the UK in this regard.

Energy Production, distribution and related activities	Relative Price change %	FWD Linkage
Steam and hot water supply	0.04	2.3650
Production of electricity by solar thermal	0.00	2.3477
Production of electricity nec	0.00	2.1013
Biogasification of sewage slugde, incl, land application	0.14	2.0827
Production of electricity by solar photovoltaic	0.00	2.0452
Production of electricity by Geothermal	0.00	1.8800
Production of electricity by biomass and waste	0.01	1.7899
Production of electricity by wind	0.02	1.7778
Production of electricity by nuclear	0.01	1.7667
Production of electricity by hydro	0.02	1.7665
Transmission of electricity	0.03	1.7513
Production of electricity by coal	0.04	1.7491
Distribution and trade of electricity	0.04	1.5764

Table 12: *The USA Energy Sectors*

Energy Production, distribution and related activities	Relative Price change %	FWD Linkage
Steam and hot water supply	0.00	2.0518
Biogasification of paper, incl, land application	0.00	1.9067
Biogasification of food waste, incl, land application	0.06	1.8724
Production of electricity nec	0.02	1.8709
Production of electricity by solar photovoltaic	0.00	1.8690
Biogasification of sewage slugde, incl, land application	0.36	1.8075
Production of electricity by biomass and waste	0.46	1.4334
Production of electricity by hydro	0.21	1.3958
Production of electricity by wind	0.24	1.3011
Production of electricity by nuclear	0.12	1.2627
Production of electricity by coal	1.07	1.2413

Table 13: *The UK Energy Sectors*

Energy Production, distribution and related activities	Relative Price change %	FWD Linkage
Production of electricity by nuclear	0.08	2.1846
Production of electricity by hydro	0.12	2.1608
Transmission of electricity	0.27	2.1393
Production of electricity by wind	0.17	2.1185
Production of electricity by biomass and waste	0.03	2.0995
Production of electricity nec	0.26	2.0926
Distribution and trade of electricity	0.23	2.0909
Production of electricity by solar photovoltaic	0.10	2.0900
Production of electricity by coal	0.47	2.0790
Biogasification of sewage slugde, incl, land application	0.37	2.0429
Steam and hot water supply	4.29	1.7730

Table 14: *The Czech Republic Energy Sectors*

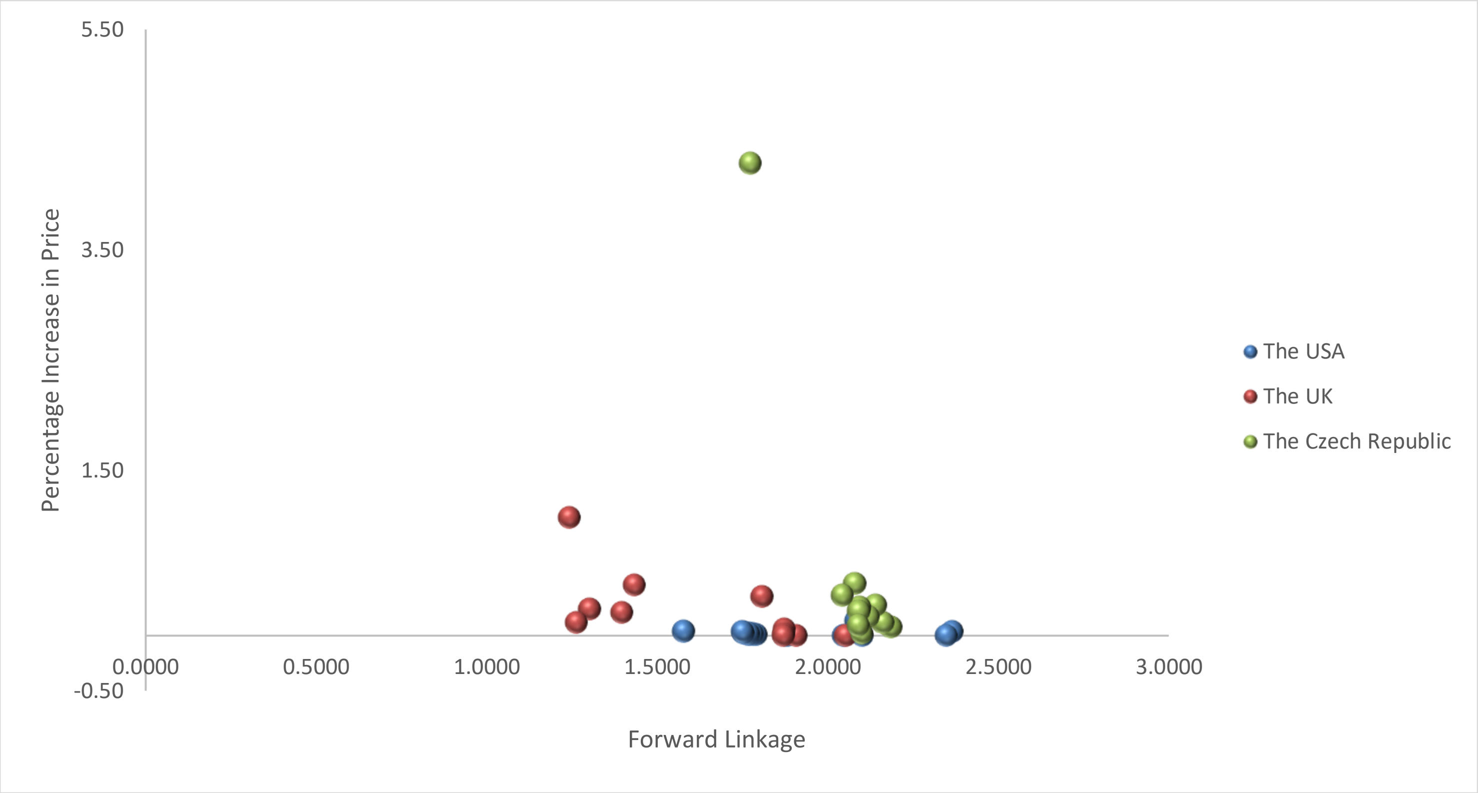

FIGURE 16: *THE USA, UK AND CZECH REPUBLICS' ENERGY SECTORS*

Figure 16 shows the effects of Peak–Oil on the energy sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors than both the USA and the UK in this regard, although some USA sectors can also be observed at around 2.3477 FWD linkage.

Retail and services related activities	**Relative Price change %**	**FWD Linkages**
Forestry, logging and related service activities (02)	0.00	2.9230
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.00	2.5751
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.00	2.3815
Renting of machinery and equipment without operator and of personal and household goods (71)	0.01	2.3546
Other business activities (74)	0.06	2.3086
Financial intermediation, except insurance and pension funding (65)	0.01	2.1357
Post and telecommunications (64)	0.00	2.1332
Activities auxiliary to financial intermediation (67)	0.01	2.0553
Wool, silk-worm cocoons	0.00	2.0183
Research and development (73)	0.24	2.0009
Publishing, printing and reproduction of recorded media (22)	0.11	1.8480
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	0.00	1.8042
Insurance and pension funding, except compulsory social security (66)	0.01	1.8023
Hotels and restaurants (55)	0.00	1.5132
Activities of membership organisation n,e,c, (91)	0.02	1.4564
Recreational, cultural and sporting activities (92)	0.05	1.3812
Computer and related activities (72)	0.03	1.3555
Education (80)	0.08	1.1871
Other service activities (93)	0.16	1.0876
Health and social work (85)	0.18	1.0287
Public administration and defence; compulsory social security (75)	0.55	1.0040
Private households with employed persons (95)	0.00	1.0000

Table 15*: The USA Retail Services and Miscellaneous Sectors*

Retail and services related activities	**Relative Price change %**	**FWD Linkages**
Transmission of electricity	0.07	2.3299
Distribution and trade of electricity	0.08	2.2704
Activities auxiliary to financial intermediation (67)	0.02	2.2673
Renting of machinery and equipment without operator and of personal and household goods (71)	0.17	2.2472
Other business activities (74)	0.28	2.2465
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.00	1.9943
Post and telecommunications (64)	0.16	1.9320
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	0.01	1.9250
Computer and related activities (72)	0.22	1.8057
Forestry, logging and related service activities (02)	0.24	1.7474
Financial intermediation, except insurance and pension funding (65)	0.25	1.7408
Research and development (73)	0.28	1.6729
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.00	1.5315
Publishing, printing and reproduction of recorded media (22)	0.26	1.4771
Insurance and pension funding, except compulsory social security (66)	0.23	1.3835
Hotels and restaurants (55)	0.07	1.3802
Other service activities (93)	0.21	1.2483
Collection, purification and distribution of water (41)	0.16	1.2380
Recreational, cultural and sporting activities (92)	0.25	1.1658
Health and social work (85)	0.51	1.1494
Public administration and defence; compulsory social security (75)	0.26	1.1424
Education (80)	0.41	1.0386
Activities of membership organisation n,e,c, (91)	0.58	1.0085
Private households with employed persons (95)	0.04	1.0000

Table 16*: The UK Retail Services and Miscellaneous Sectors*

Retail and services related activities	**Relative Price change %**	**FWD Linkages**
Activities auxiliary to financial intermediation (67)	0.07	3.0595
Financial intermediation, except insurance and pension funding (65)	0.21	2.6433
Other business activities (74)	0.50	2.5916
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	0.65	2.5681
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.55	2.5578
Renting of machinery and equipment without operator and of personal and household goods (71)	0.50	2.4788
Forestry, logging and related service activities (02)	1.19	2.3988
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.06	2.2775
Post and telecommunications (64)	0.05	2.2690
Publishing, printing and reproduction of recorded media (22)	0.27	2.2626
Computer and related activities (72)	0.32	2.2601
Research and development (73)	0.51	1.7547
Hotels and restaurants (55)	0.51	1.3794
Other service activities (93)	0.53	1.3249
Recreational, cultural and sporting activities (92)	0.54	1.1102
Public administration and defence; compulsory social security (75)	0.25	1.0630
Education (80)	0.16	1.0629
Health and social work (85)	1.55	1.0153
Activities of membership organisation n,e,c, (91)	0.56	1.0001
Private households with employed persons (95)	0.03	1.0000

TABLE 17: *THE CZECH REPUBLIC RETAIL SERVICES AND MISCELLANEOUS SECTORS*

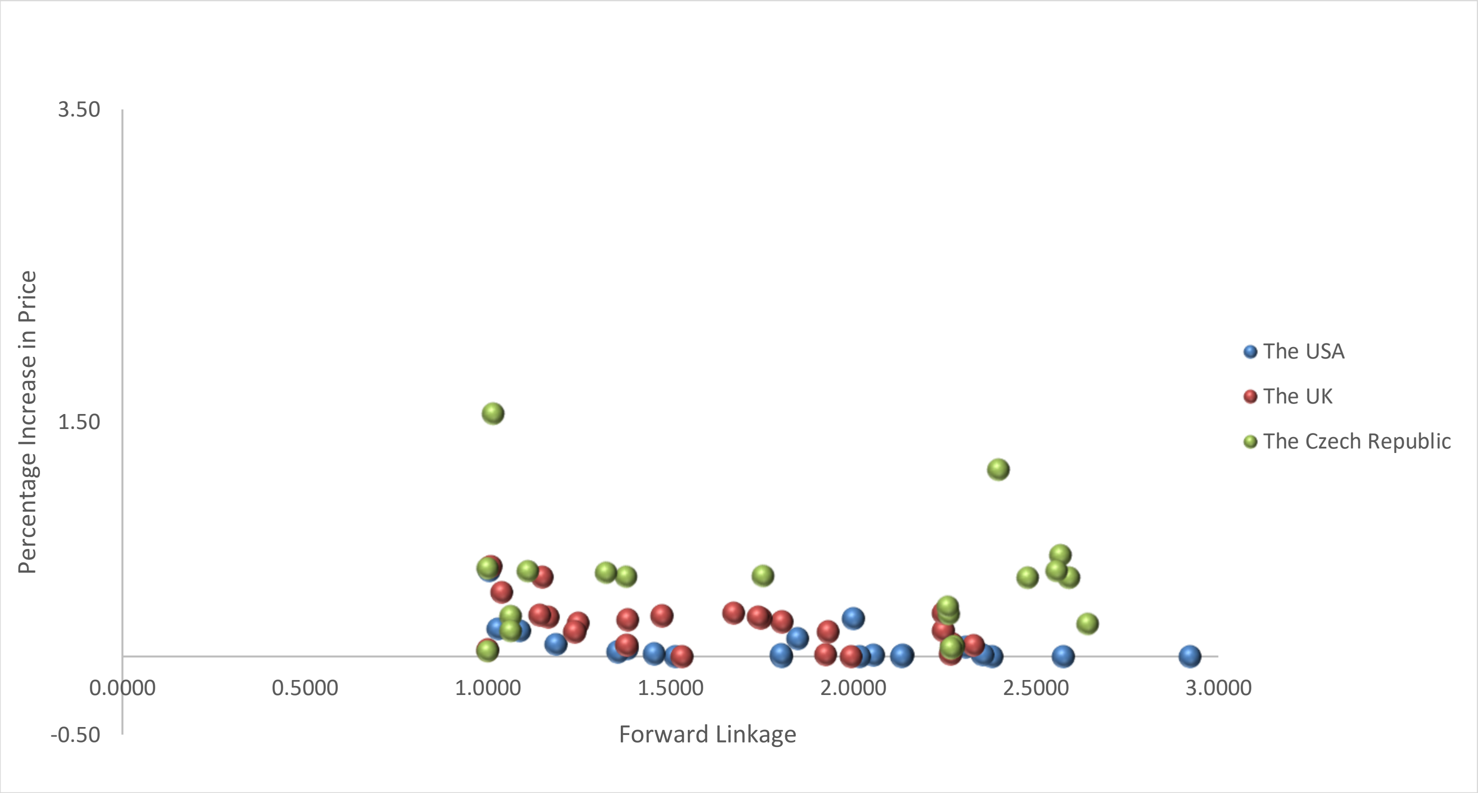

FIGURE 17: *THE USA, UK AND CZECH REPUBLICS' RETAIL, SERVICES AND MISCELLANEOUS SECTORS*

Figure 17 shows the effects of Peak–Oil on the retail sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors than both the USA and the UK in this regard, although some USA and UK sectors can also be observed at around 2.2690 FWD linkage.

Mining and related activities	Relative Price change %	FWD Linkage
Mining of precious metal ores and concentrates	0.00	4.0100
Mining of aluminium ores and concentrates	0.00	2.3120
Quarrying of stone	0.24	2.2112
Mining of uranium and thorium ores (12)	0.00	2.1221
Mining of copper ores and concentrates	0.00	2.1005
Quarrying of sand and clay	8.20	1.7561
Mining of lead, zinc and tin ores and concentrates	0.00	1.7276
Mining of other non-ferrous metal ores and concentrates	0.00	1.4308
Mining of coal and lignite; extraction of peat (10)	0.28	1.3518
Mining of iron ores	0.29	1.0046

Table 18: *The USA Mining and Related Activities Sectors*

Mining and related activities	Relative Price change %	FWD Linkage
Mining of coal and lignite; extraction of peat (10)	0.81	2.0496
Mining of lead, zinc and tin ores and concentrates	0.00	1.7789
Quarrying of sand and clay	0.46	1.7298
Mining of other non-ferrous metal ores and concentrates	0.00	1.6788
Quarrying of stone	0.63	1.5996
Mining of iron ores	0.00	1.5270
Mining of precious metal ores and concentrates	0.10	1.4945
Poultry farming	0.67	1.1866

Table 19: *The UK Mining and Related Activities Sectors*

Mining and related activities	Relative Price change %	FWD Linkage
Quarrying of stone	0.17	2.5959
Quarrying of sand and clay	0.17	2.5907
Mining of other non-ferrous metal ores and concentrates	0.01	2.3483
Mining of aluminium ores and concentrates	0.00	2.3228
Mining of coal and lignite; extraction of peat (10)	0.48	2.2114
Mining of uranium and thorium ores (12)	0.55	1.7700
Mining of iron ores	0.02	1.7051
Mining of lead, zinc and tin ores and concentrates	0.00	1.5093
Mining of nickel ores and concentrates	0.00	1.5027

Table 20: *The Czech Republic Mining and Related Activities Sectors*

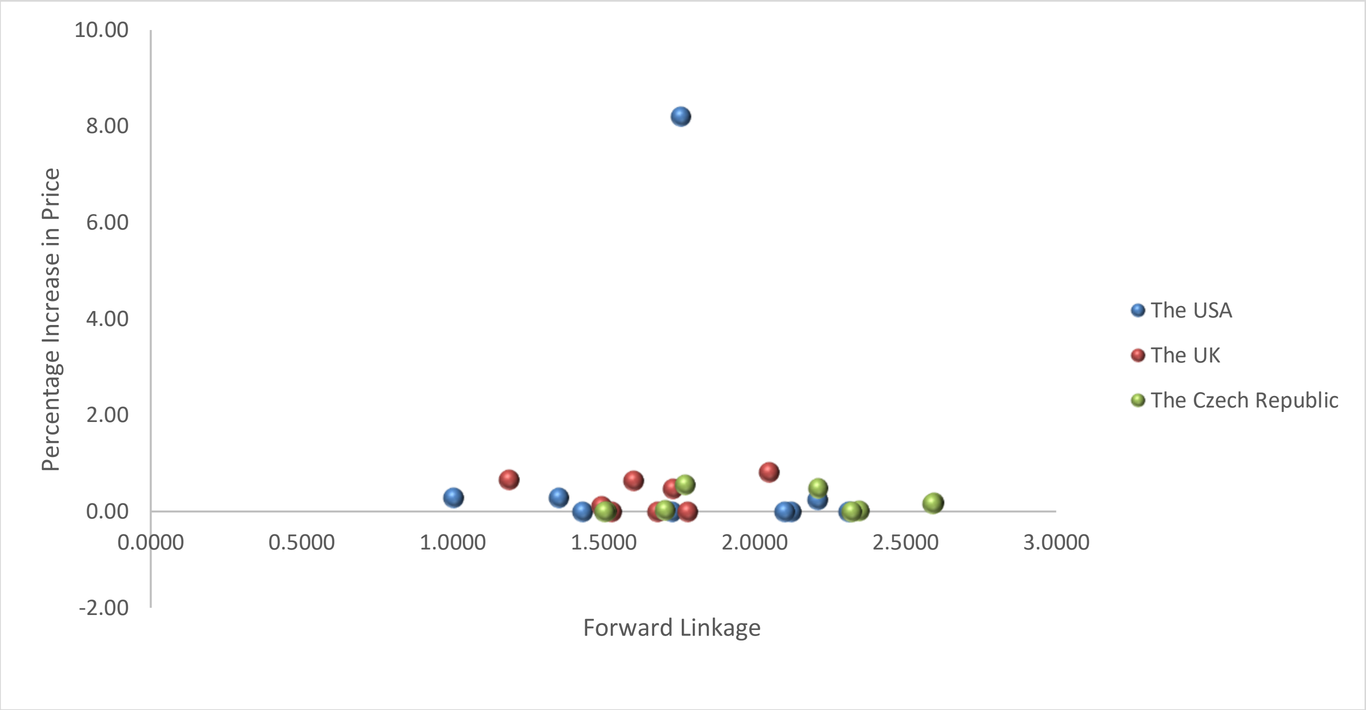

FIGURE 18: *THE USA, UK AND CZECH REPUBLICS' MINING SECTORS*

Figure 18 shows the effects of Peak–Oil on the mining sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors in this regard though the sectoral price increase does not appear to be very high. Quarrying of Sand in the USA is one sector with high indirect price rises.

Recycling, waste processing and related activities	Relative Price change %	FWD Linkage
Recycling of bottles by direct reuse	0.00	2.1510
Landfill of waste: Textiles	0.08	2.0890
Landfill of waste: Wood	0.10	2.0873
Landfill of waste: Plastic	0.15	2.0845
Incineration of waste: Textiles	0.06	2.0824
Landfill of waste: Inert/metal/hazardous	0.17	2.0760
Landfill of waste: Paper	0.17	2.0758
Composting of paper and wood, incl, land application	0.11	2.0715
Incineration of waste: Plastic	0.15	2.0695
Landfill of waste: Food	0.18	2.0689
Incineration of waste: Paper	0.17	2.0679
Incineration of waste: Food	0.14	2.0575
Incineration of waste: Wood	0.08	2.0571
Incineration of waste: Metals and Inert materials	0.11	1.9822
Incineration of waste: Oil/Hazardous waste	0.01	1.9437
Composting of food waste, incl, land application	0.01	1.9204
Waste water treatment, other	0.11	1.6130
Waste water treatment, food	0.11	1.6045
Recycling of waste and scrap	0.48	1.5383
Collection, purification and distribution of water (41)	0.02	1.3825

TABLE 21: *THE USA RECYCLING, WASTE PROCESSING AND RELATED ACTIVITIES SECTORS*

Recycling, waste processing and related activities	Relative Price change %	FWD Linkage
Incineration of waste: Textiles	0.18	1.8366
Landfill of waste: Textiles	0.30	1.8236
Landfill of waste: Wood	0.32	1.8142
Landfill of waste: Plastic	0.34	1.8127
Landfill of waste: Paper	0.34	1.8037
Waste water treatment, other	0.36	1.8031
Composting of food waste, incl, land application	0.39	1.7997
Waste water treatment, food	0.36	1.7995
Landfill of waste: Food	0.38	1.7938
Landfill of waste: Inert/metal/hazardous	0.37	1.7936
Incineration of waste: Oil/Hazardous waste	0.33	1.7899
Incineration of waste: Wood	0.21	1.7801
Incineration of waste: Food	0.32	1.7580
Incineration of waste: Paper	0.33	1.7528
Incineration of waste: Plastic	0.19	1.7234
Incineration of waste: Metals and Inert materials	0.34	1.7112
Recycling of bottles by direct reuse	0.00	1.5985

TABLE 22: *THE UK RECYCLING, WASTE PROCESSING AND RELATED ACTIVITIES SECTORS*

Recycling, waste processing and related activities	**Relative Price change %**	**FWD Linkage**
Recycling of waste and scrap	0.74	2.9168
Incineration of waste: Textiles	0.32	2.0629
Incineration of waste: Wood	0.34	2.0602
Landfill of waste: Textiles	0.43	2.0580
Landfill of waste: Wood	0.46	2.0560
Incineration of waste: Metals and Inert materials	0.41	2.0540
Landfill of waste: Inert/metal/hazardous	0.61	2.0537
Incineration of waste: Food	0.47	2.0531
Landfill of waste: Food	0.81	2.0525
Landfill of waste: Paper	0.67	2.0513
Waste water treatment, other	0.85	2.0499
Incineration of waste: Oil/Hazardous waste	0.45	2.0496
Incineration of waste: Paper	0.45	2.0476
Waste water treatment, food	0.92	2.0473
Composting of food waste, incl, land application	0.77	2.0436
Incineration of waste: Plastic	0.31	2.0416
Landfill of waste: Plastic	0.44	2.0397
Inland water transport	0.36	1.8170
Insurance and pension funding, except compulsory social security (66)	0.33	1.7191
Collection, purification and distribution of water (41)	0.35	1.5726

Table 23: *The Czech Republic Recycling, Waste Processing and Related Activities Sectors*

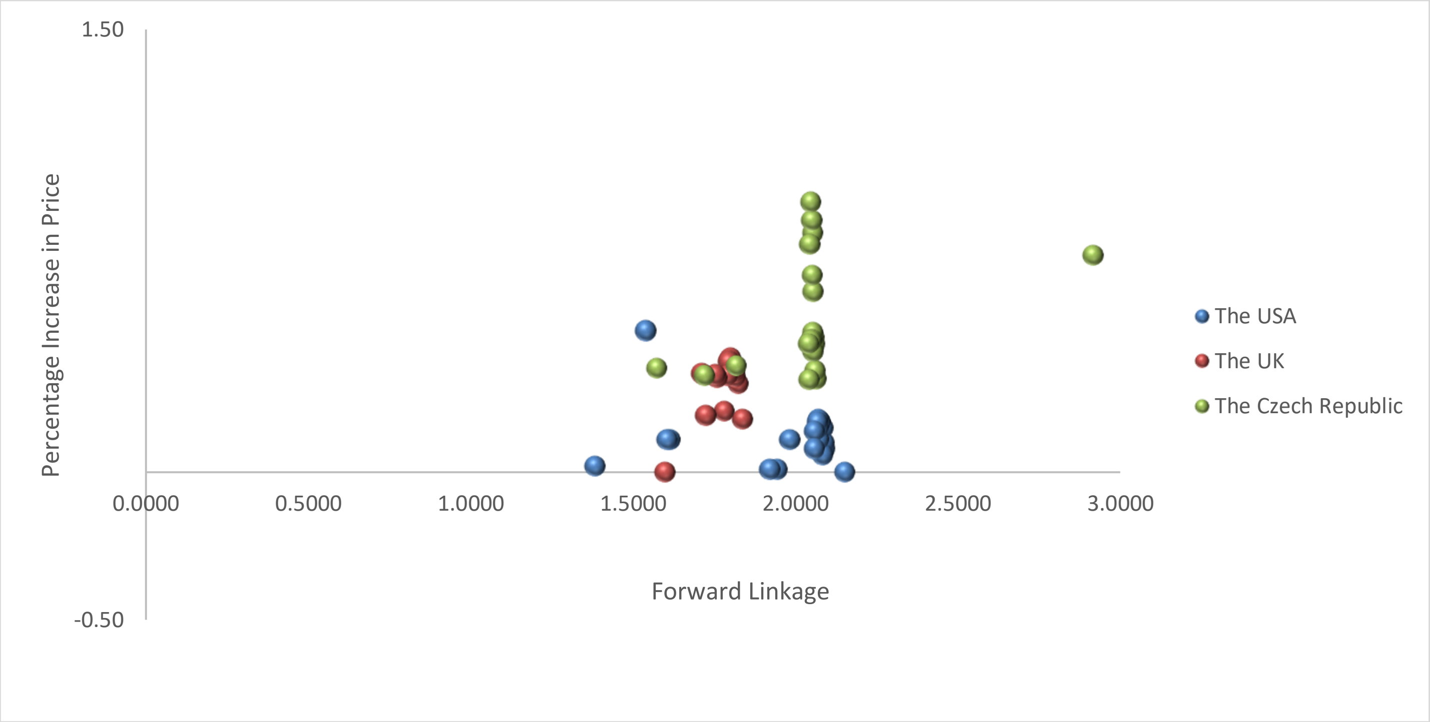

FIGURE 19: *THE USA, UK AND CZECH REPUBLICS' RECYCLING, WASTE PROCESSING AND RELATED SECTORS*

Figure 19 shows the effects of Peak–Oil on the recycling sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors in this regard with high sectoral price increase alongside a bunch of USA sectors albeit with lower price increases.

Transport	Relative Price change %	FWD Linkage
Transport via railways	0.00	2.5241
Supporting and auxiliary transport activities; activities of travel agencies (63)	0.00	2.4355
Transport via pipelines	0.00	2.1832
Other land transport	0.01	2.1324
Other land transport	0.01	2.1324
Inland water transport	0.01	1.8845
Sea and coastal water transport	0.00	1.8126
Air transport (62)	0.01	1.7066

Table 24: *The USA transport and related Sectors*

Transport	Relative Price change %	FWD Linkage
Supporting and auxiliary transport activities; activities of travel agencies (63)	0.09	2.7872
Transport via pipelines	0.11	2.5080
Other land transport	0.10	2.0634
Sea and coastal water transport	0.10	1.5810
Transport via railways	0.22	1.5749
Air transport (62)	0.13	1.3450
Inland water transport	0.30	1.0009

Table 25: *The UK transport and related Sectors*

Transport	Relative Price change %	FWD Linkage
Supporting and auxiliary transport activities; activities of travel agencies (63)	0.27	2.2840
Other land transport	0.72	2.2263
Transport via railways	0.47	2.1637
Transport via pipelines	0.05	2.1355
Sea and coastal water transport	1.20	1.9476
Air transport (62)	0.28	1.8729

Table 26: *The Czech Republic transport and related Sectors*

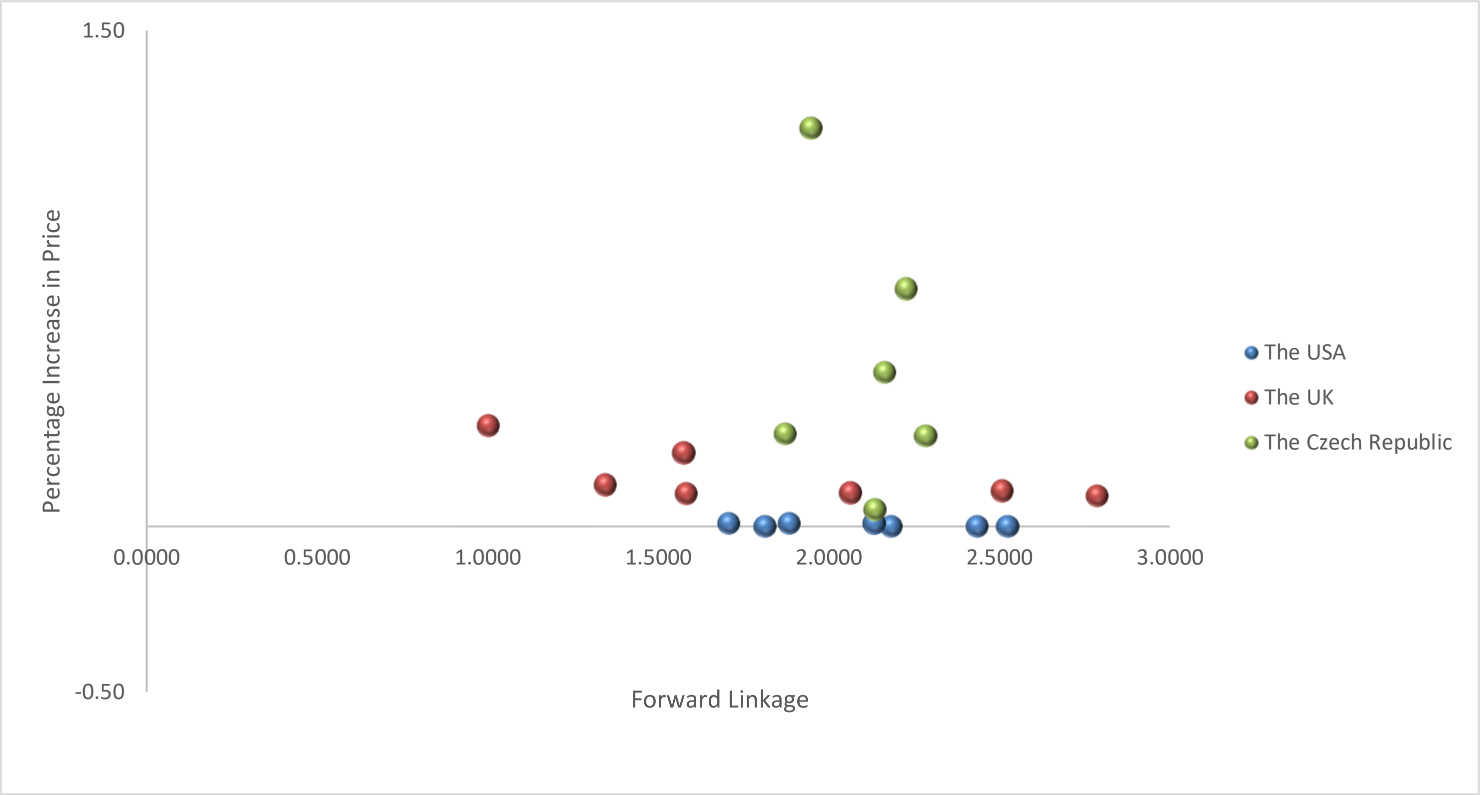

FIGURE 20: *THE USA, UK AND CZECH REPUBLICS' TRANSPORT SECTORS*

Figure 20 shows the effects of Peak–Oil on the transport sectors of the USA, UK and Czech Republic. The x-axis represents the forward linkage values. The y-axis represents the price increases that resulted in these sectors as a result of the simulation. Sectors of particular importance in terms of GDP contribution are those with high forward linkages–in this case above 2–with respect to high price increases. The Czech Republic appears to have more sectors in this regard with high sectoral price increase, although some UK sectors with high FWD linkage would mean they are more important to GDP.

Sectors	Price Model % increase	FWD Linkages (Sector Importance)	Total Output in €m	Price Increases in €m
Public administration and defence; compulsory social security (75)	0.5475	1.0040	3144141.85	17214.82
Construction (45)	0.6500	1.1346	1053967.33	6851.18
Manufacture of motor vehicles, trailers and semi-trailers (34)	0.7916	1.2605	490329.36	3881.50
Health and social work (85)	0.1753	1.0287	1669714.29	2926.68
Manufacture of machinery and equipment n,e,c, (29)	0.5188	1.1403	423289.01	2196.08
Processing of Food products nec	0.4693	1.3253	372761.53	1749.39
Re-processing of secondary plastic into new plastic	5.3578	1.3791	27824.25	1490.75
Other business activities (74)	0.0600	2.3086	2246200.78	1348.43
Manufacture of furniture; manufacturing n,e,c, (36)	0.8048	1.0719	161849.12	1302.55
Manufacture of fabricated metal products, except machinery and equipment (28)	0.3968	2.0501	309327.98	1227.27
Plastics, basic	4.7288	1.3822	24296.09	1148.91
Manufacture of beverages	0.9592	1.0601	114651.09	1099.77
Manufacture of textiles (17)	1.6506	1.2948	58149.63	959.84
Manufacture of medical, precision and optical instruments, watches and clocks (33)	0.4899	1.1062	174144.08	853.06
Paper	0.4981	2.0029	160344.89	798.68
Manufacture of other transport equipment (35)	0.2861	1.2661	251395.36	719.23
Real estate activities (70)	0.0323	1.3296	1953193.45	631.67
Manufacture of radio, television and communication equipment and apparatus (32)	0.2799	1.3999	219995.09	615.69
Manufacture of electrical machinery and apparatus n,e,c, (31)	0.3217	1.4431	129189.07	415.56
Other service activities (93)	0.1646	1.0876	243305.20	400.45
Processing of dairy products	0.4016	1.5129	98345.97	394.94
Research and development (73)	0.2428	2.0009	154204.68	374.37
Quarrying of sand and clay	8.1962	1.7561	3524.81	288.90
Publishing, printing and reproduction of recorded media (22)	0.1147	1.8480	243933.63	279.69
Education (80)	0.0781	1.1871	290278.31	226.72
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.2965	2.5633	65887.12	195.36
Manufacture of office machinery and computers (30)	0.2014	1.0383	83201.91	167.53
Re-processing of secondary steel into new steel	0.2212	2.5531	65316.69	144.47
Manufacture of cement, lime and plaster	0.3516	2.2558	39675.67	139.51
Recreational, cultural and sporting activities (92)	0.0512	1.3812	255960.51	131.10
Computer and related activities (72)	0.0293	1.3555	439584.85	128.81
Processing of meat poultry	0.2667	1.2092	47133.78	125.69
Manufacture of glass and glass products	0.5691	1.7735	18052.98	102.75

Table 27: *The most affected sectors in the USA ordered by actual price Increase*

Table 27 reports on the highest total increase in sectoral costs as a direct result of the Peak-Oil simulation. The column “Price increases in €m” represents by how much the total output has gone up. The total output includes the final demand numbers.

Sector	Price Model % Increase	FWD Linkages (Sector Importance)	Total Output in €m	Price Increases in €m
Construction (45)	0.6484	1.4964	335029.572	2172.408
Health and social work (85)	0.5062	1.1494	348198.447	1762.595
Other business activities (74)	0.2771	2.2465	348996.902	967.034
Education (80)	0.4104	1.0386	232240.215	953.120
Real estate activities (70)	0.1688	1.0500	330766.436	558.179
Public administration and defence; compulsory social security (75)	0.2646	1.1424	206631.973	546.807
Financial intermediation, except insurance and pension funding (65)	0.2525	1.7408	205625.924	519.185
Processing of Food products nec	0.8587	1.4207	47086.294	404.345
Manufacture of motor vehicles, trailers and semi-trailers (34)	0.5013	1.2345	76031.557	381.170
Computer and related activities (72)	0.2221	1.8057	105185.100	233.609
Recreational, cultural and sporting activities (92)	0.2505	1.1658	87595.360	219.459
Insurance and pension funding, except compulsory social security (66)	0.2341	1.3835	93450.054	218.771
Manufacture of other transport equipment (35)	0.4180	1.2618	42536.908	177.809
Manufacture of fabricated metal products, except machinery and equipment (28)	0.3576	1.2443	49518.938	177.080
Manufacture of furniture; manufacturing n,e,c, (36)	0.5803	1.2291	29831.146	173.116
Manufacture of machinery and equipment n,e,c, (29)	0.4207	1.2902	40332.322	169.671
Manufacture of beverages	0.9658	1.4113	17479.419	168.822
Activities of membership organisation n,e,c, (91)	0.5781	1.0085	28776.304	166.362
Post and telecommunications (64)	0.1572	1.9320	103312.613	162.372
Processing of meat poultry	2.6458	1.0104	5073.686	134.238
Manufacture of textiles (17)	1.1289	1.1709	11332.720	127.937
Quarrying of stone	0.6275	1.5996	19081.522	119.738
Hotels and restaurants (55)	0.0717	1.3802	149249.388	106.949

TABLE 28: *THE MOST AFFECTED SECTORS IN THE UK ORDERED BY ACTUAL PRICE INCREASES*

Table 28 reports on the highest total increase in sectoral costs as a direct result of the Peak-Oil simulation. The column “Price increases in €m” represents by how much the total output has gone up. The total output includes the final demand numbers.

Sectors	Price Model % Increase	FWD Linkages (Sector Importance)	Total Output in €m	Price Increases in €m
Manufacture of rubber and plastic products (25)	34.9381	1.7688	11049.364	3860.4326
Manufacture of motor vehicles, trailers and semi-trailers (34)	2.7384	1.4112	36813.157	1008.0955
Manufacture of fabricated metal products, except machinery and equipment (28)	1.4976	1.8986	15222.718	227.9774
Health and social work (85)	1.5514	1.0153	12683.194	196.7657
Real estate activities (70)	0.9166	1.5286	21088.418	193.2974
Manufacture of electrical machinery and apparatus n,e,c, (31)	1.3786	1.5422	13479.940	185.8302
Construction (45)	0.5842	1.7794	29988.379	175.1926
Manufacture of gas; distribution of gaseous fuels through mains	8.1872	1.1414	1560.575	127.7680
Manufacture of machinery and equipment n,e,c, (29)	0.8216	1.1449	15539.616	127.6740
Other business activities (74)	0.5035	2.5916	23809.623	119.8852
Manufacture of furniture; manufacturing n,e,c, (36)	1.7396	1.1968	5393.913	93.8335
Manufacture of other transport equipment (35)	3.0316	1.1467	2977.064	90.2534
Other land transport	0.7190	2.2263	10021.959	72.0544
Manufacture of radio, television and communication equipment and apparatus (32)	0.5849	1.3695	9849.660	57.6117
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	1.1720	2.2379	4152.194	48.6617
Hotels and restaurants (55)	0.5097	1.3794	8741.631	44.5562
Manufacture of medical, precision and optical instruments, watches and clocks (33)	1.5019	1.1844	2837.890	42.6227
Public administration and defence; compulsory social security (75)	0.2543	1.0630	15177.782	38.5994
Cultivation of wheat	2.3109	1.7130	1619.327	37.4218
Recreational, cultural and sporting activities (92)	0.5422	1.1102	6706.004	36.3595
Supporting and auxiliary transport activities; activities of travel agencies (63)	0.2736	2.2840	12723.843	34.8083
Processing of Food products nec	0.5422	1.3537	5992.262	32.4892
Forestry, logging and related service activities (02)	1.1941	2.3988	2520.460	30.0974
Manufacture of office machinery and computers (30)	0.3315	1.2672	8425.552	27.9334
Casting of metals	0.8803	2.4353	3164.680	27.8584
Steam and hot water supply	4.2878	1.7730	626.802	26.8762
Manufacture of textiles (17)	0.8679	1.4381	3072.650	26.6677
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	0.6464	2.5681	4049.580	26.1772
Computer and related activities (72)	0.3180	2.2601	6763.334	21.5085
Cultivation of cereal grains nec	2.0595	2.2469	1017.834	20.9621
Cultivation of oil seeds	2.2487	2.0092	830.817	18.6828
Processing of dairy products	0.4579	1.5511	3883.399	17.7833
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.7046	1.0854	2420.576	17.0548
Re-processing of secondary aluminium into new aluminium	1.1140	2.1538	1523.086	16.9675
Financial intermediation, except insurance and pension funding (65)	0.2058	2.6433	7955.805	16.3762
Manufacture of beverages	0.7204	1.5264	2197.707	15.8329
Education (80)	0.1622	1.0629	9062.917	14.6993
Transport via railways	0.4657	2.1637	2901.500	13.5127

TABLE 29: *THE MOST AFFECTED SECTORS IN THE CZECH REPUBLIC ORDERED BY ACTUAL PRICE INCREASES*

Table 29 reports on the highest total increase in sectoral costs as a direct result of the Peak-Oil simulation. The column "Price increases in €m" represents by how much the total output has gone up. The total output includes the final demand numbers.

4.3 Discussion

4.3.1 Rationales on the basis of direct consumption

In terms of price increases on the top five most affected sectors in the US economy, the Defence and National Security sector shows a significant price increase as a result of the oil prices going up. A research conducted by Crane et al., (2009) of the *RAND* cooperation presented the linkages between imported oil and the US national security. It found that the risk was major for the US national security in scenarios where a large disruption in global supplies of oil occurs and when there is an increase in payments by the US consumers due to reductions in supply by oil exporters. Both points present a scenario where an exogenous oil price increase occurs, which is consistent with the simulation technique—focusing on oil as an exogenous input—presented in this research. More recently Krane and Medlock, (2018) assessed the geopolitical dimension of the US oil security, which concluded that although the shale revolution has made the US the largest oil producer in the world, it remains a net importer. Therefore, maintaining the supply and stability of the oil trade may continue to be a crucial component of US national security. Given how invested the US Defence and Security Sector is with oil, it may be why it is one of the most affected sectors. However, the table shows that the FWD linkage for this sector is only 1.0040, which implies that it is not the most important sector to GDP according to IO logic. According to the NAICS, (2017) the Public Administration and Security sector mainly involves service sectors and Ghosh relates the sectoral gross production (physical unit of value) to the primary inputs (Miller and Blair, 2009).

The construction has the second highest price increase. In the IO tables used for this research, the construction sector is aggregated for 45 industries. The subcategories include residential and non-residential buildings, utility systems construction, land subversion, highways and streets construction as well as other heavy civil engineering construction (NAICS, 2017). Prices for highway construction may go up in the real world in relation to crude oil price hikes because asphalt cement is a by-product of crude oil refining. The construction sector is on the top end of most affected industries in both the UK and the Czech Republic as well. According to *BP*, the construction industry uses 33% of the total oil consumption in the USA alone. This finding is consistent with the price rises seen in the UK and the Czech Republic, where the construction industry is likely utilizing large quantities of crude oil as well. Construction as an engine of growth has been acknowledged in publications such as Wells, (1985). For developed economies such as the UK and the USA and to a large part the Czech Republic—who have moved on to services (exports oriented in the case of the Czech Republic)—such evidence may appear incompatible. The forward linkage for this sector is at 1.13 in the USA and 1.19 in the UK, indicating that the sector is important but not imperative to these economies. For the Czech Republic, the linkage at 1.77 is high. A possible explanation may be its economic focus on tangible wealth creation like manufacturing, whereas the UK and the USA have a large intangible services sector.

The Manufacturing industry is affected in all three countries. *BP* estimates that 42% of the crude oil consumption comes from industry in the USA. *BP* uses industry as an umbrella term (excluding transport which utilizes 19% of the total crude oil consumption in the USA). Going by that logic, the findings here are consistent. The most affected manufacturing sectors in the USA are those of the manufacture of fabricated metal products (FWDL 2.05), transport equipment (2.00), basic iron steel (2.56) and cement manufacture (2.25). The UK manufacturing sector does not seem to be as affected as the USA, as only the manufacture of plastics and rubber (1.73), manufacture of furniture (1.20) and manufacture of machinery (1.29) feature as the most affected sectors. The Czech Republic's most affected manufacturing sectors include those of rubber and plastic (1.76), motor vehicles, trailers (1.41), fabricated metal products (1.89), manufacture of electrical machinery (1.54). The high forward linkages for the manufacturing sector indicate its importance to the overall economy. With reference to IO, in a Peak-Oil scenario, a dip in the manufacturing sector may hurt a country significantly. This would also imply that monetary or other stimulus may be prioritised towards the manufacturing sectors in order to minimise economic harm.

In the USA, Deloitte, (2019) puts manufacturing as the foundation of America's success. 90% of private sector research and development as well as 12.1% contribution to GDP (around $2.1 trillion) comes from the manufacturing sector alone. Given these statistics, one may assume as to why the various manufacturing sectors have such high FWD linkages. Cement manufacturing is particularly interesting, because it feeds directly into the construction sector, which does not have an impact as significant to GDP according to its FWD linkage value of 1.13. Considering that the manufacturing sector creates forty million jobs in the USA according to Deloitte, a sudden surge in the costs of this sector may have significant impacts on the wider economy. For example, in an effort to curb costs, bosses may start cutting certain jobs in the sector. Many manufacturing jobs are threatened by automation. For example; of some 702 occupations, 47% of workers in the USA were at a high risk of potential automation. These jobs include transport and logistics services (drivers), office support (receptionists and security guards) as well as workers in sales and services. A follow on study found that 35% of the workforce is Britain was at a risk of automation (The Economist, 2016a). However, this may still not solve the energy problem and that the vast majority of the energy supplies for the USA, UK and Czech Republic come from crude oil. Substitution of conventional oil with non-conventional oil would still mean more fossil fuel use. For example, figure 14 shows the energy contribution to GDP in the UK:

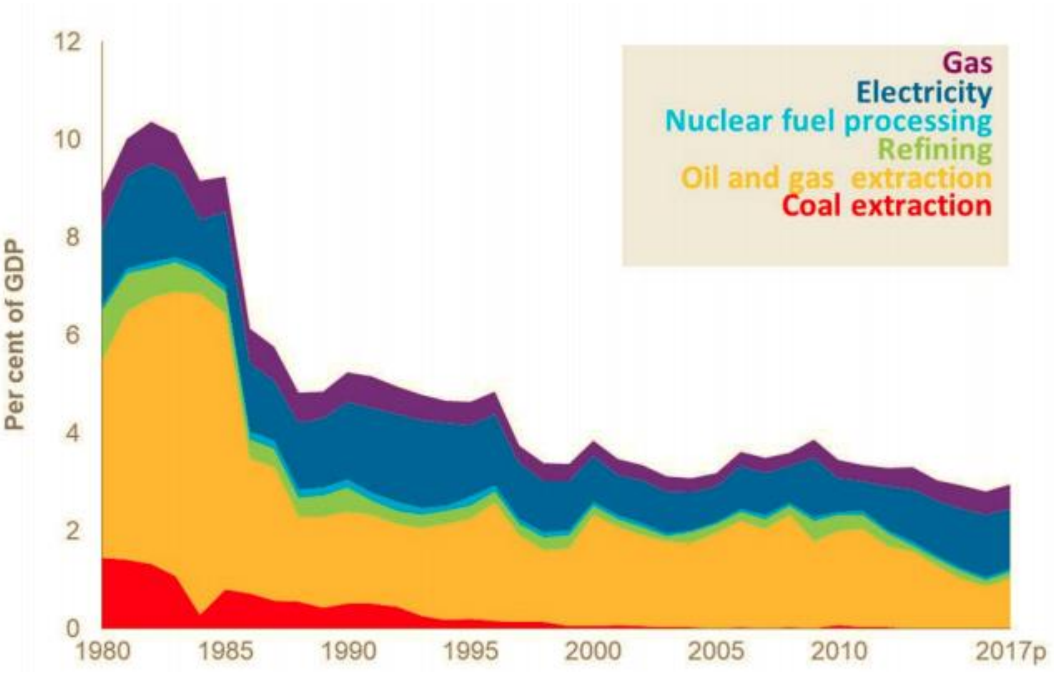

FIGURE 21: *CONTRIBUTION TO GDP BY ENERGY INDUSTRIES IN THE UK*[16]

Even though the UK fields peaked in the early 1980s, oil and gas still play an outsized role in energy production albeit with a declining trend between the 1980s and 2017. For the Czech Republic's exports oriented market economy, rising costs to manufacturing industries could mean its exports become more expensive to buy for importers. In today's globalized world, that could mean higher prices for consumers in the importing countries.

Collectively, the highest price increases in the most important sectors come down to three clusters; industry, commercial and residential construction and general business activities including the services sectors in all three economies. In the industry cluster, manufacturing is the most affected sector closely followed by electricity and production of other commodities. A question that may come to mind is what effects the oil price hike can have on the activities of industries, specifically manufacturing in the three economies discussed. A natural deduction might be that oil price volatility—factoring in a Peak-Oil scenario—may lead to a negative effect on the economy. Aye et al., (2014) conducted a case study of the South African manufacturing industry and found that overall, the primary reasons are linked to the lack of motivation for private investment, when the risk to returns is high for which oil price volatility is responsible. Therefore, strategic investment decisions might be affected. In a Peak-Oil scenario, it may be

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[16] *(*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728374/UK_Energy_in_Brief_2018.pdf*)*

plausible to assume that the sharp rise in oil prices may probably torpedo any positive effects that previous cost reductions have incurred. Furthermore, as a result of depressed investment, it may be plausible to assume that unemployment will also rise. This view is supported by Kandemir Kocaaslan, (2019) who found that the oil prices had a positive and significant impact on US unemployment. By conducting an impulse response test–much like this research's Peak-Oil simulation—they found that oil price hikes magnified and intensified unemployment in the USA. Another example of oil sector prices weakening manufacturing is in Norway, given that its economy heavily depends on offshore oil and gas extraction (EIU, 2015).

In the UK, apart from the rubber and plastics manufacturing, the other manufacturing sectors are further down the pecking order of price increases. In comparison to the USA and the Czech Republic, there are fewer manufacturing sectors in the British economy. Why this has happened may be explained through historical context. Between the 1840's and the 1960's, Britain's manufacturing sector employed 40% of its total workforce. In 2016, it employed only 8% and its contribution to GDP was 1/10th in total (The Economist, 2016b).

The shale boom has made the USA the world's top crude oil producer. A case in point is the Permian Basin, which spans 75000 sq. miles of barren landscape, yet accounts for 30% of America's oil production in 2018. With geopolitics coming into play, such as sanctions on Iranian crude, the shale production is expected to fill the gaps(The Economist, 2018a), though it is unclear how long the shale reserves would be able to do so. In this research, the Peak-Oil scenario is related to oil as an exogenous as well as endogenous source entering into the economy. Although the *EIA* puts crude oil at 78% of the gross U.S. petroleum import in 2018 (EIA, 2018), it may be plausible to assume that the largest producer of crude oil will have some cushion in dealing with a Peak-Oil scenario—at least in the short to medium term—until the shale boom reaches its inevitable physical limits. Additionally Bilgili et al., (2016) explored the US shale gas revolution and how the US economy reacted to it. They found that the shale oil and gas revolution had a positive effect on the US GDP (assuming directly and indirectly), pointing to the notion that shale gas might lower or decrease the direct energy dependence of the US. The US has always intended on energy independency since the oil crises of the 1970s. At first glance, Shale oil—though not the same quality and EROI as conventional oil, as well as shale gas with respect to the world moving towards greener energy sources—appear to make a plausible case for understanding why the most important industries in the USA have appeared to withstand the ripple effects of oil. Yet this is a speculative conclusion and requires further evidence, which is beyond the scope of this research. The USA did however provide up to $5.6 trillion in subsidies to the fossil fuel industry, which included support towards drilling costs, percentage depletion, foreign tax credits as well as final consumers paying variable prices at the pump, depending on the state (EESI, 2019). Whether these subsidies cushion the costs incurred as a result of oil price rises throughout the US economy cannot be determined due to the binary nature of the IO analysis. In a case where the US may have artificially kept oil prices low in its domestic economy relative to the world, oil prices would make the shale boom argument consistent with this research. However, this research has not come upon any such evidence.

The UK economy in comparison to the USA, is dominated by the services sector, which is not directly linked to oil as an exogenous input. Intangible wealth such as heavy investments in software and management practices have allowed British firms to grow rapidly. For example, a firm writing computer codes can export it all over the world with the touch of a button (The Economist, 2018b). This may be why the “other business activities” sector in the UK sits closest to the most price affected sectors in the UK as a whole. However, a services driven economic model may not fully vindicate the UK economy from oil shocks. Lorusso and Pieroni, (2018) conducted an assessment of the causes and consequences of oil price shocks on the UK economy, where they examined the impacts and repercussions of oil price fluctuations. Amongst the insights from their analysis, they found that the UK macroeconomic aggregates produce different responses in relation to the underlying shock affecting the oil prices. In practice, this means that GDP growth immediately slows down as a result of negative exogenous oil supply shocks, which ultimately leads to sustained inflation in the UK.

4.3.2 Indirect Impacts and forward linkages

A significant advantage of IO models is that it shows the direct as well as the indirect effects of exogenous changes. Therefore, this analysis goes further than reporting on direct price increases in each sector. According to the IO logic, a high forward linkage number indicates the importance of a given sector to the overall economy. Forward linkages of more than 2.000 are of particular importance to the discussion of a Peak-Oil scenario.

The defence and social security sector (table 15) in the USA has seen its costs rise in absolute terms, as discussed above. However, in table 15, it can be seen that the actual forward linkage of this sector is 1.0040. With respect to the IO logic, this forward linkage means that the overall contribution to the USA GDP from this sector is not very high and hence it will not necessarily cause problems for the economy. Similarly, health and social work in the UK has a high relative price change (table 16), but does not have a forward linkage above 2.000. Health and social work price increases are also high for the Czech Republic (table 17) with a lower than 2.000 forward linkage. The UK has more sectors than both the USA and the Czech Republic in the services sector because of its service based economy. Yet because of the high forward linkages, small indirect price increases in sectors like Financial Intermediation and Other Business Activities may compound and cause problems for the overall economy. From an IO perspective, there is no one “services” sector in the UK economy, but it is rather a compound of different sectors put together. A collective of service sectors would naturally contribute significantly to the UK GDP. Hence, services will suffer in a Peak-Oil induced recession, but a stimulus to services would also boost the overall economy.

The forward linkages of the construction sectors in tables 9, 10 and 11 are higher in the Czech Republic than in the UK or the USA. These higher numbers mean that the construction sector is of higher importance to the Czech economy, relative to its importance in the USA and the UK.

The three countries have many sectors with forward linkages beyond 2.000 in the retail, services and miscellaneous cluster (figure 17). As mentioned earlier, the services sector forms a large portion of intangible wealth to all three economies. Given the IO logic, cost increases in these sectors may substantially affect GDP in these countries. At the same time, fiscal stimulus to this cluster may also be one of the most helpful for the overall economy in an economic recession brought on by Peak-Oil.

There is a significant number of sectors in the recycling cluster in figure 19 with forward linkages beyond 2.000. They primarily belong to the USA and the Czech Republic. Recycling activities in these countries include sectors which recycling of waste and scrap, waste water treatment, incineration of waste etc. Higher oil prices may be a mixed bag for the recycling business. For example, higher oil prices may result in higher prices for virgin plastics and hence consumers may want to purchase recycled plastics. However, high oil prices may also raise operational costs for these industries, such as transportation of recycling material and running energy costs. From an IO perspective, the indirect effects of Peak-Oil on the recycling cluster may suggest that the USA and the Czech Republic have many sectors in this cluster, which are vulnerable due to their contribution to overall GDP and may require priority assistance to combat a downturn.

Transport cluster in the USA, UK and Czech Republic all appear affected by Peak-Oil. Though at a closer look at the cluster breakdown, the USA has very little or no price increases in sectors such as railway transport, land etc. The UK and the Czech Republic have higher increases in these sectors. One reason may be that in the UK and the Czech Republic, public transportation plays a greater role in the economy than it does in the USA. This can be observed in table 26, where railway transportation in the Czech Republic has a forward linkage of 2.1637. Overall, it appears that Peak-Oil may have a higher impact on the UK and the Czech Republic than in the USA.

5 CONCLUSION

The above analysis is an addition to the many different economic analyses conducted in the field of ecological economics, that relate to the difficulties a given economy would face as a result of a peaking resource. In the case of this research, it is oil. There are other researches on the Peak phenomena such as Peak-Phosphorous (Cordell et al., 2009) or Peak-Minerals (Prior et al., 2012) etc. The general conclusion is that Peak-Oil shall adversely affect all economies and some more than others. For the Czech Republic—which as a result of this analysis seems like the most affected economy from Peak-Oil—the EU energy consolidation policy should definitely help it to navigate the issues of Peaking Oil. Furthermore, another more pressing policy decision may be to diversify the Czech economy, which currently is very heavily reliant on manufacturing activities.

The takeaway message then points towards *substitutability, i.e.* replace oil and energy intensive activities in the economy with those that provide a similar or identical yield, yet not so energy intensive, or use oil to generate energy. This is easier said than done of-course. Nevertheless, in the view of this researcher, the first step to combating the Peak-Oil phenomenon is to invest in renewables such as solar and wind power (like those in the UK). There is also a strong argument for reducing consumption altogether. The burgeoning de-growth literature is advancing this strategy (e.g. Kerschner, 2010). The Corona virus pandemic has dampened demand since March, 2020 when the world went economy went into a state of lockdown. This development may delay the developments related to Peak-Oil but ultimately does not nullify the Peak-Oil phenomenon. If the current consumption pattern is to be retained, then renewables offer a lifeline in that not only are they already taking a slice out of the total energy production load from oil in some places, but they are also bidding to mitigate another calamity brought unto us through the oil age, threatening the very existence of the natural world itself; Climate Change.

5.1 Contribution to knowledge

This work has made the following contributions to knowledge:

- A different strategy than the one used by Kerschner et al., (2013). This research addressed the price increases of the domestic oil and gas sectors alongside an identical line of reasoning to Kerschner et al., (2013), i.e. increasing their production costs, owing to expensive extraction and scarcity as an oil source neared its peak. The second part of the simulation rationale was proposed by the researcher. This stated that all sectors identified for further price manipulation should have their oil and gas prices raised by 100%.
- Application of this model to the UK and the Czech Republic.
- Production of new results for the US economy.
- A comparative analysis of the US economy results in 2012 by Kerschner et al., (2013) and 2016 by this research.

- Introduction of fresh Peak-Oil literature. Chapter one of this research has approached Peak-Oil from a technical perspective, highlighting the importance of a coherent and scientific understanding of the topic, backed by numerous examples of actual field data as well as forecasting techniques that have or have not been used so far by the major players in the oil and gas industry.

5.2 Limitations and future work

With any empirical work, there are limitations to the extent of its use. For this research, the following apply:

- The price simulation strategy proposed by this researcher exhibits an extreme scenario of oil price increases. Although the quantitative reasoning has coherence in its own right, it must be noted that for a real-world case, using an identical line of reasoning would require the researcher to use actual percentage of oil and gas import as a proportion of the total imports. In other words, if the petroleum refining sector's oil and gas imports are 30% of its total imports, then only this 30% may be doubled and added to the total imports. The extreme case presented here homogenizes oil and gas import percentages as one number, i.e. 85%- The fact that this systematically distorts results will have to be addressed in future work with a more precise strategy. Additionally, the price of imported oil and gas will need to be raised for all sectors.
- Further improvement for this study may be achieved via actual oil use numbers by every sector in an economy. An IO table providing input of the oil and gas sectors into other sectors and vice-versa was used in this study. Instead what may have provided a greater degree of accuracy is the availability of data that directly links real oil use and each sector in all the economies. This would have facilitated a bespoke strategy where every sector would have been subject to some price increase. The researcher imagines that such an experiment would yield a better overall picture of the impact of Peak-Oil, especially on economies of the UK and USA, that seem to be robust enough to an oil price shock at the moment.
- The Price model has its limitation. One big disadvantage is that it takes the final demand as a given. Thus, the price model will only show how prices change throughout an economy due to the inflation in price of a key resource. The supply constrained model on the other hand can indicate some reaction of the final demand, but since oil is a price inelastic commodity, it may be so that demand may not significantly decrease in the short-term due to increased oil prices. From the past oil shocks, governments may opt for price controls rather than markets dictating everything (which however is difficult with global oil prices). Hence given the possibilities of large price surges and possible price controls, in terms of Peak-Oil, it may be plausible to assume a reduction in available oil than to estimate what prices may be.

5.3 Future outlook

Input-Output models have recently come back into the spotlight for they also provide emissions data by a particular country. Given that climate change has now taken center stage in world debate, a good avenue for research would be to use the IO framework and simulate scenarios, where excessive use of resources results in higher emissions for a given economy. I recommend developing a machine learning model in MATLAB or Python that would simulate a number of scenarios as parametric variables are altered. For example, how much do overall emissions go up/down when the construction industry substitutes energy from oil and gas with a renewable source such as wind power? Such an approach would facilitate future researchers in that it would outsource the number-crunching to a computer, leaving the human to determine which scenarios are best to look at in relation to the macro-economy, which would produce the most emissions and which would produce the least as well as what possible strategies can be adopted in the real world to mitigate excessive emissions and perhaps advice policy makers. Similar projects are already underway under the EU's Horizon 2020 program e.g. in the MEDEAS project. Yet researchers can add to the analysis by including S&A as Kerschner et al., (2013). An academic input of this sort would surely aid in a planet friendly output.

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Appendix 1: Additional tables for the USA Economy

Sectors	Price Model % Change	FWD Linkages
US_Private households with employed persons (95)	0.000	1.0000
US_Extraction of natural gas and services related to natural gas extraction, excluding surveying	103.124	1.0000
US_Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	101.674	1.0000
US_Animal products nec	0.144	1.0000
US_Extraction, liquefaction, and regasification of other petroleum and gaseous materials	7.859	1.0000
US_Production of meat products nec	0.318	1.0000
US_Sugar refining	0.124	1.0002
US_Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	1.460	1.0030
US_Public administration and defence; compulsory social security (75)	0.548	1.0040
US_Mining of iron ores	0.294	1.0046
US_Cultivation of vegetables, fruit, nuts	0.119	1.0153
US_Health and social work (85)	0.175	1.0287
US_Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.094	1.0331
US_Manufacture of office machinery and computers (30)	0.201	1.0383
US_Manufacture of tobacco products (16)	0.035	1.0570
US_Manufacture of beverages	0.959	1.0601
US_Manufacture of furniture; manufacturing n,e,c, (36)	0.805	1.0719
US_Processed rice	0.040	1.0769
US_Other service activities (93)	0.165	1.0876
US_Processing vegetable oils and fats	0.000	1.0933
US_Manufacture of medical, precision and optical instruments, watches and clocks (33)	0.490	1.1062
US_Cultivation of oil seeds	0.098	1.1220
US_Construction (45)	0.650	1.1346
US_Re-processing of secondary construction material into aggregates	0.015	1.1346
US_Manufacture of machinery and equipment n,e,c, (29)	0.519	1.1403
US_Education (80)	0.078	1.1871
US_Processing of meat poultry	0.267	1.2092
US_Petroleum Refinery	22.255	1.2290
US_Processing of nuclear fuel	0.000	1.2465
US_Cultivation of plant-based fibers	0.142	1.2579
US_Manufacture of motor vehicles, trailers and semi-trailers (34)	0.792	1.2605

US_Manufacture of other transport equipment (35)	0.286	1.2661
US_Manufacture of textiles (17)	1.651	1.2948
US_Processing of meat cattle	0.065	1.3202
US_Processing of Food products nec	0.469	1.3253
US_Processing of meat pigs	0.106	1.3253
US_Real estate activities (70)	0.032	1.3296
US_Mining of coal and lignite; extraction of peat (10)	0.283	1.3518
US_Computer and related activities (72)	0.029	1.3555
US_Re-processing of secondary plastic into new plastic	5.358	1.3791
US_Recreational, cultural and sporting activities (92)	0.051	1.3812
US_Manufacture of fish products	0.066	1.3818
US_Plastics, basic	4.729	1.3822
US_Collection, purification and distribution of water (41)	0.021	1.3825
US_Manufacture of radio, television and communication equipment and apparatus (32)	0.280	1.3999
US_Mining of other non-ferrous metal ores and concentrates	0.000	1.4308
US_Manufacture of electrical machinery and apparatus n,e,c, (31)	0.322	1.4431
US_Activities of membership organisation n,e,c, (91)	0.016	1.4564
US_Manufacture of ceramic goods	0.290	1.4633
US_Processing of dairy products	0.402	1.5129
US_Hotels and restaurants (55)	0.000	1.5132
US_Recycling of waste and scrap	0.481	1.5383
US_Distribution and trade of electricity	0.041	1.5764

TABLE 30

Sectors	Price Model % Change	FWD Linkages
US_Waste water treatment, food	0.111	1.6045
US_Waste water treatment, other	0.111	1.6130
US_Manufacture of gas; distribution of gaseous fuels through mains	1.531	1.6155
US_Cultivation of wheat	0.180	1.6190
US_Precious metals production	0.056	1.6237
US_Re-processing of secondary preciuos metals into new preciuos metals	0.052	1.6237
US_Re-processing of secondary lead into new lead, zinc and tin	0.000	1.6467
US_Lead, zinc and tin production	0.000	1.6474
US_Production of electricity by gas	3.950	1.7007
US_Air transport (62)	0.007	1.7066
US_Mining of lead, zinc and tin ores and concentrates	0.000	1.7276
US_Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	0.189	1.7289
US_Chemicals nec	11.999	1.7449
US_Production of electricity by coal	0.038	1.7491
US_Transmission of electricity	0.026	1.7513
US_Quarrying of sand and clay	8.196	1.7561
US_Production of electricity by hydro	0.021	1.7665
US_Production of electricity by nuclear	0.014	1.7667
US_Re-processing of secondary glass into new glass	0.288	1.7716
US_Manufacture of glass and glass products	0.569	1.7735
US_Production of electricity by wind	0.015	1.7778
US_Re-processing of secondary paper into new pulp	0.253	1.7792
US_Pulp	0.009	1.7792
US_Production of electricity by biomass and waste	0.011	1.7899
US_Manufacture of rubber and plastic products (25)	14.698	1.8010
US_Insurance and pension funding, except compulsory social security (66)	0.012	1.8023
US_Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	0.000	1.8042
US_Sea and coastal water transport	0.000	1.8126
US_Publishing, printing and reproduction of recorded media (22)	0.115	1.8480
US_Meat animals nec	0.000	1.8789
US_Production of electricity by Geothermal	0.001	1.8800
US_Inland water transport	0.005	1.8845
US_Production of electricity by petroleum and other oil derivatives	8.664	1.8934
US_Composting of food waste, incl, land application	0.009	1.9204
US_Manufacture of other non-metallic mineral products n,e,c,	0.357	1.9424
US_Incineration of waste: Oil/Hazardous waste	0.012	1.9437

US_Cultivation of cereal grains nec	0.148	1.9767
US_Incineration of waste: Metals and Inert materials	0.108	1.9822
US_Research and development (73)	0.243	2.0009
US_Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n,e,c,	0.086	2.0025
US_Paper	0.498	2.0029
US_Wool, silk-worm cocoons	0.000	2.0183
US_Other non-ferrous metal production	0.000	2.0338
US_Re-processing of secondary copper into new copper	0.121	2.0353
US_Copper production	0.202	2.0353
US_Production of electricity by solar photovoltaic	0.000	2.0452
US_Manufacture of fabricated metal products, except machinery and equipment (28)	0.397	2.0501
US_Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.000	2.0552
US_Activities auxiliary to financial intermediation (67)	0.009	2.0553
US_Incineration of waste: Wood	0.081	2.0571
US_Incineration of waste: Food	0.135	2.0575
US_Incineration of waste: Paper	0.165	2.0679
US_Landfill of waste: Food	0.182	2.0689
US_Incineration of waste: Plastic	0.145	2.0695
US_Composting of paper and wood, incl, land application	0.112	2.0715
US_Landfill of waste: Paper	0.168	2.0758
US_Landfill of waste: Inert/metal/hazardous	0.172	2.0760
US_Incineration of waste: Textiles	0.063	2.0824
US_Biogasification of sewage slugde, incl, land application	0.136	2.0827
US_Landfill of waste: Plastic	0.150	2.0845
US_Landfill of waste: Wood	0.101	2.0873
US_Landfill of waste: Textiles	0.085	2.0890
US_Cultivation of paddy rice	0.039	2.0975
US_Mining of copper ores and concentrates	0.000	2.1005
US_Re-processing of secondary wood material into new wood material	0.010	2.1010
US_Production of electricity nec	0.000	2.1013
US_Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	0.007	2.1014
US_N-fertiliser	9.987	2.1055
US_Cultivation of crops nec	0.092	2.1100
US_Mining of uranium and thorium ores (12)	0.000	2.1221
US_Other land transport	0.005	2.1324
US_Post and telecommunications (64)	0.000	2.1332
US_Financial intermediation, except insurance and pension funding (65)	0.008	2.1357
US_Poultry farming	0.110	2.1399
US_Recycling of bottles by direct reuse	0.000	2.1510
US_Transport via pipelines	0.000	2.1832

US_Quarrying of stone	0.240	2.2112
US_Cultivation of sugar cane, sugar beet	0.057	2.2271
US_Re-processing of ash into clinker	0.193	2.2554
US_Manufacture of cement, lime and plaster	0.352	2.2558
US_P- and other fertiliser	9.873	2.2737
US_Other business activities (74)	0.060	2.3086
US_Mining of aluminium ores and concentrates	0.000	2.3120
US_Pigs farming	0.027	2.3269
US_Cattle farming	0.061	2.3301
US_Production of electricity by solar thermal	0.000	2.3477
US_Renting of machinery and equipment without operator and of personal and household goods (71)	0.010	2.3546
US_Casting of metals	0.190	2.3620
US_Steam and hot water supply	0.038	2.3650
US_Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.000	2.3815
US_Manufacture of bricks, tiles and construction products, in baked clay	0.328	2.4227
US_Supporting and auxiliary transport activities; activities of travel agencies (63)	0.004	2.4355
US_Raw milk	0.074	2.4970
US_Transport via railways	0.000	2.5241
US_Re-processing of secondary steel into new steel	0.221	2.5531
US_Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.297	2.5633
US_Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.000	2.5751
US_Aluminium production	0.239	2.5946

TABLE 31

Appendix 2: Additional tables for the UK Economy

Sectors	Price Model % Change	FWD linkages
GB_Private households with employed persons (95)	0.0411	1.0000
GB_Inland water transport	0.3049	1.0009
GB_Production of meat products nec	0.5052	1.0012
GB_Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.9467	1.0023
GB_Activities of membership organisation n,e,c, (91)	0.5781	1.0085
GB_Manufacture of tobacco products (16)	0.3696	1.0086
GB_Processing of meat poultry	2.6458	1.0104
GB_Processing of nuclear fuel	0.0366	1.0267
GB_Petroleum Refinery	73.5584	1.0359
GB_Education (80)	0.4104	1.0386
GB_Real estate activities (70)	0.1688	1.0500
GB_Manufacture of gas; distribution of gaseous fuels through mains	62.2865	1.0599
GB_Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.7682	1.1165
GB_Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	0.2159	1.1185
GB_Public administration and defence; compulsory social security (75)	0.2646	1.1424
GB_Health and social work (85)	0.5062	1.1494
GB_Recreational, cultural and sporting activities (92)	0.2505	1.1658
GB_Manufacture of textiles (17)	1.1289	1.1709
GB_Poultry farming	0.6653	1.1866
GB_Manufacture of office machinery and computers (30)	0.2771	1.1896
GB_Chemicals nec	21.9190	1.1930
GB_Manufacture of radio, television and communication equipment and apparatus (32)	0.2649	1.2173
GB_Processing of meat cattle	0.8171	1.2211
GB_Precious metals production	0.0492	1.2272
GB_Manufacture of furniture; manufacturing n,e,c, (36)	0.5803	1.2291
GB_Other non-ferrous metal production	0.2696	1.2292
GB_Manufacture of motor vehicles, trailers and semi-trailers (34)	0.5013	1.2345
GB_Collection, purification and distribution of water (41)	0.1579	1.2380
GB_Production of electricity by coal	1.0702	1.2413
GB_Manufacture of fabricated metal products, except machinery and equipment (28)	0.3576	1.2443
GB_Processing of meat pigs	0.0777	1.2444
GB_Other service activities (93)	0.2126	1.2483
GB_Cultivation of crops nec	0.0000	1.2591
GB_Manufacture of other transport equipment (35)	0.4180	1.2618
GB_Production of electricity by nuclear	0.1208	1.2627

GB_Manufacture of medical, precision and optical instruments, watches and clocks (33)	0.1869	1.2870
GB_Manufacture of machinery and equipment n,e,c, (29)	0.4207	1.2902
GB_Re-processing of secondary steel into new steel	0.4401	1.2955
GB_Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.2485	1.2958
GB_Copper production	0.1352	1.2988
GB_Production of electricity by wind	0.2412	1.3011
GB_Air transport (62)	0.1252	1.3450
GB_Processing of dairy products	0.6364	1.3784
GB_Hotels and restaurants (55)	0.0717	1.3802
GB_Insurance and pension funding, except compulsory social security (66)	0.2341	1.3835
GB_Cultivation of oil seeds	0.2383	1.3842
GB_Production of electricity by hydro	0.2124	1.3958
GB_Cultivation of vegetables, fruit, nuts	0.3786	1.4070
GB_Processing vegetable oils and fats	0.0189	1.4110
GB_Manufacture of beverages	0.9658	1.4113
GB_Manufacture of electrical machinery and apparatus n,e,c, (31)	0.1854	1.4145
GB_Processing of Food products nec	0.8587	1.4207
GB_Production of electricity by biomass and waste	0.4614	1.4334
GB_P- and other fertiliser	41.9999	1.4530
GB_Processed rice	0.0970	1.4557
GB_Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	96.9208	1.4588
GB_Publishing, printing and reproduction of recorded media (22)	0.2602	1.4771
GB_Sugar refining	0.0000	1.4938
GB_Mining of precious metal ores and concentrates	0.1032	1.4945
GB_Cultivation of cereal grains nec	0.4718	1.4951
GB_Re-processing of secondary construction material into aggregates	0.0691	1.4959
GB_Construction (45)	0.6484	1.4964
GB_Paper	0.6083	1.5082
GB_Mining of iron ores	0.0000	1.5270
GB_Meat animals nec	0.2445	1.5290
GB_Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.0000	1.5315
GB_Manufacture of other non-metallic mineral products n,e,c,	0.8348	1.5353
GB_Transport via railways	0.2225	1.5749
GB_Sea and coastal water transport	0.0994	1.5810
GB_Extraction of natural gas and services related to natural gas extraction, excluding surveying	99.9976	1.5841
GB_Production of electricity by petroleum and other oil derivatives	51.4999	1.5874
GB_N-fertiliser	53.9191	1.5933
GB_Recycling of bottles by direct reuse	0.0000	1.5985
GB_Quarrying of stone	0.6275	1.5996

TABLE 32

Sectors	Price Model % Change	FWD linkages
GB_Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n,e,c,	5.6059	1.6296
GB_Manufacture of ceramic goods	0.3802	1.6530
GB_Production of electricity by gas	10.1653	1.6642
GB_Research and development (73)	0.2775	1.6729
GB_Mining of other non-ferrous metal ores and concentrates	0.0000	1.6788
GB_Cultivation of wheat	0.7618	1.7022
GB_Incineration of waste: Metals and Inert materials	0.3351	1.7112
GB_Incineration of waste: Plastic	0.1928	1.7234
GB_Animal products nec	0.0000	1.7255
GB_Quarrying of sand and clay	0.4620	1.7298
GB_Manufacture of rubber and plastic products (25)	17.6115	1.7300
GB_Financial intermediation, except insurance and pension funding (65)	0.2525	1.7408
GB_Forestry, logging and related service activities (02)	0.2439	1.7474
GB_Incineration of waste: Paper	0.3309	1.7528
GB_Incineration of waste: Food	0.3202	1.7580
GB_Mining of lead, zinc and tin ores and concentrates	0.0000	1.7789
GB_Incineration of waste: Wood	0.2078	1.7801
GB_Incineration of waste: Oil/Hazardous waste	0.3287	1.7899
GB_Landfill of waste: Inert/metal/hazardous	0.3740	1.7936
GB_Landfill of waste: Food	0.3781	1.7938
GB_Waste water treatment, food	0.3572	1.7995
GB_Composting of food waste, incl, land application	0.3866	1.7997
GB_Waste water treatment, other	0.3593	1.8031
GB_Landfill of waste: Paper	0.3446	1.8037
GB_Aluminium production	0.4306	1.8048
GB_Re-processing of secondary aluminium into new aluminium	0.2154	1.8049
GB_Computer and related activities (72)	0.2221	1.8057
GB_Biogasification of sewage slugde, incl, land application	0.3582	1.8075
GB_Landfill of waste: Plastic	0.3381	1.8127
GB_Landfill of waste: Wood	0.3242	1.8142
GB_Landfill of waste: Textiles	0.3001	1.8236
GB_Cattle farming	1.1214	1.8257
GB_Incineration of waste: Textiles	0.1801	1.8366
GB_Production of electricity by solar photovoltaic	0.0000	1.8690
GB_Production of electricity nec	0.0176	1.8709
GB_Biogasification of food waste, incl, land application	0.0620	1.8724
GB_Pigs farming	0.6205	1.8773
GB_Biogasification of paper, incl, land application	0.0000023	1.9067
GB_Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	0.0121	1.9250
GB_Post and telecommunications (64)	0.1572	1.9320
GB_Lead, zinc and tin production	0.0204	1.9364

GB_Manufacture of glass and glass products	0.6266	1.9579
GB_Re-processing of secondary glass into new glass	0.5113	1.9585
GB_Re-processing of secondary lead into new lead, zinc and tin	0.0184	1.9828
GB_Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.0000	1.9943
GB_Mining of coal and lignite; extraction of peat (10)	0.8081	2.0496
GB_Steam and hot water supply	0.0001	2.0518
GB_Other land transport	0.1011	2.0634
GB_Cultivation of plant-based fibers	0.0000	2.0916
GB_Casting of metals	0.1884	2.1440
GB_Pulp	0.5050	2.1988
GB_Raw milk	0.3213	2.2074
GB_Re-processing of secondary paper into new pulp	0.4831	2.2102
GB_Other business activities (74)	0.2771	2.2465
GB_Renting of machinery and equipment without operator and of personal and household goods (71)	0.1650	2.2472
GB_Plastics, basic	0.1958	2.2572
GB_Re-processing of secondary plastic into new plastic	0.1947	2.2596
GB_Activities auxiliary to financial intermediation (67)	0.0169	2.2673
GB_Distribution and trade of electricity	0.0798	2.2704
GB_Manufacture of coke oven products	0.0644	2.3035
GB_Re-processing of secondary wood material into new wood material	0.5732	2.3133
GB_Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	0.5300	2.3138
GB_Manufacture of fish products	0.6000	2.3175
GB_Cultivation of sugar cane, sugar beet	0.0000	2.3183
GB_Transmission of electricity	0.0702	2.3299
GB_Retail sale of automotive fuel	6.8948	2.3493
GB_Manufacture of bricks, tiles and construction products, in baked clay	0.4366	2.4189
GB_Manufacture of cement, lime and plaster	0.7524	2.4793
GB_Re-processing of ash into clinker	0.5807	2.4999
GB_Transport via pipelines	0.1079	2.5080

TABLE 33

Appendix 3: Additional tables for the Czech Republic Economy

Sectors	Price Model % Change	FWD Linkages
CZ_Private households with employed persons (95)	0.0311	1.0000
CZ_Manufacture of tobacco products (16)	0.4780	1.0000
CZ_Cultivation of plant-based fibers	0.3885	1.0001
CZ_Activities of membership organisation n,e,c, (91)	0.5624	1.0001
CZ_Processing of meat poultry	0.3001	1.0010
CZ_Processing of nuclear fuel	0.5987	1.0147
CZ_Health and social work (85)	1.5514	1.0153
CZ_Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	0.3461	1.0374
CZ_Education (80)	0.1622	1.0629
CZ_Public administration and defence; compulsory social security (75)	0.2543	1.0630
CZ_Other non-ferrous metal production	0.7295	1.0691
CZ_Extraction of natural gas and services related to natural gas extraction, excluding surveying	109.3436	1.0816
CZ_Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0.7046	1.0854
CZ_Re-processing of secondary steel into new steel	0.6634	1.0886
CZ_Recreational, cultural and sporting activities (92)	0.5422	1.1102
CZ_Re-processing of secondary plastic into new plastic	1.5958	1.1213
CZ_Manufacture of coke oven products	0.6813	1.1317
CZ_Manufacture of wearing apparel; dressing and dyeing of fur (18)	0.5626	1.1382
CZ_Manufacture of gas; distribution of gaseous fuels through mains	8.1872	1.1414
CZ_Plastics, basic	0.1882	1.1421
CZ_Manufacture of machinery and equipment n,e,c, (29)	0.8216	1.1449
CZ_Manufacture of other transport equipment (35)	3.0316	1.1467
CZ_Manufacture of medical, precision and optical instruments, watches and clocks (33)	1.5019	1.1844
CZ_Manufacture of furniture; manufacturing n,e,c, (36)	1.7396	1.1968
CZ_Manufacture of office machinery and computers (30)	0.3315	1.2672
CZ_Manufacture of fish products	0.7029	1.2705
CZ_Production of meat products nec	0.0413	1.3000
CZ_Other service activities (93)	0.5344	1.3249
CZ_Processing of meat cattle	1.0196	1.3301
CZ_Sugar refining	0.1042	1.3323

CZ_Copper production	0.5419	1.3466
CZ_Processing of Food products nec	0.5422	1.3537
CZ_Chemicals nec	30.4903	1.3539
CZ_Cultivation of vegetables, fruit, nuts	1.4868	1.3682
CZ_Manufacture of radio, television and communication equipment and apparatus (32)	0.5849	1.3695
CZ_Hotels and restaurants (55)	0.5097	1.3794
CZ_Precious metals production	0.9885	1.3932
CZ_Processing of meat pigs	0.3796	1.4091
CZ_Manufacture of motor vehicles, trailers and semi-trailers (34)	2.7384	1.4112
CZ_Manufacture of textiles (17)	0.8679	1.4381
CZ_Processed rice	0.4201	1.4474
CZ_Processing vegetable oils and fats	0.2061	1.5001
CZ_Mining of nickel ores and concentrates	0.0000	1.5027
CZ_Mining of lead, zinc and tin ores and concentrates	0.0012	1.5093
CZ_Manufacture of beverages	0.7204	1.5264
CZ_Real estate activities (70)	0.9166	1.5286
CZ_Manufacture of electrical machinery and apparatus n,e,c, (31)	1.3786	1.5422
CZ_Processing of dairy products	0.4579	1.5511
CZ_Collection, purification and distribution of water (41)	0.3522	1.5726

TABLE 34

Sectors	Price Model % Change	FWD Linkages
CZ_Paper	0.5750	1.6307
CZ_Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	0.9804	1.6493
CZ_Wool, silk-worm cocoons	0.2317	1.6554
CZ_Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n,e,c,	23.8045	1.6879
CZ_Mining of iron ores	0.0238	1.7051
CZ_Cultivation of wheat	2.3109	1.7130
CZ_Insurance and pension funding, except compulsory social security (66)	0.3281	1.7191
CZ_Petroleum Refinery	49.4626	1.7279
CZ_Re-processing of secondary lead into new lead, zinc and tin	0.0934	1.7379
CZ_Lead, zinc and tin production	0.1132	1.7409
CZ_Research and development (73)	0.5131	1.7547
CZ_Manufacture of ceramic goods	0.1613	1.7650
CZ_Manufacture of rubber and plastic products (25)	34.9381	1.7688
CZ_Mining of uranium and thorium ores (12)	0.5505	1.7700
CZ_Production of electricity by petroleum and other oil derivatives	33.3549	1.7721
CZ_Steam and hot water supply	4.2878	1.7730
CZ_Construction (45)	0.5842	1.7794
CZ_Re-processing of secondary construction material into aggregates	0.0768	1.7798
CZ_Production of electricity by gas	27.0480	1.7800
CZ_Inland water transport	0.3609	1.8170
CZ_Meat animals nec	0.2193	1.8223
CZ_Air transport (62)	0.2804	1.8729
CZ_Manufacture of fabricated metal products, except machinery and equipment (28)	1.4976	1.8986
CZ_Poultry farming	0.4261	1.9395
CZ_Cattle farming	0.4059	1.9432
CZ_Sea and coastal water transport	1.2049	1.9476
CZ_Manufacture of other non-metallic mineral products n,e,c,	0.7875	1.9656
CZ_Re-processing of secondary glass into new glass	0.7038	2.0053
CZ_Manufacture of glass and glass products	0.5387	2.0089
CZ_Cultivation of oil seeds	2.2487	2.0092
CZ_Animal products nec	0.1828	2.0267
CZ_Landfill of waste: Plastic	0.4352	2.0397
CZ_Incineration of waste: Plastic	0.3134	2.0416
CZ_Biogasification of sewage slugde, incl, land application	0.3660	2.0429
CZ_Composting of food waste, incl, land application	0.7720	2.0436
CZ_Waste water treatment, food	0.9154	2.0473

CZ_Incineration of waste: Paper	0.4454	2.0476
CZ_Incineration of waste: Oil/Hazardous waste	0.4502	2.0496
CZ_Waste water treatment, other	0.8526	2.0499
CZ_Landfill of waste: Paper	0.6683	2.0513
CZ_Landfill of waste: Food	0.8113	2.0525
CZ_Incineration of waste: Food	0.4739	2.0531
CZ_Landfill of waste: Inert/metal/hazardous	0.6130	2.0537
CZ_Incineration of waste: Metals and Inert materials	0.4096	2.0540
CZ_Landfill of waste: Wood	0.4579	2.0560
CZ_Landfill of waste: Textiles	0.4347	2.0580
CZ_Incineration of waste: Wood	0.3439	2.0602
CZ_Incineration of waste: Textiles	0.3169	2.0629
CZ_Pulp	0.6558	2.0714
CZ_Re-processing of secondary paper into new pulp	0.4809	2.0730
CZ_Production of electricity by coal	0.4711	2.0790
CZ_Production of electricity by solar photovoltaic	0.0958	2.0900
CZ_Distribution and trade of electricity	0.2260	2.0909
CZ_Production of electricity nec	0.2576	2.0926
CZ_N-fertiliser	21.0485	2.0927
CZ_Production of electricity by biomass and waste	0.0263	2.0995
CZ_Production of electricity by wind	0.1718	2.1185
CZ_Cultivation of crops nec	2.3737	2.1209
CZ_Transport via pipelines	0.0512	2.1355
CZ_Transmission of electricity	0.2745	2.1393
CZ_Aluminium production	1.1696	2.1518
CZ_Re-processing of secondary aluminium into new aluminium	1.1140	2.1538
CZ_Production of electricity by hydro	0.1223	2.1608
CZ_Transport via railways	0.4657	2.1637
CZ_Pigs farming	0.4086	2.1796
CZ_Production of electricity by nuclear	0.0786	2.1846
CZ_Manufacture of bricks, tiles and construction products, in baked clay	0.4225	2.1989
CZ_Mining of coal and lignite; extraction of peat (10)	0.4828	2.2114
CZ_Other land transport	0.7190	2.2263
CZ_Cultivation of sugar cane, sugar beet	0.0230	2.2333
CZ_Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	1.1720	2.2379
CZ_Re-processing of secondary wood material into new wood material	1.4446	2.2406
CZ_Cultivation of cereal grains nec	2.0595	2.2469
CZ_Computer and related activities (72)	0.3180	2.2601
CZ_Publishing, printing and reproduction of recorded media (22)	0.2708	2.2626
CZ_Post and telecommunications (64)	0.0515	2.2690

CZ_Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	0.0630	2.2775
CZ_P- and other fertiliser	20.8358	2.2778
CZ_Manufacture of cement, lime and plaster	0.3514	2.2815
CZ_Re-processing of ash into clinker	0.3492	2.2833
CZ_Supporting and auxiliary transport activities; activities of travel agencies (63)	0.2736	2.2840
CZ_Mining of aluminium ores and concentrates	0.0001	2.3228
CZ_Mining of other non-ferrous metal ores and concentrates	0.0093	2.3483
CZ_Raw milk	0.4420	2.3892
CZ_Forestry, logging and related service activities (02)	1.1941	2.3988
CZ_Casting of metals	0.8803	2.4353
CZ_Renting of machinery and equipment without operator and of personal and household goods (71)	0.5019	2.4788
CZ_Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	0.5457	2.5578
CZ_Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	0.6464	2.5681
CZ_Quarrying of sand and clay	0.1654	2.5907
CZ_Other business activities (74)	0.5035	2.5916
CZ_Quarrying of stone	0.1729	2.5959
CZ_Financial intermediation, except insurance and pension funding (65)	0.2058	2.6433
CZ_Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	117.6551	2.7010
CZ_Retail sale of automotive fuel	19.0809	2.7363
CZ_Recycling of waste and scrap	0.7355	2.9168
CZ_Activities auxiliary to financial intermediation (67)	0.0742	3.0595

TABLE 35