Department of Economics

Master's Programme in Economics

Assessing the Effects of Global Oil shocks on Carbon Emissions

by

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Abstract: Innovations in the real price of oil triggered either by supply disruption or aggregate demand or even precautionary demand, have significant effects on macroeconomic aggregates and on environmental metrics including carbon emissions. It is with the purpose to assess the amplitude and mechanisms behind these effects that this study contributes. Thus, a surge in the price of oil, generally followed by a recession period implies a decrease with a lag of less than one year in energy consumption. This decrease reduces carbon emissions in the same period, revealing a negative relationship with oil price fluctuations. The significance of this causality relationship is mitigated in the long run by the continuous decrease in energy intensity and better energy efficiency as well as technological progress.

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Contents

1

Introduction

"Our enemies are fully aware that they can use oil as a weapon against America. And if we don't take this threat as seriously as the bombs they build or the guns they buy, we will be fighting the War on Terror with one hand tied behind our back". These were the words of Senator Barack Obama during his speech at the Governor's Ethanol Coalition in Washington D.C. on the 28th of February 2006. This claim perfectly illustrates the major role played and still play by oil in our economies. It also gives a sound indication of how oil supply and prices can be used as geopolitical leverage against western countries. Famous historical examples of geopolitical motivated oil shocks include the 1973's crisis when Arab members of OPEC decided to quadruple the price of oil to almost $12 a barrel and to prohibited oil exports to the United States, Japan and Western Europe (Kettel and Tikkanen, 2014). A decision that was made in retaliation of the Western support for Israel in the war against Syria and Egypt. Another vocal example of sudden rise in oil prices is the one occurred in 1979 and related to the Iranian Revolution (1978-79). Indeed, Kettel and Tikkanen, 2014 reported that the uncontainable social unrest has damaged the Iranian oil industry, leading to a large loss of output. However, oil shocks can be also demand-driven shocks. Thus, the 2003's shock with a rise in price above $30 was mostly attributed to the soaring demand for crude oil fueled by a booming world economy and especially from China. It appears therefore that oil shocks are not the same, there are diverse and lead to diverse effects.

Considering the central place of energy and more particularly of oil in our economies, many studies have explored the differences in these oil crises and have tried to identify their corresponding impacts. Most of them have highlighted the effects on GDP and inflation levels. With so many occurrences of oil shocks and the growing interest of the public related to environmental questions such as the levels carbon emission, one would think that the link between those two has been more investigated academically speaking. Unfortunately, that is not the case. The evidence regarding the effects of oil shocks and then oil prices on CO2 emissions are limited. Evidence has been established on the links between energy consumption, growth in income and Greenhouse Gas emissions yes (Soytas, Sari, Ewing, 2007, Grubb, Butler, Feldman, 2006, Mahamat Hamit-Haggar, 2011), but few about the specific matter of our concern. And it is with the goal to first, review and synthesize the scientific literature around the determinants of oil shocks, second to assert the declination of their impacts on the environmental field, that this paper contributes.

Assessing these impacts is critical if we want to build sound and lasting environmental policies. It is also decisive in the formulation of arguments in order to push forward an agenda for bigger use of alternative sources of energy and it allows a better understanding of transmission channels of oil shocks effects in our economy and even in stock markets. This paper is an empirical work that contributes to the field of the impacts of oil shocks in the following manner. Firstly, it reviews several definitions of oil shocks that range from the common knowledge and intuitive in nature like the one from Kettel, 2014 to the more empirical definition of Hamilton, 2000. Secondly, this study highlights the different types and sources of oil shocks using among others the well-known works of Lutz Kilian, 2009 and Kilian, 2014. Thirdly, it explores the amplitude and the response period of these sudden rises in oil prices. Studies such as the ones by Herrera and Rangaraju, 2018 and Lutz Kilian, 2009 are used to provide reliable evidence in each case. Fourthly, this paper discusses the effects of oil shocks on GDP through several channels such as the investment channel, the inflation channel or even the monetary policy side. Papers like Herrera, Karaki and Rangaraju, 2019 or Hamilton, 2000 precise the sources and corresponding effects of the fluctuations. This work does not omit to reveal the contradictions in findings observed in some studies related to this topic. Finally, the paper identifies the GHG and more precisely the carbon emissions path during and after an oil shock thus accounting for the effects of these latter in our living environment. It also lightens the link between carbon emissions related to oil consumption, energy use and GDP. However, a proper study about economic growth, energy and oil consumption, carbon emissions, environmental degradation cannot be led without mentioning the Environment Kuznets Curve - EKC model as the paper by Jie He and Patrick Richard, 2009 did in the Canadian case.

This paper is organized as followed. Section 2 on one hand, takes a look at the various definitions of oil shocks. Section 3 on the other hand, precises types and natures of oil shocks with their determinants. Section 4 instead, analyzes the impacts of oil shocks on GDP through the various canal with sounds examples using U.S., Turkey and Asian economies cases. Section 5 presents related effects of oil shocks on carbon emission levels by first investigating the relationship between carbon emissions and GDP and after between oil price, energy use and emissions.

2

Defining Oil Shocks

Before one can attempt to identify relevant determinants of oil shocks, it is appropriate to first come up with an exploitable definition that is clear, concise and transparent. One might think that it's a pretty easy task, but the truth is that there are some wrong widespread conceptions in the common knowledge and unfortunately among economists that need to be corrected. Conceptions, such as the one expressed by Steven Kettell, 2014, an oil shock is a sudden rise in the price of oil that is often accompanied by decreased supply, are not accurate with regard to historical facts and scientific papers on the subject. Several of these scientific studies asserted instead that oil shocks are sudden rises in the prices of oil due to an increase in oil demand. Thus, determining a single uniform definition that is accepted by economists has proven to be a somewhat arduous task. This section reviews several definitions that focus on the empirical perspective of oil shocks, highlighting the similarities and differences between the researcher's conceptions on the topic.

An intuitive definition of an oil shock can be expressed in the following manner: a sudden or unexpected change in the path of crude oil real prices on the global market illustrated with the appearance of peaks. These peaks can be downward peaks expressing, therefore, a decrease in the real price of crude oil and a negative shock. Or, they can be upward peaks illustrating an increase in the real price and hence, a positive shock. Among the notorious surges in the real price of crude oil we can identify: the OPEC oil embargo of 1973-1974, the shock related to the Iranian revolution of 1978-1979, the Iran-Irak war initiated in 1980, the Persian Gulf war in 1990-91 and the oil price spike of 2007-2008 James Hamilton, 2011. Baking this previous intuitive definition, Lutz Kilian, 2014 formulates alternative explanations of oil price fluctuations in the U.S. Thus, comparing the price of West Texas Intermediate (WTI) crude oil for 1948-1973 and the U.S. producer price index for crude oil, he found out an identical pattern since there was no global market during this period and the U.S. was self-sufficient. Conversely to the typical commodity prices, the oil price remained unchanged for extended periods, followed by occasional large discrete adjustments. He asserted, based on the work by Hamilton, 1983, that these adjustments reveal in fact crude oil price regulation by the U.S. government. The goal was to maintain stable oil prices by assessing the needs in oil consumption and setting, therefore, the perfect level of production. However, occasional unanticipated oil supply disruptions were not necessarily corrected, regulator, choosing to exploit these events to set huge increases in the price of oil.

By 1973 however, the crude oil market becomes global. The U.S. was not any more auto-sufficient and they became a net importer with a particular dependence on oil coming from the Middle East, recalled Kilian, 2014. The U.S. government hence lost his regulatory power over the crude oil market even if domestically produced crude oil remained regulated to some extent until the early 1980s. Kilian, 2014 mentioned that regulators, yet allowed the price to gradually converge toward the global price of crude oil. He also highlighted the fact that starting from that period, 1974, the fluctuations of the real price of crude oil appears to follow the same path that other commodities prices that are established in global markets with their ups and downs. Alquist et al. 2013 said nothing else by arguing that since 1974, the real price of oil has been endogenous with respect to macroeconomic conditions. This means that, all else equal, surge in one direction of the real price of oil impacts macroeconomic indicators in oil-importing countries. It also means, all else equal, that the opposite is valid. However, the mechanisms behind these phenomena have been and still be a keenly debated topic.

3

The Determinants of Oil Shocks

Early investigations following the oil crises of the 1970s, asserted that oil price spikes result from disruptions in the Middle East and therefore exogenous to an oil-importing country macroeconomic outcomes. It was back then common to study the effect of oil price shocks on aggregate economic activity without differentiating the source of the shock since there was only one shock that matters. Some researchers such as Herrera, Karaki and Rangaraju, 2019 recalled that this practice lasted until the early 2000s but in the last fifteen years or so, it appeared obvious that this empirical strategy was incorrect. Thus, using the extended literature reviews aiming to disentangle the role of supply and demand-driven oil price shocks and particularly the one provided by the latter three mentioned above, B. Barsky and Kilian, 2002 were identified as the pioneers that assumed exogeneity was problematic. They were indeed the first to argue reverse causality from macro aggregates to oil prices, meaning that the cause and effect are no longer well defined when relating fluctuations in the real price of oil to macroeconomic aggregates.

Going further, Kilian, 2009b proposed what turned out to be a landmark for many studies on this topic: a structural VAR model of the global crude oil market that jointly tackled the endogeneity identified but also the indirect effect working through the price of oil and the prices of other industrial commodities. He was fully aware of the fact that understanding the source of these fluctuations was decisive to properly take into account their effects on economic activity. It allows, to recognize the transmission channels as well as time-varying of these different shocks. Thus, based on dry cargo single voyage ocean freight rates data, he was able to design a monthly index of global real activity in order to capture shifts in the demand for industrial goods. Since it is well established that world economic activity is the most important determinant of demand for transport services and therefore for oil consumption, this measure is used in the attempt to identify demand and supply shocks in the global crude oil market. Kilian, 2009b proposed then a structural decomposition of the real price of crude oil into three component: crude oil supply shocks; shocks to the global demand for all industrial commodities (aggregate demand shocks); and precautionary demand shocks). The last shock capture shifts in the real price of oil associated with uncertainty about shortfalls of expected supply relative to expected demand. Having controlled for both oil supply shocks and aggregate demand shocks, he allowed a structural dynamic simultaneous-equations model to pin down the oil market-specific component of demand as the residual. By doing this, Kilian, 2009b made sure that the factors in this vector were orthogonal to crude oil supply shocks and to world demand for industrial commodities through his model designed. In what concerns oil supply shocks identification and design, several studies have been conducted with various methodologies. Not all are relevant.

3.1 Oil Supply Shocks

Crude oil supply shocks are defined as unpredictable innovations to global oil production. These innovations can be due to political events or due to shifts in the demand for oil. Given the costs of adjusting oil production and the uncertainty about the state of the crude oil market, oil-exporting countries are slow to respond to demand shocks (Kilian, 2009b).

Surges in the real price of crude oil-related to disruption in the production have been broadly studied. These disruptions were, for long time, assumed to be responsible for the major episodes of oil price spikes, researchers had accounted. Hamilton, 2003 for instance, considering the U.S. economy, argued that big fluctuations in the price of oil can be attributed to exogenous shortfalls in crude oil production notably the ones triggered by political events in the Middle East. He highlighted as typical illustrations of such political unrest, the 1973 Yom Kippur War followed by the Arab oil embargo in 1973/74, the Iranian Revolution of 1978/79, the Iran-Iraq War of 1980-1988, the Persian Gulf War of 1990/91, the Venezuelan Crisis of 2002, the Iraq War of 2003, and the Libyan uprising of 2011, as recalled by Kilian, 2014 in his paper.

Analyzing each of these events, Kilian, 2014 pointed out some problems arising from this explanation. The shock related to the Arab-Israeli War of 1973 for instance, albeit exogenous with respect to the U.S. economy, was not a shock to the flow of crude oil supplies since the conflict did not reach the territory of oil-producing economies and no oil production facilities were damaged. The Arab oil embargo, on the contrary, did affect the flow of oil supplies, but the decision was taken explicitly to hit the U.S. and western countries supporting Israel (Kilian, 2008a). During this crisis, the nominal price of oil quadrupled over the course of half a year. However, based on regression analysis conducted by Kilian, 2008a,b, it appeared that only 25% of the observed price was explained by quantitative measures of exogenous oil supply disruption. Furthermore, in the Iranian Revolution case, there was instead a remarkable delay in the response of the real oil price. The surge in the price started in May 1979 after the oil supply disruption in Iran was over. Also, observing disruptions in production related to Iran-Iraq War episodes of 1980 and early 2003 as well as disruptions related to Venezuelan crisis of 2002, he found a very weak effect of these disruptions on real oil prices.

Focusing particularly on the Arab oil embargo in 1973/74, since only 25% of the surge in price was explained by the supply disruptions, it remains logically around 75% that must be attributed to other factors. Barsky and Kilian,2002 identified a global aggregate demand boom in the early 1970s in all industrial commodity at all level. Also between November 1971 and February 1974, there was a surge in the price of industrial raw materials and metals by about 95%. Similarly, the real non-oil industrial commodity prices in the absence of supply shocks cumulatively increased by about 75%, corresponding to 75% increase attributed to the other factors (Kilian, 2014). Many researchers asserted that these other factors cannot be something else than spikes in the demand in industrial commodities across the world or across a region that proves to have a significant impact on the global aggregate demand. And even in the case where supply disruptions did happen, according to Kilian, 2008a argument, it is less the physical supply disruptions than the increased precautionary demand for oil stirred up by uncertainty about future oil supply that drives the price of oil. Thus, through the Monthly Energy Review, 2015, it has been made clear that the 1979's shocks, known as the second oil shocks, was driven mostly by a widespread panic due to the Iranian revolution followed by the beginning of the Iran-Iraq war. During that period, oil prices more than doubled reaching 39.50$ over the year after while the Iranian production has decreased by only 4%. Also retracing the 2003's shocks (Iraq and Afghanistan US military invasion), he indicated that the surge in the price of oil was primarily driven by the cumulative effects of positive global demand shocks as the business cycle was on the expansion path. Furthermore, Herrera and Rangaraju, 2018 reviewing several studies related to oil shocks, suggested that estimates of the effect on the real oil price of an unexpected decline in world oil supply expressed by a 1% reduction in monthly world oil production induce a variation in the price from 0.05% to 4.27% with the peak occurring at four and two months after the shock, respectively. It appears therefore that oil crude supply shocks have little impact on the surge of the real price of oil within the first year. It's also important to mention as did by Kilian and Murphy, 2014 that models imposing a small short-run price elasticity of supply display finally a smaller response of the real oil price to oil supply disruptions than specifications that allow for a larger elasticity (Baumeister and Hamilton, 2018).

Only the 1990's shock can be identified as non-negligible (Kilian and Murphy, 2014). But how to properly measure these supply shocks? And especially how to properly frame and exploit the data related to these innovations in sound regression models?

In order to properly take into account, the specific effects of these supply shocks on macroeconomic aggregates, Kilian, 2006 introduces a new methodology for quantifying the shortfall of OPEC oil production caused by exogenous political events. The ultimate goal of this approach is to provide a monthly time series of exogenous oil supply shortfalls since 1973. Thus based on monthly production data for all OPEC countries and for aggregate non-OPEC oil production that are available from U.S Department of Energy since January 1973, he formulated his analysis by integrating the counterfactual path of oil production in the absence of an exogenous event. The intent was to determine production level for the oil-exporting country in question by extrapolating its pre-crisis production level based on the average growth rate of production in other countries subject to the same global macroeconomic structure and economic incentives, but not involved in any particular geopolitical crisis. Countries in this benchmark group must be decided on a case by case basis. Through this approach, Kilian, 2006 was finally able to evaluate the change over time, expressed as a percentage share of world oil production, of the exogenous oil supply disruptions due to political events.

Unlike Hamilton, 2003 with his quantitative dummy variables approach, this methodology displays some strong advantages. First, it does not impose the assumption that the level of oil production would have never changed in the absence of exogenous political crisis. Moreover, this approach takes into account the fact that the response of oil production to these exogenous events can be immediate or delay; can be long-lasting; can be time-varying and most importantly the response can be a positive or negative changing sign over time (Kilian, 2006). Focusing on this last point, he explained that in the case of a war in the Middle East, instead of a disruption, the oil production may actually increase when the countries involved, rely on oil exports to finance the war.

As a result, this innovative methodology helped Kilian, 2006 to draw graphs in Figure 1, 2 and 3. Figure 1 displays the quarterly analogue of the monthly measure of the baseline exogenous production shortfall series expressed in the unit of 1000 barrels/Day. The path of the production shortfall series appears to back the analysis of supply shocks formulated above and reflects key historical events. Thus, Kilian, 2006 analyzing the 1973/74, 1978/79, 1980/81 and 2002/03 episodes observed first negative spikes representing an increase in oil production shortfalls. He made clear that these temporary increases were followed logically by positive spikes since the disruptions were at least partially reversed. The 1990-1995 also followed the same path except that the negative and positive spikes were respectively more gradual. Furthermore, considering the positive shocks after 1981, he explained that both Iran and Iraq were able on average to increase their oil output in an effort to finance the war between them. Using monthly data with twelve lags of the exogenous oil supply shock series expressed in percent share of world production (Figure 2) as well as its First difference graph (Figure 3), the results remain the same.

3.2 Aggregate Demand Shocks

Since it appears that oil supply disruptions explained only a small fraction of the variation in the real price of oil, many studies have been conducted to investigate the other significant determinants of these shocks.

Kilian, 2008a and 2009 for instance, highlighted the fact that fluctuations in the real price of oil have been historically driven mostly by global aggregate demand and precautionary demand shocks, rather than oil supply shocks, as commonly believed. He suggested that the sudden and wide change in the price during some political crises, for instance, is rather due to an increase in precautionary demand than to disruption in the supply, conforming thus the previous observations. In the same vein, Bernanke, Gertler and Watson, 1997 believed that the 1970s and 1980s exogenous oil shocks derived from global macroeconomic conditions and were transmitted to the economy through monetary policy, causing stagflation in the process. In fact, facing inflationary pressures caused by theses innovations in the prices of oil, the monetary policymakers reacted by increasing the interest rated, a policy that led to a deep recession.

Furthermore, focusing on the emerging Asia, Kilian, 2009a and Kilian and Hicks, 2009 did not say something else. They asserted that oil price spikes during the 2000s arose mainly from the fast and strong economic growth observed in countries like China and India. The low-interest rates set by the Federal Reserve leading to a weak value of the U.s. Dollar at that time created the perfect framework that allowed these economies to thrive. It resulted hence, as they mentioned it, an excess demand for oil and industrial commodities.

Analyzing these shocks to the global demand for all industrial goods and the precautionary demand shocks instead, and considering also the consensus that had emerged regarding the smaller role of supply relative to demand-driven shocks (Baumeister and Kilian, 2016), one may be concerned by how yo disentangle both shocks. The global business cycle helps us to identify when the global economy is on the path of expansion rather than contraction. In a period of expansion, for instance, there is an increase in the aggregate demand for industrial goods that induce an increase in production capacity or level. There is thus more outputs and these outputs need to be transported from one point to another across the globe. But it's important to mention that both the production and transport of those industrial goods are highly energy consuming and notably fossil fuels consuming. A wrong forecast of that demand real level or even a deliberate decision of producer countries and OPEC members can easily lead to significant changes in the world oil prices. Also to take into account this additional demand, producers, in a coordinated way, have to decide the new level of supply that reaches the demand, knowing that each of them has different economical and political agendas as well as different production structures. This situation can create a delay in the response to the global demand shifts resulting then to a shock. Using the positive correlation between oil prices and the prices of some commodity, Barsky and Kilian, 2002 argued that the major change in oil prices in the 1970s and early 1980s appear to be associated in large part with fluctuations in the global business cycle. Moreover, Kilian, 2009b, using a structural vector autoregressive model of the global market of crude oil, demonstrated that most large and persistent fluctuations in the real price since the 1970s have been linked with the cumulative effects of oil demand rather than oil supply shocks. He was able to come out with these finding by computing for his analysis a Monthly measure of Global Real Economic Activity. In fact, since the global business cycle appeared positively correlated with the aggregate demand of crude oil, he designed, based on dry cargo single voyage ocean freight rates, a measure of the component of the Global real economic activity that drives demand for industrial commodities in global markets. The concept was quite simple. An increase in the freight rates may be used as indicators of strong cumulative global demand pressures. This allowed him to identify periods of high and low real economic activity.

Constructed from data from the monthly report on Shipping Statistics and Economics, the index can integrated freight rates as far back as January 1968, thus giving the opportunity to compare majors demand-driven crude oil price shocks with the data. Albeit reflecting a measure of the global real economic activity in all countries, measure that does not require exchange-rate weighting, and incorporating already changes in the propensity to import industrial commodities for a given unit of real output, Kilian, 2009b did mention some precautions to consider using this index. The shipbuilding and scrapping cycle induced by the model may weaken the link between real economic activity and the freight rate index. In fact, when there is global economic growth, one will expect an increase in freight rates. However, the global number of ships is not unlimited. In a time of global business cycle expansion, there are more exchanges of industrial goods. This situation requires more ships and before the building of new vessels, the spare capacity cushions the impact of higher demand on freight rates. Therefore, the real freight rate index created lags increases in real economic activity and it also leads to decreases in real economic activity since the arrival of new ship depresses freight rates. Another particularity considered by Kilian, 2009b is that dry cargo freight rates may increase during oil price shocks not because they reflect higher demand for commodities, but because the provision of the shipping services uses bunker fuel oil as an input. He thus allowed first, feedback from crude oil prices to shipping freight rates and secondly he imposed that innovations in these latter do not respond to change in the price of crude oil within the same month.

After eliminating fixed effects for different routes commodities, and ship sizes and computing the Equal-weighted index based on average of growth rates, Kilian, 2009b finally provided an index deflated with US CPI and linearly detrended. Figure 4 of Appendix A displays the result of this work and provides the deviations of the real freight rates from their long-run trend. The fluctuations of the rate are matched with some of the major crude oil shocks. Thus, it's easy to observe for instance that the higher real activity period between late 1972 and early 1975 matches with the October War/Embargo of 1973-74. Also, Kilian, 2009b highlighted the reminiscent and persistence of the strong high levels of real activity since 2002 compared to those observed after 1979. This episode coincided with Venezuela's civil unrest of 2002 and the Irak War of 2003 proving one more time that these events cannot be totally separated with periods of high real economic activity and high demand for industrial goods.

3.3 Precautionary Demand Shocks

According to Lutz Kilian and Thomas K. Lee, 2013, the real price of crude oil depends on shocks to the flow supply of oil (defined as the amount of oil being pumped out of the ground), on shocks to the flow demand for crude oil that reflect the state of the global business cycle, on shocks to the speculative demand for oil stocks above the ground, and on other more idiosyncratic oil demand shocks. If it is true that disruptions in oil supply due to political crises have negligible effects in oil price fluctuation, it doesn't mean that those political events do not matter. These events create uncertainty about future shortfalls of expected supply relative to expected demand that drive oil prices. This point was made evident by Alquist and Kilian, 2010 as well as by Kilian and Lee, 2014. Moreover, Lutz Kilian, 2009b interpreted this precautionary demand shocks as arising from a shift in the conditional variance, as opposed to the conditional mean, of oil supply shocks. He agreed that they reflect the convenience yield from having access to inventory holdings of oil that can serve as insurance against interruption of oil supply. Storage appears therefore as a way of transferring current oil availability to future periods and storers or speculators can be defined as the ones that buy oil from exporting countries at the spot price and optimally decide how much to sell or store. With this factor integrated, the real price of oil becomes a function of availability. It's determined by new production plus shifts in oil storage relative to total demand. Thus when there is a positive storage demand shock, for instance, availability of oil decreases and the price rises (Deren Unalmis, Ibrahim Unalmis, D. Filiz Unsal, 2012).

Furthermore, using a Dynamic Stochastic General Equilibrium, these latter researchers (Deren Unalmis, Ibrahim Unalmis, D. Filiz Unsal, 2012) came out with some important findings when focusing on precaution or storage shock. First, they recognized that aggregate demand shocks are the principal drivers of innovations in the real price of oil and storage demand shocks play a significant role as well even if it is in a lesser extent. Second, accounting for storage demand shocks allows, to avoid upward bias in the estimated contribution of oil supply shocks to oil price fluctuations. Third, speculative pressures in the storage component mitigate or intensifies in oil prices depending on the source of the shock.

Besides, when the precautionary demand shocks are labelled specifically as speculative demand shocks, the standard econometric oil market models are invalidated because speculators respond to information not available to the econometrician attempting to disentangle demand and supply shocks based on historical data (Lutz Kilian and Thomas K. Lee, 2013). This forward-looking behaviour of the speculators had for long been difficult to identify. The solution found by Kilian & Murphy, 2013 to address the problem was to build a proxy that would reflect shifts in the demand for above-ground crude oil inventories. Shocks to this expectations-driven or speculative component of inventory demand may be identified and estimated jointly with all other shocks within the context of a fully specified structural vector autoregressive model. Thus, based on the accounts of crude oil inventory stocks by region as well as oil at sea and oil in transit provided by the U.S. Energy Information Administration, they were able to build an accurate proxy that is easy to validate externally and which improves the predictive power of the VAR model (Alquist, Kilian and Vigfusson, 2012). The strategy applied was quite simple: scale U.S.crude oil inventory data by the ratio of OECD petroleum inventories over U.S. petroleum inventories.

Using this methodology and an alternative time series from the private company Energy Intelligence Group, Lutz Kilian and Thomas K. Lee, 2013 suggested that speculative pressures were the driving force behind the surge in the real price of crude oil in the 1979 after the Iranian Revolution, in 1990 near the time of the invasion of Kuwait, in 2002 in the months leading up to the 2003 Iraq War, in early 2011 during the Libyan crisis and also in early 2012 during the Iranian crisis. They also found evidence that a reduction in speculative demand can lower oil prices with the illustration of the speculative downward pressures associated with the episode of the late 2008 and early 2009. In this case, the reduction of the price reflected expectations of a prolonged global downturn rather than improved oil supplies. Furthermore, focusing on speculation in financial markets for oil, they found that what matter are shifts in inventory demand and not really speculation per se, consistent with Büyükşahin and Harris, 2011 and Irwin & Sanders, 2012 for instance.

3.4 An example of VAR Model

Since we have now defined the different determinants influencing the real price of oil, it is relevant to provide an example of how exactly to account for these three factors at the same time through a robust Vector Auto-Regressive (VAR) Model. The one briefly exposed in this section is from Kilian, 2009b and has been considered among researchers as a true landmark.

Using monthly data for the sample period 1973:1–2007:12 of $z_t = (prod_t, rea_t, rpo_t)$

where prod is the percent change in global crude oil production; rea, expressed in logs, represents the index of real economic activity and rpo, also in logs, reports to the real price of oil Kilian, 2009b was able to propose the following structural VAR representations:

$$(1) \qquad \mathbf{A}_0 \mathbf{z}_t = \boldsymbol{\alpha} + \sum_{i=1}^{24} \mathbf{A}_i \mathbf{z}_{t-i} + \boldsymbol{\varepsilon}_t,$$

where $\boldsymbol{\varepsilon}_t$ denotes the vector of serially and mutually uncorrelated structural innovations. I postulate that $\mathbf{A}_0^{-1}$ has a recursive structure such that the reduced-form errors $\mathbf{e}_t$ can be decomposed according to $\mathbf{e}_t = \mathbf{A}_0^{-1} \boldsymbol{\varepsilon}_t$:

$$\mathbf{e}_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \end{pmatrix}$$

The model postulates a vertical short-run supply curve and shifts of the demand curve driven by either of the two demand shocks result in an instantaneous change in the real price of oil as do oil supply shocks as well. Also Kilian, 2009b imposes some restrictions. First crude oil is assumed not to respond to innovations to the demand for oil in the same month. Second, increases in the real price of oil driven by shocks specific to the oil market will not lower global real economic activity immediately, but with a delay of at least one month. Third, changes in the real price of oil that cannot be explained by oil supply shocks or aggregate demand shocks by construction will reflect innovations in oil-specific demand shocks (precautionary demand).

Consistently estimated by the least-squares method, Kilian, 2009b obtained from the estimates of his VAR model some useful representations that enabled him to effectively identify and assess the impacts of these innovations. Thus, observing results displayed by Figure 5 that plots the time path of the various structural shocks identified by the model, he was able to first suggest that the real crude oil price responds to a multitude of shocks. Also focusing for instance on the 1979/80 episode, he found no evidence of a global oil supply disruption and asserted that the disruption associated to the Iranian Revolution has been more than offset by the increase in supply elsewhere. He instead observed spikes in the precautionary demand in 1979 as well as in the global aggregate demand in 1978,1979 and 1980. This comforted him in his analysis suggesting that surge in the real price of oil in these years were mostly driven by the business economic cycle and the concerns raised by political unrest in the Middle East.

Through Figure 6 representing the responses to one-standard deviation structural innovations, he was able to assert for instance that an oil supply shock leads to a small, transitory and partially significant rise in the real price of oil for nearly eight months. Kilian, 2009b also found that this situation causes a small slowdown of real economic activity. Analyzing the aggregate demand shocks, on the other hand, he observed a large, persistent and statistically significant increase in the real price of oil with a delay of around six months while the real economic activity only declines after fourteen months. For the oil market-specific demand shocks however, he identified a positive impact on the real price that is large, immediate, persistent with a highly statistically significance. He linked these shocks with a temporary increase in real economic activity and a very short-run decline in oil production.

4

Investigating the Impacts of Exogenous Oil Shocks on GDP

Since not all oil shocks are alike, as asserted by Kilian, 2009b and proved in the previous section, it's therefore obvious that the amplitude, rapidity or time-varying responses of macroeconomic aggregates to these changes are not the same from one shock to another. They also differ depending on whether it is an oil-exporting or an oil-importing country. The evaluation of these responses is an important step toward the assessment of oil shocks effects on carbon emission since the well-spread opinion is that, oil price affects economical activities and economical activities determine the levels of emission.

To properly perform this study, let's not forget that an oil shock can be expressed by an increase in the real price of oil or by a decrease, with the nature of the shock playing a major role in the analysis of the effects and their amplitude. Indeed, in the case of an unexpected increase in the price of imported crude oil, the immediate impact is the reduction of the purchasing power of domestic households as income is transferred abroad (Kilian, 2014). This situation implies a reduction in the aggregate demand and the anticipation of this reduction lead ultimately to a reduction of the aggregate supply. Furthermore, in this framework, producer of industrial goods, for instance, face an increase in the cost of production of domestic output leading to a reinforcement of the downturn path of the aggregate supply. Kilian, 2014 concluded this analysis by acknowledging that an unexpected increase in the real price of oil causes aggregate production and income to fall by as much as an unexpected decline in the real price of oil of the same magnitude causes aggregate income and production to increase. This result let us suppose a linear relation and a negative correlation between oil prices and economic activity. However, considering the case of oil-exporting countries such as the members of the Gulf Cooperation Council (GCC) for instance, the results are quite different. For these oil-depending countries with the largest proven oil reserves in the world, Bahrain, Kingdom of Saudi Arabia, Kuwait, Qatar, Sultanate of Oman and United Arab Emirates (UAE), positive oil prices changes increase real GDP with a larger significant effect than the negative changes which instead decrease real GDP (Salah A. Nusair, 2016). Since oil-revenues accounted for about 83% of government revenues and 44% of GDP on average according to this latter study, a rise in the price of crude oil, as the one observed between 2002 and 2008, leads to strong economic growth. Therefore, considering that particular episode, the GCC countries accumulated massive amounts of wealth invested in Sovereign Wealth Funds (SWFs) as recalled by Salah A. Nusair, 2016, SWFs which represented sources of liquidity for Western Financial institutions during the US financial crisis that occurred just after (Ulrichsen, 2014). A positive shock in the real price of oil increases their purchasing power and their demand for industrial goods. El Anshasy and Bradley, 2012 didn't say anything else when they asserted that an increase in oil prices stimulates both GDP and government expenditure in oil-exporting countries. It however relevant to precise that these positive innovations in the price may also worsen the economic conjuncture in the exporting countries. They can lead to phenomena like rent-seeking, currency appreciation, poor policy-making and slow-down in the diversification of the economy thus mitigating the economic growth as expressed by Moshiri and Banijashem, 2012. In addition, Cologni and Manera, 2013 focusing on the same GCC group over the period 1994-2009 concluded that positive spikes in oil prices generate negative effects on private investment and capital. Both studies revealing what is commonly known as "Dutch Disease". In this particular framework, the onset of a negative shock could only worsen the situation by leading to major revenue cuts and stagnation in the economy. This result corresponds to the one found by Moshiri and Banijashem, 2012 in their paper when using a VAR model with annual data over the period 1979-2009 for six OPEC countries and accounting for asymmetries between oil price shocks and economic growth. They also found that these negative effects are not significant for Saudi Arabia and Kuwait while suggesting that increases in the price do not provide strong economic growth. Outcomes that back their findings when they assumed in the first-place linear relationship and found no significance between crude oil price and GDP. A clear sign of asymmetry.

Similarly, a large body of research suggested the same when around the mid-1980s it appeared, as recalled by Cologni and Manera, 2008 that decrease in oil prices have smaller positive impacts on economic growth. Same for Hamilton, 1996 and for Brown and Yucel, 1999 who mentioned a nonlinear relationship between oil prices and economic activity. In the same vein, Kilian, 2014 explained, based on articles reviewed in his paper, that the response of the economy is asymmetric in positive and negative oil price shocks such that positive oil price shocks generate large recessions, whereas negative oil price shocks have little if any, effects on the economy. Lee et al., 1995 supports that claim and even go beyond arguing impact on GDP to oil price shocks depends mostly on the stability of the oil price environment. Innovation in a stable environment is more likely to have bigger impact on GDP than in a volatile environment. This is also why Hamilton, 2000 indicated that oil price increases affect the economy whereas decreases do not, and increases that come after a long period of relatively stable prices have a more significant effect than those that simply correct previous decreases. There is also strong evidence from this latter study that the use of nonlinear functions of oil prices fluctuations is the best solution if the goal is to forecast GDP growth.

One aspect of these effects to not neglect lies is the source behind the shock. Herrera, Karaki and Rangaraju, 2019 in their recent work observed for instance that an oil price hike caused by curtailed oil production has little effect on consumption while demand shocks in the crude oil market have an important effect on households spending. Investigating the investment channel also, they gave an insight into studies that pointed out the large adverse effect on investment in the oil sector due to the recent oil price decline. Moreover, accounting for the effects of oil shocks on US economy, Lutz Kilian, 2009b found out first, that oil supply disruptions cause a temporary decline in the real GDP and have little effect on the price level. He also noticed that positive aggregate demand shocks initially have a positive net effect on the economy, consistent with the fact that in the short run, the direct stimulating effect of higher global demand on the US economy, for instance, will dominate the indirect growth-retarding effect of higher oil prices. But that stimulus does not last. After a certain period, the negative effect of higher oil (and commodity) prices triggered by the shock takes over, making the effects of the positive aggregate demand shock recessionary with a delay. Finally, he asserted that positive precautionary demand shocks lower real GDP and raise consumer prices.

In addition to the effects already expressed, we need to take into account some indirect effects such as the reallocation effect, the uncertainty effect, and the systematic monetary policy responses (Kilian, 2014). Focusing on the reallocation effect, and according to the work done by Hamilton, 1988, he considers that oil price shocks are relative price shocks that can be viewed as allocative perturbations that cause sectoral shifts throughout the economy. One sector where there is obvious evidence of this effect is the automobile sector. In this energy-intensive sector, he believed that unexpected high real oil prices tend to cause a reallocation of capital and labour as consumers switch toward more energy-efficient vehicles. This claim was also backed by Bresnahan and Ramey, 1993. Unfortunately, if the workers in the sectors where these shifts occur are ill-skilled to face the change and reconvert in the alternative sector, this situation can result in job losses.

The uncertainty effect, on the other hand, is revealed by the fact that irreversible investments with crude oil prices as a major variable are affected when there is an increase in uncertainty. Bernanke's, 1983 conceded that increased uncertainty about oil prices lead firms and even consumers of durable goods to delay their investments, causing investments expenditure to drop.

Furthermore, Bernanke et al., 1997 complained about the role played by the Federal Reserve in the response to oil price shocks. They argued that the systematic monetary policy responses adopted in the case of inflationary pressures due to sudden oil price increase worsen the recessions following positive oil price shocks. Indeed, by increasing the interest rate to counter inflation, the Bank policy amplified the economic contraction.

5

Oil Shocks and Carbon Emissions

5.1 Carbon emissions and GDP

The relationship between those two variables is a widely debated topic. Many studies in the literature have been conducted to determine the growth of which variable granger causes the growth of the second. Studies have also tried to figure out whether restricting emissions is likely to impair economic growth. The Russia Journal 2003 have reached that conclusion arguing that economic growth involves an increase in emissions of carbon dioxide and that any attempt to curtail emissions will restrict economic growth. Others researchers reached results different from that one. Thus, using a simple data analysis in a range of countries, Grubb, Butler and Feldman 2004 concluded that there is not a unique relationship between emissions and income per capita that applies regardless of time and place. They emphasized the fact that the nature of the relationship depends on the specific circumstances and the policies adopted in each country. So an economic growth does not necessarily lead to an increase in emissions.

Moreover, focusing on CO2 emissions which is one of the most abundant greenhouse gases in the atmosphere, many researchers demonstrated an inverted-U-shaped relationship between the emission of CO2 and the real gross domestic product per capita (Environmental Kuznets Curve-EKC). According to the EKC hypothesis, in the course of development and industrialization occurs an important depletion of natural resources with an accumulation of waste. There is a positive link between income per capita and environmental degradation during this period. At higher levels of income, structural change towards information-intensive industries and services, associated with environmental awareness, policies and expenditures, better technology shift the path and prompt to a gradual decline of environmental degradation Stern 2004 and Kaika and Zervas 2013. Equally, Sengupta 1996; Iwata et al. 2010 for instance, observed an increase in emissions in the first phase of the relationship, a decrease up to a certain level in the second phase, and finally a return to growth. This result is consistent with Kijima et al. 2010. In other words, as per capita income rises, environmental degradation intensifies, but in later levels of economic growth, it tends to subside. Economic growth becomes then a solution rather than a source of the problem Rothman and de Bruyn 1998. However, Zanin and Marra 2013, found nonlinear shapes in the historic range of real GDP for Finland (inverted-L-shaped relationship), Canada (a special case of inverted-L-shape) and Denmark (M-shaped relationship). In the case of Canada, the curve exhibits an early stage of increase in CO2 emissions followed by a second stage with levels of emissions substantially stable for the highest values of real GDP. It appears therefore that the EKC model preached in the literature cannot be affixed to every country. Furthermore, Soytas, Sari & Ewing 2006 went deeper analyzing the effect of energy consumption and output on carbon emissions in the US. They revealed that income does not Granger cause carbon emissions in the US in the long run, but energy use does. Therefore the decrements models advocated by some are not then the way out since income growth itself is not a solution to environmental problems. According to them, the US may consider reducing energy consumption as a serious environmental policy that does not harm long-run growth prospects. This is also the solution reached by Jie He and Patrick Richard 2009 in their analysis for an Environmental Kuznets Curve for CO2 in Canada over a period of 57 years (1948 - 2004). Applying a more flexible method, different from parametric models, they observed that the relationship between GDP per capita (GDPpc) and CO2 emissions per capita (CO2pc) is monotonically increasing but the slope of this function changes often over time. The major changes between the time trend and CO2pc and possibly between GDPpc and CO2pc occurred at a point in time corresponding to the oil shock of the 1970s. They were changes in the slope, not a reversal of the curve. They interpreted this result as maybe an adjustment towards less polluting technology in response to more expensive oil and concluded that since there is no evidence of EKC for Canada, just waiting for the automatic arrival of the turning point for CO2 emission will not be a feasible solution in the battle against climate changes. Another analysis that backs the idea that EKC is not generally fit for all countries.

Out of the frame of EKC model, Zhang and Cheng 2009 used time series to check the existence of causality between economic growth, energy consumption, and carbon emissions in China over the period 1960 - 2007. They claimed that GDP/energy consumption unidirectionally Granger-causes energy consumption/carbon emissions but neither carbon emissions nor energy consumption causes economic growth. Besides this, Mahamat Hamit-Haggar 2011 has been more specific. Using a panel cointegration analysis from Canadian industrial sector, he established a short-run unidirectional Granger causality running from energy consumption and GDP growth to greenhouse gas emissions. This means that in the short-run, industrial production have a greater impact on industrial emissions. In addition, he also concluded to a weak short-run unidirectional Granger causality running from economic growth and greenhouse gas emissions to energy consumption. Thus alleviating the concerns related to policies promoting energy efficiency, he asserted. Finally, he discovered for the long-run a weak unidirectional causality running from energy consumption and economic growth to greenhouse gas emissions.

5.2 Oil shocks, Energy Consumption and Carbon emissions

Following the analysis of the causality link between carbon emission and GDP performed above, it appears that it is not GDP growth that drives carbon emissions, but more energy consumption.

Energy consumption is at the heart of all economic activity. Without energy, you cannot produce, you cannot conserve, you cannot transport and even you cannot sell. However, energy consumption and more particularly oil consumption which represented 36.9% of the global figure of energy consumed in 2006 (EIA, 2017), implies high levels of carbon emissions. It appears therefore that fluctuations in the price of that particular input play a major role in our living environment. Investigating that role of oil price movements in the conventional Environmental Kuznets Curve of the Turkish economy, Katircioglu 2017 found out that the effects of oil prices on carbon dioxide emissions are negative and they are significant. The basic assumptions of this paper were then validated: as oil price have a statistically significant impact on energy consumption and energy consumption has an impact on CO2 emissions, therefore, oil price might have indirect effects on the level of CO2 emission. These findings allow one to assert that increases in oil prices, for instance, lead to declines in the levels of carbon emissions. The logic behind this result relies on the fact that growing oil prices push households and companies to reduce consumption and find alternatives that are more efficient in energy consumption and then less polluting. It is at this point that intervenes the notion of energy intensity.

Analyzing determinants of emissions growth in OECD countries, Hamilton and Turton, 2000 discovered that growth in emissions over the period 1982-1997 has been mainly due to economic growth (both GDP per capita and population growth), as well as an increase in primary energy (e.g: crude oil) required for final energy consumption (e.g: electricity), offset by falling energy intensities and a declining share of fossil fuels. To perform their study, they introduced a decomposition methodology, based on the famous IPAT expression, which decomposes energy-related emissions growth or decline for a given year in an economy, into shifts in selected demographic, economic and energy and emissions-related variables. The equation they obtained, can be expressed as follows:

$$CO_2 = \frac{CO_2}{FOSS}\frac{FOSS}{TPES}\frac{TPES}{TFC}\frac{TFC}{GDP}\frac{GDP}{POP}POP,$$

where CO_2 is energy-related CO_2 emissions; FOSS, fossil fuel consumption; TPES, total primary energy supply; TFC, total final consumption of energy; GDP, gross domestic product; and POP, population.

Each factor in the equation can be interpreted as follows:

$\frac{CO_2}{FOSS}$ *The CO_2-intensity effect* is the CO_2 intensity of fossil fuel combustion, mainly reflecting the fuel mix;

$\frac{FOSS}{TPES}$ *The fossil fuel-intensity effect* indicates the proportion of total energy obtained from fossil sources;

$\frac{TPES}{TFC}$ *The conversion-efficiency effect* represents the amount of primary energy required to deliver energy for final consumption and reflects both conversion efficiency and the fuel mix. The share of electricity in final consumption is the main influence;

$\frac{TFC}{GDP}$ *The energy-intensity effect* is the energy intensity of economic output, reflecting both efficiency of energy use and economic structure;

$\frac{GDP}{POP}$ *The growth effect* is a measure of economic output per capita; and

POP *The population effect* measures the influence of population growth alone.

This methodology helped them to conclude that overall, there have been important decreases in energy intensity across OECD economies over 1982-1997. Especially in industry and services sectors with a notable exception of rising energy intensity of the service sector in Japan. They also suggested that growth in emissions depends on how effectively energy use can be changed in order to offset the effects of economic growth.

It is this observation that explains the switch to renewable energy sources noticed in many countries of the world (Sadorsky, 2009). Nevertheless, it's relevant to mention that he believed the part of oil prices surge in the switch toward renewable energy consumption is small. Indeed, some researches such as Henriques and Sadorsky, 2008 expressed that the stock prices of alternative energy companies respond more to shock to technology index than to shocks to oil prices. However, using the Markov-Switching Vector Autoregressive (MSVAR) models, Managi and Okimoto, 2008 detected a positive and consistent impact of higher oil prices on clean energy stock prices after the structural break of 2007. They identified structural changes in the market during November and December of 2007, coinciding with a spike in the price of oil and the beginning of the U.S. economic recession. This last finding comes in contradiction with Vielle and Viguier, 2006 understanding when they asserted that high oil prices cannot serve as substitutes for effective climate policies. In fact, using a computable general equilibrium, these latter insisted on the fact that reduction in Green House Gas (GHG) emissions due to high oil prices might be considered as relatively limited as regards to the magnitude of the price rise. According to them, there is an adverse substitution effect in energy consumption. When oil prices increase, the reduction of global emissions is curtailed by the opportunity to substitute oil and gas by other energy inputs that have greater carbon content coefficients such as coal. As an illustration of the phenomenon, when they accounted in 2015 a worldwide decrease in gas, oil and electricity consumption by 33%, 32% and 9%, respectively, they observed instead, a spike in coal consumption by +20% compared to the initial levels. They also highlighted the mitigated sectoral impact that occurs. A strong positive impact on emission levels in the transportation sector and the chemical industry and in contrast, an increase in CO2 emissions in the electricity sector as a result of fuel mix changes. Finally, they ended up asserting that emission reductions obtained from higher oil prices and the welfare costs associated would be unequally distributed across regions and sectors and a high burden would-be put-on oil-dependent developing country.

Let's not forget the second face of the coin. A reduction in the global oil demand, creating a fall in the prices, leads to an increased energy intensity in industrial goods resulting in a rise of CO2 emissions. Consumers and government become lazier and less determined to tackle environmental degradation due to emissions. This is certainly the worst nightmare for all environmental researchers and policy activists. Faced with such a situation, Soytas, Sari and Ewing, 2006 argued that the relevant emission reduction policy variable is, therefore, energy consumption. Reducing energy consumption will decrease carbon emissions without harming economic growth since there is no evident causal relation between energy use and income. They also proposed alternatives policies such as decreasing energy intensity, increasing energy efficiency or increasing the utilization of cleaner energy sources the time that technological innovations enable a full switch from fossil fuels to cleaner energy sources and fewer emissions.

5.2.1 A synthetic effort

It has been established in the short-run unidirectional Granger causality running from energy consumption and GDP growth to greenhouse gas emissions Mahamat Hamit-Haggar, 2011. In the long run, the causality relationship remains the same except that the significance is weaker because of technological progress and better energy efficiency that may occur. Thus, despite the growth in economic activity and demography, in the long run, the emission levels don't follow with the same amplitude. It's less than what we can expect in the short run. This weaker significance is also explained by the rising popular consciousness and the incessant political initiatives like the "Regulatory Framework for Air Emissions (2007)" enacted by the Canadian government. Furthermore, Zhang and Cheng, 2009 claimed that GDP/energy consumption unidirectionally Granger-causes energy consumption/carbon emissions but not the other way around. It has also been established by many among whom Katircioglu, 2017 that oil price has a statistically significant impact on energy consumption and energy consumption have an impact on CO2 emissions, hence oil price have indirect effects on the level of emissions.

In an attempt to confirm by my own these findings, and using World Bank data for annual crude oil prices average as well as data for U.S. annual energy use and annual CO2 emissions over the period 1960 - 2014, I performed a standard correlation test between the variables that matter in these data and their respective growth rates. The results are displayed in Table 1. With a significance level established at 5%, it easy to observe that there is a strong positive correlation between energy consumption and emission levels (0.87), a negative correlation between crude oil price and CO2 emissions (-0,36) and also negative correlations between crude oil prices and energy use and carbon emissions growth rates (-0.44 and -0.42 respectively). Of course, the strong positive correlation between energy consumption and CO2 emissions growth rates is no longer to be demonstrated (0.96). All these correlations are significant at 5%.

However, since this simple correlation analysis doesn't really take into account the lags that can exist between a surge in oil prices and the paths of energy consumption and CO2 emissions, and also knowing that it does not help in the identification of the causality relationship between them, an advanced analysis would be a Granger causality test. Thus, after performing a VAR test with one lag on these variables and undertaking the Granger causality test (displayed by Table 2), it appears that lagged values of crude oil price cause C02 emissions and also cause energy use with a p-value equal to 0.000 each time. The direction of the causality is therefore from crude oil prices to CO2 emissions and from crude oil price to energy use. Inverses are not validated at 5% of significance level. Furthermore, observing the results of the test, one might think that there is no causality relationship between energy use and emission levels, a result that contradicts the above conclusions. There is nothing more wrong. In fact, since the causality test is conducted on yearly time series data, these result just display that CO2 emissions react to changes in energy consumption in less than one year, one year being the defined lag for this brief study. A result that seems quite obvious.

In addition, the findings of two previous tests are confirmed with graphs in Figure 7. Thus, displaying the U.S. growth rates of energy use and CO2 emissions with crude oil price growth rates over period (1960 - 2014), I observed the quasi perfect positive correlation between energy use growth rates and CO2 emissions growth rates, with deviations at each up and down of both curves occurring first in energy consumption. The CO2 emissions curve following almost immediately after. On the other hand, observing the crude oil price growth path through the years, it appears that the spikes in oil prices curve are prior to those in the other two variables and the negative correlation between them is well highlighted. Also matching these ups and downs with the different oil shock episodes studied, it easy to identify, for instance, the October War/Embargo of 1973/74, the Iranian Revolution of 1978/79 as well as the drop in crude oil prices related to the 2008 economic and financial crisis.

Extending the analysis to world data and juxtaposing both world energy use graph (Figure 8), expressed in kg of oil equivalent per capita, and world C02 emissions graph (Figure 9), expressed in metric tons per capita, we also found evidence of the findings consistent with some of the major oil shock episodes. Considering the 1973 oil shock, for instance, we have both a drop in energy use and CO2 emissions in the same year until 1975 before a rise in price. The scenario was quite the same for the 1979 episode except that the associated decrease in energy use and CO2 emissions were deeper and lasts longer. Moreover, the analysis of both graph and especially their respective slops helps to better understand the role played by energy intensity decrease and carbon efficiency increase, since for increasing demographic growth and increasing energy use there is a more moderate carbon emission increase.

Finally, since oil accounts for around 37% of the total energy consumed across the world, and despite the decrease of energy intensity in the last decades, oil price shocks prove also to impact emissions by pushing to shifts toward clean energies illustrated through the stock prices of these latter after a structural break. However, these different effects may be considered as of relatively limited magnitude because of the substitutions effects that may occur in energy consumption toward energy sources with higher carbon content as coal. We shouldn't as well neglect the role played by technological innovations.

6

Conclusion

Oil price shocks can be of two nature: positive shock with an increase in the real price or negative shock with a decrease in the price. These shocks can result from various sources and hence display different effects since the canal of transmission, the magnitude and time-varying of the effects depend largely on that source. There is among researchers a consensus around three major sources: oil supply shock, aggregate demand shock and precautionary/speculative demand shock. It is in order to synthesize the scientific literature around the determinants of these innovations in the real price of oil and how to identify them that this paper intervenes with the particularity to assess the relationship between these shocks and carbon emissions. From this analyze, it appears that oil prices have an indirect impact on carbon emissions through energy consumption and not necessarily through GDP as many can imagine. A surge in the price of oil followed generally by a recession period as was the case in 1973/74, leads to a drop in energy use and in CO2 emission levels in the same period. However, the amplitude of this impact is mitigated by the decrease in energy intensity and the increase in carbon efficiency observed in the last decades. The shift toward more polluting substitutes in the context of a shock has to be considered as well.

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(38)(51)(17)(24)(22)(40)()(28)(27)(25)(23)(19)(4)(27)(5)(38)(40)(36)(37)(28)(43)(6)(37)(9)(39)(4
)(44)(10)

Appendix A

Appendix

A.0.1 Figure 1: Exogenous Oil production Shortfall: OPEC (in 1000 Barrels/Day)

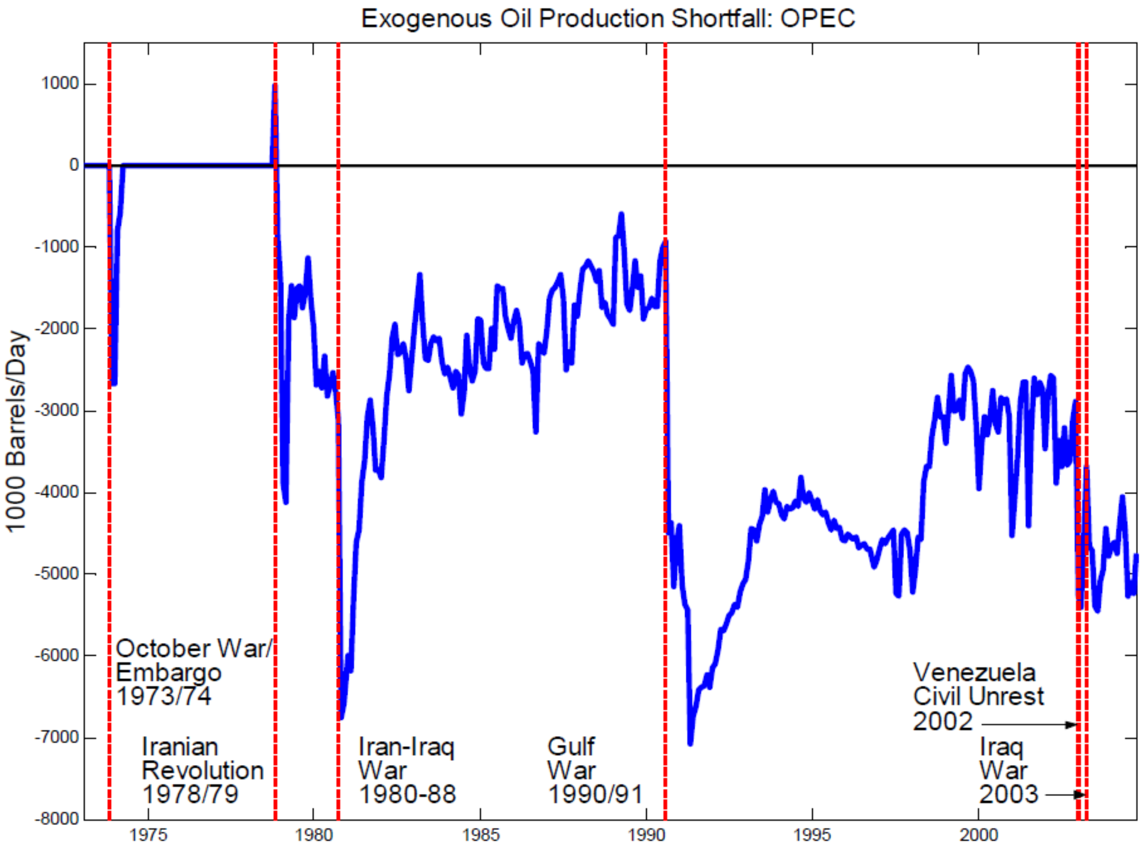

Figure A.1: Exogenous Oil production Shortfall: OPEC (in 1000 Barrels/Day)

Note: Figure 1, reproduced from Kilian, 2006, represents the quarterly analogue of the monthly measure of the baseline exogenous production shortfall series.

A.0.2 Figure 2: Exogenous Oil production Shortfall: OPEC (in Percent Share of World Production)

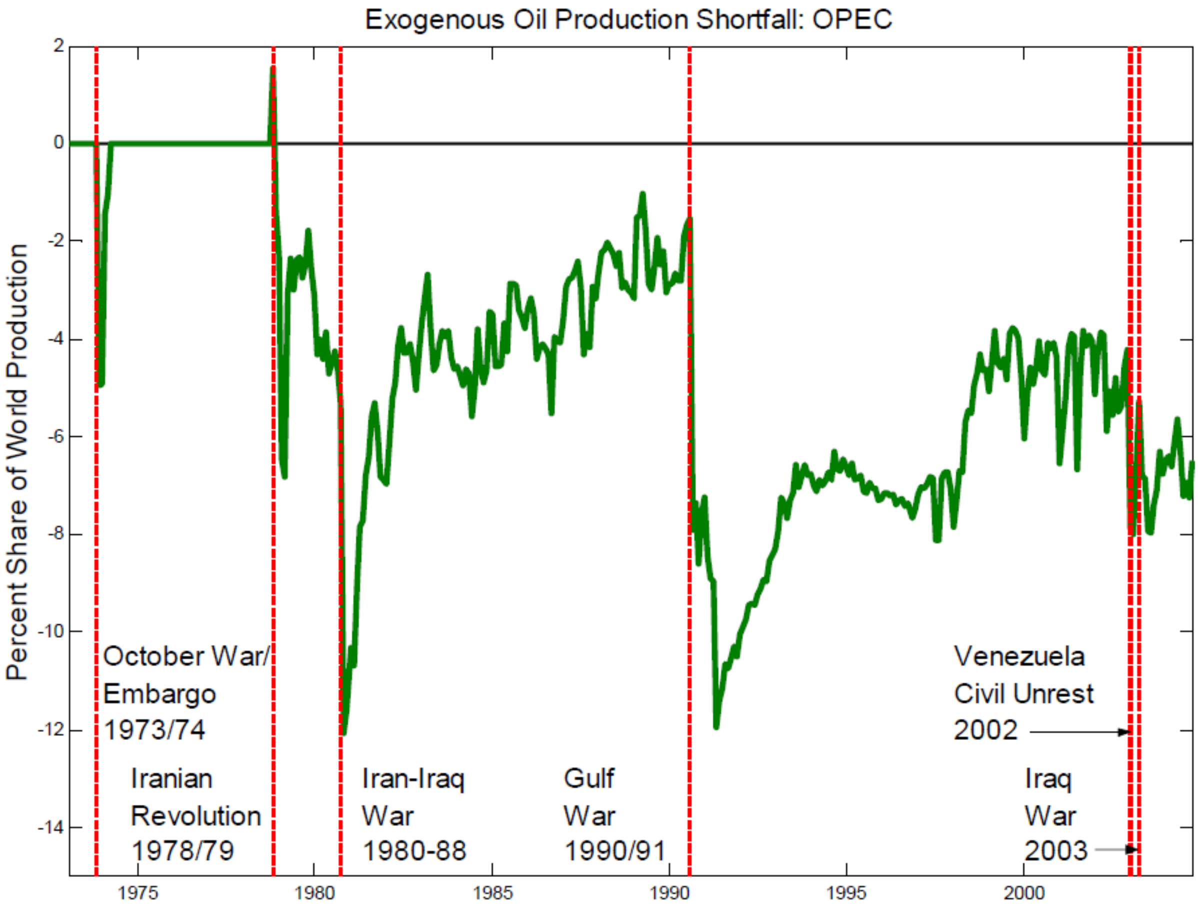

Figure A.2: Exogenous Oil production Shortfall: OPEC (in Percent Share of World Production)

Note: Also reproduced from Kilian, 2006, Figure 2 represents the monthly data with twelve lags of the exogenous oil supply shock series expressed in percent share of world production.

A.0.3 Figure 3: First Difference of Exogenous Oil production Shortfall: OPEC (in Percent Share of World Production)

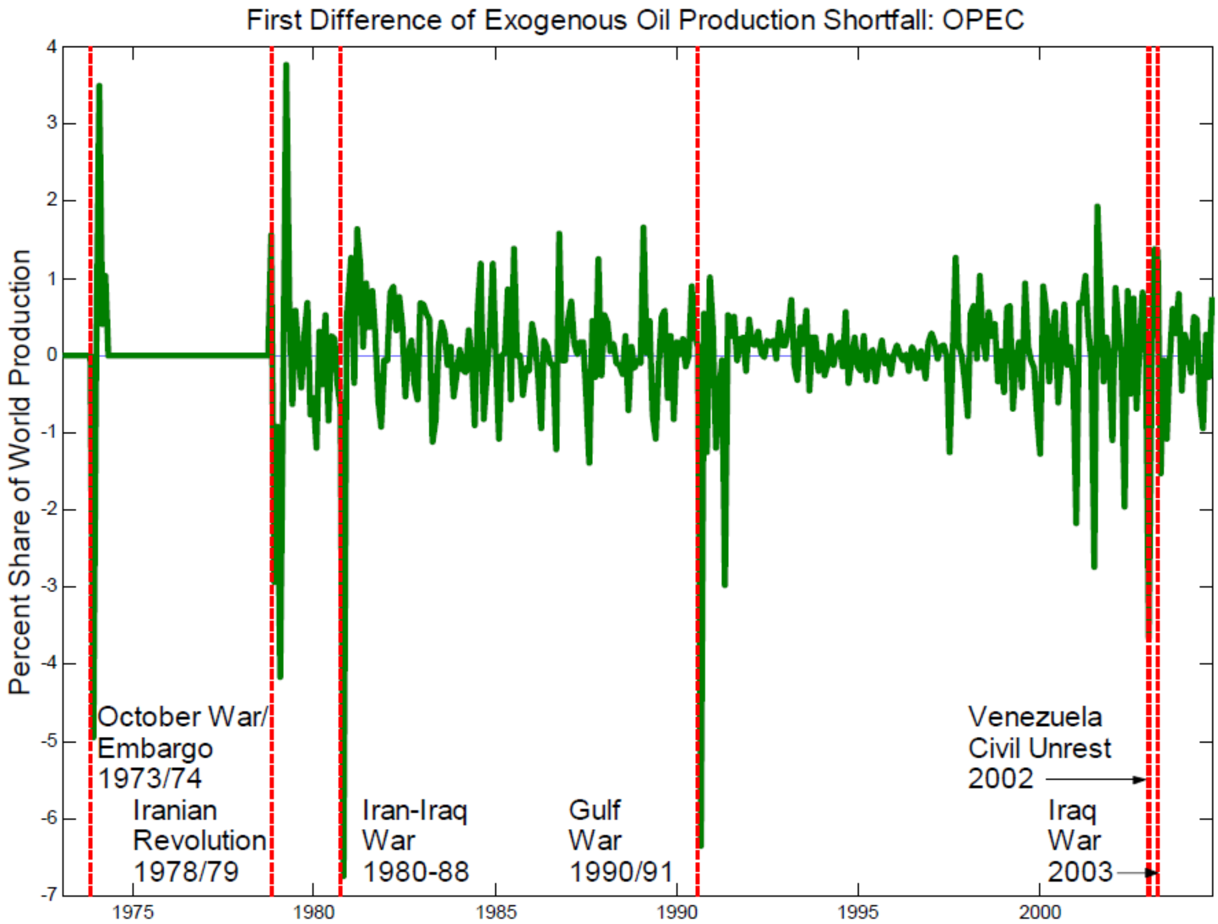

Figure A.3: First Difference of Exogenous Oil production Shortfall: OPEC (in Percent Share of World Production)

Note: Figure 3 instead, reproduced from Kilian, 2006 as well, represents the First Difference Graph of Exogenous oil production shortfall.

A.0.4 Figure 4: Monthly Index of Global Real Economic Activity based on Dry Cargo Bulk Freight Rates

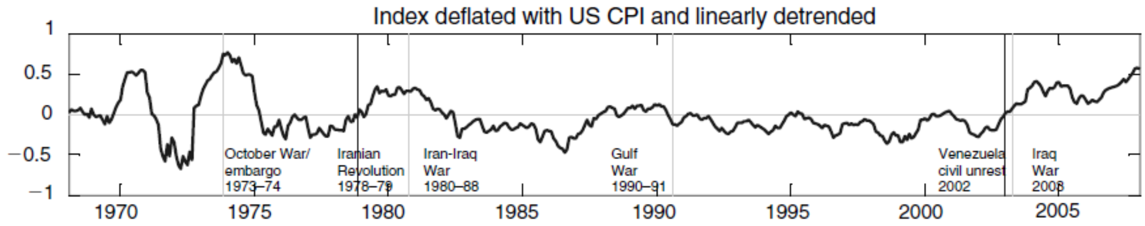

FIGURE 1. MONTHLY INDEX OF GLOBAL REAL ECONOMIC ACTIVITY BASED ON DRY CARGO BULK FREIGHT RATES *(1968:1–2007:12)*

Figure A.4: Monthly Index of Global Real Economic Activity based on Dry Cargo Bulk Freight Rates

Note: Reproduced from Kilian, 2009b, Figure 4 represents the Monthly Index of Global Real Economic Activity based on Dry Cargo Bulk Freight Rates. The data were manually collected from Drewry's Shipping Monthly and compiles indices of iron ore, coal, grain, oil-seeds, fertilizer, and scrap metal.

A.0.5 Figure 5: Historical Evolution of the Structural Shocks, 1975-2007

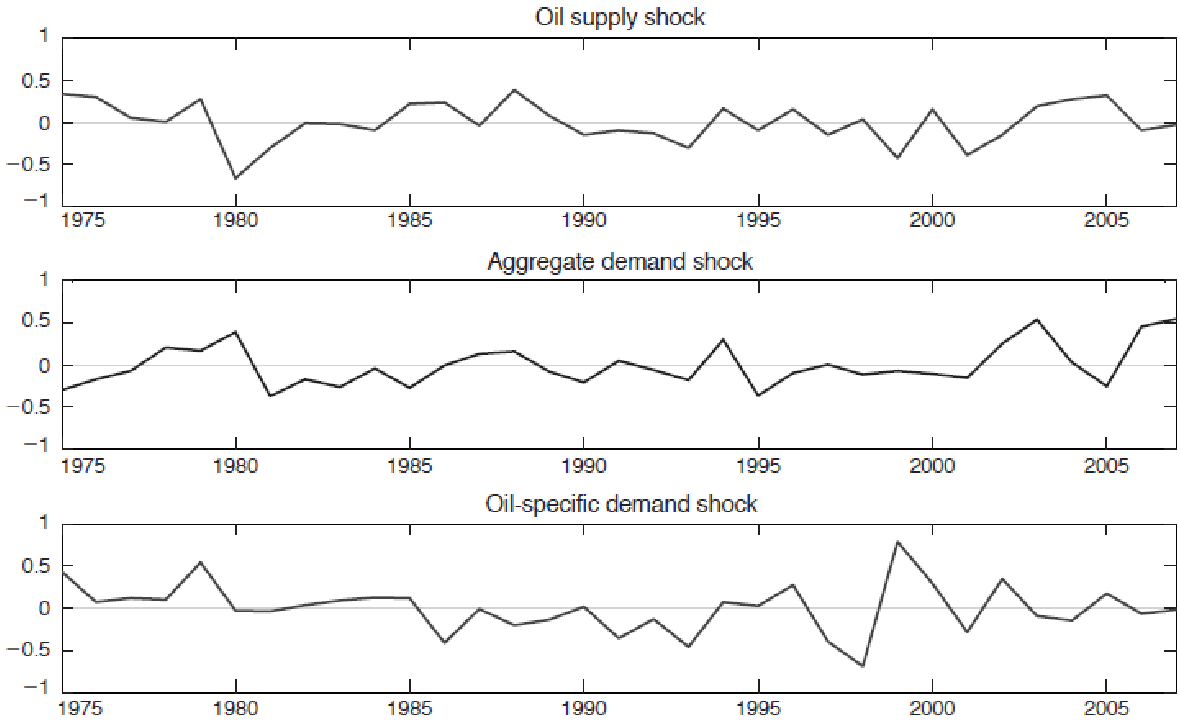

Figure 2. Historical Evolution of the Structural Shocks, 1975–2007

Note: Reproduced from Kilian, 2009b, Figure 5 plots the time path of the various structural shocks identified by the defined VAR model in the Study, over the considered period (1975 - 2007).

A.0.6 Figure 6: Responses to One Standard-Deviation Structural Shocks

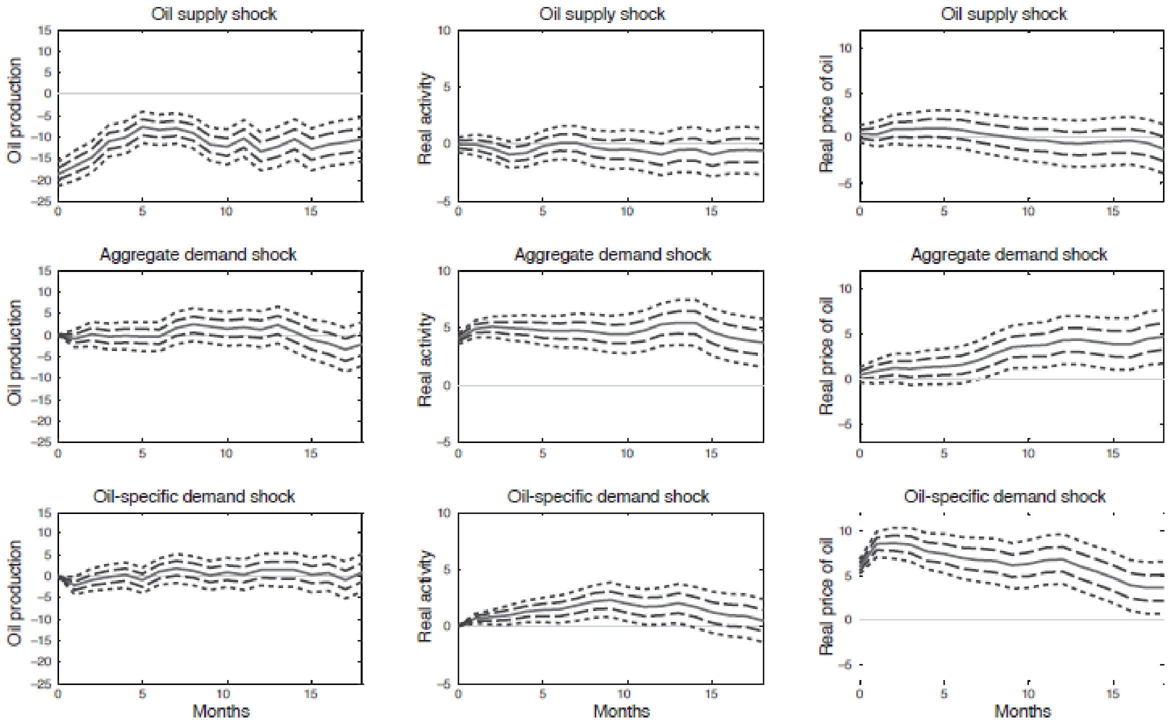

FIGURE 3. RESPONSES TO ONE-STANDARD-DEVIATION STRUCTURAL SHOCKS

(Point estimates with one- and two-standard error bands)

Note: Similarly reproduced from Kilian, 2009b, Figure 6 displays the responses of global oil production, real economic activity and the real price of oil to one-standard deviation structural innovations.

A.0.7 Table 1: Correlation Analysis

```
. pwcorr, star(0.05) sig
```

	Years	Energy~e	CO2emi~s	crudeo~e	g_crud~e	g_Ener~e	g_CO2e~s
Years	1.0000						
Energyuse	0.3704*	1.0000					
	0.0054						
CO2emissions	-0.1093	0.8698*	1.0000				
	0.4268	0.0000					
crudeoilpr~e	0.8021*	0.0298	-0.3596*	1.0000			
	0.0000	0.8292	0.0070				
g_crudeoil~e	-0.0561	0.2809*	0.3681*	0.0135	1.0000		
	0.6870	0.0396	0.0062	0.9226			
g_Energyuse	-0.4227*	-0.1291	0.0866	-0.4430*	-0.1401	1.0000	
	0.0015	0.3523	0.5334	0.0008	0.3122		
g_CO2emiss~s	-0.3634*	-0.0593	0.1416	-0.4250*	-0.1521	0.9562*	1.0000
	0.0069	0.6700	0.3071	0.0014	0.2722	0.0000	

Figure A.5: Table 1: Correlation Analysis

Note: Table 1 represents a standard correlation analysis with p-values displayed and a significance level established at 5% identified by the (*) sign. The analysis is conducted using World Bank datasets for annual crude oil prices average expressed in ($/bbl), data for U.S. annual energy use expressed in kg of oil equivalent per capita and finally data for U.S. annual CO_2 emissions expressed in metrics tons per capita. For each of these three variables, I computed respective growth rates going from 1960 to 2014 and represented by g_crudeoilprice, g_Energyuse and g_CO2emissions. This helped me to finally draw, using Stata software and time series techniques, the correlation coefficients between the variables and their significance's.

A.0.8 Table 2: Granger Causality Analysis

```
. vargranger
```

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
CO2emissions	Energyuse	1.8546	1	0.173
CO2emissions	crudeoilprice	17.587	1	0.000
CO2emissions	ALL	23.893	2	0.000
Energyuse	CO2emissions	2.9947	1	0.084
Energyuse	crudeoilprice	14.84	1	0.000
Energyuse	ALL	18.296	2	0.000
crudeoilprice	CO2emissions	.18307	1	0.669
crudeoilprice	Energyuse	.63195	1	0.427
crudeoilprice	ALL	1.5728	2	0.455

Figure A.6: Table 2: Granger Causality Analysis

Note: Table 2 represents a Granger Causality Test performed using Stata and drawn from the same World Bank datasets defined above for Table 1's Correlation Analysis. The variables considered are then: CO2emissions, Energyuse and crudeoilprice. After performing a VAR test on these variables with 1 lag, I finally performed Granger Causality tests in order to identify which variable Granger causes the others.

A.0.9 Figure 7: Correlations and Growth rates paths

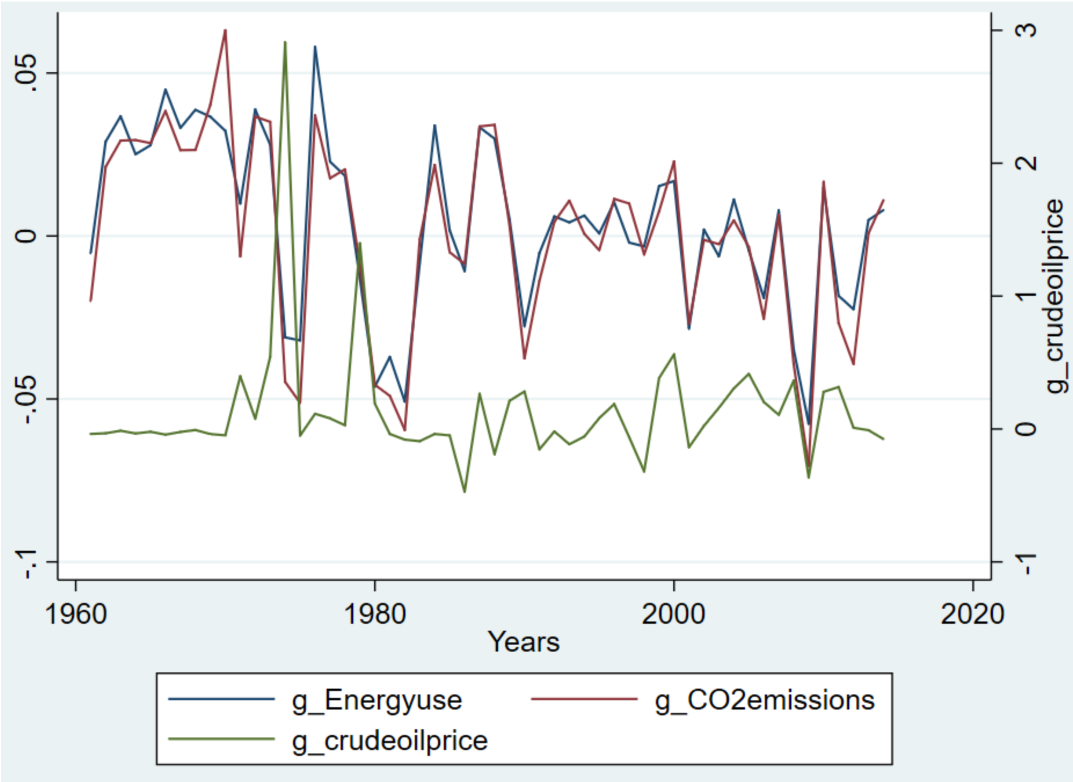

Figure A.7: Correlations and Growth rates paths

Note: Figure 7 displays the paths of the different growth rates obtained for the above correlation analysis. It shows the evolution of the growth rates, over the considered period (1960 - 2014), of crude oil prices on commodity markets, represented by the variable g_crudeoilprice (green color on the graph) as well as the evolution of U.S growth rates of CO_2 emissions and Energy consumption respectively identified by g_CO2emissions (red color) and g_Energyuse (blue color). In order to properly observe these curves and consistent with our previous analyses, I had to impose two different scales for the vertical axis since crude oil price variations are significantly larger than variations of the others.

A.0.10 Figure 8: World Energy use (kg of oil equivalent per capita)

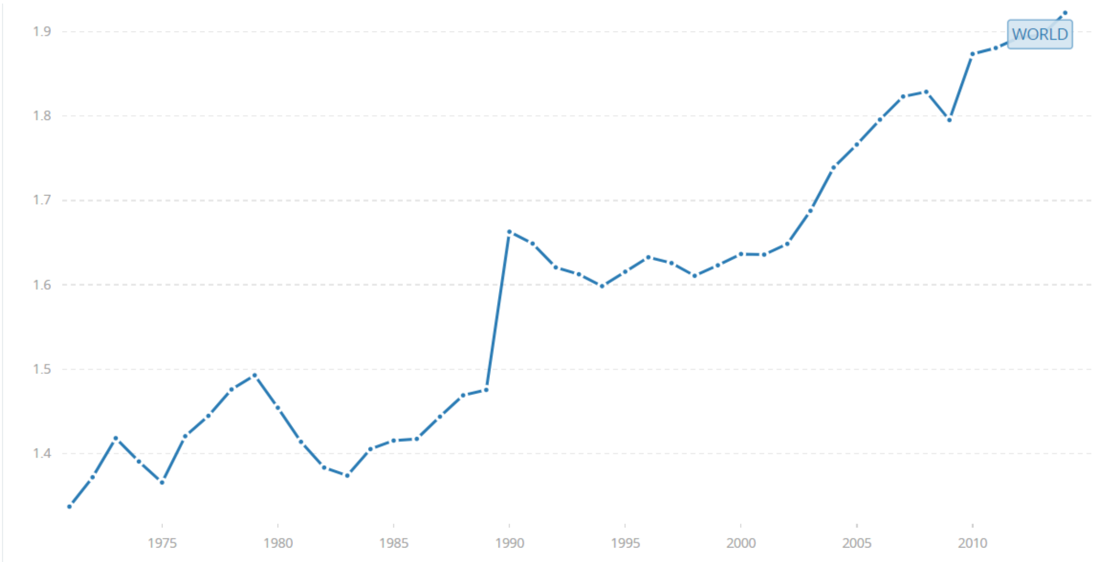

Figure A.8: World Energy use (kg of oil equivalent per capita)

Note: Figure 8 represents the annual world energy use graph, expressed in kg of oil equivalent per capita, from 1971 to 2014 provided by The International Energy Agency (IEA) in 2014. It is provided by the Carbon Dioxide Information Analysis Center from the Environmental Sciences Division of the Oak Ridge National Laboratory, Tennessee, United States and also recoverable in the World Bank Datasets.

A.0.11 Figure 9: World CO2 emissions (metric tons per capita)

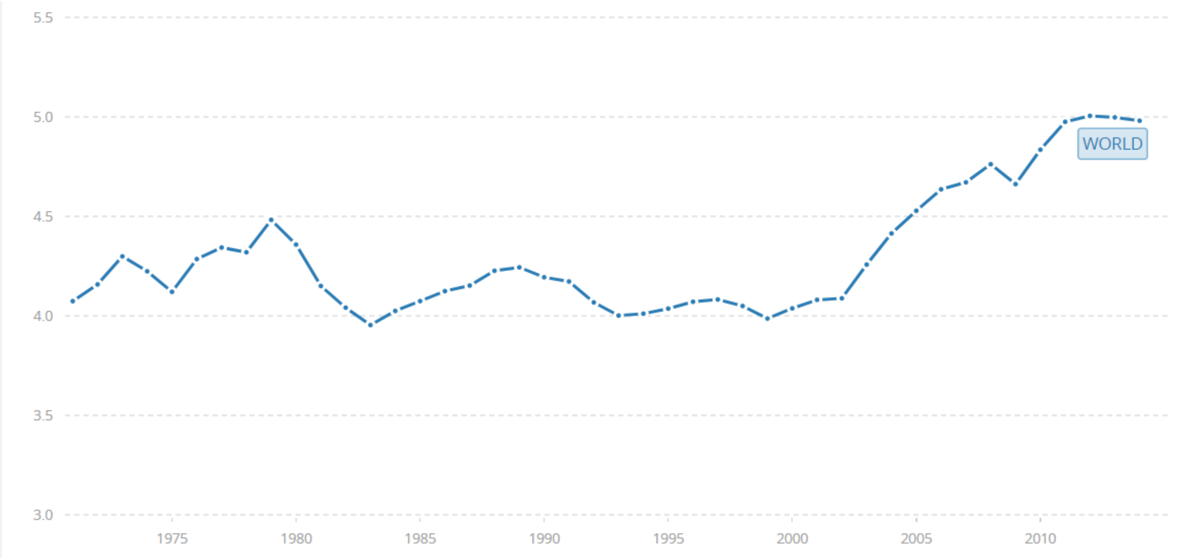

Figure A.9: World CO2 emissions (metric tons per capita)

Note: Provided by the Carbon Dioxide Information Analysis Center from the Environmental Sciences Division of the Oak Ridge National Laboratory, Tennessee, United States and located in the World Bank Datasets, Figure 9 represents the annual world CO2 emissions graph, expressed in metric tons per capita, over the period 1971-2014.