Oil Cycle Dynamics and Future Oil Price Scenarios

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Abstract

We review the oil cycle and evoke future scenarios as to how it will end.

1 Introduction

Many authors consider exergy production (commonly known as energy production in which we include food production) to be an essential factor in economic production Cantillon (1755); Jevons (1866); Meadows (1974); Mollison and Holmgren (1978); Fraser and Rimas (2011); Reynolds (2002); Montgomery (2007); Hamilton (2009); Ayres and Warr (2009); Kümmel (2011); Giraud and Kahraman (Giraud and Kahraman); Hamilton (2013); Illig and Schindler (2017); Charlez (2017); Schindler and Schindler (2018); Hall and Kittgard (2018). In Diamond (1998), Jared Diamond argues convincingly that a large part of technological progress is opportunity. We believe that opportunity is tied to exergy production and its decreasing cost share in periods of economic growth. In this work we make the ansatz that economic growth is reduced to exergy production. In Section 2 we give an energy centric explanation of the secular cycles described in Turchin and Nefedov (2009) based on the economic production theory developed in Illig and Schindler (2017) and Schindler and Schindler (2018).

Oil is a finite resource. Oil extraction has been increasing since 1857. It will one day peak and go into decline. Serious estimates as to when that peak will occur vary from 2018 to 2050 Babusiaux and Bauquis (2017). The primary dispute among these estimates is with respect to the classification of resources as reserves or not. Resources are defined as the quantity of oil in place, reserves are the subset of resources that can be profitably be extracted. The divergence

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of opinions is most significant with respect to unconventional and frontier oil. In a nutshell: most of these oils were known to exist for over 50 years, the price of their extraction prevented their classification as reserves until recently, and their extraction produces more contingent pollution.

In Section 3.1 we investigate an empirical model for oil prices based on historical extraction rates and interest rates of the Federal Reserve. Our analysis suggests that peak oil occurs not from lack of oil, but rather from the cost of extraction rising faster than market prices. We believe low prices resulting in political instability in oil producing nations will cause the peak to occur sooner, rather than later.

We will use the following notation throughout the text: Y is a measure of economic production expressed in currency. The subset $Y_E \subset Y$ is the amount of money spent on exergy (including food). We will denote the complement of Y_E in Y by $Y_{E^\complement}$ thus $Y = Y_E + Y_{E^\complement}$. $Y_{E^\complement}$ contains such things as government bureaucracy, the military, luxury items, education, entertainment, etc. The *cost share* of energy in the economy is defined as

$$C = \frac{Y_E}{Y} = \frac{Y_E}{Y_E + Y_{E^\complement}}. \tag{1.1}$$

In the sequel, p will loosely denote the market price of oil which is used as a proxy for the market price of exergy in the oil cycle.

We believe that the correct term is oil extraction, however the oil industry and out data refers to oil production. We use the terms interchangeably.

In Section 4, we make some recommendations as to positive directions civilization could take in the post oil cycle.

2 Exergy Centric Economic Production Functions and Secular Cycles

We look at secular cycles as described in Turchin and Nefedov (2009) from the perspective of economic production function theory Schindler and Schindler (2018); Illig and Schindler (2017) and an energy centric view of the economy. We refine the analysis in Schindler and Schindler (2018) which used the conatus principle of Spinoza, promoted as a fundamental principle in economics by Frédèric Lordon Lordon (2003).

Several authors have linked the decline of civilizations to nonrenewable food production Montgomery (2007); Fraser and Rimas (2011); Diamond (1998, 2011); Schindler and Schindler (2018). We use this as a justification for (H1) below.

We make the following hypotheses:

(H1) The source of economic production is exergy.

(H2) Growing industries pay relatively good wages.

(H3) Contracting industries pay relatively poor wages.

(H4) Profits are used to expand.

(H5) Large cost shares lead to political power.

(H6) A small cost share of exergy implies great economic diversity.

(H7) People are more sensitive to the derivative of their situation, or their relative situation than their absolute situation.

From (H1) we reduce economic growth to exergy production and then explain secular cycles using the dynamic production function equations Illig and Schindler (2017); Schindler and Schindler (2018).

A growth period starts from profitable exergy (food) production. From (H1), (H2), and (H4), this leads to expansion with relatively good wages. From (Illig and Schindler, 2017, Equation (5.10)), we see that at constant price, if the derivative of the cost share is negative, exergy production produces stronger economic growth. We believe that the beginning of the stagflation period begins when the size of the cost share of exergy begins to grow. If the exergy production is still growing, the derivative of the cost share of exergy becomes positive due either to nonrenewable agricultural techniques, environmental degradation, or depletion of resources. This slows economic growth and decreases economic diversity. We believe that the first macroeconomic symptom of rising exergy cost share is lower wages. From (H5), we see that a sector of the economy having positive derivative during the growth phase does not contribute to economic growth but gains political power as the growth phase continues. Moreover, government support of sectors in $Y_{E^\complement}$ leads to fewer resources dedicated to Y_E and hence lower or contracting growth rates. Citizens are unhappy with their government during the stagflation phase not only because their financial situation stagnates, but also because of apparent corruption as the government attempts to hold up portions of the economy that do not contribute to economic growth (for example banks that are "too big to fail"). It is tempting to believe that in the case of shortage of an essential item in the economy the price of that item will rise. This is disputed in Illig and Schindler (2017) and Schindler and Schindler (2018) where it is clearly not indicated by the dynamic production function equations. Indeed the authors speculate that as exergy goes into decline,

$$\frac{\partial p}{\partial E} \geq 0, \tag{2.1}$$

so that price actually declines with production. Shortage of an essential item causes the economy to contract which reduces the price. Furthermore price depends to a large extent on the distribution of wealth. If those who are hungry do not have money, clearly a rise in the price of food will be limited in the event of a food shortage. Therefore a shortage of exergy leads to increased importance of exergy in the economy, decreased wages which increases the difference between the productive class and the elite class, a negative cost share derivative and possibly a positive derivative of price with respect to quantity producing a negative feedback loop accelerating decline.

There are two recurring currents in political history. One is egalitarian, the other is fascist by which we mean non egalitarian advocating violence as a means to maintain hierarchy. We argue that egalitarian thinking dominates growth phases of economic development. During the stagflation phase fascist sentiment rises. In growth phases, profits of exergy production rise and these profits are shared generously amongst increasing numbers. Reasons for a non egalitarian society may be skin color, religion, skills, education, birth rights, etc. But in the end, non egalitarian thinking boils down to being able to impose a non egalitarian system. Fascism may be a defense for survival. For example if suddenly only enough food is produced for 70% of the population. If the food is shared equally, everyone starves. If a fascist pecking order is implemented, only a percentage of the population will die. In any case, rising inequality during stagflation creates divisions in the society as those with an egalitarian vision decry the inequality and those with fascist tendency advocate a hierarchy for wealth distribution defended with the use of force. What is obvious to both sides is the dysfunction of the status quo. This raises the probability of violence.

Tverberg Tverberg (2017a) noticed a flattening in per capita exergy production between 1920 and 1940 to which she attributes the economic depression (stagflation) of the 1930s which eventually led to the second world war. Anthracite coal extraction peaked in 1914. The flattening of global exergy per capita may have been due to lower quality coal replacing high quality coal causing an increase of the cost share of exergy. Exergy per capita increased after the second world war because of a shift from coal to oil as a primary motor of economic growth.

High quality resources are extracted first. As high quality resources are depleted two competing tendencies appear: decreasing quality of the resource tending to raise cost share and technology permitting more efficient use and extraction of the resource decreasing cost share. When the cost share of exergy increases (particularly food), so does the probability of violence Lagi et al. (2011). A rise in authoritarianism has been postulated in Heinberg and Crownshaw (2018).

From (H7), we see that stagflation tends to breed fear of resource scarcity and fascist sentiment rises. Thus we make the conjecture that fascist leaders are more likely to gain power in stagflationary times where as egalitarian leaders are more probable during times of growth.

3 The Oil Cycle

In Illig and Schindler (2017), the authors consider different scenarios for post peak oil extraction using the hypothesis:

(H8) For most of the contraction phase of oil extraction, $\dfrac{\partial Y}{\partial E} > 0$ and is relatively large.

We update the possible scenarios scenarios giving more precise macro economic characterizations using the insights provided by an updated price model and considering more precise possible economic policy of governments and central banks.

3.1 An Empirical Study of Oil Prices

In this section we study empirical data in order to understand what the price dynamics of the contraction phase of oil extraction might be. The idea behind the price models from Illig and Schindler (2017) was that since the primary source of wealth is energy production, much of current price should be determined by the time series generated solely by production. This was successful during the growth period of oil production from 1937 to 1970 when oil extraction rates grew at at more than 7% per year. During the stagflationary period of oil from 1965 to 2017 the effort was only satisfactory. Many authors have written on the relationship between interest rates and oil prices for example Likvern (2015); Tverberg (2015, 2017b). We thus include the Federal Reserve rate with the time series of oil extraction in the new model. We use the Federal Reserve rate as a proxy of interest rates on oil because the U.S. dollar is the primary currency in which oil was traded in the studied time period.

We worked with data from BP's 2018 Statistical Review and from the Fedfund 2017. We used prices and extraction data from the BP's data set:

- Annual crude oil prices in 2017 US dollars per barrel (deflated using the Consumer Price Index for the US) available from 1861 to 2017.

- Annual world oil production expressed as a daily mean in millions barrels per day (MMbbl per day) from 1965 to 2017. These data include crude oil, shale oil, oil sands and NGLs (natural gas liquids - the liquid content of natural gas where this is recovered separately). However, these data exclude liquid fuels from other sources such as biomass and derivatives of coal and natural gas.

Remark 3.1. *All data we use is very approximate. Laherrère Laherrère (2014) has exhaustively documented incoherence in extraction data from all standard sources. Laherrère states (correctly) that since the data is accurate to at most 3%, it is both illogical and misleading to provide the data beyond 2 decimal points. We repeat the error of BP of including extra decimals because we did not want to alter the data. We use a single price for the price of oil provided by BP, but there is a large spectrum of prices for oil of different densities, chemistry, and provenance Laherrère (2015). BP groups extraction data for crude oil, condensate, and NGL's, a large spectrum of products not all used for the same purpose and of course with different prices. The fact that our regression analysis works suggests that there are correlations within the data and averaging going on.*

In Figure 1 we show the extraction rate in millions of barrels per day (MMbbl per day) from 1965 to 2017. In Figure 2 we represent the federal funds rate.

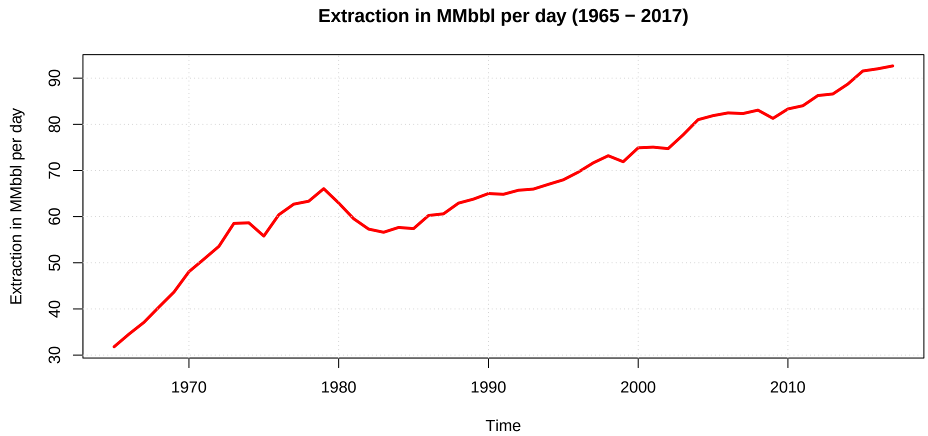

Figure 1:

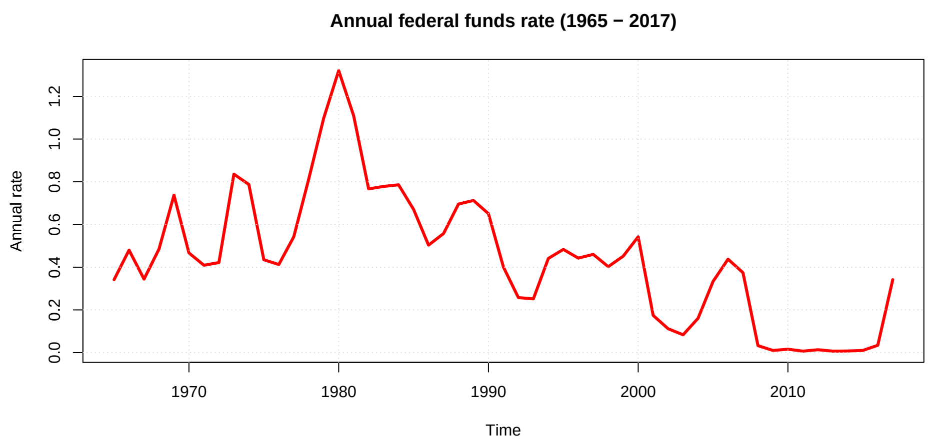

Figure 2:

In light of Remark 3.1, our aim is not to get the best fit possible, but to understand factors that influence price.

Let $(P_t)_t$ denote the time series of oil prices (in 2017 dollars adjusted for inflation) from year 1965 to year 2017 and $(Q_t)_t$ the time series of quantities of oil extracted (in million barrels daily) from year 1965 to year 2017 for BP data.

3.1.1 Price explained by oil extraction and interest rates

The approach we consider here is structural. We try to derive information on the price from the time series of oil extraction and interest rates. From Figure 3, one sees that Q_t cannot explain P_t because the price P is not uniquely determined by the extracted quantity Q, in other words several prices correspond to the same produced quantity. For this reason, we use, in addition to Q_t and the interest rate τ, the lag-1 difference and of the series $(Q_t)_t$ at year t:

$$\nabla Q_t \overset{\text{def}}{=} Q_t - Q_{t-1}. \tag{3.1}$$

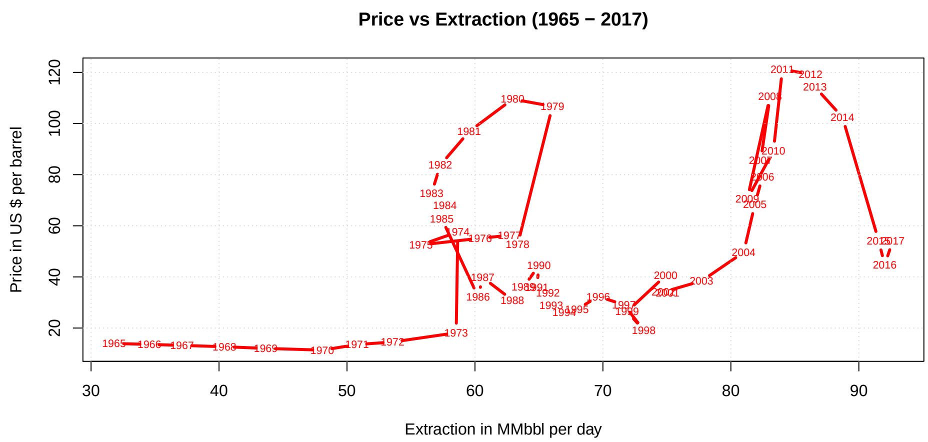

Figure 3:

We consider the following model:

$$p_t = a\tau + b\,Q_t + c\,\nabla Q_t + \epsilon_t \tag{3.2}$$

where a, b, c are coefficients determined by the linear regression and $(\epsilon_t)_t$ is a centered second order stationary process. Defining $P_t \overset{\text{def}}{=} \exp(p_t)$, equation (3.2) is equivalent to

$$P_t = \exp(a\tau + b\,Q_t + c\,\nabla Q_t + \epsilon_t). \tag{3.3}$$

The dependency of price P_t on these variables is non-linear. As the logarithm function flattens large values, the model takes into account the inelasticity of oil prices. That is, small changes in the supply provoke large changes in price.

The R output for the linear regression with the data starting at year 1965 is given in Appendix A. Note that we have lost a year because of the lag-1 differences $(\nabla Q_t)_t$ that are only available form year 1966 with the data set starting in 1965. Adjusted R-squared being almost 0.99 means that the model explains the variation in price as well as can be hoped for given the quality of the data. From the stars in the R output, we obtain that all coefficients in the model are significant. The estimated values are:

$$\begin{aligned} a &\approx 1.17 \\ b &\approx 0.05 \\ c &\approx -0.07 \end{aligned}$$

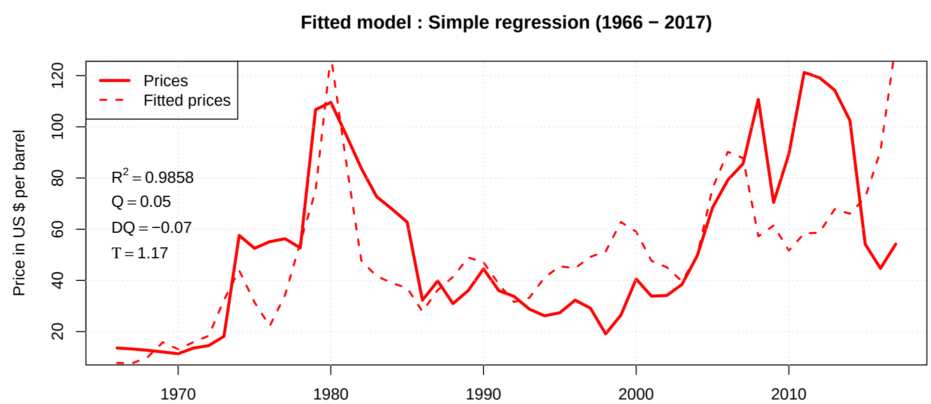

Figure 4:

We have plotted the adjusted prices and the real prices in Figure 4.

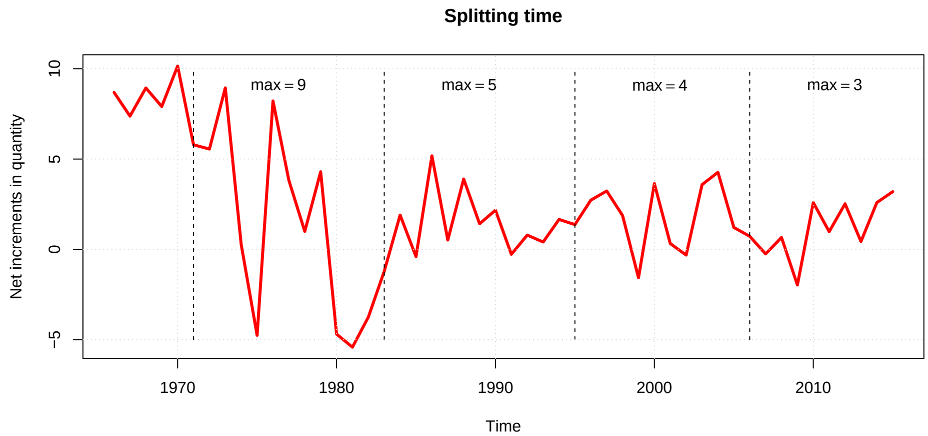

Figure 5: Percent increases in quantity from 1971 to 2015

We tested the stability of the coefficients by trying the regression in different sub-intervals and found that the coefficients for Q and ∇Q were relatively stable but that the coefficient for interest rates was not, see Figure 6. All coefficients were more stable than in the model studied in Illig and Schindler (2017). It is clear that the model cannot be used to estimate future prices because we do not know what future interest rates will be. We can however make scenarios based on different interest rate policies from the Federal Reserve and more generally, central banks, if we can understand the role of interest rates.

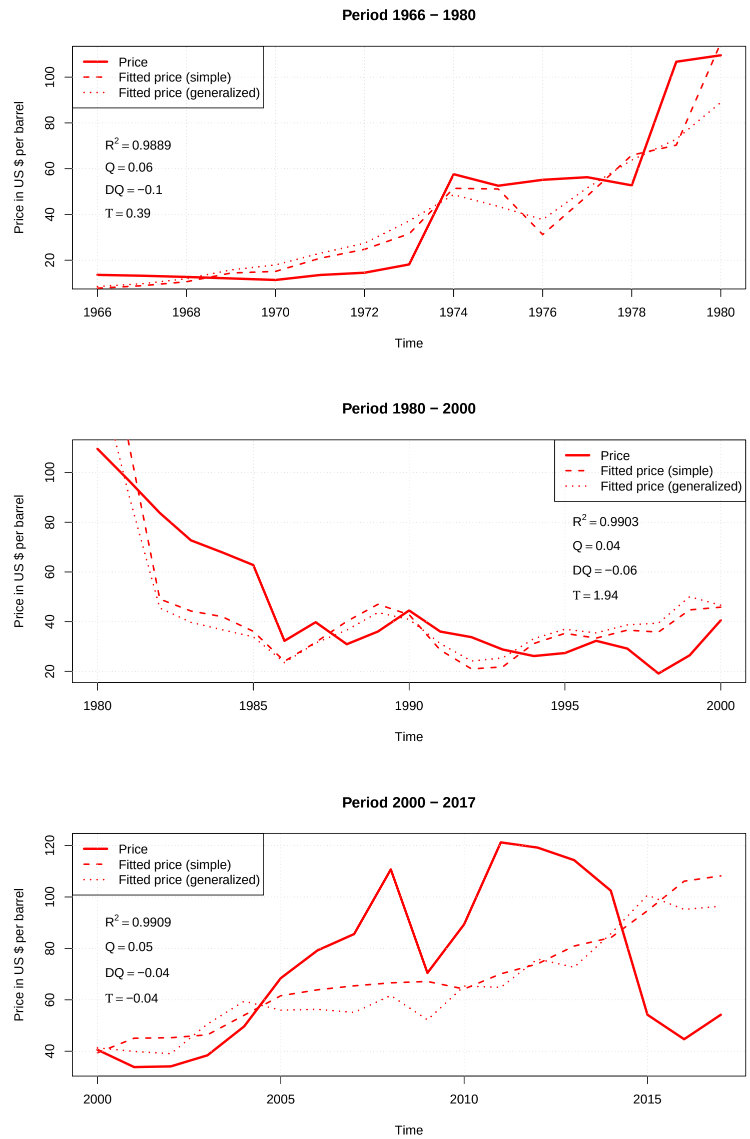

Figure 6: Adjusted price and linear regression coefficients for three periods

3.2 Interpretation of the results

We compare and contrast the model with that in Illig and Schindler (2017). The interest rate coefficient replaces the constant term in Illig and Schindler (2017), (better) explains the information in the second derivative term and part of the first derivative term. Thus it contains a great deal of information with respect to the price.

In the current capitalist system, a primary source of money creation is debt Dalio (2015). We distinguish between the financial economy and the real economy where the real economy is the amount of goods and services in the economy and the financial economy is based on currency exchanges. If too much money is in circulation, the financial economy gets "ahead" of the real economy and inflation increases. If on the other hand, too little money is in circulation, the financial economy can smother the real economy because not enough money circulates causing deflation leading to a negative feedback loop with respect to investment Dalio (2015). We make the following hypothesis:

(H9) Decreasing interest rates stimulates borrowing which creates money stimulating the financial economy. Increasing interest rates has the opposite effect.

In light of (H9), it is significant that the coefficient of interest rates is positive in the global model and in the first two split periods. It is slightly negative in the last period indicating a switch in Federal Reserve policy. From 1980 to 1995, the major concern of the Federal Reserve was inflation. High oil prices were associated with high inflation so that high oil prices triggered higher interest rates. In the late 1990s, the concern switched to deflation. Or perhaps the finance industry pushed policies that increased asset prices, or a combination of both factors influenced Federal Reserve policy. In this period, we believe that we are seeing the effects of (H9). Note that this is the period in which the fitted complete model has the worst fit. We note also that central banks have been using more than interest rates since the financial crisis in 2008 to stimulate the economy. Central banks have been buying financial assets, mostly bonds, but also stocks and currently own approximately 10% of all financial assets, bought with freshly created money Prins (2018). As a consequence, long term rates are lower. We therefore believe that the official Federal Reserve rate since 2008 is high relative to what the true borrowing rate of the economy is.

We note also that the coefficient of extraction rate remains positive globally and in each subinterval. Thus $\dfrac{\partial p}{\partial q} > 0$ as one expects from the dynamic production function equations. In Illig and Schindler (2017) it was speculated that oil production was less important during the 1990's because the coefficient of production was negative with that model. The current model suggests that interest rates were the factor damping oil prices during this time.

The coefficient of the derivative term is negative and greater than the coefficient of quantity explaining why prices rise when extraction rates fall (at least initially). But the relative size is much smaller than in the Illig and Schindler (2017) model. When oil extraction rates fall, the real economy slows depressing the financial economy encouraging lower interest rates which support prices. If the prices rise too much, interest rise because of fears of inflation.

It is well known that oil price is correlated to world GDP. We also note that the interest rate of the Federal Reserve is correlated to margins in the fossil fuel industry Damodaran (2015). The preceding correlations lead us to the following conjectures:

Conjecture 3.1. 1. *The "best" rate for the Federal Reserve in order to fit the real economy with the financial economy is the margin for exergy production.*

2. *Three years of exergy production data coupled with the margins of the exergy sector give a more informative measure of the economy than the world GDP.*

In other words, we postulate that the margins of exergy production give interest rates which fulfill the Federal Reserve's mandate rather than vice-versa. Conjecture 3.1 suggests that the model underestimates the price in the period 2010 to 2014 because interest rates below profit margins in exergy production. When interest rates are too low, investment choices tend to be worse than normal Dalio (2015) leading to high inflation. The inflation, though not present in common metrics, can be seen where the money has been created since 2008, in asset values.

3.3 The oil cycle

The oil industry has struggled with over production since its inception creating boom bust cycles. Unregulated producers will extract as much oil as they can until the market price exceeds production costs causing a fall in investment which leads to slower (possibly negative) production growth and hence price spikes which leads to another investment phase. Because of the nature of the oil industry, there is a lag between the start of investment and an increase in production just as there is a lag between a drop of investment and a decrease in production. The industry is very capital intensive. Offshore projects can take as long as 10 years to bring online. Moreover, oil wells that don't pay out are not plugged until operating expenses (or lifting oil expenses, LOE) are below the market price for oil. If a well doesn't pay out, bankruptcy is declared, creditors become owners who generally push the well as hard as possible to get as much money back as quickly as possible. Financial stress leads to short term thinking Mullainathan and Shafir (2013). Short term thinking means producing as much as possible immediately to pay creditors regardless of the market price and putting off long term projects such as prospecting or long term development projects.

Remark 3.2. *Hypotheses (H2) and (H3) imply that during boom cycles, wages and hence extraction costs rise while during bust cycles, wages and hence production costs fall. This is observed empirically with the cost of oil extraction services rising during boom periods and falling during bust periods Babusiaux and Bauquis (2017).*

Rockefeller and Standard oil attempted to rein in overproduction using monopoly tactics in the 1890's but these attempts were deemed anti competitive and Standard Oil was broken up. In 1928 the dominant oil producers attempted to rein in production at Achnacarry with a cartel agreement but the discovery of the East Texas super giant oil field in 1930 soon drove the price of oil below production costs. This lead to regulation by the Texas Rail Road Commission in the 1930's necessary until sub $10 oil peaked in the 1970's. Internationally, the so called seven sisters used their financial clout to limit production. They bought the rights to develop oil fields in the Persian Gulf and then did not develop the fields. The price spikes of the 1970's and early 1980's enabled the oil companies to make the necessary investments in Alaska and the North Sea to bring on sub $20 oil Auzanneau (2016). These investments allowed production to continue rising in the low price period 1986–2002, when lack of long term investment finally lead to a drop in production.

We have two competing forces on prices and supply of exergy. Carey King King (2015) postulates a global minimum in the cost share of exergy around 2000 due to increased extraction costs. From our analysis of the dynamic production equations, this indicates slower economic growth and lower wages. The first industry to suffer from slower economic growth should be the financial industry which depends on economic growth to make returns. Central banks however since the financial crisis in 2008 have engaged in unprecedented money creation Prins (2018) to buy financial assets (mostly bonds). Central banks own $ 22 trillion worth of assets (nearly $ 3000 per world capita) which were purchased from money created out of thin air. Not only is this highly inflationary, raising the price of financial assets, but it encourages financial bubbles Ayres (2014). Inflation is a surreptitious way of reducing wages. The most obvious way in which this inflation is expressing itself is the increase in land prices in large metropolitan cities which increases the cost of housing for tenants and prevents wage earners from being able to purchase real estate.

Remark 3.3. *From 1930 to the present, the cost share of the financial sector has grown significantly with the economy. This indicates a positive derivative of the cost share of the financial sector which shows that the financial sector is very inefficient. If the financial sector were efficient, it would direct resources to sectors of the economy that would grow faster than itself and the cost share of the financial sector would decrease with an expanding economy.*

The oil extraction rates have continued to increase since the price downturn in 2014 for several reasons.

1. The years of increasing investment took several years to bear fruit. Production was essentially flat from 2005–2010. Similarly when prices decreased, the resulting decrease in investment requires several years to be observed in production rates.

2. As mentioned, short term thinking pushes oil companies to prioritize projects that produce oil quickly at the expense of projects that would produce oil after 2020.

3. The fore mentioned increase in asset prices because it is very capital intensive: raising equity and borrowing have been made easier. In other terms, the increase in asset values has allowed $c_E > Y_{E_p}$, where c_E is the cost of extracting petroleum and Y_{E_p} is the amount spent on petroleum.

Between 2000 and 2013, oil industry capital expenses increased by almost 11% per year Kopits (2014); Mushalnik (2016). After the stagnant extraction rates between 2005 and 2010 the increase in capital spending brought up production by around 10% from 2010 to 2016. Capital spending dropped significantly in 2015 and 2016 before stabilizing in 2017 Tuttle (2017). Since the price drop in November 2014, Short term thinking is rife not only within the industry but for investors. Prospecting budgets have dropped. Discoveries are at historic lows Staff (2017a). The increase in production has been accompanied by a corresponding increase in debt Staff (2017b). The common accounting principle of computing net present value means that the most economic way of exploiting an oil field is to front load production. Investors have poured money into Light Tight Oil, or LTO, produced from fracking. This production is extremely front loaded, around 45% of a well's total production occurs in the first three years of production Peters (Peters) so increasing production requires constant drilling. Moreover LTO has only been marginally profitable and carries an immense amount of debt Likvern (2017); Cunningham (2018). As of August 31, 2018, Haynes and Boone has tracked 160 North American bankruptcies concerning \$ 92.9 billion worth of debt since the beginning of 2015 of which 22 producers concerning \$ 9 billion worth of debt occurred in 2018 Staff (2018b). Several banks and the International Energy Agency are warning of supply problems in the early 2020's if investment does not increase Rapier (2018). These are signs of rising cost share of oil. If the monetary expansion should cease, and the financial sector require payment of dues, a deflationary debt spiral can ensue causing decreased production. The monetary expansion has helped the financial industry which has indirectly helped oil production as a large part of new investment has been in oil production.

During the growth phase, oil extraction payed for government bureaucracy through taxes, paid investors with positive returns, payed workers with good salaries. In the current stagflation phase, salaries in the oil and gas industry are declining, oil extraction often benefits from tax breaks paying for less government bureaucracy, and investors are making poor returns. Hypothesis (H8) and (Illig and Schindler, 2017, Equation (5.7)) give the following bound on price increases in the case of a contraction in supply:

$$I_p(t_1, t_2) < I_C(t_1, t_2)/I_E(t_1, t_2), \tag{3.4}$$

where $I_x(t_1, t_2) \stackrel{\text{def}}{=} x(t_2)/x(t_1)$ is the index of the quantity $x(t)$. If Conjecture 3.1 is correct, our empirical model suggests that returns will be lower than many investors anticipate.

The example of the Soviet Union shows that oil extraction and the economy can collapse even though resources are available. Soviet oil extraction peaked in

1987. It fell sharply until after the Soviet Union had collapsed in 1991. Russian oil extraction, with the aid of foreign investment beginning in the mid 1990's, has been rising since 2000 achieving 1988 levels in 2014. This indicates that a negative feedback loop with respect to extraction rates can appear if too many resources are devoted to $Y_{E^{\mathtt{C}}}$. Venezuela seems to be falling into a deflationary debt spiral leading to loss of production. That is to say the financial sector lent Venezuela more money than the country can pay back with oil revenues. The debt payments required by the financial sector do not leave enough resources to maintain production levels. As production falls, the State oil company is even less able to pay the financial sector and the process self reinforces. Officially Venezuela has the largest oil reserves in the world, and yet production has fallen by about 1/3 in 2 years and workers are quitting because of low pay and poor working conditions Buitrago and Ulmer (2018).

3.4 Scenario Update

In Illig and Schindler (2017) some common future scenario's were evaluated. Since that time, oil production has been higher than many analysts had predicted, notably with respect to unconventional LTO in the U.S. and oil sands in Canada. However, we see the probability of an asymmetric production curve increasing.

The end of stagflation is characterized by inter-elite competition Turchin and Nefedov (2009). From In Illig and Schindler (2017) a Seneca cliff Bardi (2011), or fast decline in oil production was evoked with respect to conflict in the Middle East. Here we highlight additional factors rendering a fast decline in oil production more probable.

1. Competition between elite energy producers.
2. Competition between elite energy producers and elite investors.
3. Enhanced Oil Recovery (EOR) techniques.
4. Armed conflict.
5. Economic collapse.

Note than during the energy growth period of the 20th century, energy producers in general were not in competition. Growth of one sector of energy production did not decrease production in another sector. An increase in one area could actually increase production in another sector if energy from one sector was used in the production of another, for example oil could be used to mine uranium increasing nuclear energy production. Competition among energy producers is a sign of scarcity, for example kerosene replaced whale oil because there were fewer whales and whale oil production was going into decline Bardi (2004). In the same way, we believe that replacement of coal power plants by gas fired electricity generation is a sign of peaking of coal production. For oil, until recently, if low prices lead to a reduction in production, it was via low cost producers in the Middle East rather than high cost producers. This is because low cost Middle East producers where not under financial stress and could have a longer term perspective. Financial stress leads to production at as high a rate as possible in efforts to force competition out of the market and unaware of (2.1). Thus, since the price downturn in 2014, producers have been producing as fast as possible to drive competition from the market. The loser in the competition has been long term projects offshore where projects have been postponed and lower prospecting budgets have contributed to discoveries dropping to historic lows Staff (2017a).

The financial sector can lead to negative feedback cycles by simultaneously requiring debt repayments and cutting off additional financing. In this scenario $c_E > E_p$ for a length of time after which the investment community demands debt repayment and cuts off new funding. This leads to a deflationary debt spiral in which lower production leads to more financial stress, leading to less lending and less debt repayments so money exits the system reducing prices forcing wages to go down, etc. This is the current situation in Venezuela. Officially Venezuela has the highest oil reserves of any nation, there is oil in the country but because of debt defaults, investors refuse to lend money. Because spending on oil production infrastructure has lagged, oil production is falling making current debt repayments increasingly difficult. Wages are falling and workers are leaving Buitrago and Ulmer (2018) (we are speaking of dollar denominated wages, the local currency suffers from hyperinflation with prices rising faster that wages).

We anticipate more countries following Venezuela into a deflationary debt spiral leading to lower oil production, decreased economic activity, and heightened tension between the financial sector and the oil extraction industry and contributing to political instability. Countries that seem to be coming off of plateau or increasing decline in oil extraction include Algeria, Angola, Colombia, China, and Mexico. Iran's oil fields have suffered from years of under investment Staff (2018a). Sanctions kept production down during several years of high prices. The end of sanctions lead to increase oil extraction rates, but in a low price environment. Now as oil prices climb, President Trump has renewed sanctions which could push Iran into a production decline.

EOR techniques in general help old oil fields maintain plateau production but when decline finally sets in, the rates are higher Babusiaux and Bauquis (2017).

Armed conflict such as in Libya can affect oil production by discouraging investors and out right destroying oil production and storage infrastructure.

Because of increasing extraction costs the oil industry needs higher prices to make good returns. In 2005, $50 a barrel was considered a high price, in 2015, it was considered a low price. Increasing decline rates mean that production is more sensitive to a bust cycle. The 1986-2002 bust cycle saw 15 years of increasing production despite the bust. The bust cycle that began year end 2014 will probably see decline in production in less than 7 years. The debt of the oil industry is higher than it was at the end of the last bust cycle. Debt maturities will increase into the early 2020's, precisely when several analysts are predicting problems with supply. For these reasons we believe that extraction rates will not rise quickly (if at all) in the next boom cycle.

The high oil prices of the next boom cycle will increase food prices and hence political instability Lagi et al. (2011). Many oil producing countries will devote resources to $Y_{E^\complement}$ rather than oil extraction precipitating a decline in production and a deflationary spiral.

The vast money creation by central banks since the 2008 financial crisis has made the world financial system more fragile Prins (2018); Ayres (2014) and created distortions in the value of assets. The economist Kenneth Rogoff Rogoff (2016) has proposed to eliminate cash in order to prepare for negative interest rates to solve the next financial crisis.

Dissatisfied voters are electing more outside candidates whose policies may well provoke violence. We also expect more autocratic governments, an idea explored in Heinberg and Crownshaw (2018).

The most common economic system is a system in which money is created through debt. It is easier to repay debt when the economy is growing Tverberg (2012). It is not clear that the current economic system can function in the face of sustained economic contraction. A decrease in oil production could cause a spike in oil prices causing defaults in $Y_{E^\complement}$ provoking a collapse in world markets and loss of confidence in the system which permits oil extraction.

With the current economic system, the end of any mineral extraction business is bankruptcy. As long as the financial system allocates funds, the business will continue. When the business becomes chronically unprofitable, the financial sector will cut off funding and the business will fail.

4 Recommendations

The destruction of the cedar forest by Gilgamesh and Enkidu shows that the problem of over exploitation of resources is as old as civilization itself. Capitalism's imperative of economic growth makes the economic system very susceptible to over exploitation of resources. Though we expect increased violence and tensions in the next few years, there are opportunities to change the direction of civilization and put it on a more sustainable trajectory.

The goal of reducing violence and suffering is incompatible with the goal of infinite economic growth. Clarifying our goals is the first step in changing the direction of civilization. In the last 100 years we have learned a great deal about human behavior which we could use to devise better political systems.

A word about agriculture. Agriculture is the source of 25% of global greenhouse gas emissions while all of transportation is only 176% The so called "green" agricultural revolution more appropriately called industrial agriculture revolution optimized productivity in the sense that the maximum amount of food per hour of human labor was produced using large fossil fuel inputs. This decreased the cost share of food as long as labor is expensive and energy is cheap. However ecoagricultural techniques produce more food per unit area de Schutter (2014) with minimal fossil fuel inputs at the price of greater labor inputs. Ecoagricultural techniques sequester carbon from the atmosphere into the soil. The best indicator of high quality soil is the amount of carbon it contains. Moving towards ecoagricultural techniques not only gives local resilience in the face of rising prices of industrial agriculture, but is probably the most powerful tool in fighting global warming Toensmeier (2016). After the collapse of the Soviet Union, oil supplies to Cuba and North Korea dropped abruptly. An estimated 3 to 5 % of North Korea's population starved to death. Cuba adopted ecoagricultural techniques and avoided famine Schindler and Schindler (2018). Embracing ecoagricultural techniques should be a priority.

The political commentator Étienne Chouard encourages people to practice writing constitutions in order to have something to propose in the event of a failed government. He notes that it is not that hard to write more egalitarian constitutions that are better adapted to make political decisions than the constitutions currently in use.

There are broad international movements, exploring the next economic system which one might broadly characterize as transition movements Hopkins (2008). These grass roots movements, emphasizing local resilience with respect to food and energy production have the potential to greatly reduce future stress.

Blockchain technology offers the possibility of exploring new currencies. The first "free" as in freedom currency based on the relative theory of money. The $\bar{\text{G}}$1 went into circulation in 2017. Just as "free" software is software in the service of humanity rather than profits, the $\bar{\text{G}}$1 is a currency in the service of humanity rather than speculators.

A R output

```
Call:
lm(formula = log(Price66) ~ Quantity66 + DQuantity66 + Rate66 +
    0)

Residuals:
     Min       1Q   Median       3Q      Max
-0.98697 -0.29023 -0.03503  0.50101  0.91086

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
Quantity66   0.04891    0.00151  32.387  < 2e-16 ***
DQuantity66 -0.07328    0.03407  -2.151   0.0365 *
Rate66       1.16999    0.17885   6.542  3.4e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4692 on 49 degrees of freedom
Multiple R-squared:  0.9858,    Adjusted R-squared:  0.9849
F-statistic:  1132 on 3 and 49 DF,  p-value: < 2.2e-16
```

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