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Fossil Fuel Producers Under Threat

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FOSSIL FUEL PRODUCERS UNDER THREAT[1]

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ABSTRACT

Oil and gas producers face three threats: prolonged low oil and gas prices, tightening of climate policy and a tough budget on cumulative carbon emissions, and technological innovation producing cheap substitutes for oil and gas. These threats pose real risks of putting oil and gas producers out of business. They lead to the problem of stranded assets and a significant downward valuation of oil and gas producers. This calls for divesting from and shorting coal, oil and gas. The economies of oil- and gas-rich countries are typically in a deplorable state, since they did not use their past windfalls to build up buffers and invest in a diversified economy. More rapacious depletion of their oil and gas reserves will not help. After the crash in oil and gas prices these countries are facing serious problems and it is difficult to see how they will cope with the outlined threats.

Keywords: fossil fuel producers, low oil and gas prices, climate policy, technological innovation, stranded assets, rapacious depletion

JEL codes: E62, F41, G11, O33, Q33, Q34, Q35, Q40, Q54

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I. INTRODUCTION

Times are difficult and prospects gloomy for producers of oil and natural gas across the globe for at least three reasons. First, oil and gas prices have plummeted in recent years and may stay low for decades to come. Second, the countries signing the recent COP21 United Nations Climate Change Conference promise to deliver, for the first time in decades, significant action to curb global warming to below 2 degrees Celsius and to aim for level well below that. Third, technologies for both shale gas and renewable energy are being developed at an expanding rate and yield substitutes for coal, oil and gas, which are getting cheaper all the time as production increases and cost reductions result from learning by doing. These developments are good news for consumers throughout the world and also for the fight against global warming, but potentially very bad news for countries specialised in the production of fossil fuel and for international companies extracting fossil fuel. Given the size of these risks, these are potential catastrophes waiting to happen. We aim to shed light on these threats for oil- and gas-producing countries and discuss what an appropriate response might be. Before we do that we must understand how many oil and gas producers have managed their natural resource wealth in the past. This history suggests that many oil- and gas-producing countries are placed in a bad position to deal with the three threats outlined above.

II. PAST EXPERIENCE: CURSED BY OIL AND GAS WINDFALLS

It is well documented that countries that have experienced natural resource windfalls often have terrible growth performances. This has happened in sub-Saharan Africa, e.g., Nigeria or Congo, where successive military dictatorships have plundered natural resource wealth and where the economies have been stifled by conflict. But it has also happened in oil-exporting countries such as Iran, Venezuela, Libya, Iraq, Kuwait or Qatar which have experienced negative growth rates for many decades. Other countries such as Botswana, Chile or Norway have had more joy from their natural resource windfalls. So the crucial question is why is it that natural resource booms sometimes have turned out to be a "curse" and at other times have turned out to be a "blessing"?

The traditional explanation for the natural resource curse is the Dutch disease, which states that a resource bonanza leads to an inflow of foreign cash and thus induces appreciation of the real exchange rate in as far as the cash is converted to home currency and spent on home goods. This causes a shift of labour and capital from the non-traded to the traded non-oil and non-gas sectors, contraction of the traded non-oil and non-gas sectors, and expansion of the non-traded sectors (e.g., Corden and Neary, 1982). This is an appropriate general equilibrium response if there are no induced market failures in which case it would be odd to speak of a 'disease'. But

traded non-oil and non-gas sectors such as the manufacturing industries typically enjoy agglomeration advantages and learning-by-doing spill-over effects, and can potentially function as the engine of growth and development for the country. The problem is that these advantages and spill-over effects are seldom fully internalised in a market economy, so that a natural resource windfall that leads to a contraction of the traded non-oil and non-gas sectors will lead to temporary losses in agglomeration advantages and learning by doing. As a result, a *temporary* windfall of oil and gas revenue causes a temporary fall in growth and a *permanent* fall in GDP (e.g., van Wijnbergen, 1984). The first cross-country evidence indicates a negative link between the GDP share of natural resource exports and growth even after controlling for openness of trade, investments, rule of law or institutional quality, and population growth (Sachs and Warner, 1997). So countries with bad institutions, poor rule of law and trade restrictions have poor growth performance, but if in addition they experience foreign exchange windfalls from the sale of oil and gas they fare even worse.

The resource curse is not cast in stone. For example, natural resource windfalls produce a shift from profit-making entrepreneurship towards socially inefficient rent seeking in those countries that have bad institutions but the opposite in countries with good institutions. Cross-country empirical evidence confirms that the resource curse can indeed be turned into a blessing for countries with good institutions (e.g., Mehlum et al., 2006). Countries with an institutional quality above a certain threshold enjoy a boost to growth after an increase in the GDP share of oil and gas export revenue and those below this threshold suffer a decline in growth. Furthermore, cross-country evidence indicates that the curse is more pronounced for point-based resources such as oil and gas with concentrated production and that are easier to appropriate than for diffuse natural resources such as rice and coffee (Bosschini, et al., 2007).

There is also econometric support for the hypothesis that the quintessential nature of the natural resource curse is the *volatility* rather than the *level* of oil and gas income that is pouring into the country (van der Ploeg and Poelhekke, 2009). Better developed financial systems make this volatility curse less severe and can potentially overturn it. The empirical evidence also suggests that the volatility curse is more pronounced in countries that are landlocked, are restricted to international trade, are open to rapid international capital movements, and have a high degree of ethnic fractionalisation.

The resource curse is also stronger for natural resources that are exploited onshore rather than offshore and in countries with presidential, rather than parliamentary democracies (Andersen and Aslaksen, 2008). Empirical evidence also offers support for the hypothesis that oil and gas windfalls increase corruption, especially in countries with non-democratic regimes, and vice

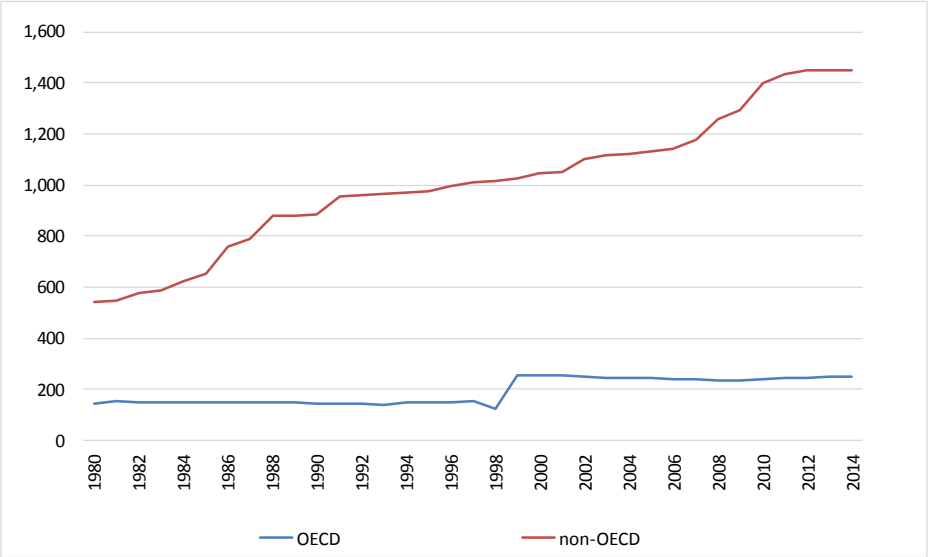
versa more oil typically leads to less democracy (Tsui, 2011). Also, countries rich in oil and gas reserves often suffer from rapacious rent seeking (e.g., van der Ploeg, 2011) and armed conflict (e.g., Collier and Hoeffler, 2004; Lei and Michaels, 2014), both of which can destroy growth prospects. A higher price of capital-intensive resources such as oil or gas induces a higher return on capital relative to the wage and thus boosts armed conflict; a higher price of labour-intensive resources such as coffee or rice boosts the wage relative to the return on capital and makes fighting less attractive. The empirical evidence for Columbia supports this hypothesis: guerrilla attacks (paramilitary conflict) in Columbia increased by 18 and 8 percent (31 and 14 percent) during the period 1997-2003 with a hike in the world price of oil of 137 percent and a fall in the world price of coffee of 68 percent, respectively (Dube and Vargas, 2013).

Finally, natural resource riches encourage unsustainable economic policies such as excessive borrowing on international capital markets when the price is high, import substitution favouring inefficient home manufacturing industries and giving them big subsidies, inefficient public investment projects ('white elephants'), and excessive welfare benefits and bloated public sectors. The real folly of such policy failures is typically only seen once the windfalls dry up or once oil and gas prices tumble.

III. RELENTLESS INCREASE IN OIL AND GAS DISCOVERIES

Figure 1 shows that proven oil reserves have increased steadily during the last three decades, driven almost exclusively by non-OECD oil reserves. The global frontier of oil discoveries has thus shifted from the North to the South of the globe since 1980. Much of this shift has been driven by learning from liberalisation experiences of neighbouring oil- and gas-rich countries and from improved institutions rather than driven by the growing demand for oil and gas from South-East Asia or increasing extraction costs as the more easily accessible reserves are depleted in the north (Arezki, et al., 2016). The main take-home message is, however, that given the right institutions and the right price of oil, oil reserves seem to be plentiful and growing steadily in contrast to what has been suggested by the peak-oil hypothesis. Recently, there have been big new discoveries of oil and gas in the North; e.g., the shale gas explosion in the United States, the big finds in the Mediterranean, in the Gulf of Mexico, and exploration of the Antarctic. Of course, in the longer run, these newly discovered fields will remain unexploited unless the oil or gas price is high enough.

Figure 1: Proven oil reserves in OECD and non-OECD countries



Note: Data are from BP Statistical Indicators. Units are thousands of millions barrels.

Once discoveries of oil and gas have taken place, it typically takes six or seven years of investment before pumping starts and the revenue starts flowing in. As a result of borrowing on international capital markets and smoothing consumption over time, the current account goes into deficit during this period but once the pumping starts moves into a surplus, as predicted by the permanent income hypothesis (Arezki et al., 2015). Of course, if countries have borrowed a lot in anticipation of the future windfall, they will be stung if future oil and gas prices turn out much lower than expected. This has happened during the recent drop in oil and gas prices.

Increased discoveries will thus lead to a boom in oil and gas foreign direct investment (FDI). However, empirical evidence indicates that this boom in oil and gas FDI is associated with a slump or stagnation of non-resource FDI flowing into the country: for those countries which were not an oil or gas producer before, a resource discovery causes non-resource FDI to fall by 16% in the short run and by 68% in the long run; for those countries which were already an oil or gas producer, doubling of resource rents induces a 12.4% fall in non-resource FDI (Poelhekke and van der Ploeg, 2012). These results imply that, on average, the contraction in non-resource FDI outweighs the boom in oil and gas FDI, and as a result aggregate FDI falls by 4% with a doubling of oil and gas revenue. Since non-resource FDI is the main transmission channel for the transfer of new technology from abroad and thus a key driver of growth and development, these results indicate that oil and gas discoveries might harm non-oil and non-gas FDI and thereby harm growth and development of the rest of the economy.

It is important to remember the unfettered optimism that prevailed during the decade long commodity boom that ended in 2014. For example, Kofi Annan stated during the 2013 Africa Progress Panel that: '[There is] good reason to be optimistic ... economic governance continues to improve, providing protection against the boom-bust cycle fuelled by earlier commodity booms ... Defying the predictions of those who believe that Africa is gripped by a 'resource curse', many resource-rich countries have sustained high growth'. It is not clear that this sense of optimism was justified given that the recent bust in commodity prices and in oil and gas prices. Many of the oil- and gas-rich countries find their economies in disarray, which illustrates how dangerous it is to create an economy that is overly dependent on a volatile and finite stream of oil and gas revenues.

Summing up, many developing countries have liberalized their economies and have become more open to international oil and gas companies and as a result have seen a big boost to their discoveries of oil and gas during the big hike in oil and gas prices that occurred since the end of the 1990s. However, the boost to oil and gas FDI has crowded out FDI into manufacturing and other growth-producing sectors of the economy. Furthermore, oil- and gas-producing countries have not made the best of their windfalls and have not made sufficient provisions to deal with the eventuality of prolonged lower oil and gas prices. As we will see, this threat and two others to do with tightening up climate policy and technological progress lead to a seismic shift of the global economy that is putting oil- and gas-producing countries sooner or later out of business.

IV. THREAT: PROLONGED LOW OIL AND GAS PRICES

The first and most immediate threat to oil- and gas-producing countries is that oil and gas prices stay low for decades to come. Since the 1880s the real price of crude oil (in 2010 dollars) has been relatively low and stable at below 30 dollars per barrel. At the end of the 1970s the price went up to almost 100 dollars per barrel and then crashed to just below 20 dollars at the end of the 1990s. It then shot up again to almost 100 dollars towards the ends of the 2000s, for a large part driven by rising Chinese demand for oil and gas, and has crashed since. During this price hike many marginal reserves (e.g., U.S. shale, Canadian tar sands, Brazil or East Africa) became profitable to extract and thus boosted the world supply of fossil fuel. The world price of crude oil stands in December 2015 at 37 dollars per barrel and has fallen by almost two thirds since the peak in the middle of 2014. Although the slowdown of the Chinese economy and the accompanying slowdown in Chinese demand for fossil fuels is part of the reason for the drop in oil and gas prices, supply factors play an important role too. Perhaps, a fifth to a third was due to demand shifts and the remainder was due to supply expansions such as the faster than

expected recovery of Libyan oil production in September 2014, unaffected production of oil and gas in Iraq despite unrest, and most importantly the willingness of Saudi Arabia as the dominant member of OPEC not to offset the steadily increasing supply of oil from other OPEC and non-OPEC producers (Arezki and Blanchard, 2014).

The Saudis might have simply found it too costly to keep the world price of oil up by being the swing producer and cutting oil production when other suppliers of oil and gas are increasing their production. Others have also highlighted that the drop in oil and gas prices is to a large extent due to the rulers of Saudi Arabia no longer wanting to be the swing producer, because they have a large, young and rapidly growing population that need to be given handouts to avoid mutiny in the Kingdom and because they use limit pricing, got rid of their output ceiling to keep out competitive energy suppliers and have plenty of spare capacity (e.g., Fattouh and Sen, 2015). But oil exporters such as Venezuela, Russia, Brazil and Saudi Arabia also need to balance their budgets and keep supply up even when oil and gas prices are falling. Nigeria is also facing bleak prospects. The problems in Russia are exacerbated, since it faces sanctions from the West. It seems likely that this change in policy by Saudi Arabia has triggered a shift in the market's expectations about future oil supply. Combined with the expansion of shale gas, the switch from fossil fuel to renewable energy and new low-carbon technologies, it is clear that Hubbert's peak-oil hypothesis must be buried and that low oil and gas prices will be with us for a long time to come (Helm, 2015). The old idea that oil and gas prices will revert back to higher levels is rapidly losing ground, so there is a real possibility that the world has to get used to prolonged low oil prices at say 30 or 40 dollars per barrel. It is true that China has decided in December 2015 to suspend refined product (gasoline and diesel) prices as the price of crude oil continued to tumble. This may give a signal to OPEC from its largest customer, but it is unclear that will stop the price of crude oil falling.

The sustained drop in world oil and gas prices creates havoc in terms of budget deficits and falling foreign reserves for those countries that depend for their welfare on the sale of oil and gas on the global oil market. The fiscal break-even oil prices, i.e., the prices at which governments balance their budgets, are often high: 54 dollar per barrel for Kuwait to 60 dollar for Venezuela, 106 dollar for Saudi Arabia 184 dollar for Libya (Arezki and Blanchard, 2014). At current oil and gas prices it is not surprising that many oil and gas producers are suffering high budget deficits. The fiscal tightening that is required to balance the books will throw their economies into recession. Much of the sale of oil and especially gas is managed via long-term contracts well into the next decade. This means that the adverse shocks to oil- and gas-producing countries resulting from a sustained fall in world oil and gas prices may not be

immediately fully felt and will have much stronger impact in the longer run. That is bad news too for oil and gas producers.

V. THREAT: GLOBAL WARMING AND STRANDED ASSETS

The second threat to oil- and gas-producing countries is the biggest externality facing our planet: global warming and stranded assets. At the recent COP21 United Nations Climate Change Conference politicians finally promised to take action to price carbon emissions and take other steps to curb the maximum global warming to 2 degrees Celsius and possibly even to 1.5 degrees Celsius. These are just promises that are not legally binding and given that three decades of climate negotiations have not led to any significant results (e.g., Helm, 2012), perhaps not too much should be expected. However, unexpected climate catastrophes might spur politicians around the globe to come more quickly into action in an effective fashion. Pricing carbon is the royal way to slash fossil fuel (especially coal) demand, encourage quicker and more substantial use of various types of renewable energy and nuclear energy, boost R&D into green technologies, stimulate carbon capture and sequestration, and to lock up fossil fuel in the crust of the earth. Integrated assessment models of climate change and economic growth such as DICE suggest that 1, 2 or 4 degrees Celsius (relative to pre-industrial temperatures) of global warming would cost, respectively, less than 0.5 percent, 1 percent and 4 percent of global GDP. Using these models and damages, one can calculate the optimal social cost of carbon (i.e., the present discounted value of all future marginal damages to output caused by burning one tonne of carbon today) and set the price of carbon equal to that (e.g., Nordhaus, 2008, 2014). This price can be levied via a specific global carbon tax or be the outcome of a global market in tradable emission permits. If the welfare of future generations is for ethical reasons discounted less heavily (Stern, 2007) or damages are more convex and global warming affects the growth rate rather than the level of productivity of the economy (e.g., Dietz and Stern, 2015; Rezai and van der Ploeg, 2015), more aggressive climate policy has to be undertaken and carbon will need to be priced higher. Using Epstein-Zin preferences, one can show that the price of carbon has to be higher if society displays greater relative risk aversion or has less intergenerational inequality aversion (especially if trend growth is expected to be high). Furthermore, the price of carbon will have to grow roughly in line with world GDP if damages to future production of burning one additional tonne of carbon are proportional to aggregate production (e.g., Golosov et al., 2014).

The price of carbon has to be raised a lot more if one takes account of the risk of climate tipping. For example, if there is an annual risk of 5 percent of a 5 percent drop in market and

non-market goods at 4 degrees Celsius the price of carbon has to rise by a factor 3 (e.g., Cai, et al., 2015). Another study finds that the risk of tipping with sudden and irreversible impacts necessitates doubling the price of carbon (Lontzek et al., 2015). Fat-tailed risks and "unknown unknowns" also demand a higher price of carbon for prudential reasons (e.g., Wagner and Weitzman, 2015, Chapter 3). The above implies a ballpark price for emissions of say 45 to 100 dollar per tonne of carbon dioxide (corresponding to an extra 15 to 35 dollar per barrel of oil), which then has to grow at the trend rate of growth of the world economy (about 2 percent per annum). Scandinavia is one of the few countries that put a serious price on carbon, albeit with plenty of exceptions for heavy polluters. It is clear, however, that most countries including those in the rest of Europe charge a much too low price for carbon emissions.

In fact, fossil fuel is *subsidised* globally to the tune of 15 dollar per tonne of carbon dioxide (think of petrol subsidies and all the exemptions on the most polluting manufacturing industries) whilst carbon emissions should be *taxed* at least triple that amount. As long as post-tax fossil fuel subsidies (i.e., including the failure to price negative externalities such as global warming at the appropriate price) take up about 5 trillion dollars or 6.5 percent of world GDP in 2013 as calculated by Coady et al. (2015), there is no hope of reaching the global warming objectives recently agreed on in COP21. These subsidies constitute 13-18 percent of GDP in emerging and developing Asia, the Middle East, North Africa and Pakistan (MENAP) and the Common Wealth of Independent States (CIS). These figures should be treated with caution, since the current world price of oil which has fallen substantially and the study seems to allow for little pass through on price volatility, is partial equilibrium and assumes a specific and somewhat arbitrary value for the carbon price. Furthermore, these figures for fossil fuel subsidies consist to a large extent of taxes. However, Stefanski (2015) gives an indirect method of inferring distortions in fossil fuel prices from a panel of 170 countries over the period 1980-2010. He finds that they are large, increasing and often hidden and his counterfactual exercise suggests that they are responsible for 36 percent of global carbon emissions between 1980 and 2010.

The biggest subsidies are for coal, which per energy unit harms global warming most out of all fossil fuels. The current era of low oil and gas prices provides an excellent opportunity to remove fossil fuel subsidies without causing too much political upheaval. At the same time, policy makers should not allow low oil and gas prices to derail the transition to clean energy (cf., Arezki and Obstfeld, 2015). Against the background of low oil and gas prices, policy makers should thus boost the *specific* price of carbon to speed up the transition from fossil fuels to renewable energy and to offset the existing *ad valorem* levies on fossil fuel use.

One of the key aims of pricing carbon is to lock up fossil fuel and curb cumulative carbon emissions into the atmosphere and thereby put a ceiling on global warming. One can also achieve this with renewable subsidies, but these are typically more costly in terms of lost aggregate production and consumption. The alternative of geo-engineering such as shooting sulphur particles in the atmosphere mimics the 1991 volcanic explosion of Mount Pinatubo which depressed global temperature by 0.5 degrees Celsius for a few years before it was ramped up, but is at most a "planetary chemo-therapy" that (like other methods to reflect heat such as creating clouds or painting all roofs white) does not attack the root of the problem of global warming and is so cheap that it might induce climate warfare (Wagner and Weitzman, 2015, Chapters 5 and 6).

Physicists and the IPCC have therefore argued for a long time that to limit anthropogenic global warming to at most 2 degrees Celsius relative to pre-industrial temperatures with a probability of 66% requires that cumulative emissions from 2011 onwards have to stay below 1 trillion tonne of carbon dioxide or 270 billion tonnes of carbon to keep global warming below 2 degrees Celsius (e.g., Allen et al., 2009; Millar et al., 2015). This amounts to a mere 9 years of current fossil fuel use, but longer if annual fossil fuel use can be curbed. The situation is, in fact, worse as fossil fuel use is projected to rise. Renewable energy thus must displace fossil fuel in the short to medium run rather than in the longer run even when reckoning with the fact that switching from oil to less carbon-intensive gas gives a window of opportunity. To keep global warming below 1.5 degrees Celsius (the ambition of COP21) implies an even lower carbon budget and thus necessitates a quicker switch to the carbon-free era. This is why a large chunk of global fossil fuel reserves has to be locked up in order that it can never be burnt. It is unfortunately only a threat, because the commitment of COP21 members to cut fossil fuel demand by 30 to 40 percent in the next two decades is not enough to stay within these carbon budgets and it is not even clear whether countries will deliver on this.

Recent calculations based on differences in the costs of extraction and production and in carbon intensities of the various types of oil, gas and coal across the globe indicate that as much as a third of global oil reserves, half of global gas reserves and over four fifths of global coal reserves (mostly in China, Russia and the United States) should be left unburnt to ensure that global warming stays below 2 degrees Celsius (McGlade and Ekins, 2015). Table 1 indicates what is required of the various regions in the global economy. Canada should not touch any of the tar sands and the Antarctic should be left unexploited all together. In the Middle East alone 260 billion barrels of oil should be left unburnt. This study suffers from restricting the period under consideration to the year 2050 as it is based on a scientific study that related cumulative

carbon emissions during 2000-50 with the risk of global temperature rising above 2 degrees Celsius (Meinshausen, et al., 2009). What really matters to keep maximum global warming below 2 degrees Celsius is to keep cumulative carbon emissions *forever after* below 270 billion tonnes of carbon (Allen et al., 2015). Still, we expect that the basic insight that a substantial amount of oil, gas and coal reserves should be left unburnt remains valid.

Table 1: What is needed to keep below 2 degrees Celsius?

Percentage Unburnt Reserves	Oil	Gas	Coal
Middle East	38	61	99
OECD Pacific	37	56	93
Canada	74	25	75
China and India	25	63	66
Central and South America	39	53	51
Africa	21	33	85
Europe	20	11	78
United States	6	4	92

Source: McGlade and Ekins (2015)

The Climate Risk pedagogical app developed by the Paris-based Novethic (www.climate-risk.com) gives an interactive map whose five chapters allow a multi-faceted way of visualising the climate risks and the fraction of unburnable fossil fuels for each country that is required to limit global warming to a 2 degrees Celsius threshold before 2100. This app also visualises how states, investors and companies are committing to combat climate change via new regulation, new business models and new investments.

In fact, fossil fuel reserves of international companies are three times and resources are 10-11 times the carbon budget compatible with maximum 2 degrees Celsius global warming (Carbon Tracker Initiative, 2005). Hence, fossil fuel companies risk wasting up to 2.2 trillion dollars in the next decade. This would threaten investor returns in those companies by undertaking exploration and exploitation projects that would be uneconomic when governments around the globe finally manage to put policies in place that limit global warming to 2 or even 1.5 degrees Celsius and when the rapid advance in clean technologies proceeds relentlessly.

VI. THREAT: NEW TECHNOLOGIES

The third threat faced by oil- and gas-producing countries is the emergence of cheap and effective substitutes for oil and gas on the market. After all, technical innovations will render oil or gas less relevant. The last few decades have seen a revolution in the exploitation of shale gas

in the United States. Much of this is driven by technological innovations such as hydraulic fracturing and horizontal drilling. This will change the geopolitics as the United States will be shifting from being an importer of oil and gas to an exporter of fossil fuel as it starts to sell shale gas on world markets. Hence, there will be less appetite to militarily intervene in the Gulf to safeguard oil and gas supplies. Other forms of technological progress such as sub-surface platforms and sea bed extraction also drive the relentless expansion of conventional oil and gas, shale gas and other unconventional oil. These developments should be a big headache for oil- and gas-producing countries. Furthermore, oil- and gas-producing countries will face severe competition not only from the United States but also from emerging shale gas producers such as Algeria and Poland.

Another technological revolution is the possibility of cheap LNG that can be transported over land or sea without the need for expensive and inflexible pipe networks. This means that a country like Russia which is reliant on exporting its natural gas through an elaborate network of pipelines will experience new competition from LNG imported from Asia. The rise in LNG capacity for Europe is to some extent triggered by rising capacity in the United States, Canada and Australia and makes European markets less dependent on Russian gas. Furthermore, non-Russian pipeline output is expected to outpace Russian production in the near future whilst gas revenue matters a lot to Russia in an era of sustained low gas prices. Europe will continue to consume large amounts of Russian gas which is cheaper than gas from other potential European suppliers, but will benefit as it can improve its bargaining position with Russia as it becomes less reliant on pipelines and can import LNG whilst Russia has few options other than to export to Europe in the medium term.

It is not only the threat of rival cheap oil and gas coming to market, but also oil- and gas-producing countries suffer as technological innovations drive down the cost of carbon-free energy sources such as wind, solar, hydro and geothermal energy. Putting a price on carbon emissions and subsidising renewable energy and its development will spur this type of technological progress. The most rapid reductions in the cost of these alternative energy sources are for solar energy as costs fall due to learning-by-doing effects. If carbon would be priced at the optimal social cost of carbon and existing fossil fuel subsidies would be abolished, solar energy and possibly wind energy too will become competitive. Other renewable energy sources such as energy from algae might become competitive too in the future. There is even a small chance of a breakthrough technology such as fusion energy in small-scale reactors becoming economically viable in the next fifty years. All these energy sources have the advantage that at the margin they can be supplied at almost zero cost (not unlike mobile telephony and internet), but the main challenge is that many of these energy sources are intermittent and thus their

success depends on cheap and effective storage devices (batteries) attached to every wind and solar energy generator. If technological breakthroughs occur in energy storage too, then renewable energy will impose yet another existential threat to oil- and gas-producing countries.

VII. RISK OF STRANDED ASSETS

All three threat lead to the risk of fossil fuel companies and oil- and gas-producing countries run the risk of ending up with stranded assets. Let us first focus on the second threat of world leaders agreeing to credibly curb cumulative carbon emissions so that global warming does not rise about 2 degrees Celsius. From that point of view, the United States has the greatest financial exposure of $412 billion of unneeded fossil fuel projects to 2025, followed by Canada ($220 billion), China ($ 179 billion), Russia ($ 147 billion) and Australia ($103 billion). In the light of this it is not surprising that campaigns to divest from fossil fuel are gaining traction globally. Some of the biggest pension funds in the world (e.g., GPGF in Norway and ABP in the Netherlands) are already moving in this direction, and other investors may follow suit. Institutional investors who do not hedge against the risk of a tightening of climate policy face severe risks of a drop in the value of their portfolio.

Thankfully, it turns out that one can design dynamic investment strategies that allow long-term investors to hedge long-term climate risk without sacrificing financial returns (Andersson, et al., 2014). Such a strategy consists of, on the one hand, divestment away from high carbon footprint or stranded-assets stocks, and, on the other hand, optimisation of the composition of the low-carbon portfolio so as to minimise the tracking error with the reference benchmark index. Indeed, the low-carbon indices that have been constructed in this way have already matched or outperformed their benchmark. The beauty is that on the day that carbon emissions are properly priced, these low-carbon indices will outperform the benchmark.

One of the most foremost risk and asset managers has stated that "it's very possible that fear of catastrophic outcomes will lead to rational global pricing of emissions much sooner than the market has built into current prices of stranded assets" (Litterman, 2013). The market may simply not realise that the slow policy ramp for pricing carbon on which the world seems to be on due to all kind of national and international political obstacles is irrational as it does not take catastrophic or fat-tailed risk into account. Once the correction comes and most likely much sooner than markets expect, the price of carbon will jump up and then fall over time as uncertainty is resolved and the problem of global warming becomes less severe as a result of fat-tailed risk necessitating a negative rate of discount. This is the prime reason why financial markets should be worried about stranded assets and should short assets such as tar sands or

coal and a have a total return swap strategy to hedge against stranded assets in the portfolio without otherwise disturbing the portfolio.

But the other two threats of decades of low oil and gas prices and a rapid pace of cheap substitutes coming to market clearly also contribute to the risk of stranded assets. In fact, all of them depress the price oil and gas producers can fetch for their products. The main reason for Shell stopping exploration in the Arctic was not the risk of a seriously high carbon price being charged or cheap solar or fusion energy coming to market, but the depressing reality of low oil and gas prices rendering Arctic oil reserves uneconomical. Similarly, many shale gas producers in the United States have found it uneconomical to continue. This suggests that the sustained fall in the oil price might well lead to stranded assets and a downward revaluation of fossil fuel companies well before carbon is properly priced and or alternatives to oil and gas have become cheap enough (cf., Helm, 2015).

VIII. OIL AND GAS CURSE IN REVERSE?

The natural resource wealth that has been bestowed in past decades has alas not always led to good fortune. Countries that have had a large GDP share of oil and gas exports have had poor growth performance compared to countries without oil or gas. This natural resource curse has been most severe for countries that have bad institutions, poor financial development and lots of different ethnic factions. It is not only the share of oil and gas exports but also the notorious volatility of oil and gas prices that has hurt growth and development. Oil- and gas-rich countries have also been more prone to conflict and wars and to rent seeking and corruption.

Many countries have thus in the past not made the most of their natural resource discoveries and have been bad at transforming below-ground natural resource wealth into above-ground financial, physical or human wealth. Natural resource discoveries and past hikes in oil and gas prices should have provided excellent opportunities to provide for a rainy day, but many oil- and gas-rich countries have been unable to harness these windfalls for growth and development. These countries have suffered from Dutch disease, excessive specialisation and an excessive reliance on natural resource income (e.g., Michaels, 2011). As a result, manufacturing industries in those countries, which often were hardly there in the first place, has dwindled as the currency appreciates in real terms and countries have missed out on years of learning by doing in manufacturing. Services have increased during the past few decades in those countries, but it is hard to transform the boom in services and other non-traded sectors into sectors that deliver lasting growth and development for the future.

Although oil- and gas-producing countries have typically not invested enough and missed out on growth prospects, they often have consumed an excessive proportion of their natural resource wealth. Current generations of citizens have thus benefited from higher consumption, but at the expense of future generations. If current generations are much poorer than rich generations, this is not necessarily bad (e.g., van der Ploeg and Venables, 2012). However, some countries that have experienced the biggest natural resource windfalls have used this revenue to give handouts to their people to prevent rebellion or increase the chances of clinging on to power and staying in office. Not enough of the newly found oil and gas wealth has been put in a sovereign wealth fund that invests its assets abroad in a fully diversified portfolio with Norway being an exception or has been used to invest in a strong diversified domestic economy and to boost consumption of current generations when access to international capital markets is restricted and investment is sub-optimally low. A good principle is to follow the Hartwick (1977) rule. This demands that any depletion of below-ground oil and gas wealth must be transformed into above-ground financial, human or other wealth. Unfortunately, this is seldom done and as a result many oil- and gas-rich countries have squandered their natural resource wealth and have no precautionary saving funds to dip into when times are bad.

The big question is how countries will respond as the oil and gas curse goes in reverse as a result of the three pending threats outlined above: a collapse of oil and gas revenue driven by a prolonged fall in world oil and gas prices and the resulting drying up of oil and gas exploration and extraction; a gradual tightening of climate policy; and technological innovations bringing good substitutes for conventional oil and gas to market. One answer to this question is to be fairly relaxed and not worry about the adverse consequences of oil and gas discoveries and oil and gas price hikes. According to this optimistic view, the real appreciation associated with Dutch disease will turn into a real depreciation of the exchange rate and a boost to manufacturing and other traded sectors. There will be less infighting and corruption, so that a transparent and less dishonest political system might emerge. And there will be less armed conflicts.

This view is much too optimistic as damages in terms of less learning by doing and depressed growth resulting from the large oil and gas windfalls in the past have already been incurred. Furthermore, fossil fuel will still be used in the decades to come but most probably at much lower prices. Oil- and gas-producing countries such as Nigeria, Brazil, Venezuela and Russia are already suffering severe turmoil and economic distress caused by sharp depreciations of their exchange rates, high inflation rates and big budget deficits. Some of these countries are heading towards bankruptcy. Because these countries did not develop a plan B for the eventuality that their oil- and gas windfalls would dry up and their economies have become very

specialised, they are not well prepared for a future with a sharp reduction in oil and gas revenue. Furthermore, they failed to build a big sovereign wealth fund when oil and gas prices were high and thus have no buffer to dip into when prices are low. In the longer run, they have no other option than to invest in sound institutions, human capital, flexible product and labour markets, and a reliable economic infrastructure in order to obtain an economy which can develop and grow without relying on oil and gas revenue.

IX. DANGER OF RAPACIOUS OIL AND GAS DEPLETION

Global warming poses an existential risk for oil- and gas-producing countries (i.e., the second threat). But badly designed climate policies can be counter-productive. For example, politicians that postpone carbon taxation for fear of electoral consequences bring fossil fuel consumption forward and thus accelerate global warming (Sinn, 2008). Similarly, if politicians believe that the electorate prefers the carrot to the stick, they might use high renewable energy subsidies as a second-best policy to compensate for the political infeasibility of pricing carbon (witness the high subsidies for solar energies in German electricity generation). In that case, fossil fuel producers also accelerate extraction of fossil fuel and thereby accelerate global warming. These adverse effects on short-run carbon emissions underpin the Green Paradox (e.g., Sinn 2008). Furthermore, these adverse effects that result from rapacious depletion of oil and gas reserves occur also if fossil fuel producers fear rapid future technical innovations and the coming to market of cheap and effective alternatives for oil and gas driven by rapid technological innovations (the third threat).

This analysis only tells part of the story as it starts from the common premise that total oil and gas reserves are fixed and all reserves must be depleted. This ignores the fact that in the real world the optimal amount of explored oil and gas reserves themselves respond positively to the world price of oil and gas and negatively to the price of substitutes such as shale gas and renewable energy. This is clearly an unsatisfactory premise as it implies that the total cumulative carbon budget and maximum global warming are mechanically given by existing oil and gas reserves too. But climate policy should attack two margins: how fast to extract a given stock of fossil fuel reserves, and how much fossil fuel to lock up in the earth and thus how much carbon to emit in total into the atmosphere. One way to model these two margins is to have oil and gas extraction costs rise as reserves diminish and less accessible reserves have to be explored or more generally to allow for endogenous discoveries. In that case, postponing carbon taxation or renewable energy subsidies induce, on the one hand, rapacious depletion of oil and gas and thus accelerated global warming, and, on the other hand, a cut in the total amount of

fossil fuel that is burnt and thus in cumulative fossil fuel emissions (e.g., van der Ploeg and Withagen, 2012). Oil and gas have higher scarcity rents that are under greater threat from further technical progress and gradual tightening of climate policy than those of more abundant coal, so this acceleration of global warming is particularly strong for oil and gas.

Whether there is a *strong* Green Paradox in the sense that the welfare costs of an increase in carbon emissions in the short run - the *weak* Green Paradox - outweigh the welfare gains from having locked up a greater proportion of fossil fuel reserves and thus limiting cumulative carbon emissions crucially depends on the price elasticities of oil and gas demand versus those of fossil fuel reserves. If reserves are more responsive to oil and gas prices than demand as is more likely in the longer than in the shorter term and the social rate of discount is small enough as argued by the Stern Review on ethical grounds (Stern, 2007), postponing carbon taxation or subsidising renewable energy as a second-best strategy boosts global welfare (i.e., private welfare minus the damages from global warming) despite some adverse weak Green Paradox effects in the short run (van der Ploeg, 2015). Even if this condition is not met, oil and gas importers can *unilaterally* raise carbon taxes and thereby steal part of the scarcity rents of oil and gas producers and boost their own welfare at their expense. It is then also optimal to levy an asset holding tax on oil and gas producers to avoid aggressive depletion of their reserves. These second-best climate policies effectively put oil and gas producers out of business. The first-best climate policy is to price carbon at a price equal to the social cost of carbon (the present discounted value of marginal damages to production from burning one extra tonne of carbon) and also puts oil and gas producers out of business, but does not have the unpleasant side effects caused by the weak Green Paradox.

Second-best climate policies such as postponing carbon taxation or renewable subsidies and technological progress in renewable energies carry the danger of a *vicious spiral*: faster pumping of oil and gas and acceleration of global warming induce policy makers to intensify their climate policy and to the extent that they remain second best they will cause further acceleration of global warming. This inherent instability is akin to the problem of mutually assured destruction in warfare, where the countries concerned fear that being the second to fire will not be possible, as the first to fire will destroy all they have.

Rapacious depletion of oil and gas reserves caused by unintentionally badly designed climate policies and the anticipation of cheap carbon-free alternatives to fossil fuel coming to the market will accelerate global warming. This should incentivise politicians throughout the world to move away from a too slow policy ramp and have more immediate climate action by bringing forward the pricing carbon (via taxes or a permit system), but this seems unlikely as politicians

have not even got rid of the huge fossil fuel subsidies let alone priced carbon appropriately. From the point of view of oil and gas producers, it makes sense to speed up the rate of extraction of oil and gas reserves as they face the threat of being put out of business. But this on its own is a short-term strategy to finance exploding deficits and does nothing to improve growth and development prospects. Their priority should be to make their economies less reliant on the production and export of oil and gas.

If fossil fuel is abundant, near zero-cost renewable energy alternatives are rapidly coming to market and old fossil fuel technologies in transport and electricity generation are being phased out, the prices oil and gas producers can fetch for their produce will be pushed downwards. In that case, the global economy may well enjoy falling oil and gas prices for some time to come as it then makes sense for oil and gas producers to pump even more quickly in which case the prediction of falling oil and gas prices will be self-fulfilling (cf. Helm, 2015).

X. CONCLUSION

We end with a pessimistic note on the plight of oil- and gas-producing countries. They suffer three existential threats: a sustained period of low oil and gas prices, tightening of climate policy leading to a much lower amount of carbon that can be burnt in the next two or three decades before the world economy finally switches to carbon-free renewable energy, and a fast pace of technological innovation bringing cheap shale gas and cheap carbon-free substitutes such as solar energy and possibly in the future fusion energy to the market. Many of these countries have mismanaged their oil and gas windfalls in the past. And now these countries are suffering from high inflation, high budget deficits, dwindling foreign reserves at the central bank, rapidly depreciating currencies, and unhappy citizens who have their expectations squashed. The anticipation of cheap alternatives to oil and gas coming to market and the need to finance rising budget deficits in the face of falling world prices for oil and gas forces these countries to pump the oil and gas more vigorously out of the ground whilst the going is good and these threats have not materialised fully yet (the Green Paradox effect). This policy reaction is understandable, but rapacious depletion of oil and gas reserves only combats the symptoms of the problem and frustrates global attempts to stop the planet getting heated up.

Unfortunately, due to years of not benefiting from learning-by-doing and agglomeration effects these countries find themselves in a worse position than before their oil and gas windfalls and before the crash in oil and gas prices. This is typically exacerbated by oil and gas activities being located in geographical and economic enclaves from where it is difficult to start a path of sustained growth. Norway has put its oil and gas revenue in an independent sovereign wealth

fund and now has substantial buffers to weather the storm whilst oil and gas prices remain low. Furthermore, the Norwegian fund is sensibly now divesting away from fossil fuel to be less vulnerable to the risk of stranded assets. As a result of Norway's savings policy, consumption is smoothed and thus the real exchange rate is smoothed too. This and the dirty float of the Norwegian Krone meant that it has depreciated much less than the currencies of other oil- and gas-producing countries who failed to save their windfalls just as the Krone did not appreciate much during the last hike of oil and gas prices as the monetary authorities were selling the Krone to prevent this happening. Furthermore, Norway's inflation rate is a modest 2 percent per year and its public finance are not in disarray despite the sustained fall in oil and gas prices and Norway being a high-cost economy for visitors and Norwegians alike.

Most oil- and gas-producing countries have never satisfactorily answered the question of how they will earn their income when oil and gas reserves run out and have failed to invest their windfalls in either a substantial sovereign wealth fund or a strong and diversified economy. This is why they are ill prepared to deal with the perfect storm of these three existential threats and the consequent catastrophic drop in demand for their oil and gas. There is simply no solid industrial or other base to make up for the loss of oil and gas income and it is unclear how and if they will generate sufficient income to keep the welfare up for future generations. The real challenge for these countries is thus to make themselves less vulnerable and less reliant on their windfalls by transitioning away from their over-dependence on oil and gas and excessive specialisation of their economies. This requires developing an industrial strategy, trustworthy institutions and flexible product and labour markets that lead to long-run growth and development. That is very tough.

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