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The geopolitical impact of the shale revolution: Exploring consequences on energy prices and rentier states

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HIGHLIGHTS

- We quantitatively explore geopolitical consequences of the shale gas revolution.
- We use a multi-model approach to generate and use energy price scenarios.
- Simulations show that current low oil prices could be part of a hog cycle.
- The shale gas boom was an early warning for the drop in oil prices.
- Low prices due to shale gas can reduce internal stability in rentier states.

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ABSTRACT

While the shale revolution was largely a US' affair, it affects the global energy system. In this paper, we look at the effects of this spectacular increase in natural gas, and oil, extraction capacity can have on the mix of primary energy sources, on energy prices, and through that on internal political stability of rentier states. We use two exploratory simulation models to investigate the consequences of the combination of both complexity and uncertainty in relation to the global energy system and state stability. Our simulations show that shale developments could be seen as part of a long term hog-cycle, with a short term drop in oil prices if unconventional supply substitutes demand for oil. These lower oil prices may lead to instability in rentier states neighbouring the EU, especially when dependence on oil and gas income is high, youth bulges are present, or buffers like sovereign wealth funds are too limited to bridge the negative economic effects of temporary low oil prices.

1. Introduction

In recent years, a spectacular rise in natural gas extraction capacity from unconventional resources has dramatically changed the US' energy landscape, turning the country into a natural gas exporter. This development is often referred to as the 'shale gas revolution' and was made possible by the process of hydraulic fracturing, or 'fracking'. As a consequence of the shale gas revolution, US' gas prices have dropped significantly, giving a competitive advantage to the US' industry. The spectacular rise in extraction of shale oil resources only adds to that advantage.

The shale revolution was thus far largely an US' affair, as outside of Northern America hardly any commercial exploitation of shale resources took place. This can be primarily explained by institutional differences between the US and other countries (Kuuskraa et al., 2013; Tian et al., 2014), as significant technically recoverable shale resources can be found outside of North America (Kuuskraa et al., 2013). Notwithstanding the fact that the shale revolution has not spread across the world (Melikoglu, 2014), the large-scale extraction of shale deposits has affected the global energy system through LNG trading, which is still a minor part of global natural gas trade (BP, 2015), and through substitution of other, easier transportable primary energy sources. The impact of the shale revolution on global energy markets is the starting point of this research.

Research regarding the impact of the shale revolution mainly focussed on direct extraction effects like the effects of shale gas

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drilling on the environment (e.g., Baranzelli et al., 2015; Jenner and Lamadrid, 2013; Kargbo et al., 2010; Meng and Ashby, 2014; Olmstead et al., 2013), the public support for shale gas and fracking (e.g., Boudet et al., 2014; Jaspal et al., 2014; Perry, 2012), and the impact on the local economy (e.g., Asche et al., 2012; Kinnaman, 2011; Lee, 2015). In some research, the economic impact was related to energy security (e.g., Jaspal et al., 2014; Richter and Holz, 2015; Victor et al., 2014). Others studied the impact of shale gas exploration on energy prices, mainly for oil and gas (e.g., Asche et al., 2012; De Silva et al., 2016). Asche et al. (2012) acknowledged that it would be interesting to look at the interplay with coal, another primary energy source, which we do in this paper. However, to the best of our knowledge, more indirect consequences of the shale revolution have not been investigated.

One of these potential indirect effects is the impact of the shale revolution on intra-state stability of major oil and gas exporting countries, also referred to as 'rentier states' (Mahdavy, 1970), through changing oil and gas prices. Price fluctuations may have consequences for the financial-economic stability of rentier states due to the dependence on 'resource rents' (World Bank, 2011) for supporting the economy and government spending. That is, fluctuations in resource prices may influence the development of the local economies in oil and gas exporting countries. In turn, worsening economic conditions are known to have an impact on population discontent, potentially leading to intra-state instability (Collier and Hoeffler, 2004; Ross, 2004). Similar indirect effects may occur due to structural changes in the global energy system induced by climate mitigation policies. However, these effects are complex and uncertain.

Both the global energy system and the relation between resource income and instability are highly complex and deeply uncertain. Feedback effects add to dynamic complexity (Sterman, 2000). An example of a feedback effect in the global energy system is the interaction between supply and demand which results in resource price dynamics. On a country scale, decreasing resource prices may lead to increasing unemployment and a reduction of purchasing power, which may cause frustration among the population and reduce internal stability. This feedback loop is closed if state instability in turn affects resource extraction. Both the global system and national systems are also characterised by 'deep uncertainty' (Lempert et al., 2003). Situations are deeply uncertain if they are characterised by important presently irreducible uncertainties related to how issues could or should be modelled, likelihoods of inputs and outcomes, and the desirability of outcomes. To give examples: on a global scale, the strength of the feedback effect between prices and demand is deeply uncertain, while on a national scale, the influence of population discontent on a country's polity is also deeply uncertain.

Complexity and uncertainty impede mental simulation of both the global energy system and state stability (Sterman, 1994). Quantitative simulation may enable one to deal with these issues though. Since the 1950s, modelling and simulation approaches have been developed and used to support policy-makers and decision-makers addressing complex issues. Since the early 1990s (Bankes, 1993), model-based methodologies and techniques have been developed to simulate sets of models under deep uncertainty.

In this paper, we use simulation models to explore the indirect consequences of the shale revolution on the global energy system and rentier state stability. For this purpose, we apply a 'systems-of-systems' (DeLaurentis and Callaway, 2004) multi-model approach for dealing with complexity and uncertainty. We use a global energy-mix model for supply, demand, and trade of, and substitution between six primary energy sources to generate oil and gas price scenarios. In these scenarios, the focus lies on price scenarios that fall outside the scope of more traditional forecasts of energy prices using a base-case (e.g., IEA, 2012). These scenarios are subsequently used as input for a country-stability model, focussing on economic discontent (i.e., 'greed' in Collier and Hoeffler, 2004). As such, the price scenarios are used for stress testing rentier state country stability, more specific those in the vicinity of the European Union (EU). These countries are Algeria, Azerbaijan, Kazakhstan, Qatar, Russia, and Saudi Arabia.

The setup of this paper is as follows. In Section 2, we explain the use of Exploratory Modelling and System Dynamics in this study, the model structures of the energy-mix model and the country-stability model, and the metrics for choosing 14 price scenarios. Based on these scenarios, we present the results on country stability by taking Algeria and Russia as examples in Section 3. Finally, we discuss the results of this approach in Section 4, and draw conclusions regarding the geopolitical consequences of the shale revolution in Section 5.

2. Methods

In this research, we use an exploratory modelling scenario approach. First, we simulate and investigate the consequences of the shale revolution to generate global oil and regional gas price scenarios. Second, a subset of these price scenarios is used to stress-test intra-stability of rentier states in the vicinity of Europe. In this section, we introduce this model-based scenario approach (Section 2.1), as well as the modelling and simulation method (Section 2.2), and the two models used in this research (Section 2.3). At the end of this section we explain the research setup in more detail (Section 2.4).

2.1. Exploratory Modelling

'Exploratory Modelling' is a research methodology that uses computational experiments to analyse deeply uncertain issues (Bankes, 1993; Bankes et al., 2013; Kwakkel and Pruyt, 2013; Lempert et al., 2003). It consists of a set of the development of plausible quantitative simulation models and associated uncertainties, the process of exploiting the information contained in such a set through a large number of computational experiments, the analysis of the results of these experiments, and the testing of promising policies for policy robustness (Bankes, 1993).

In exploratory modelling, models are used to generate a wide variety of what-if scenarios, which is an important use case of simulation models (Oreskes et al., 1994). These what-if scenarios are usually generated such that they comprehensively cover presently irreducible uncertainties. Exploratory modelling, therefore, does not focus on generating a base case, but instead on generating a bandwidth of plausible futures, including the circumstances (i.e., ranges of specific uncertainties) for which these occur.

2.2. System Dynamics

System Dynamics (SD) is a modelling and simulation method to describe, model, simulate, and analyse dynamically complex issues or systems (Forrester, 1961; Pruyt, 2013; Sterman, 2000). The SD approach was first proposed and developed by Jay W. Forrester in the late 1950s. SD aims to provide a holistic and systemic view of an issue under study and its interconnections to its environment, and simulate and analyse the resulting system dynamics over time. More specifically, SD is a method for modelling and simulating dynamically complex systems or issues characterised by feedback and accumulation effects (Sterman, 2000).

Together, feedback and accumulation effects generate dynamically complex behaviour both inside SD models, and, so it is assumed by System Dynamicists, in real systems (Pruyt, 2015).

Using SD models can, therefore, be useful for dealing with complex systems characterised by important feedback and accumulation effects. SD modelling is mostly used to model core system structures or core structures underlying issues, to simulate their resulting behaviour, and to study the link between the underlying causal structure of issues and models and the resulting behaviour. SD models, which are mostly relatively small and manageable, can be used for experimental or exploratory purposes too.

There are many SD models regarding energy systems. Well-known examples are the Limits to Growth studies (Meadows et al., 1972), studies regarding national energy transitions (Naill, 1977, 1992; Sterman, 1981), power plant construction and electricity generation (Ford, 1999), and externalities of energy economics (Fiddaman, 1997), but there are also more recent examples (e.g., Chyong Chi et al., 2009; Osorio and van Ackere, 2016). In two cases this included the use of SD for exploratory modelling and the design of robust policies (Eker and van Daalen, 2015; Hamarat et al., 2013, 2014). While Hosseini and Shakouri (2016) used oil price scenarios as input to an SD model, to our knowledge there are no SD studies beyond our line of research in which energy models are used to generate scenarios related to energy price developments.

There are also SD models regarding social unrest. For example, Wils et al. (1998) presented a model to simulate and assess the development of internal and external pressure related to resource use. Further, Anderson (2011) used an SD model for looking at the effects of counterinsurgency policy in relation to public support and other factors. Finally, Pruyt and Kwakkel (2014) simultaneously used three SD models to simulate the rise of activism, extremism, and terrorism. In none of these models, however, external price scenarios were used for ‘stress testing’ state stability.

2.3. Model descriptions

In this research, we use two SD models. Scenarios developed with the first model provide input for the second model (Fig. 1). We now discuss these models on a high level of aggregation. A more elaborate description of an earlier version of these models can be found in Auping et al. (2014). Both models were extensively verified and validated by means of partial model tests, unit checks, sessions with experts and stakeholders, and extreme value tests. In order to assess the effects of long delays in the system, such as developments in extraction capacity in the energy-mix model or demographic effects in the country-stability model, we simulated both models for the time period between 2010 and 2050.

2.3.1. The energy-mix model

The energy-mix model is subdivided in 5 sub-models, which are interlinked (Fig. 2). We look at the demand development, supply development, prices of the different primary energy sources, costs development of the supply, and trade between the different regions. We included six primary energy sources (i.e., oil, natural gas, coal, nuclear, biofuels, and other renewables), in line with the definitions provided by the EIA (2015). The development of demand, supply, and prices of the six energy sources are important given the feedback effects connecting supply and demand through prices. The extraction costs sub-model is important for simulating the effects of depletion on extraction costs and the development of the costs of renewables. Finally, as a greater availability of natural gas may lead to a larger share of LNG entering global markets, it is important to consider trade between the different regions of the tradable resources, in this case gas (LNG), oil, coal, and biofuels. Trade of the two remaining primary energy sources (i.e., nuclear and other renewables) is thus not considered here.

In the model, 4 different regions are defined: Northern America (i.e., US and Canada), Europe and adjacent regions (i.e., Europe, non-European CIS, Middle East, and North Africa), the Far East (i.e., China, India, Japan, and South Korea), and the rest of the world. The first two regions are grouped bearing the availability of overland gas pipelines in mind. The Far East, which is presently a major user of LNG (BP, 2015), is included as a separate region given the fact that pipeline infrastructure to other regions is very limited. The effects of political instability on energy supply are not considered in the energy-mix model. Furthermore, policy measures aimed at changing the composition of the energy mix are considered only as a driver for the development of renewable energy capacity.

2.3.2. Country-stability model

The country-stability model also consists of 5 interlinked sub-models (Fig. 3). These sub-models group variables related to the development of resources, the economy, the population, national institutions, and instability. In this resources sub-model, the development of the extraction of oil and gas is a function of endogenous cost developments and exogenous energy price scenarios generated with the energy-mix model. The economy is influenced by resource income (i.e., resource prices times resource extraction capacities), an exogenous economic growth factor constant over the run time, and endogenous negative economic effects of political instability. The economic sub-model also contains modules for the available workforce and work, and for purchasing power. When the amount of work available is lower than the workforce, the rest of the workforce is unemployed. In this way, male youth unemployment can be calculated, which is a well-known factor causing frustration and internal instability (Cincotta et al., 2003; Urdal, 2006).

The population sub-model contains an endogenous population development structure within which fertility and mortality are a function of GDP per capita, and the population aging chain is subdivided in 5-year cohorts. Next to the population composition, we calculate the education level of the population both for the average population and the young population. We assume that rising education levels increase the democratic expectations of the population, although we treat the exact relation between education and polity expectations as deeply uncertain.

In the institutions sub-model, we take the government type into account following the ‘Polity IV’ scoring system (Marshall et al., 2014). In the Polity IV score, countries' polities are measured between −10 (i.e., fully autocratic) and +10 (i.e., fully democratic). Statistical analysis shows that autocracies are five times as stable as countries with a polity score of 0, and that democracies are 10 times as stable as countries with a polity score of 0 (i.e., partial democracies or anocracies) (Marshall et al., 2014). In our model, the government type follows the expectations of the population relative to the average educational level when internal tension is

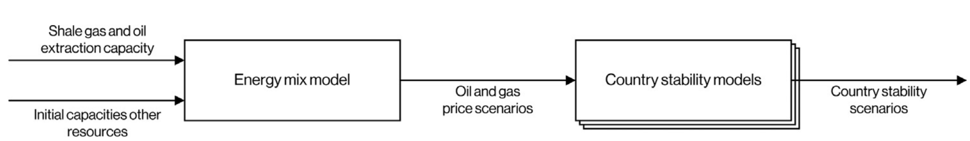

Fig. 1. Research design for this study, containing two SD models. The country-stability model is parametrised for six different countries. Model parameterisations also includes other uncertainties besides the inputs shown in this figure.

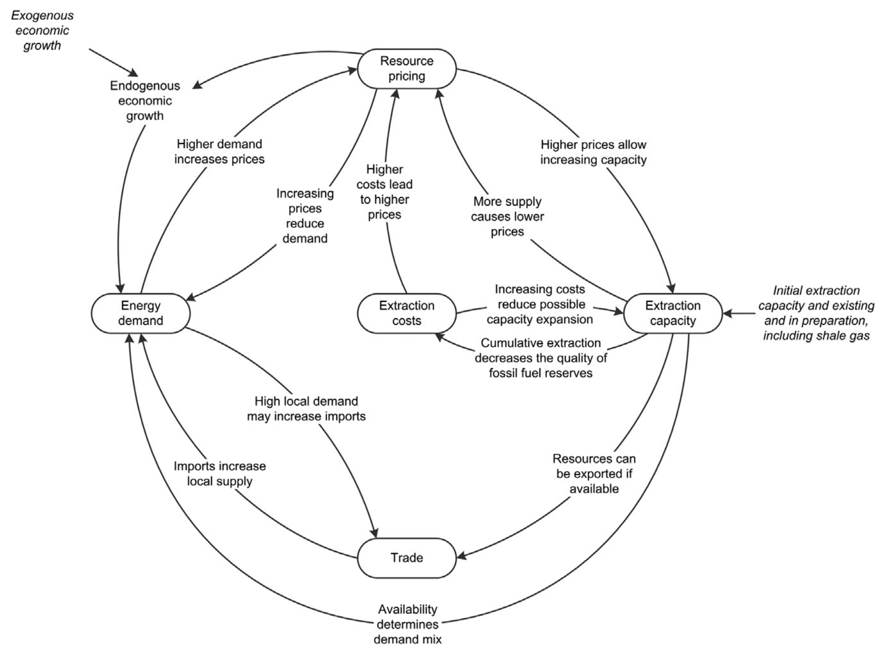

Fig. 2. Sub-system diagram (Morecroft, 1982; Sterman, 2000) of the energy-mix model. Sub-models are displayed in a rounded box. Important initial conditions are shown in *italics.*

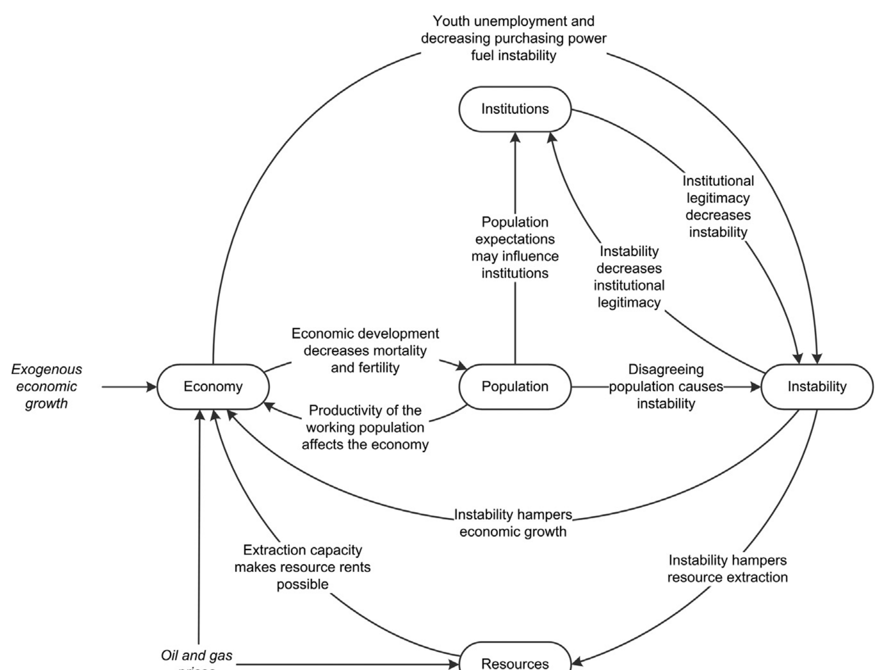

Fig. 3. Sub-system diagram of the country-stability model. Sub-models are displayed in a rounded box. External trends and important initial conditions are shown in *italics*.

low, and becomes more autocratic when tension is high. The institutions sub-model further captures government legitimacy as function of absence of violence, and government financial reserves and expenditure. If financial expenditure is too high, and government debt becomes untenable, existing food and fuel subsidies are cut. On the other hand, if there is abundant income, sovereign wealth funds (Sovereign Wealth Fund Institute, 2013) may be developed, which increase the resilience of the nation by acting as a buffer for temporarily lower resource income.

Finally, the instability sub-model contains an ageing chain to capture the level of frustration of citizens (i.e., those who support the government, non-activist opposition, activist opposition, and extremist opposition) in line with other SD models on instability and terrorism (Anderson, 2011; Pruyt and Kwakkel, 2014; Sterman, 2000). Origins of frustration are, in this model, economic in nature (e.g., unemployment, especially male youth unemployment, and purchasing power). This corresponds with the 'greed' aspect of state instability (Collier and Hoeffler, 2004). The size of the security forces works as balancing factor for civil frustration and instability. The ratio between the strength of the security forces and the extremist cohort of the population is used as proxy for the level of political unrest.

2.4. Research setup

First, we generated 1000 runs with the energy-mix model. The

Table 1
Data for the year 2010 for resource turn-over, government type, youth unemployment, and the size of the sovereign wealth funds for the seven rentier states studied. These data functioned as initial conditions in the country-stability model.

Country	Oil and gas income (% of GDP)[a]	Polity IV score[b]	Unemployment, youth male (% of male labor force ages 15-24)[c]	Sovereign wealth fund (% of GDP)[d]
Algeria	45	2	19.1	47
Azerbaijan	63	−7	17.0	67
Kazakhstan	37	−6	4.8	48
Qatar	40	−10	11.0	90
Russia	29	4	16.9	11
Saudi Arabia	67	−10	23.6	160

[a] Author's own calculations: defined here as (resource prices [\$/bbtu] × resource extraction capacity [bbtu/year])/GDP [\$/year].
[b] Marshall et al. (2016).
[c] World Bank (2016).
[d] Sovereign Wealth Fund Institute (2013).

model was integrated with the Runge-Kutta 4 numerical integration method with automatically adjusted step size. Sampling of the 118 uncertainties happened with Latin Hypercube (LH) sampling (McKay et al., 1979), assuring that each run covers a different part of the total uncertainty space. While 1000 runs may seem rather limited given the large number of uncertainties, it proved sufficient for the goal of this research, which was to generate a limited number of sufficiently different energy price scenarios, and not to exhaustively explore the complete behavioural space of the energy-mix model.

We selected eight scenarios representing plausible, yet extreme, situations in terms of the energy mix from the 1000 runs. Each scenario represents an internally consistent, plausible future for how energy mix, absolute and relative regional demand shares, and energy prices may evolve between 2010 and 2050. The selection criteria for these scenarios (Table 2) were chosen to maximise the bandwidth of potential significant demand fluctuations, leading to a relatively broad selection of price scenarios. To extend this bandwidth further, we also included the 3 scenarios with the most volatile oil price dynamics.

Second, 100 separate cases created with the country-stability model with the same integration method as used for the energy-mix model. These cases were parametrised using LH sampling for 60 general and 13 country specific uncertainties. A selection of important country specific uncertainties can be found in Table 1. Again, the number of runs may seem limited given the number of uncertainties. It proved sufficient, however, for the goal of this part of the research, which was to look at the impact of different energy price scenarios across potential development paths of rentier states. Finally, for each of the 100 cases, we tested the effects of the oil and gas prices represented by the eight scenarios, together with two dynamic price scenarios representing a moderately decreasing and increasing oil and gas price, and a reference scenario representing a constant oil and gas price. Therefore, in total 1100 runs were performed per country.

Mathematically, this research setup can be described with E as the ensemble of cases generated with energy-mix model f, and with F_c as the ensemble of cases generated with country-stability model g for country c:

$$E_{KPI} = \left[f_{1,KPI}(\vec{x}_1, t) \ \dots \ f_{1000,KPI}(\vec{x}_{1000}, t) \right], \tag{1}$$

$$F_{c,KPI} = \begin{bmatrix} g_{1,s_1,c,KPI}(\vec{y}_1, t) & \dots & g_{100,s_1,c,KPI}(\vec{y}_{100}, t) \\ \vdots & \ddots & \vdots \\ g_{1,s_{11},c,KPI}(\vec{y}_1, t) & \dots & g_{100,s_{11},c,KPI}(\vec{y}_{100}, t) \end{bmatrix}, \tag{2}$$

where the number of elements in E_{KPI} is 1000, $f_{i,KPI}(\vec{v}_i, t)$ is the function describing outcome KPI in model parameterisation $\vec{x}_i$ for model run index i, and $t \in [2010, 2050]$ with time step $\Delta t = 0.25$. For the country-stability model, the number of elements in $F_{c,KPI}$ is 100 runs for 11 different oil and gas price scenarios $(s_1, \dots, s_{11})$. The model parameterisations are LH samples of the uncertainty space U_f of the energy-mix model, and uncertainty space U_g of the country-stability model:

$$\mathrm{LH}_{1000}(U_f) = \left[\vec{x}_1 \ \dots \ \vec{x}_{1000} \right], \tag{3}$$

$$\mathrm{LH}_{100}(U_g) = \left[\vec{y}_1 \ \dots \ \vec{y}_{100} \right]. \tag{4}$$

The volatility of a run v_i is determined here as part of all runs' volatilities V:

$$V = \left[v_1 \ \dots \ v_{1000} \right] = \left[L_1 \cdot mcr_1 \ \dots \ L_{1000} \cdot mcr_{1000} \right] \tag{5}$$

where the length L_i and the mean crossing rate mcr_i of a curve describing the oil price behaviour are:

$$L_i = \sum_{t=2010}^{2050-\Delta t} \left| f_{i,Oilprice}(\vec{x}_i, t+\Delta t) - f_{i,Oilprice}(\vec{x}_i, t) \right|, \tag{6}$$

Table 2
Metrics for selecting oil and gas price scenarios from the energy-mix model runs. Only energy-mix model generated scenarios are numbered.

Scenario number	Scenario metric	Definition
	Reference scenario	Constant oil and gas prices
	Moderate decreasing price	Prices are 30% lower in 2050 compared to 2010
	Moderate increasing price	Prices are 30% higher in 2050 compared to 2010
1	Highest coal share	Prices for run where: $f(x_i, 2050) = \max(E_{relative\ coal\ share})$
2	Highest gas share	Prices for run where: $f(x_i, 2050) = \max(E_{relative\ gas\ share})$
3	Highest other renewables share	Prices for run where: $f(x_i, 2050) = \max(E_{relative\ other\ renewables\ share})$
4	Highest oil share	Prices for run where: $f(x_i, 2050) = \max(E_{relative\ oil\ share})$
5	Highest biofuels share	Prices for run where: $f(x_i, 2050) = \max(E_{relative\ biofuels\ share})$
6	Volatile scenario	Prices for run where: $f(x_i, t) = \max(V)$
7	Volatile scenario	Prices for run where: $f(x_i, t) = \max\left(V / \{ V_{s_6} \}\right)$
8	Volatile scenario	Prices for run where: $f(x_i, t) = \max\left(V / \{ V_{s_6}, V_{s_7} \}\right)$

$$mcr_i = \sum_{t=2010}^{2050} \begin{cases} 1 & \text{if}\left(f_{i,Oilprice}(\vec{x}_i, t) = \bar{f}_{i,Oilprice}(\vec{x}_i, t)\right) \wedge \left(\dfrac{df_{i,Oilprice}(\vec{x}_i, t)}{dt} \neq 0\right); \\ 0 & \text{else} \end{cases} \quad (7)$$

with $\bar{f}_{i,Oil\,price}(t)$ as the mean value of a curve. For every scenario, we used the oil and gas prices of the corresponding run index.

The impact of oil and gas prices on country stability is largely a one way process. However, as instability impacts the development of GDP and resource extraction capacity, this effect is reinforcing. Some other, minor feedback effects exist between stability and economy. Examples are the effects of population size on the fertility and mortality levels, which may cause a deadlock situation with high population growth and too little economic development. Another example is the effect of immigration on the workforce, and the effect of the available workforce on immigration. A last example occurs when the regime is susceptible to the discrepancy between on the one hand the democratic expectations of the population, and on the other hand the present polity. However, instability may again counteract this development if the government reacts in a more autocratic way to a crisis in the country.

Resource prices may influence countries' economies in many, potentially counteracting, ways. For example, price increases have a positive effect on government finances, and create more employment, but they have an adverse effect on purchasing power of the population. It depends on the specific conditions in a country whether the positive or the negative effects will be dominant.

3. Results

In this section, we discuss the results generated with both the models. In Section 3.1, we analyse the oil price dynamics generated with the energy-mix models, followed by the selection of the eight oil and gas price scenarios. In Section 3.2, we analyse the effects of these scenarios on rentier state stability as simulated with the country-stability model.

3.1. Effects on global energy markets

The oil price dynamics (Fig. 4) generated with the energy-mix model show an initial dip for all runs. Analysis of this dip reveals a clear connection to the overcapacity due to the US' shale revolution. While the depth of the dip differs greatly between runs, it shows that, based on the assumptions underpinning the model, it is impossible to not have a temporary decrease in oil prices. The more direct causes of the dip lie in substitution effects. The abundant supply of natural gas finds its way into the global energy

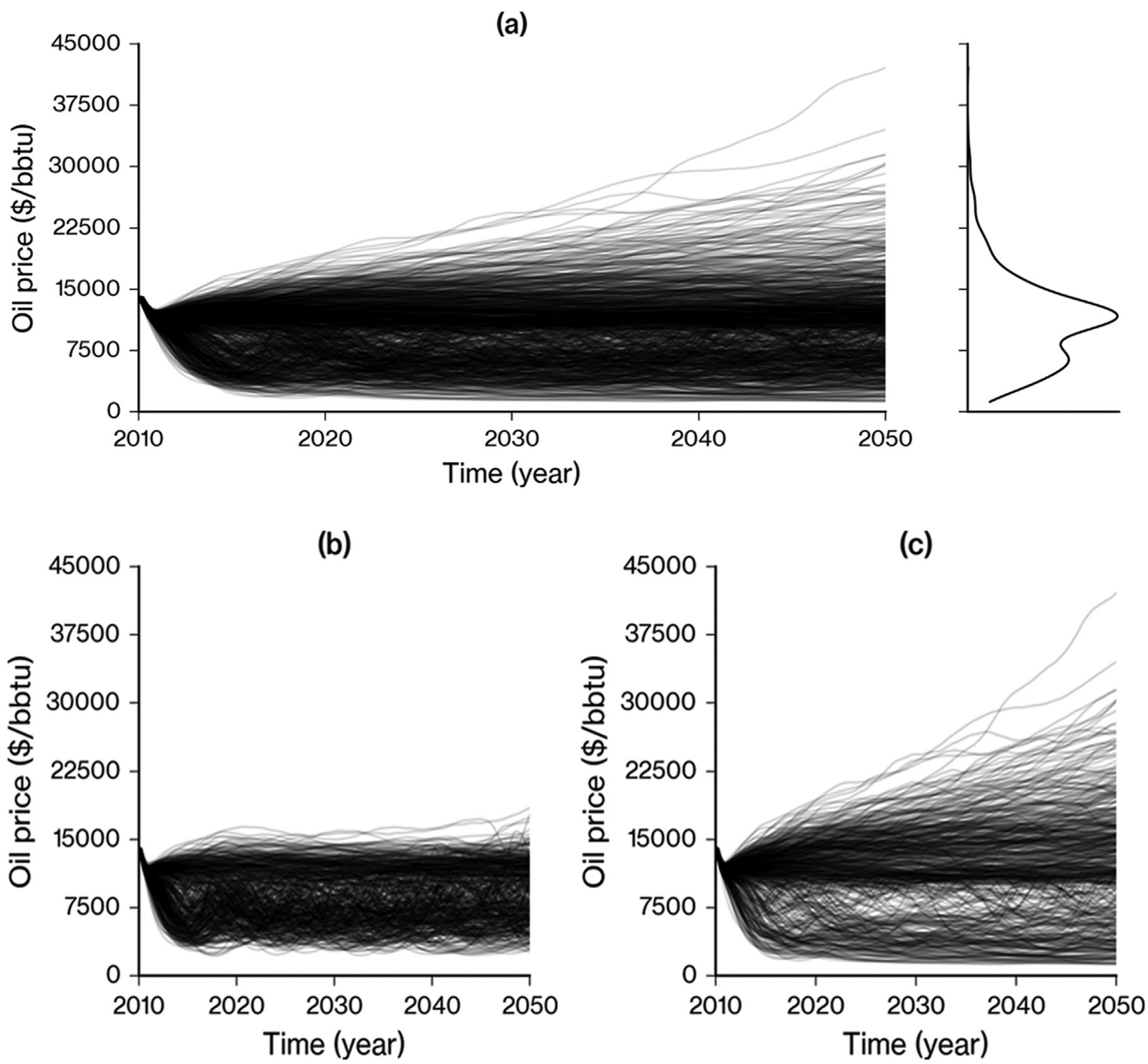

Fig. 4. 1000 runs for the energy-mix model (a), the 500 runs with most oscillatory volatile behaviour (b), and the 500 runs with least oscillatory volatile behaviour (c).

market by substituting other primary energy sources. For those energy sources that allow for accumulation of over-production, such as in the case of oil, there can be a more significant long-term price effect than with natural gas alone.

Besides the initial dip, however, the dynamics show a wide variety of behaviours. Roughly half the runs primarily show oscillatory volatile behaviour. Oscillatory volatile behaviour is measured here by the number of times each time series crosses its own mean value combined with the length of the line. Using this measure, runs that are primarily characterised by oscillatory volatile behaviour and runs with long-term increasing oil prices are classified differently, even if the runs with long-term increasing oil prices are characterised by oscillatory behaviours too. Runs that are primarily characterised by this behaviour represent those situations in which the oil price periodically oscillates between relatively low oil prices, roughly half or even less of the 2010 price level and high levels like the 2010 level.

The volatile runs resemble to 'hog cycles' (Hanau, 1928). The periods between the ups and downs are thus related to the delay time for new extraction capacity development, which is found to be generally between eight and fifteen years (MinesQC, 2016). This is consistent with the observed periodicity in the volatile runs. Similar dynamics are not found for the gas price, as massive accumulation of overproduction of gas is assumed to be too expensive. Consequentially, gas prices show far less long-term volatility. Such dynamics are found for many openly traded resources, but it could be argued that due to OPEC's market power in last decades, hog cycles were less of a problem in the oil market.

The runs with the least oscillatory volatile behaviour mostly show oil prices staying at a price level similar to the 2010 level or rising prices. The rising prices are caused mainly by a combination of continuously rising demand and rising resource extraction costs. Finally, for a last set of runs, the shale revolution leads to permanently lower price levels. This behaviour occurs when decoupling – of energy demand and the size of the economy – outgrows economic growth.

We selected eight runs as price scenarios for the second step of the analysis by using the metrics listed in Table 2. The result of this step for both the oil and the gas price is visible in Fig. 5. By choosing both extreme energy mix scenarios and volatile scenarios, we covered the dynamic behaviour space of all runs relatively well. Finally, the figure shows that the oil price is more volatile than the gas price in all scenarios.

3.2. Effects on rentier states

Fig. 6 shows for how many of the 100 cases per country the state stability improved for all time steps (i.e., desirable) or on average (i.e., mostly desirable), or deteriorated for all time steps (i.e., undesirable) or on average (i.e., mostly undesirable) compared to a constant oil and gas price.

All six countries in the analysis become more stable when oil prices increase over time. The importance of the oil price can be explained by the fact that only Qatar receives an equal amount of income from gas extraction, while having the opportunity to expand that share of resource income. All other countries earn considerably more resource income from oil. All countries experience more internal instability when oil prices decrease over time.

Especially Algeria and Russia are vulnerable to the effects of the shale revolution, which causes in any case at least a periodic downturn in oil prices. In both countries, the partial democracy is less stable than the more autocratic regimes of Azerbaijan, Kazakhstan, Qatar, and Saudi Arabia. Further, the causes for vulnerability of Russia and Algeria are quite different. In the case of Algeria, it is especially male youth unemployment, combined with a very young population, which makes the country vulnerable. Russia, on the other hand, has a more aged population, but has – compared to the size of the economy – a relatively modest sovereign wealth fund. Russia thus lacks the options to survive one or more prolonged periods of low oil prices.

Although, the other countries analysed in this study are less vulnerable due to either limited youth unemployment (e.g., Kazakhstan and Qatar), or the more significant size of their sovereign wealth fund (e.g., Azerbaijan, Qatar, and Saudi Arabia), they are certainly not immune to the effects of a prolonged downturn in oil prices. The austerity measures in Saudi Arabia (Kerr, 2015), the downgrade of Azerbaijan's credit rating (Agayev, 2016), and the massive currency devaluation in Kazakhstan (Farchy, 2015) are illustrative of the difficulties these countries already experience. However, their overall resilience may prove to be higher than that of Algeria and Russia.

4. Discussion

This research was originally performed in 2013. Earlier versions of the work reported here (De Jong et al., 2014) were presented at the Dutch Ministry of Foreign affairs in the autumn of 2013, and at

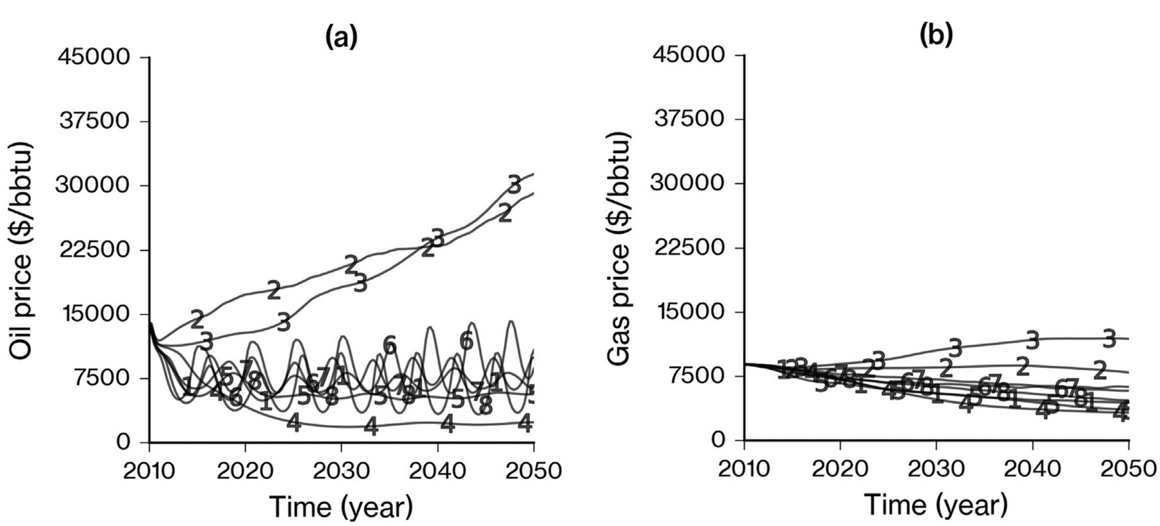

Fig. 5. Selected oil (a) and gas (b) price scenarios.

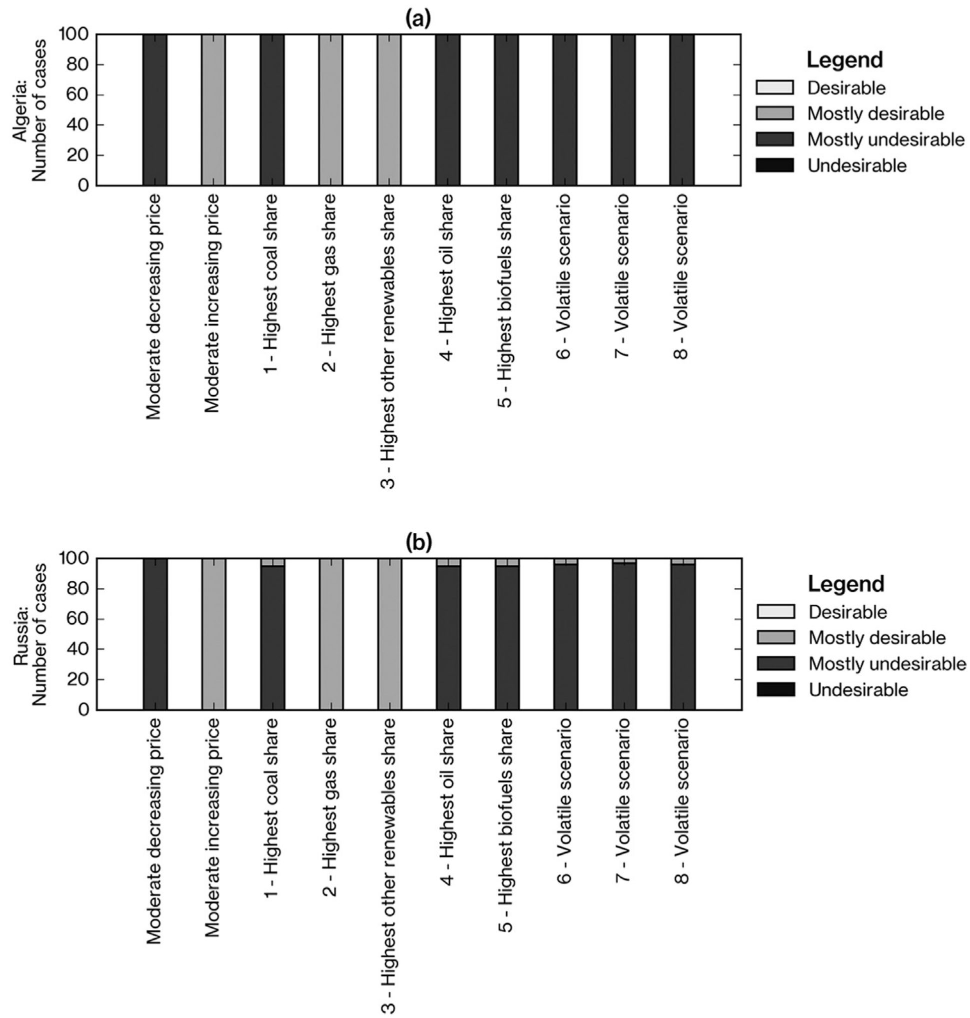

Fig. 6. Effects of the price scenarios on state stability of Algeria (a) and Russia (b).

the NATO headquarters in the spring of 2014. The attendees of these presentations found the idea of potentially decreasing oil prices hard to accept, and rather believed that they would continue to rise. Recent price developments, however, corroborate the results we presented in this paper. The belief that oil prices would continue to rise are consistent with the 'fixed-stock' paradigm regarding resource availability, which is in contrast to the 'opportunity costs' paradigm underlying our energy-mix model (Tilton, 1996). As opposing paradigms can be seen as a form of deep uncertainty, it fits our line of research to not oppose ideas like these, but rather to include alternative perspectives and look at our findings as plausible futures, which may inform the development of more robust policies.

The scenarios we generated only provide a limited view on the future of energy prices, as the simulation models used in this research are necessarily simplifications of reality. One example of such a limitation is the fact that we disregarded the existence of strategic reserves in our model. When these are taken into account, the price dynamics, especially the initial shale induced dip, may be delayed over time. This could explain why the real decrease in oil prices only happened from the second half of 2014 on, instead of immediately as in our simulation results.

A further limitation of our research can be found in the fact that we did only very rudimentarily take climate and energy policies into account. Exploring our results, we found that decoupling of economic growth and energy demand has, ceteris paribus, a profound negative effect on energy price levels. Again, especially oil prices are vulnerable to these developments. As decoupling due to increased energy efficiency is arguably at the core of climate mitigation policies, it is to be expected that these policies will, similar to the shale revolution, have a profound effect on long-term state stability. As emission targets may also provide a structural change in the global energy system, this may be a far longer-lasting effect than the surge in previously unconventional energy sources. Therefore, countries less vulnerable to periodically lower oil prices due to well-developed sovereign wealth funds, but highly dependent on income from oil and gas, may be especially vulnerable to climate mitigation policy developments. Saudi Arabia is a good example of such a rentier state. These countries should urgently start up a transition process of economic reconversion. Further research with a similar research methodology could increase knowledge about secondary effects similar to those of climate and energy policies.

The country-stability model is, just like the global energy-mix model, a simplification of reality. While much research exists that argues that economic factors as discussed in this paper are relevant and important for understanding the onset of internal instability, there are other factors, not considered here, which may either mitigate or reinforce this effect. An example of a mitigation factor may be nationalism, potentially induced by interstate war. An example of reinforcing factors may be grievance related issues like ethnic diversity, combined with a government that only represents a part of the ethnic groups in a country.

5. Conclusions and policy implications

In this paper we investigated potential indirect effect of the US' shale revolution on state stability of rentier states. To this purpose, we built and used two SD simulation models, one for the global energy mix consisting of six primary energy sources, and one to assess the impact of oil and gas prices on intra-state stability. The SD models were used to explore the consequences of uncertainties combined with the complexity and non-linear behaviour characterising both energy markets and state stability.

We found that the shale revolution has a periodic negative effect on oil prices in any simulated case. These lower prices can be part of a hog cycle in the energy market, where periods with relatively low oil prices alternate with periods with relatively high oil prices. An example of such a high price period is the pre-2014 period, while current price levels are an example of a period with low prices. If indeed the oil price will behave in this way, then it is to be expected that the price level will stabilise only when supply and demand balance. After this moment, the price may remain rather stable for a number of years, until the effect of underdevelopment of new extraction capacity generates under-capacity in supply. At that moment, the accumulation of oil on the market will decrease and lead to increasing price levels. The long-term gas price will then behave, if the market remains structured as it is currently, in a less volatile way.

As the surge in shale extraction capacity depended on the period with high prices, and the high price levels were incompatible with the amount of new capacity that became available, the shale revolution can be explained as an early warning indicator and partial cause of the 2014–2015 drop in energy prices. This is in itself an indirect effect, as the volatility of oil prices can be explained by a systematic difference between oil trade and gas trade: a surplus of oil is accumulated, while a surplus of natural gas supply is mostly flared. The urge for natural gas suppliers to partly substitute oil demand for their surplus is thus very high.

Low oil prices caused by the shale revolution can have a profound impact on state stability. This effect is caused by the negative economic effects of reduced price levels, which in turn affect male youth unemployment levels and purchasing power. These are underlying causes for population discontent and political instability. Buffers like sovereign wealth funds and immigration workers increase the resilience of countries to these developments.

We found that between the six countries investigated in our research, especially Russia and Algeria are vulnerable to lower oil price levels due to the shale gas boom. The partial democratic ('anocratic') polity of these countries increases their vulnerability. Not all causes are shared by these countries, however, as for Algeria the high male youth unemployment and the youth bulge are detrimental, while for Russia the limited size of the sovereign wealth funds as part of the GDP is problematic to politically survive periodic low oil prices. The other countries were found to be less vulnerable to the lower price effects, mostly as their buffer capacity is larger and their polity more stable (Azerbaijan, Kazakhstan, Qatar, and Saudi Arabia).

The policy implications of these conclusions pertain mostly to the security and international relations domains. We believe, however, that indirect consequences of energy policies should be taken into account in the design of these energy policies. The increased turmoil around Europe's borders is already a difficult policy problem. While this has no direct link to energy policies in itself, the plausibility of energy price related unrest does mean that investment in measures for dealing with these circumstances, both militarily and non-militarily, should be taken sooner rather than later.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2016.08.032.

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