STAFF MEMO

Nonlinearities in the relationship between oil price changes and movements in the Norwegian krone

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Nonlinearities in the relationship between oil price changes and movements in the Norwegian krone

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Anecdotal evidence as well as previous empirical analysis indicates that the relation between oil price changes and movements in the Norwegian krone is not stable over time. We can observe that there is no or only a weakly significant correlation between oil price changes and Norwegian krone depreciation in some periods, but a strong correlation in other periods. This memo proposes some explanations for these nonlinearities and summarizes the results of empirical tests conducted to investigate the nonlinearities in the oil price-Norwegian krone relation. It is found that the Norwegian krone reacts stronger to oil price changes when these are larger than average, and that the most relevant threshold level for the 2014 price drop was USD 75.

1. Introduction

Since the summer of 2014, we have witnessed a large and persistent fall in oil prices. This has affected the Norwegian krone more than most (empirical) models would have predicted. Anecdotal evidence as well as previous empirical analysis indicates that the relation between oil price changes[2] and movements in the Norwegian krone is not stable over time. For example, Akram (2004) documents that the impact of falling oil prices was stronger when the oil price was particularly low, below USD 14 in his sample. In times when a barrel of oil costs over USD 100, an oil price of USD 14 is quite hard to imagine. However, there are indications that the Norwegian krone depreciates more strongly when the oil price drops below certain threshold levels, and that these threshold levels change over time. More generally, we can observe that there is no or only a weakly significant correlation between oil price changes and Norwegian krone depreciation in some periods, but a clear correlation in other periods[3]. This memo proposes some explanations for these nonlinearities and summarizes the results of empirical tests conducted to investigate the nonlinearities in the oil price-Norwegian krone relation. It is found that the Norwegian krone reacts stronger to oil price changes when these are larger than average, and that the most relevant threshold level for the 2014 price drop was USD 75.

The memo is set up as follows. Section 2 introduces the data. Section 3 sets out the regression specifications and summarizes the results. Section 4 discusses the results and proposes some possible explanations for the nonlinearities that are found. Section 5 concludes.

[1] I received valuable comments and input during presentations at Norges Bank, as well as from discussions with Arne Kloster, Tom Bernhardsen, Einar Nordbø, Alexander Flatner, Hong Xu, Kjetil Martinsen, Farooq Akram, and Drago Bergholt. This Staff Memo should not be reported as expressing the views of Norges Bank. The views expressed here are those of the author and do not necessarily reflect those of Norges Bank.

[2] In this memo I use the term 'oil prices' in a general way, not specifically referring to spot or futures prices. Analyses are all done with spot prices, but are robust to the use of futures prices. Although futures prices generally move less sharply than spot prices, they are highly correlated.

[3] See Figure 2.

2. Data

The analyses are conducted on monthly data from January 2001 to August 2015. The sample starts in 2001 for two main reasons: Norges Bank officially adopted its inflation targeting regime in March 2001[4], simultaneously with the introduction of the 4% budgetary rule ('fiscal spending rule')[5].

Figure 1 shows the evolution of the Brent price of oil (in US dollars) and the nominal Norwegian effective exchange rate (I44) during the sample period. Note that a positive change in I44 implies a depreciation of the Norwegian krone.

I use logs of the oil price and I44 in the empirical analysis. Other variables used are 12-month Norwegian money market rates and 12-month foreign money market rates.

I44 is a trade-weighted average of the Norwegian krone against the currencies of Norway's 44 most important trading partners[6]. The foreign money market rate is a weighted average of Norway's seven biggest trading partners. Those seven countries make up about 75% of the weights in I44.

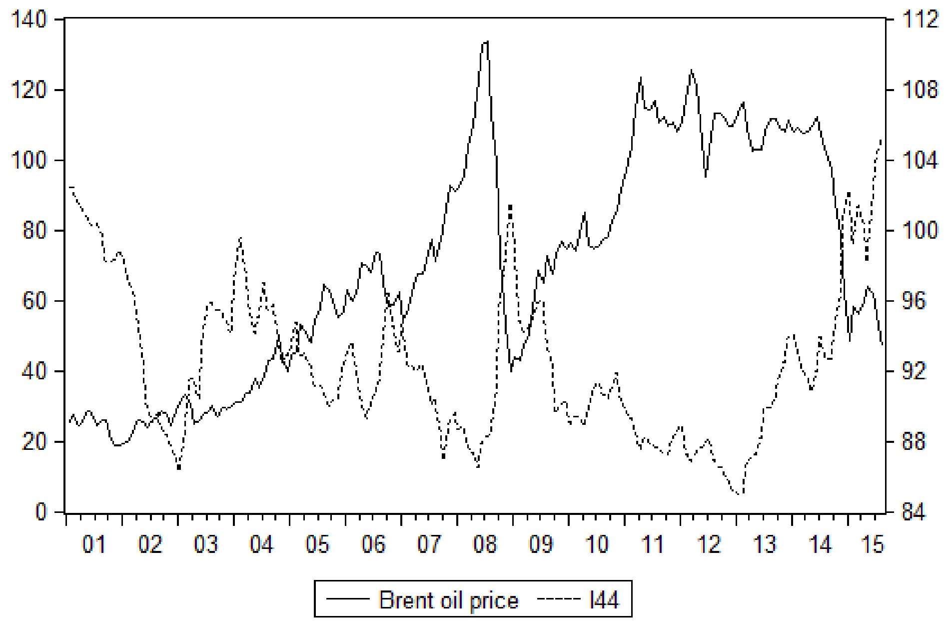

Figure 1. The solid line shows the price of a barrel of Brent oil in USD (left-hand axis). The dotted line shows the value of I44, the import-weighted effective exchange rate for Norway (right-hand axis).

[4] Although there had been a flexible exchange rate regime since the early nineties, I choose to start the sample in the year that the inflation target was officially introduced.

[5] The budgetary rule dictates that, over the course of a business cycle, an average of 4% of the value of the Government Pension Fund Global (GPFG) may be used each year over the government budget (the expected real return of the fund). More about the GPFG in Section 4 and at http://www.nbim.no/en/the-fund/.

[6] http://www.norges-bank.no/en/Statistics/exchange_rates/Calculated-rates---explanation

3. Regression specifications and results

For the analysis I will consider one base specification, where the relation between oil prices and the effective exchange rate is linear, and several alternative specifications to capture various types of nonlinearities. All are estimated using ordinary least squares.

3.1 Linear specification

In the linear specification, Δs_t, the monthly log change in I44, is a function of Δoil_t, the log change in the price of oil in the same month, the lagged interest differential with main trading partners $(i_{t-1} - i_{t-1}^*)$, and the contemporaneous change in this interest differential $(\Delta(i_t - i_t^*))$.

These control variables remain the same for all alternative nonlinear specifications. It is only the oil price term that is assumed to affect I44 in a nonlinear manner[7].

$$\Delta s_t = \alpha + \beta_1 \Delta oil_t + \beta_2 (i_{t-1} - i_{t-1}^*) + \beta_3 \Delta(i_t - i_t^*) + \varepsilon_t \tag{1}$$

The results are summarized in Table 1 (with t-statistics in parentheses). We can see that over the period from 2001 to 2015, a 10% change in the oil price corresponds to a 0.6-0.7% change in I44 on average. As a comparison, Bernhardsen (2008) finds that the long-term relation between the oil price and a Trade Weighted Index of the Norwegian krone estimated on monthly data is 0.06. Bjørnland and Hungnes (2002), who use a sample until 1999, find a long-run coefficient of roughly 0.03[8].

Changes in the interest differential yield similar coefficient estimates in all specifications, with the expected signs.

To get an indication of whether the relation between changes in the Norwegian nominal effective exchange rate and oil price changes is nonlinear, I plot the time-varying relation (β_1 from Equation 1) between those two variables in Figure 2. This is based on a rolling regression with a moving window of 24 months, thereby controlling for the interest rate differential between Norway and its trading partners, and changes in the differential (as in Equation 1)[9]. The figure shows that there are episodes when there is a significant negative relation between changes in the exchange rate and oil prices, and episodes when the coefficient estimate is still negative but not statistically significant. I take this as a starting point for further analysis.

[7] As the focus is on short-run effects here, I run a simple linear base regression. An alternative would be to control for the long-run relation between oil and the Norwegian krone by estimating an error correction model that allows for mean reversion to the long run equilibrium. The findings in this paper are qualitatively robust to this specification, but differ a bit quantitatively because the oil coefficient picks up short-term movements and possibly some of the long-run mean reversion.

[8] Corresponding to a 0.3 to 0.6% change in the exchange rate following a 10% oil price change.

[9] I control for the interest rate differential to show that the nonlinearities are not caused by omitting this variable. The results without these controls are very similar.

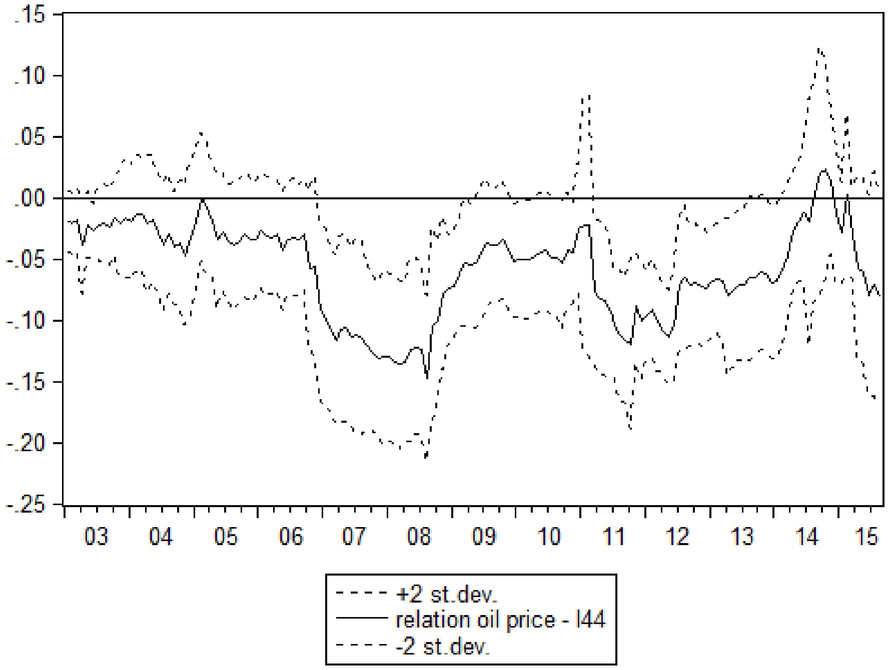

Figure 2. Relation between oil price changes and I44 changes (with confidence bands), controlling for interest rate differentials and changes in the differential. The sample runs from January 2001 to August 2015, and the size of the rolling window is 24 months.

3.2 Alternative nonlinear specifications

I estimate various nonlinear specifications to investigate the possible time-varying impact of oil prices on I44. For all these specifications, I also check whether the results are driven by the simultaneous NOK depreciation and oil price drop in 2008 (see Figure 1). Although part of the depreciation may be related to the oil price drop, it is more likely that both the fall in the oil price and the NOK depreciation were caused by economic and financial market uncertainty during the global financial crisis (GFC). I therefore only consider the results robust when they are not purely driven by this episode.

3.2.1 Asymmetric effects

The first nonlinear specification considers asymmetric effects of oil price changes on I44, depending on whether the price change is negative or positive. Hamilton (2003) finds that for a net oil importing country such as the United States[10] oil price increases matter more than oil price decreases. Since Norway is a large oil exporter, we may not find such results for Norway. The effect may even be reversed (i.e. a negative price change may have a bigger impact than a positive price change).

$$\Delta s_t = \alpha + \beta_1 \Delta oil^{+}{}_t + \beta_2 \Delta oil^{-}{}_t + \beta_3 (i_{t-1} - i^*_{t-1}) + \beta_4 \Delta(i_t - i^*_t) + \beta_5 \Delta oil_t{}^{crisis} + \varepsilon_t \qquad (2)$$

In the above specification, β_1 measures the impact of positive price changes, and β_2 measures the impact of negative price changes. The last (oil price) term controls for the correlation between oil

[10] Although it can be argued that the United States are moving more in the direction of an oil exporting country in more recent years, it was certainly still an oil importing country at the time of Hamilton's analysis.

price changes and I44 during some crucial months of the global financial crisis, from August to December 2008.

As described in the previous subsection, I want to control for the simultaneous oil price drop and NOK depreciation in 2008. Because there were many other events that may have influenced the oil price as well as the Norwegian krone, the correlation between the oil price and I44 may appear too high during this period. I therefore add a term that multiplies a dummy variable that has the value of 1 from August 2008 until December 2008, and 0 otherwise, with the change in the oil price, to distinguish the 2008 episode from the rest of the sample

The results can be found in the third column of Table 1 (under "asymmetric"). The coefficients accounting for possible asymmetry in the response of I44 to an oil price change show a stronger effect for a positive price change than a negative price change. However, a Wald test shows that the difference is not statistically significant.

3.2.2 Magnitude of shocks

We may expect that large oil price changes affect I44 more than small oil price changes[11]. I test this by estimating the following equation:

$$\Delta s_t = \alpha + \beta_1 \Delta oil_t + \beta_2 \Delta oil^{large}{}_t + \beta_3 (i_{t-1} - i^*_{t-1}) + \beta_4 \Delta(i_t - i^*_t) + \beta_5 \Delta oil_t{}^{crisis} + \varepsilon_t \qquad (3)$$

In the above specification, β_1 measures the base impact of oil price changes, and β_2 measures the additional impact of large oil price changes. A large price change is defined as a price change that is larger than the average of all price changes over the past 24 months.

The results of estimating Equation (3) can be found in the fourth column of Table 1 (under "big change"). As β_2 measures the *additional* impact of large price changes, the total effect of large oil prices (obtained by summing β_1 and β_2) is shown next to "aggregate effect" and is -0.0772. Large oil price changes (price changes that are larger than average) have a significantly stronger impact on I44 than small changes. Since the major part of oil profits is invested abroad through the Government Pension Fund Global (GPFG), an explanation for the differentiated impact of large versus small price changes could be that through the setup of the GPFG, government spending is less affected by relatively small oil price changes, and hence the effect of oil price changes on the Norwegian economy might be dampened. This is discussed in Section 4.

3.2.3 Threshold levels

Breakeven prices may be quite important for oil companies to decide whether to continue production, spend money on oil field maintenance, and invest in new oil fields. I therefore consider the following specification, in which β_1 measures the base impact of oil price changes, and β_2 measures the additional impact of a price change when it drops below a certain threshold level.

$$\Delta s_t = \alpha + \beta_1 \Delta oil_t + \beta_2 D^{<\$xx} \Delta oil_t + \beta_3 (i_{t-1} - i^*_{t-1}) + \beta_4 \Delta(i_t - i^*_t) + \beta_5 \Delta oil_t{}^{crisis} + \varepsilon_t \qquad (4)$$

[11] See section 4 for a discussion of possible explanations for this and other nonlinear effects.

Table 1. Results from regressions (1) to (4).

	linear	asymmetric	big change	threshold \$75	threshold \$85	threshold \$95
Constant	0.0018	0.0025	0.0020	0.0016	0.0018	0.0018
	(1.2960)	(1.3992)	(1.3857)	(1.1860)	(1.2970)	(1.2957)
oil price change	-0.0661		-0.0405	-0.0623	-0.0658	-0.0659
	(-4.9851)		(-2.4898)	(-5.1848)	(-4.9876)	(-4.9610)
positive oil price change		-0.0776				
		(-3.1713)				
negative oil price change		-0.0562				
		(-2.2304)				
big oil price change			-0.0367			
			(-1.8672)			
oil drops under \$XX				-0.0611	-0.0305	-0.0251
				(-1.9012)	(-1.7179)	(-1.7839)
Aggregate effect (base + nonlinearity)			-0.0772	-0.1235	-0.0963	-0.0909
interest rate differential		-0.0015	-0.0016	-0.0014	-0.0015	-0.0015
		(-1.9094)	(-2.0241)	(-1.8482)	(-1.8676)	(-1.8672)
change in interest rate diff.		-0.0275	-0.0258	-0.0250	-0.0264	-0.0265
		(-6.3554)	(-5.4953)	(-5.3700)	(-5.6562)	(-5.6170)
crisis control dummy		-0.0219	-0.0062	-0.0038	-0.0072	-0.0087
		(-0.8503)	(-0.3458)	(-0.2249)	(-0.3928)	(-0.4992)
adjusted R^2	0.3367	0.3339	0.3403	0.3441	0.3345	0.3339

Notes: This table summarizes the results from regressions (1) to (4), with t-statistics shown in parentheses. The analyses are conducted on monthly data from January 2001 to August 2015. A big oil price change is defined as a price change that is larger than the average of all oil price changes over the past 24 months.

Out of a range of threshold levels ranging from USD 60 to USD 95, with a step of USD 5, we can distinguish three relevant threshold levels[12]: USD 75, USD 85, and USD 95, of which USD 75 seems to have the largest impact[13]. The impact of an oil price change on I44 is much larger when it drops below these levels: -0.1233 for USD 75, -0.0963 for USD 85, and -0.0910 for USD 95, compared to circa -0.065 at other times.

Although threshold levels matter, the relevant threshold changes over time. Figure 3 shows how often the oil price dropped below the three mentioned threshold levels throughout the sample. Up until 2007, the oil price had never even reached a price of USD 75. In Akram (2004), where a sample from 1986 to 1998 is used, the nonlinearity comes from a threshold level of USD 14, more than 5 times smaller than the most relevant threshold level over the past years.

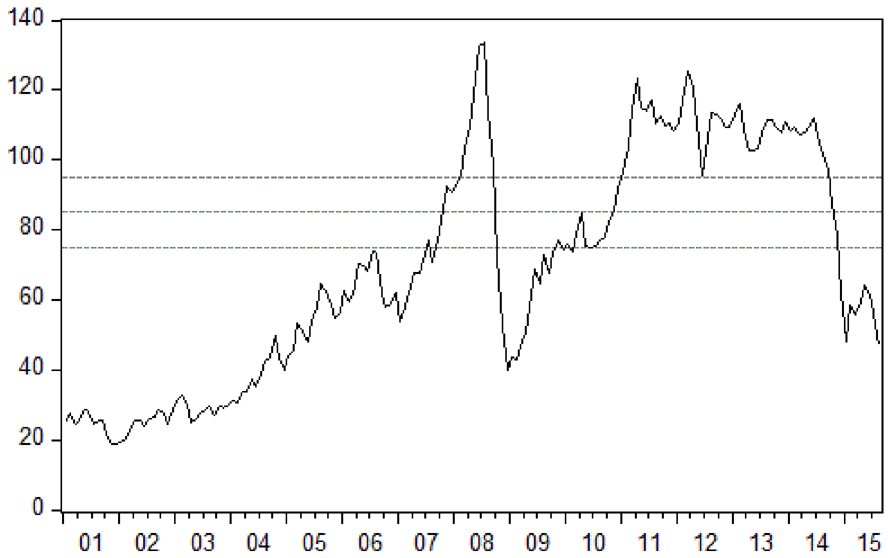

Figure 3. The price of a barrel of Brent oil in USD, and three lines indicating the USD 75, USD 85, and USD 95 threshold levels. The sample runs from January 2001 to August 2015.

The threshold levels I find here are very close to the prices that are relevant for the petroleum-related turnover of Norwegian enterprises (between USD 70 and USD 80), as found in Brander, Brekke and Naug (2013).

There is reason to believe that a threshold oil price is relevant due to breakeven prices that are around the same level as that threshold. As will be further discussed in Section 4, these breakeven prices are time-varying and often a function of the recent oil price. Unfortunately, the data available on breakeven prices is scarce, imprecise, and irregular. I therefore do not consider using it to complement the analysis. Several specifications with a threshold level being a certain function of the past oil price did not yield any significant results.

[12] When I include all three thresholds at the same time, only USD 75 stays significant.
[13] As can be seen from Table 1, differences in explanatory power (R^2) are very small for all specifications.

3.3 Time-varying effects

Finally, we look at the rolling correlation coefficient between oil price changes and changes in I44 again (i.e. β_1 in Equation 3). This time however, we also control for large oil price shocks. The aim of this exercise is to see whether the time-variation in the base effect of the oil price is reduced by controlling for this nonlinear effect. The results can be seen in Figure 4.

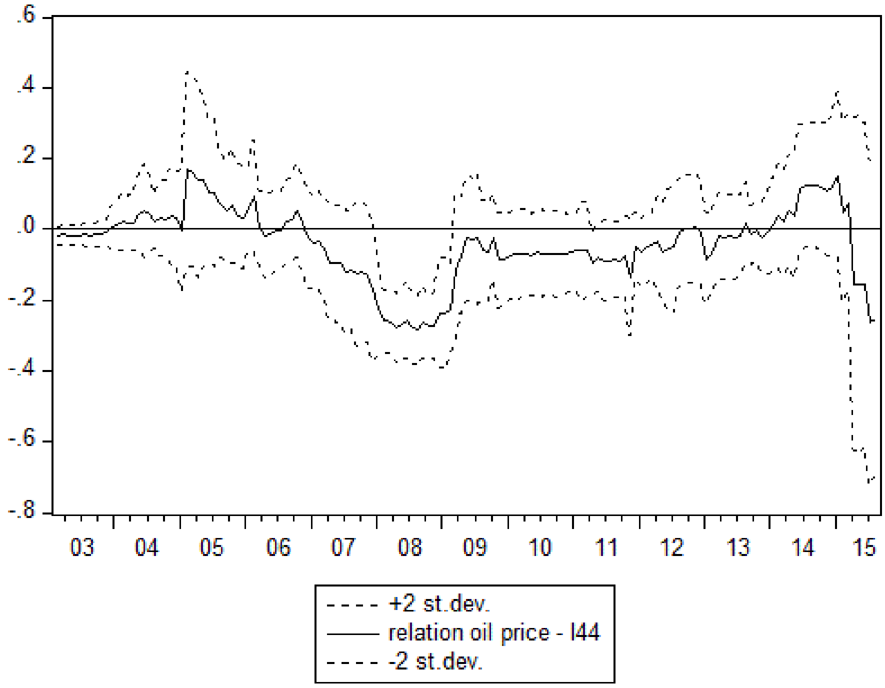

Figure 4. Relation between oil price changes and I44 changes (with confidence bands), controlling for interest rate differentials, changes in the differentials, and large oil price changes. The sample runs from January 2001 to August 2015. Note that the window size is 25 months here, for estimation purposes (the dummy for large changes is estimated over 24 past months).

Looking at the graph, we can see that the time-variation in the base effect of oil price changes is substantially reduced after controlling for the magnitude of oil price changes. Except for the 2008 episode (which was not controlled for in this regression), the effect is insignificant, indicating that it is only large price movements that matter for I44.

4. Discussion

Norway is different from other oil and commodity exporting countries in various dimensions. These may provide us with some explanations for why the relation between the oil price and the Norwegian krone is not linear.

4.1 Government Pension Fund Global

In 1996 the Government Pension Fund Global (GPFG) was set up to shield the Norwegian economy from fluctuations in the oil price and to safeguard wealth for the benefit future generations. Through this mechanism, revenues stemming from the oil industry (taxes, dividends from Statoil, etc.) are invested abroad, and the government can spend an average of up to 4% of the value of the fund annually[14]. This is in contrast to many other commodity exporting countries, where most of the commodity revenues can be used for the current government budget[15]. As a result, government spending should be less affected by oil price changes than without such a mechanism, and the effect of oil price changes on the Norwegian economy might be dampened. However, this does not necessarily mean that government spending of oil revenues is countercyclical. Bjørnland and Thorsrud (2015) find that fiscal policy is still procyclical despite the GPFG due to the large inflows into the fund when oil prices are high.

4.2 Sticky oil production and investments

Norwegian oil fields are offshore and are not as easily accessible as oil fields of some of the OPEC countries[16]. Therefore, large investments are needed before oil production can be started, both in terms of exploration and extaction. Once oil production has started, it is very costly to reduce or stop production. Therefore, small changes in the oil price leave oil production unchanged. In other words, Norwegian oil investment and production are very sticky and do not move with relatively small price changes. However, when oil price changes are large, this has an amplified effect on both production and investments. A large and persistent price drop can drive revenues to negative levels and may force oil companies to stop production at some oil fields. At the same time, an oil price increase has to be large and persistent to spur investment in oil exploration and production. In summary, sticky oil investment and production have the following effect: small movements in the oil price do not affect production and investment, a large drop may slow down production and stop investment, and new investment will only start to take place when oil prices are high and are likely to persist.

4.3 Oil price-dependent breakeven prices

A third reason for nonlinear responses to oil price changes may lay in the time-variability of breakeven prices. When oil prices have been high for some time, it becomes more costly for oil companies to obtain labor, services and materials. In addition, government focus on health and security regulation may have intensified over time, arguably in relation to the high profitability of the industry, which engenders higher production costs.

This means that breakeven prices are a function of the oil price. When oil prices have been high for a while, suppliers of labor, services, and materials are in a better position to negotiate and will demand higher prices. Therefore, high (low) oil prices correspond to high (low) breakeven prices.

4.4 Effects on monetary policy

In an economic commentary about oil and the Norwegian economy, Nordbø and Stensland (2015) state that the "steep rise in oil prices between 2000 and 2014 has contributed to rapid market growth for Norwegian firms specializing in deliveries to the petroleum sector". Brander, Brekke and Naug (2013) study the effects of a drop in oil prices on the turnover of Norwegian enterprises, and find that "a share of sales will be affected if oil prices fall below USD 90 and that a drop to USD 70 or lower will have a severe adverse impact on petroleum-related sales in the Norwegian economy". Specifically, they find that around 75% of the enterprises surveyed (weighted by petroleum-related employment) state that they would experience severe adverse effects on their petroleum-related sales at an oil price of between USD 70 and USD 80 (in 2012).

[14] This fiscal rule was established in 2001.
[15] Up until the creation of the GPFG, Norway was not different from those countries in this respect.
[16] It should be noted that similar effects could also be expected for other countries with offshore oil fields.

When a change in the oil price starts to affect the real (mainland) economy as a whole, this can have an effect on output and inflation expectations, and may hence have an effect on the monetary policy of a central bank that has a (flexible) inflation target. Therefore, large movements in the oil price may affect the exchange rate through actual and expected monetary policy.

4.5 Effects on the equilibrium exchange rate

Whereas monetary policy may respond to short- to medium-term fluctuations in the oil price, a very large and persistent change in the oil price may have consequences for the long-term growth outlook of a (oil-dependent) country. Such an oil price change could therefore affect the real equilibrium exchange rate. Considering that the equilibrium rate is hard to measure and therefore not easy to account for in empirical models, a movement towards this new equilibrium rate may show up as an increased effect of the oil price on the exchange rate.

5. Conclusion

The relation between oil price changes and Norwegian krone depreciation is found to be nonlinear. In some periods there is no relation between these variables at all, whereas there is a strong significant relation in other periods. Due to the fact that Norway is a small open economy, we can assume that in these cases it is the oil price that affects the Norwegian effective exchange rate, and not the other way around.

I do not find evidence of an asymmetric effect. There is no significant difference between the effect of a positive oil price change and a negative oil price change on the Norwegian nominal effective exchange rate. I find two interesting results. The first one is that the impact of large oil price changes is almost twice as strong as the impact of small oil price changes. The second result is that thresholds matter: the effect of an oil price is much stronger when the oil price drops below certain presumably 'crucial' levels. However, the relevant threshold changes over time, possibly due to time-varying breakeven prices.

I also describe possible explanations for the nonlinearities that I find. First of all, the Government Pension Fund Global (GPFG) mechanism may smooth the impact of fluctuating profitability of the oil sector on the Norwegian economy. However, when the change in oil price is larger than average or when the oil price drops below certain threshold levels (possibly related to marginal costs in the oil sector) the rest of the economy is affected, which can affect the Norwegian krone through, among other things, actual and expected monetary policy.

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