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# **The Implications of oil market volatility on the credit risk of some oil-exporting countries**

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## **Abstract**

The credit risk of oil-exporting countries could depend on the evolution of oil market. Indeed, the instability of oil prices can cause defaults on debt repayments, with a consequent deterioration in the credit quality of exporting countries. In this paper, through an econometric analysis between oil price and other variables of oil market and CDS premium volatilities, we highlight causalities between some variable of the oil market and the variation of the credit default of some oil-exporting countries. For illustration, we have randomly chosen to treat these oil-exporting countries: Saudi Arabia, Venezuela, Russia, Norway, Kazakhstan and Qatar. A particular focus of our analysis is to study the slump of oil market in mid-2014 on the six countries credit default spreads volatility.

## **1- Introduction and related literature.**

After the fall in oil prices in 2014, marked by the entry into production of the shale oil industries, the economy of oil-exporting countries was affected in several respects. Among the various difficulties encountered by oil-exporting countries, one can mention the increase in the probability of defaulting on debt repayment, with, as a corollary, the deterioration of the credit rating of the countries concerned (**Breunig and Chia, 2015**). Much more than in the past, the need for diversification is imposed by the risk that some countries will experience the social unrest that Venezuela (the world's largest holder of oil reserves) is going through, partly due to a continuous decline in oil prices. As with companies, financial markets pay a lot of attention to the ability of countries to ensure their solvency through reliable or at least stable sources of income. The case of oil-rich countries is particularly interesting because oil is among the most volatile commodities due to geostrategic developments and the effect of financialization, even if the debate is not completely settled. Generally, credit default swaps (hereafter CDS) can be used to hedge against a credit event on a debt security issued by a company or a government. They are also often used as an indicator for assessing default risk of a country or a company. In addition to the oil spot market, the oil futures market is a particularly active market that contributes to intensifying oil volatility. This article aims to study the econometrics causalities between oil price and CDS premium volatility. It would alert oil exporting countries and their lenders (financial institutions, IMF, World Bank, ... etc.) and other partners, regarding the causality between the volatility of oil prices and the deterioration of their credit rating. Indeed, a high variability of credit default swap premiums indexed on bond debt means a high risk of a future default by the country in question, which may manifest itself either in a moratorium on interest payments or on the principal of the debt. In an environment where the cartel of oil-exporting countries OPEC (Organization of the Petroleum Exporting Countries) is losing more and more of its power as the first supplier in the oil market and therefore as a price maker, it seemed appropriate to question the solvency of the latter in an environment increasingly marked by cheap oil and therefore close to the production costs of the member. Indeed, erratic movements in oil prices are likely to shape public spending (**El Anshasy and Bradley, 2012**) and contribute to increase the frequency by which these countries resort to the financial markets in order to finance their deficits. Although the question of institutions,

or the level of public accounts such as the level of debt or the history of default are essential factors in measuring their solvency and therefore their refinancing costs (**Akitoby 2008; Hooper 2015**), the source of fluctuation of the price of their resource of export (oil) should not be ignored. The currencies in which the debt is repaid are obtained through the sale of oil. So the higher the oil price, the less erratic and better it would be for oil-exporting countries. Such a situation would translate in stable public accounts and macroeconomic stability ensured by stable flows of income and thus in the promise of enhanced solvency for investors. If the price or its return summarize the development of the oil market, it is better to directly analyze the effects of the main determinants of this price on CDS premium variability. And importantly the effect of the default risk of oil rich countries on the oil market has been understudied. Indeed, as has been often argued in the literature, the presence of heterogeneous actors (**Terraza and Melhem, 2010**) on the oil market or the existence of an oil financial market through futures markets in addition to the traditional physical market often results in the loss of the informational content of oil prices. Furthermore **Hamilton (2009) and Kilian (2007)** suggest that different shocks in the oil market have different effects on stocks markets. **Baumesteir and Peersman (2012), Basher et Al (2012), Kilian and Lewis (2011), Fillis and Al (2011), Lippi and Nobili (2012), Kilian and Park (2009), Apergis and Miller (2009), Lescaroux and Mignon (2008), Kilian(2008) and Barsky and Kilian (2004)** also illustrate the importance of taking into consideration the origins of the oil prices shock. Even though some empirical evidence show the importance of oil prices for large developed countries (**Lee and Al.,2017**) and volatility for oil-exporting countries (**Shahzad et Al., 2017**) less is known about the linkages between oil market fundamentals and sovereign credit risk of big and small oil producer member or not of OPEC cartel. Also, there is a lack of studies showing if the OPEC members status and their proven reserve make any sense in these linkages. So, the purpose of our work is to study these linkages in the frame of the 2014 oil slump by comparing members and non-members of OPEC cartels with different capacity of production. Furthermore, our study differs from previous one (**Bouri and al 2019**) by approximating the sovereign credit risk by the volatility of sovereign cds spreads by garch modelling. According to **Castellano and D'Ecclesia (2012)** the volatility of cds spreads are a better measure of credit quality than the simple CDS spreads. Further our study is at daily frequency<sup>1</sup> as in **Bouri and Al (2020)** which is important

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<sup>1</sup> Cubic interpolation has been used to harmonize the daily frequency of cds spreads and the monthly

in order to better capture the dynamics of the relationships among the oil and cds markets, rather than using weekly (**Shahzad et Al.,2017**) or monthly data (**Lee et Al., 2017**). The sample covers the 2014 slump in order to assess the effect of oil market stress period on sovereign credit risk like in **Bouri and Al (2019)**. Above all we add to oil market fundamental variables, price and oil volatility, the three months anticipated price of oil to take into account the role of oil market anticipation on sovereign credit risk of oil exporting countries. Oil price expectations is used in investment decisions under uncertainty and play an important role in macroeconomic projections of central bankers and international organization (potential lenders to oil exporting countries) (**Baumesteir and Kilian, 2016**). Our results are consistent with previous studies and show that oil producer react and influence differently the oil market following to their status as big oil producer and the state of the oil market except Norway. The rest of the paper is structured as follows. The following section presents the data and the econometric approach, section 3 presents and discusses the results while the last section concludes.

## **2- Data description and econometric approach.**

### **2-1 Data description**

Depending on the availability of our data, our sample is made up of spreads of 5-year cds of six countries among the highly dependent oil exporters (over 50% of their revenues stem from oil exportation in 2018) on a daily frequency. They are among the biggest proven oil reserve holder, member and non-member of OPEC cartel (see table 1). 5-year cds is the most liquid maturity tranche of the sovereign credit default swaps market (**Fonseca and Al, 2016**). The variables linked to the supply and stocks of the oil market are extracted from the database of the international energy agency as well as the spot price. The demand of oil is approximated by the global ocean freight index constructed by **Kilian (2009)** as well as the three-month anticipated price series of oil. To conduct our study, we cut our sample into two subsets. The first period predates the fall in oil prices in June 2014 from April 2010 to mid-June 2014. It nevertheless includes a period of strong tension for the sovereign debt

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frequency of the oil market variables (see the annex for a detailed presentation of cubic spline methodology).

market caused by the European debt crisis covering the period of 2010 to 2013. The second sub-period for its part contains the post-slump period of 2014 which represents a period of stress on the oil market due to the market share policy maintained by OPEC cartel with a sustained level of oil production despite the growing level of production of shale oil in the United States and Canada. The figure 1 presents the evolution of the 5 years spreads and the oil price returns and we can see that after the oil slump, the returns of cds spreads significantly rised, showing that the oil slump had opened a period of growing risk on the debt of oil exporting countries. The Venezuelan spreads are the highest comparing to other cds spreads and the more unstable (see table 2, highest standard deviation). To conduct our empirical analysis, we use the logarithmic returns of crude oil spot price changes, the 3 months anticipated prices, the CDS spreads changes and changes in the levels of oil market fundamentals. The summary of the statistics of the different variables given in table 2, shows that the highest mean and standard deviation are for Venezuela followed by Saudi Arabia. All the series present asymmetry and leptokurticity according to the levels of the skewness and the kurtosis. The returns are also characterized by a non-normal distribution according to the value of Jarque-Bera test. All the variables possess auto-correlation and arch effect. We also apply two-unit root tests, the augmented Dickey-Fuller Test and Phillips Perron (PP) as described in **Dickey and fuller (1979)** and **Philipp and Perron (1988)** respectively to figure out the stationarity of our variables. The results reported in table (3) on the CDS changes, oil price returns, anticipated price at three months returns, supply, kilian index and stocks changes show that all the variable are stationary. These tests are also applied to the variable in level and are not stationary.

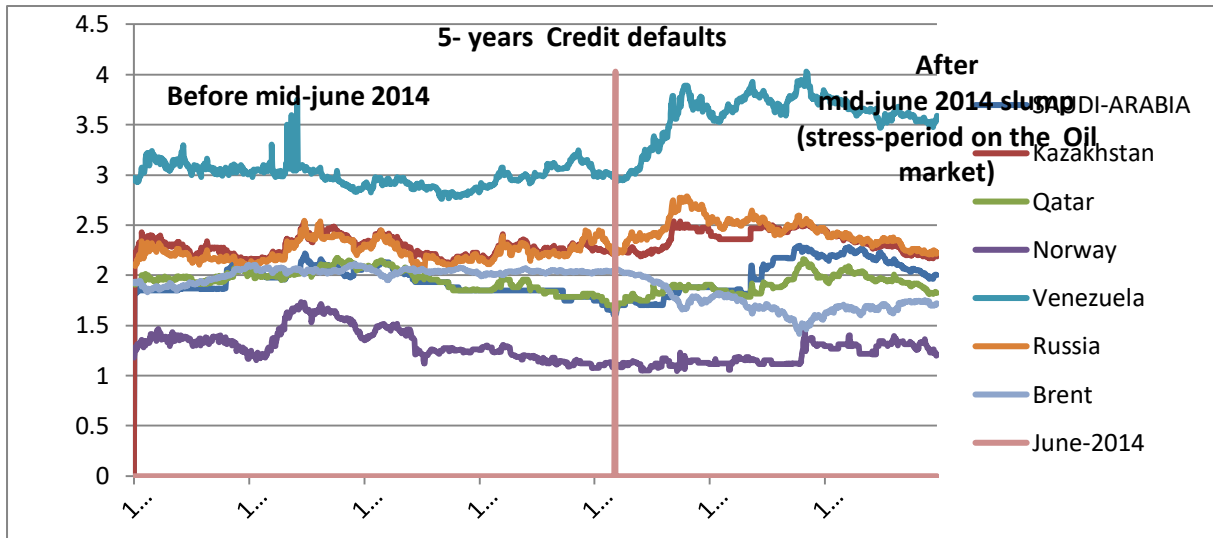


Figure 1: Authors's compilation.

## 2-2 - Econometric approach.

### 2-2- 1 - Garch-based models of volatility

The econometric study is done in three stages. The first step consists in bringing the variables back to the same time scale by using a cubic interpolation method which makes it possible to provide the missing data for the variables having a monthly scale, therefore reduced observations. Then, we test several competing volatility models. We use Garch-based models to model the volatility of financial variables and to capture some stylized facts that usually characterized the financial variables. We respectively use the basic *Garch* model of Bollerslev (1986) ; the EGARCH model of Nelson (1991) to capture the leverage effect of our variables ; the asymmetric GARCH of Glosten and Al (1993) which adds an asymmetric term to capture the asymmetric response of the conditional variance to shocks; and the FIGARCH model of Engle and Bollerslev (1996) to capture the long memory effect that characterizes the problem of liquidity of some cds returns. These different models stand as follows:

The GARCH(1,1) model of **Bollerslev (1986)**.

$$y_t = c + u_t, \text{ with } u_{it} = \sigma_{i,t}\varepsilon_{it}, \text{ and } \varepsilon_{it} \rightarrow \text{elliptical distribution}$$

$$\sigma^2_t = V(y_t|F_{t-1}) = \alpha_0 + \alpha\varepsilon_{t-1} + \beta\sigma_{t-1} \quad (1)$$

Where  $\sigma_t^2$  is the conditional variance,  $\epsilon_{t-1}$  is the innovation,  $\alpha$  measures the arch effects which represents the effects of past innovations and  $\beta$  measures the effect of past variance on the current variance. This is the *GARCH* term.

The EGARCH(1,1) model of **Nelson and Cao (1991)**

$$\ln(\sigma_{i,t}^2) = \alpha_0 + \alpha_1(\varphi z_{t-1} + \gamma [|z_{t-1}| - E|z_{t-1}|]) + \beta \ln\sigma_{t-1}^2 \quad (2)$$

With  $z_{t-i} = \frac{\epsilon_{t-i}}{\sigma_{t-i}}$ .

The conditional variance  $h_t$  shows a sign effect denoted by  $\alpha_1\varphi z_{t-1}$  and an amplitude effect measured by the model of Engle and **Bollerslev (1996)** FIGARCH(1,1)

$$\sigma_t^2 = \alpha_0 + \left[1 - (1 - \beta(L))^{-1}(1 - \varphi(L))(1 - L)^d\right] \epsilon_t^2 + \beta\sigma_{t-1}^2 \quad (3)$$

Here  $d$  is the long memory parameter. It measures the long memory effect presents in the model of volatility.

The model of Glosten-**Jaganathan-Runkle (1993)**

GJR – GARCH(1,1)

$$\sigma_t^2 = \alpha_0 + \alpha \epsilon_{t-1}^2 + \gamma I_{t-1} \epsilon_{i,t-1}^2 + \beta\sigma_{t-1}^2 \quad (4)$$

Where  $I$  is a dummy variable that measures the asymmetric response of the conditional variance to shocks it takes a value of unity in response to negative shocks. In addition to the constraints required to the standard *garch* to ensure stationarity and positivity ( $\omega > 0, \alpha \geq 0; \beta \geq 0; \alpha + \beta < 1$ ) and additional constraints has to be respected in the case of GJR-GARCH ( $\alpha + \beta + 0.5\gamma < 1$ ). To decide which Garch-based model has a superior fit (the order of ARMA specification in the mean equation; the type of the GARCH specification and the density of the error distribution, normal, t-student distribution or generalized error distribution) we follow Beine and Laurent (2003) and use the Schwarz information criteria. We conduct all the diagnostics tests for the residuals and the squared residuals to evaluate the goodness of fit of the selected models. Compared to an ad-hoc selection, such a well-developed pre-selection in the univariate GARCH modelling would potentially reinforce the efficiency of the related estimators and thus lead to more valid estimates of the volatility.



## 2 - 2- 2 Causality Test.

After isolating the best volatility model for cds returns and oil price returns, we apply a causal analysis in the sense of Granger (1969). Granger (1969) causality makes it possible to analyze the predictive link that can exist between numbers of economic quantities. For two stationary variables  $x_t$  and  $y_t$ , the linear causality test is based on an auto-regressive vector representation (VAR) that stands as follows:

$$\begin{cases} x_t = a_1 + \sum_{i=1}^k \alpha_i x_{t-i} + \sum_{i=1}^k \beta_i y_{t-i} + \varepsilon_{1t} \\ y_t = a_2 + \sum_{i=1}^k \gamma_i x_{t-i} + \sum_{i=1}^k \delta_i y_{t-i} + \varepsilon_{2t} \end{cases}$$

Where  $k$  is the length of vector delays  $x_t$  and  $y_t$ .

The following two null hypotheses can therefore be tested this way:

- (a)  $y$  does not cause  $x$  which is represented as follows  $H_0^1: \beta_i = 0$  for  $i = 1 \dots k$  and
- (b) The hypothesis that  $x$  does not cause  $y$ , which is presented as follows  $H_0^2: \delta_i = 0$  for  $i = 1 \dots k$ .

In the first case, the causality tested is the one that runs from  $y_t$  to  $x_t$  when the null hypothesis is rejected. In the second case, the causality tested is the opposite (from  $x_t$  to  $y_t$ ) when the null hypothesis is rejected. Bivariate causality is retained when the two null hypotheses initially mentioned are both rejected. The statistics of the test for these assumptions follows a Fisher distribution of  $(k, T - 2k - 1)$  degrees of freedom with  $T$  being the number of observations. The two hypotheses when rejected simultaneously, conclude to the presence of bidirectional causality between variables  $x$  and  $y$ , reflecting a feedback effect between the variables involved. In the case that all of the above assumptions are rejected, it will be said that the variables involved in our analysis exhibit no causal link between them, in either direction. In other words, neither of the two variables improves the predictability of the other.

### 3- Results and Discussion.

The analysis of the causality between the credit quality of the oil-exporting countries (cds spreads volatility) and the fundamentals of the oil market reveals patterns of causality well differentiated according to the countries present in our sample.

In the case of Venezuela, the first holder of oil reserves in the world (see table 1) on the first sub-period, no causal link is detected between the supply of production and the credit quality. The causal relationship only appeared after the slump of 2014. This is a one-way historical causality which stems from the volatility of cds premiums to stocks. So, in fact the causality over the global period is the result of the change in dynamics that occurred after the slump of 2014. We could have expected causality to run from supply to cds volatility, however, Venezuela has the particularity of being a member of OPEC and the world largest oil proven reserves holder (see table 1). It can be estimated that after the slump of 2014, the foreign exchange reserves had decreased to a point that the country was obliged to mobilize all of its production capacities to face the slump of oil price in mid-2014 and to meet its needs of currencies.

The same argument can be established in the case of stocks. Over the global period, in the Granger' sense, stocks cause Venezuela's cds volatility. This causality can be partly attributed to the events of the second sub-period in this case from 2014-2017 (fall of prices in 2014 and restructuring of the country's debt in November 2017). Intuitively, it can be estimated that when stocks in OECD countries are high on the market, the market power of the OPEC cartel over prices diminishes. A weak grip of the cartel on prices favoring lower prices and therefore close to the production costs of oil exporting countries and contribute to make them less solvent in the eyes of investors. Similarly, the other direction of causality from the volatility of cds to the stocks of OECD countries could be partly explained by the country's status as a member of OPEC cartel and the level of its oil proven reserves. A deterioration in the credit quality of the country following a drop in oil prices for example could push the latter to deviate from the quota policy set by the OPEC cartel within the limits of its production capacities in order to meet its currency needs. Given the limited production capacity of this country, the markets can enter into a precautionary approach by

favoring the constitution of stocks all the more since the country does not have a production capacity as flexible as that of the countries of the Gulf like Saudi Arabia. The relationship over the global period is only the result of the events which favored the causal pattern on the second sub-period, namely the boom in the production of shale oil, a declining demand for energy from emerging markets and political instability reinforced by the fall in prices in the specific case of this country.

Regarding the demand, the causality is bidirectional and appears on the second subperiod, it is therefore a causality favored by the elements mentioned above and an aggressive policy of the OPEC cartel against the development of shale oil in the United States and Canada.

As for prices, the causality is bidirectional and instantaneous over the global period and this pattern subsists well before the episode of mid-2014 slump even if it is more marked (threshold of 5%) going from the volatility of cds towards oil prices. The fact that causality is attenuated in the second sub-period would be due to the fact that Venezuela is not really the leader of the strategy within OPEC and that its production capacities are not as expandable as the other members on the market. These results of causality reinforce the intuitions of **Sharma and Thurasaimy (2013)** that, by a test of predictability establish that the oil price returns predict the returns of the cds of a sample of Asian countries.

The volatility of oil, which sums up the instability of the oil market, causes the volatility of Venezuela's cds volatility to have a retroactive effect. The causality is apparent in the first sub-period in only one direction (from price volatility to volatility of cds).

Similarly, expectations about oil prices appear to have a retroactive effect on the volatility of cds meaning that the credit quality of this country affects the anticipation in the oil market and that anticipation of oil prices affects the credit quality of this country.

Concerning the other countries of our sample, the causal pattern appearing at the end of our analysis is necessarily different and variable depending on the country or countries considered.

The first explanatory element is that countries have different endowments in oil reserves. **Hooper (2015)** has shown that in the case of Venezuela and Russia, the reserves of natural resources were understood as collateral in the assessment of the credit quality of exporting countries. The second element that could explain this difference in the link between the causality of these countries would be the quality of the institutions, the nature

of monetary policy in this case the exchange rate policy being implemented in the considered country . **Chuffart and Hooper (2019) show** that the reaction of cds spreads is sensitive to the current exchange rate regime by comparing Russia and Venezuela. The last potential factor that is able to explain this causal pattern is fiscal policy and its backing in certain countries to a sovereign fund with different sizes from one country to another. Indeed for **Mohaddes and Raissi (2017)**, sovereign wealth funds make it possible to mitigate the volatility of growth in an environment endowed with solid institutions and therefore to ensure macroeconomic stability which would favor a lower risk of default (**Hilscher and Nosbuch, 2010**).

Hence, in the case of Saudi Arabia, the causality appears over the global period only in the case of stocks where it is uni-directional from stocks to volatility of cds. This causality is bidirectional on the first sub-period and disappears on the second sub-period. That said, the more important the oil stocks built up by the OECD countries, the more it erodes the credit quality of the oil exporting countries. This is explained by the fact that the country is the largest exporter of oil and the build-up of stocks by the importing countries makes it lose all power to influence prices and therefore affect its reserves in foreign currency. Regarding the demand, the causality is bidirectional. The credit quality of this country has a retroactive effect on the demand for oil. Prices cause volatility of cds only during periods of oil market stress. On the first sub-period (period corresponding to the European debt crisis) the volatility of cds granger-cause prices and on the second sub-period the causality is bidirectional. As the world's second largest oil reserve holder behind Venezuela, it has a residual production capacity that gives it decision-making power within the cartel and is seen as a swing producer in the global oil market. This partly explains its resilience to the instability (volatility) of oil prices and to price expectations.

The case of Russia is close to Venezuela with a special status as the largest holder of proven oil reserve non-member of OPEC cartel. Russia's oil has been subject to sanctions since the annexation of Crimea. This has made Russia sensitive to oil market developments.

No causality, however, appears between supply and volatility of cds over the total period except for the second sub-period. A causality which runs from the volatility of cds of the country towards supply. This is not trivial because it corresponds in addition to the slump of 2014 to the period of annexation of Crimea by Russia. Over the global period, the

prices (whether anticipated or not including volatility) granger-cause the volatility of the cds of Russia with a retroactive effect on the global period of analysis. And finally, a bi-directional causality for stocks and demand are noted. This interconnection in the case of Russia appears almost over the two sub-periods. The country's de-dollarization policy and the exchange rate regime (**Chuffart and Hooper,2019**), mixed with political issues, are often advanced in the literature to explain this reinforced connection with the markets. The exchange rate also partly explains the scheme of the causal link in the first sub-period (2010-2014) which corresponds to the period of the European debt crisis. Indeed, in November 2014, the country switched from a free-floating exchange rate regime to a stricter exchange rate regime.

Amazingly, Norway, which has the greatest sovereign fund in the world and a global benchmark in terms of oil rents management, exhibits a strong connection with the oil market. One of the possible explanations for this situation could be the quality of the debt of this country which could be well rated by the investors and the holding by its sovereign fund a significant part of its 1000 billion of funds in the oil field ( Around 70 billion dollars of assets are related to oil sectors). This causal pattern in the case of Norway partly explains the government's decision in November 2017 to withdraw all of its assets from the oil sector.

In the case of Qatar, supply granger-causes volatility of cds over the total period. This causal link may be due to the presence of causality over the first sub-period corresponding to the period of the European debt crisis with a retroactive effect . A two-way causality is noted between oil spot prices and the volatility of cds over the global period. In the second sub-period, causality runs from the volatility of cds towards the spot price. A two-way causality is identified with the anticipated oil price prices. This causality probably has been accentuated by the European debt crisis which generated mistrust in the credit quality of Qatar (causality running from the volatility of cds towards expected prices).Indeed the Qatari fund holds assets around the world, particularly in Europe; this would have affected the relationship between the two markets during the first sub-period corresponding to a stress in the debt market. In the case of Kazakhstan, a relatively small producer compared to the other countries of our sample (see Table 1), supply causes the volatility of cds over the global period .

It is bidirectional in the first sub-period (period of stress on the sovereign debt market) and runs from the volatility of cds towards supply in the second sub-period. In terms of stocks, causality is only present in the first subperiod and is bidirectional. There is a two-way causality between demand and volatility of cds over the global period. Oil prices granger-cause volatility in cds over the global period while it is reversed in the first sub-period and bidirectional in the second sub-period. So to speak, the transmission of information between the two markets is reversed depending on the sub-period in which the two markets are located.

	Saudi Arabia			Venezuela			Russia			Kazakhstan			Qatar			Norway			
	Bef ore	Af ter	To tal	Bef ore	Af ter	total	Bef ore	Af ter	To tal	Bef ore	Af ter	To tal	Bef ore	Af ter	To tal	Bef ore	Af ter	To tal	
<b>Supply</b>		⇔			<=	< =		<=		⇔	<=	=>	⇔		=>	=>	⇔	⇔	
<b>Stock</b>	⇔		=>		⇔	⇔		=>	⇔	⇔								<=	
<b>Kilian Index</b>			⇔		⇔		⇔	<=	⇔			⇔		<=				<=	<=
<b>Oil price</b>	<=	⇔		⇔	⇔	⇔	=>	=>	=>	=>	<=	=>		<=	⇔	=>	⇔	⇔	
<b>Oil volatility</b>		=>		=>	⇔	⇔	=>	=>	⇔	=>	⇔	<=				=>	⇔		
<b>Anticipated price</b>	<=				⇔	⇔	⇔	⇔	⇔	⇔		⇔	<=		⇔		⇔	⇔	

Table 2: Summary of causal link between oil market fundamental and credit quality (Cds volatility) of Oil rich countries.

		Saudi Arabia			Venezuela			Russia			Kazakhstan			Qatar			Norway		
		Before	After	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After	Total	Before	After	Total
<b>Supply</b>	(1)	0.89 (0.61)	<b>4.45</b> <b>(0.03)</b>	0.920 (0.5133)	0.56 (0.95)	<b>2.02</b> <b>(0.00)</b>	0.99 (0.46)	0.60 (0.94)	1.19 (0.23)	0.64 (0.91)	<b>1.86</b> <b>(0.03)</b>	0.86 (0.66)	<b>1.67</b> <b>(0.03)</b>	<b>2.68</b> <b>(0.02)</b>	0.81 (0.73)	<b>2.26</b> <b>(0.02)</b>	<b>1.87</b> <b>(0.04)</b>	<b>2.855</b> <b>(0.00)</b>	<b>2.09</b> <b>(0.04)</b>
	(2)	0.785 (0.764)	<b>2.886</b> <b>(0.013)</b>	0.215 (0.995)	0.334 (0.999)	<b>1.6</b> <b>(0.046)</b>	<b>4.27</b> <b>(0.03)</b>	0.656 (0.900)	<b>2.311</b> <b>(0.011)</b>	0.588 (0.947)	<b>3.174</b> <b>(0.000)</b>	<b>1.849</b> <b>(0.019)</b>	0.903 (0.582)	<b>3.118</b> <b>(0.008)</b>	1.194 (0.235)	1.063 (0.382)	0.836 (0.696)	<b>1.903</b> <b>(0.013)</b>	<b>2.194</b> <b>(0.025)</b>
<b>Stock</b>	(1)	<b>4.19</b> <b>(0.04)</b>	0.68 (0.87)	<b>1.68</b> <b>(0.019)</b>	1.21 (0.23)	<b>8.85</b> <b>(0.00)</b>	2.01* (0.06)	0.80 (0.74)	<b>2.20</b> <b>(0.01)</b>	<b>2.25</b> <b>(0.04)</b>	<b>14.42</b> <b>(0.00)</b>	0.52 (0.92)	0.88 (0.63)	0.674 (0.88)	1.08 (0.35)	0.77 (0.77)	1.17 (0.28)	0.954 (0.52)	0.89 (0.61)
	(2)	<b>6.427</b> <b>(1.152e-09)</b>	0.501 (0.980)	0.446 (0.815)	1.054 (0.390)	<b>25.40</b> <b>(5.855e-07)</b>	<b>1.83</b> <b>(0.02)</b>	1.256 (0.18)	0.771 (0.570)	2.162* (0.055)	4.491 (0.000)	0.369 (0.998)	0.979 (0.492)	0.796 (0.749)	0.596 (0.941)	0.423 (0.832)	0.693 (0.867)	<b>2.79</b> <b>(0.002)</b>	0.732 (0.827)
<b>Kilian Index</b>	(1)	0.811 (0.73)	0.65 (0.89)	<b>4.63</b> <b>(0.000)</b>	0.46 (0.98)	<b>2.906</b> <b>(0.013)</b>	0.97 (0.49)	2.79* (0.09)	1.08 (0.34)	<b>1.81</b> <b>(0.02)</b>	0.74 (0.80)	0.38 (0.99)	2.353* (0.095)	1.16 (0.25)	0.890 (0.22)	0.91 (0.58)	0.69 (0.86)	1.17 (0.25)	0.99 (0.46)
	(2)	0.956 (0.525)	0.709 (0.850)	<b>2.8466</b> <b>(0.014)</b>	0.334 (0.999)	<b>4.28</b> <b>(0.01)</b>	0.576 (0.9)	<b>12.12</b> <b>(1.909e-11)</b>	<b>7.226</b> <b>(0.007)</b>	<b>3.280</b> <b>(0.020)</b>	0.629 (0.921)	0.748 (0.807)	<b>12.61</b> <b>(0.00)</b>	1.045 (0.403)	1.748* (0.066)	0.681 (0.848)	0.834 (0.698)	<b>1.913</b> <b>(0.047)</b>	1.723* (0.07)
<b>Oil price</b>	(1)	0.71 (0.84)	1.67* (0.08)	0.17 (1.00)	<b>2.85</b> <b>(0.014)</b>	<b>8.44</b> <b>(8.e-08)</b>	<b>3.20</b> <b>(0.00)</b>	<b>56.48</b> <b>(1.1e-13)</b>	<b>57.71</b> <b>(2.2e-16)</b>	<b>20.87</b> <b>(2e-16)</b>	<b>2.00</b> <b>(0.03)</b>	0.79 (0.74)	<b>13.67</b> <b>(0.00)</b>	0.952 (0.53)	0.74 (0.81)	<b>4.76</b> <b>(0.02)</b>	<b>4.40</b> <b>(0.00)</b>	<b>6.78</b> <b>(0.00)</b>	<b>11.31</b> <b>(0.00)</b>
	(2)	3.09* (0.078)	<b>3.143</b> <b>(0.008)</b>	0.268 (0.99)	1.894* (0.092)	<b>2.078</b> <b>(0.002)</b>	<b>3.646</b> <b>(0.012)</b>	0.965 (0.512)	0.688 (0.871)	0.856 (0.669)	1.271 (0.213)	<b>5.186</b> <b>(0.000)</b>	1.039 (0.409)	0.883 (0.629)	<b>2.225</b> <b>(0.038)</b>	<b>4.336</b> <b>(0.037)</b>	0.836 (0.696)	<b>9.524</b> <b>(0.002)</b>	<b>3.911</b> <b>(0.008)</b>
<b>Oil volatility</b>	(1)	0.96 (0.51)	<b>7.27</b> <b>(0.00)</b>	0.23 (1.00)	1.76* (0.09)	<b>2.47</b> <b>(0.03)</b>	<b>3.34</b> <b>(0.035)</b>	<b>2.99</b> <b>(0.010)</b>	<b>5.87</b> <b>(0.01)</b>	2.13* (0.09)	<b>3.95</b> <b>(0.00)</b>	<b>3.01</b> <b>(0.00)</b>	1.03 (0.41)	0.41 (0.99)	0.85 (0.66)	0.634 (0.917)	1.51* (0.06)	<b>1.70</b> <b>(0.03)</b>	1.13 (0.29)
	(2)	0.521 (0.975)	0.646 (0.907)	0.11 (1.00)	0.871 (0.647)	<b>2.323</b> <b>(0.041)</b>	<b>13.428</b> <b>(1.1e-8)</b>	0.965 (0.512)	0.731 (0.827)	2.131* (0.094)	0.416 (0.995)	<b>3.002</b> <b>(0.006)</b>	<b>2.884</b> <b>(0.000)</b>	0.804 (0.7401)	0.894 (0.614)	0.916 (0.582)	1.097 (0.337)	<b>6.783</b> <b>(0.009)</b>	1.133 (0.295)
<b>Anticipated price</b>	(1)	0.63 (0.91)	0.69 (0.86)	0.33 (0.99)	0.57 (0.95)	<b>3.60</b> <b>(e-06)</b>	<b>2.007</b> <b>(0.010)</b>	<b>6.06</b> <b>(0.01)</b>	<b>2.68</b> <b>(0.03)</b>	<b>5.47</b> <b>(5e-05)</b>	1.65* (0.08)	0.443 (0.991)	<b>3.79</b> <b>(4.e-05)</b>	1.19 (0.23)	0.78 (0.76)	<b>7.06</b> <b>(0.00)</b>	1.0 (0.45)	<b>15.09</b> <b>(0.00)</b>	<b>3.02</b> <b>(0.00)</b>
	(2)	1.47* (0.061)	0.593 (0.942)	0.575 (0.95)	1.029 (0.423)	<b>5.97</b> <b>(2.015e-05)</b>	<b>3.816</b> <b>(4.0e-5)</b>	2.568 (0.025)	<b>2.667</b> <b>(8.21e-05)</b>	<b>4.041</b> <b>(0.000)</b>	<b>4.857</b> <b>(0.000)</b>	0.185 (1)	<b>12.868</b> <b>(0.000)</b>	<b>2.057</b> <b>(0.025)</b>	0.483 (0.985)	<b>7.359</b> <b>(0.006)</b>	0.876 (0.640)	<b>4.215</b> <b>(0.015)</b>	<b>6.810</b> <b>(2.6e-6)</b>

Table holds test coeffs values and their p-values in (.). (1) refers to causality test of left hand side variable on CDS vol while (2) refers to causality test of CDS vol on left hand side variable. Values in bold indicate significance at 5% or less, while \* designate significance as

#### 4- Conclusion.

The causal analysis between oil market variables and the credit quality of oil exporting countries reveals several conclusions. First, the slump of mid-2014 created a strong connection between the variables of the oil market and the credit quality of the oil-exporting countries.

Secondly, there is a clear difference between the oil exporting countries with a rather unexpected result for the case of Norway. Saudi Arabia seems to be the most resilient country compared to the other exporting countries confirming its status of leading country in the OPEC cartel. Venezuela and Russia show a strong connection between the variables of the oil market with predominance for Venezuela. Kazakhstan, a relatively small producer, exhibits only an intermediate connection over the entire period, but mainly caused by factors prior to the mid-2014 slump. The countries' membership of the cartel does not seem to be a determining factor in the causal link between the variables of the oil market and the credit quality, however the effect of the reserves is rather nuanced. We note that overall, the credit quality of the oil exporting countries constitutes a growing risk weighing on the oil market and that the latter is affected by the variables of the oil market.

These results also confirm the intuition behind the wave of downgrading of the ratings of oil-exporting countries that Moody's have done after the slump of 2014. In terms of economic policy, we can draw several recommendations.

The oil exporting countries states could draw on these results to better guide their policy of refinancing by the financial market. Also, the slump of mid-2014 created an additional risk on the respect of quota policies within the OPEC cartel and the extended cartel to countries like Russia (OPEC +) which translate into tension on oil market equilibrium. These results can therefore be used as indicators in the oil demand policy formulation for oil importers like emerging countries and for portfolio managers as it allows them to better rebalance their portfolio according to the trends on the oil market and the debt market. In times of tension, whether on the debt market or on the oil market, the connection between the two markets is strengthened depending on the country. The case of Norway calls for further analysis of the relationship between the two markets and the determinants of this causal link. One of the elements of assessment would be to mobilize a



multiscale analysis to better detect the role of agents' investment horizons which could be a factor explaining the causal links (Benhmad, 2012) or Sadefo-Kamdem et al. (2016).

**Annex :**

**Table 1**

	Production of barrel per day	Production per head	Proven oil reserve in barrel	Revenue as % of 2018 exports	OPEC Members
<b>Saudi Arabia</b>	12 000 000	324 866	266 578 000 000	77%	Yes
<b>Russia</b>	10 800 000	73 292	80 000 000 000	52%	No
<b>Venezuela</b>	2 276 967	69 914	299 953 000 000	98%	Yes
<b>Norway</b>	1 647 975	313 661	5 497 000 000	62%	No
<b>Kazakhstan</b>	1 595 199	88 686	30 000 000 000	70%	No
<b>Qatar</b>	1 800 000	78 5	25 244 000 000	81%	Yes (till 2019)

**Table 1: (Authors' compilation from World Bank indicators (WDI))**

**Table 2 : Descriptive statistics of CDS and oil returns**

Country	Mean	Min	Max	Stand deviation	Ljung Box Test	Arch test	Skewness	Kurtosis
<b>Venezuela</b>	<b>3.238</b>	<b>2.7584</b>	<b>4.0277</b>	<b>0.1155</b>	<b>1799.8</b>	<b>447</b>	<b>0.5719</b>	<b>1.780</b>
<b>Saudi Arabia</b>	<b>1.956</b>	<b>1.608</b>	<b>2.294</b>	<b>0.0244</b>	<b>1812.3</b>	<b>33.35</b>	<b>0.2465</b>	<b>2.070</b>
<b>Norway</b>	<b>1.276</b>	<b>1.0426</b>	<b>1.7306</b>	<b>0.0232</b>	<b>1797.9</b>	<b>52.1</b>	<b>0.890</b>	<b>3.268</b>
<b>Kazakhstan</b>	<b>2.307</b>	<b>2.1120</b>	<b>2.5389</b>	<b>0.0102</b>	<b>1782.4</b>	<b>140</b>	<b>0.318</b>	<b>2.106</b>
<b>Russia</b>	<b>0.0230</b>	<b>2.0492</b>	<b>2.7892</b>	<b>0.0230</b>	<b>1800.3</b>	<b>61.7</b>	<b>0.678</b>	<b>2.969</b>
<b>Qatar</b>	<b>1.932</b>	<b>1.6582</b>	<b>2.1732</b>	<b>0.0111</b>	<b>1798.5</b>	<b>121</b>	<b>-0.026</b>	<b>2.393</b>
<b>brent</b>	<b>1.903</b>	<b>1.4151</b>	<b>2.1076</b>	<b>0.0287</b>	<b>1817.6</b>	<b>156</b>	<b>-0.733</b>	<b>2.151</b>

**Table 3: Stationarity Test.**

<b>Variables</b>	<b>Levels series</b>		<b>Returns series</b>	
	<b>ADF Test</b>	<b>PP-test</b>	<b>ADF Test</b>	<b>PP-test</b>
<b>Saudi Arabia</b>	-1.65	-5.77	-40.0***	-1651***
<b>Kazaakhstan</b>	-3.01	-15.4	-45.8***	-1820***
<b>Qatar</b>	-2.57	-10.1	-46.7***	-1862***
<b>Norway</b>	3.07	-12.3	-47.4***	-1794***
<b>Venezuela</b>	-2.57	-10.2	-59.0***	-2062***
<b>Oil</b>	-1.86	-5.99	-40.7***	-1757***
<b>Kilian Index</b>	-0.37	-6.61	-18.41***	-738***
<b>Stocks</b>	-1.41	-5.17	-18.50***	-754***
<b>Supply</b>	0.556	-3.03	-18.61***	-760***
<b>Anticipated price</b>	-2.45	-3.2	-18.36***	-730***

**Table 3 : Stationnarity Test**

		Oil	Saud. Arabia	Kazakhst	Norway	Russia	Venezuela	Qatar
<b>From 2010 to May 2014</b>								
<i>Mean Equation</i>	Constant	0.0001 (0.252)	0.000 (0.911)	0.000 (0.139)	-0.00012 (0.4395)	-0.000 (0.399)	-0.002 (0.513)	-5.9E-5 (0.000)
	<i>AR(1)</i>	<b>-0.145</b> <b>(0.000)</b>	<b>0.458</b> <b>(0.000)</b>	<b>0.067</b> <b>(0.000)</b>	0.011 (0.5545)	<b>1.675</b> <b>(0.000)</b>	0.198 (0.708)	<b>0.510</b> <b>(0.000)</b>
	<i>AR(2)</i>	<b>-0.991</b> <b>(0.000)</b>	0.027 (0.5787)	<b>-0.088</b> <b>(0.000)</b>		<b>-0.749</b> <b>(0.000)</b>		
	<i>MA(1)</i>	<b>0.137</b> <b>(0.000)</b>	<b>-0.594</b> <b>(0.000)</b>	<b>-0.0647</b> <b>(0.000)</b>		<b>-1.631</b> <b>(0.000)</b>	-0.200 (0.706)	-0.532 (0.000)
	<i>MA(2)</i>	<b>0.999</b> <b>(0.000)</b>	0.042 (0.177)	<b>0.087</b> <b>(0.000)</b>		<b>0.693</b> <b>(0.000)</b>	0.0282 (0.317)	
<i>Variance Equation</i>	Constant	<b>0.000</b> <b>(0.389)</b>	0.000 (0.904)	0.000 (0.916)	0.000 (0.998)	-0.442 (0.470)	<b>0.000</b> <b>(0.001)</b>	0.000 (0.981)
	$\alpha$	<b>0.0254</b> <b>(0.002)</b>	<b>0.930</b> <b>(0.000)</b>	0.0602 (0.237)	<b>0.0668</b> <b>(0.000)</b>	<b>0.191</b> <b>(0.002)</b>	<b>0.507</b> <b>(0.000)</b>	0.061 (0.699)
	$\beta$	<b>0.936</b> <b>(0.000)</b>	<b>0.069</b> <b>(0.000)</b>	<b>0.858</b> <b>(0.000)</b>	0.9331	<b>0.943</b> <b>(0.000)</b>	<b>0.491</b> <b>(0.00)</b>	<b>0.859</b> <b>(0.000)</b>
	$\gamma$	<b>0.051</b> <b>(0.003)</b>		<b>0.8457</b> <b>(0.000)</b>		0.371** (0.062)		<b>0.843</b> <b>(0.000)</b>
	$d$			<b>0.846</b> <b>(0.000)</b>				<b>0.843</b> <b>(0.000)</b>
	Shape	<b>1.368</b> <b>(0.000)</b>	<b>2.293</b> <b>(0.000)</b>	<b>0.435</b> <b>(0.000)</b>	<b>2.499</b> <b>(0.000)</b>	<b>2.561</b> <b>(0.000)</b>	<b>2.612</b> <b>(0.000)</b>	<b>0.280</b> <b>(0.000)</b>
<i>Diagnostics tests</i>	$Q - Squ(5)$	3.600 (0.3082)	0.042 (0.999)	2.7117 (0.4622)	1.708 (0.6887)	1.086 (0.839)	0.218 (0.991)	0.443 (0.966)
	$Q - Squ(9)$	4.446 (0.515)	0.090 (1.000)	3.7431 (0.6326)	3.233 (0.7199)	1.607 (0.946)	1.584 (0.948)	0.766 (0.994)
	ARCH (5)	0.722 (0.817)	0.0333 (0.997)	3.226 (0.2587)	1.984 (0.4748)	0.834 (0.782)	0.228 (0.958)	0.307 (0.938)
	ARCH (7)	1.0898 (0.998)	0.0789 (0.999)	3.370 (0.446)	2.7276 (0.5664)	1.145 (0.889)	0.4293 (0.984)	0.439 (0.984)

**Table 4 : Volatility estimation of 5 years cds spreads and oil returns**

		Oil	Saud. Arabia	Kazakhst	Norway	Russia	Venezuela	Qatar
<b>From June 2014 to March 2017</b>								
<i>Mean Equation</i>	Constant	<b>-6E-4</b> <b>(0.003)</b>	0.00004 (0.000)	-0.00 (0.4807)	<b>2E-5</b> <b>(0.000)</b>	<b>0.0001</b> <b>(0.000)</b>	<b>4E-4</b> <b>(0.000)</b>	-0.000 (0.192)
	<i>AR(1)</i>	0.020 (0.487)	-0.0033 (0.000)		<b>-0.6195</b> <b>(0.000)</b>			<b>0.262</b> <b>(0.000)</b>
	<i>AR(2)</i>				<b>-0.2544</b> <b>(0.000)</b>			
	<i>MA(1)</i>			0.0403 (0.1658)	<b>0.6193</b> <b>(0.000)</b>	<b>0.072</b> <b>(0.000)</b>	<b>0.0078</b> <b>(0.000)</b>	<b>-0.260</b> <b>(0.000)</b>

	<i>MA(2)</i>			0.0374 (0.1106)	<b>0.259</b> <b>(0.000)</b>			
<i>Variance Equation</i>	<b>Constant</b>	0.0002 (0.937)	<b>0.0017</b> <b>(0.000)</b>	<b>2.124</b> <b>(0.0001)</b>	0.000 (0.899)	<b>0.0607</b> <b>(0.000)</b>	0.287 (0.126)	0.00 (0.9372)
	<i>α</i>	<b>0.081</b> <b>(0.000)</b>	-0.074 (0.1959)	-0.041 (0.665)	0.058 (0.5071)	<b>0.0534</b> <b>(0.000)</b>	0.0836 (0.4487)	<b>0.0518</b> <b>(0.000)</b>
	<i>β</i>	<b>0.976</b> <b>(0.000)</b>	<b>0.900</b> <b>(0.000)</b>	<b>0.764</b> <b>(0.000)</b>	<b>0.8502</b> <b>(0.000)</b>	<b>0.9929</b> <b>(0.000)</b>	<b>0.962</b> <b>(0.000)</b>	<b>0.918</b> <b>(0.000)</b>
	<i>γ</i>	<b>0.119</b> <b>(0.000)</b>	<b>0.329</b> <b>(0.000)</b>	<b>0.731</b> <b>(0.000)</b>		<b>-0.0328</b> <b>(0.000)</b>	<b>0.22</b> <b>(0.0018)</b>	0.017 (0.4967)
	<i>d</i>				<b>0.8418</b> <b>(0.000)</b>			
	<b>Shape</b>	<b>1.241</b> <b>(0.000)</b>	<b>0.314</b> <b>(0.000)</b>	<b>2.100</b> <b>(0.000)</b>	<b>0.1898</b> <b>(0.000)</b>	<b>1.2307</b> <b>(0.000)</b>	<b>0.643</b> <b>(0.000)</b>	<b>0.2249</b> <b>(0.000)</b>
<i>Diagnostics tests</i>	<i>Q – Squ(5)</i>	3.333 (0.354)	0.068 (0.999)	0.227 (0.990)	1.1994 (0.8131)	1.8312 (0.6588)	1.067 (0.844)	4.019 (0.0634)
	<i>Q – Squ(9)</i>	4.6063 (0.4894)	0.113 (1.00)	0.3279 (0.9996)	1.3511 (0.9668)	2.8462 (0.7841)	1.7697 (0.9306)	4.428 (0.5885)
	<i>ARCH (5)</i>	4.533 (0.1316)	0.055 (0.994)	0.1789 (0.9704)	0.3054 (0.9388)	3.129 (0.2716)	1.0378 (0.7217)	0.8223 (0.7863)
	<i>ARCH (7)</i>	4.735 (0.2527)	0.083 (0.999)	0.2054 (0.9969)	0.3414 (0.9904)	3.516 (0.9218)	1.3936 (0.8425)	1.4618 (0.8290)

**Table 5 : Volatility estimation of cds and oil returns**

	<b>Oil</b>	<b>Saud. Arabia</b>	<b>Kazakhst</b>	<b>Norway</b>	<b>Russia</b>	<b>Venezuela</b>	<b>Qatar</b>	
<b>From 2010 to May 2014</b>								
<i>Mean Equation</i>	Constant	0.0001 (0.252)	0.000 (0.911)	0.000 (0.139)	-0.00012 (0.4395)	-0.000 (0.399)	-0.002 (0.513)	-5.9E-5 (0.000)
	<i>AR(1)</i>	<b>-0.145</b> <b>(0.000)</b>	<b>0.458</b> <b>(0.000)</b>	<b>0.067</b> <b>(0.000)</b>	0.011 (0.5545)	<b>1.675</b> <b>(0.000)</b>	0.198 (0.708)	<b>0.510</b> <b>(0.000)</b>
	<i>AR(2)</i>	<b>-0.991</b> <b>(0.000)</b>	0.027 (0.5787)	<b>-0.088</b> <b>(0.000)</b>		<b>-0.749</b> <b>(0.000)</b>		
	<i>MA(1)</i>	<b>0.137</b> <b>(0.000)</b>	<b>-0.594</b> <b>(0.000)</b>	<b>-0.0647</b> <b>(0.000)</b>		<b>-1.631</b> <b>(0.000)</b>	-0.200 (0.706)	-0.532 (0.000)
	<i>MA(2)</i>	<b>0.999</b> <b>(0.000)</b>	0.042 (0.177)	<b>0.087</b> <b>(0.000)</b>		<b>0.693</b> <b>(0.000)</b>	0.0282 (0.317)	
<i>Variance Equation</i>	<b>Constant</b>	<b>0.000</b> <b>(0.389)</b>	0.000 (0.904)	0.000 (0.916)	0.000 (0.998)	-0.442 (0.470)	<b>0.000</b> <b>(0.001)</b>	0.000 (0.981)
	<i>α</i>	<b>0.0254</b> <b>(0.002)</b>	<b>0.930</b> <b>(0.000)</b>	0.0602 (0.237)	<b>0.0668</b> <b>(0.000)</b>	<b>0.191</b> <b>(0.002)</b>	<b>0.507</b> <b>(0.000)</b>	0.061 (0.699)
	<i>β</i>	<b>0.936</b> <b>(0.000)</b>	<b>0.069</b> <b>(0.000)</b>	<b>0.858</b> <b>(0.000)</b>	0.9331	<b>0.943</b> <b>(0.000)</b>	<b>0.491</b> <b>(0.00)</b>	<b>0.859</b> <b>(0.000)</b>
	<i>γ</i>	<b>0.051</b> <b>(0.003)</b>		<b>0.8457</b> <b>(0.000)</b>		0.371** (0.062)		<b>0.843</b> <b>(0.000)</b>
	<i>d</i>			<b>0.846</b> <b>(0.000)</b>				<b>0.843</b> <b>(0.000)</b>
<b>Shape</b>	<b>1.368</b> <b>(0.000)</b>	<b>2.293</b> <b>(0.000)</b>	<b>0.435</b> <b>(0.000)</b>	<b>2.499</b> <b>(0.000)</b>	<b>2.561</b> <b>(0.000)</b>	<b>2.612</b> <b>(0.000)</b>	<b>0.280</b> <b>(0.000)</b>	
<i>Diagnostics tests</i>	<i>Q – Squ(5)</i>	3.600 (0.3082)	0.042 (0.999)	2.7117 (0.4622)	1.708 (0.6887)	1.086 (0.839)	0.218 (0.991)	0.443 (0.966)
	<i>Q – Squ(9)</i>	4.446 (0.515)	0.090 (1.000)	3.7431 (0.6326)	3.233 (0.7199)	1.607 (0.946)	1.584 (0.948)	0.766 (0.994)
	<i>ARCH (5)</i>	0.722 (0.817)	0.0333 (0.997)	3.226 (0.2587)	1.984 (0.4748)	0.834 (0.782)	0.228 (0.958)	0.307 (0.938)
	<i>ARCH (7)</i>	1.0898 (0.998)	0.0789 (0.999)	3.370 (0.446)	2.7276 (0.5664)	1.145 (0.889)	0.4293 (0.984)	0.439 (0.984)

## Cubic Interpolation

The spline method creates a function  $C^2$  of polynomial functions to join the observations of a couple of data that we denote  $(x_i, f(x_i))_{i \in [0, n]}$ . If we consider a polynomial function of degree 3 on each sub-interval  $[x_i, x_{i+1}]$ , we can then have a Taylor expansion of the function denoted by  $p$  at the neighborhood of  $x_i$  :

$$p_i(x) = f_i + f'_i(x - x_i) + \frac{f''_i}{2!}(x - x_i)^2 + \frac{f'''_i}{3!}(x - x_i)^3, i \in [0, n - 1] \quad (1)$$

The meaning of the interpolation is then to find the values of the constants  $(f_i, f'_i, f''_i, f'''_i)_{i \in [0, n-1]}$  by using data available in the initial data pairs  $(x_i, f(x_i))_{i \in [0, n]}$ . So that the function  $p_i$  can join the coordinate points  $(x_i, f(x_i))$  and reach the final limit of the interval, that is to say  $p_i(x_i) = f(x_i)$  for everything  $i \in [0, n - 1]$  and  $p_{n-1}(x_n) = f(x_n)$ , the function must fulfill the following conditions:

The function must be of  $C^0$  class, that is to say for everything  $i \in [0, n - 2]$ ,  $p_i(x_{i+1}) = p_{i+1}(x_{i+1})$ . The function must also be of  $C^1$  class, that is to say for everything  $i \in [0, n - 2]$ ,  $p'_i(x_{i+1}) = p'_{i+1}(x_{i+1})$ . Finally the function must be of class  $C^2$ , that is to say for everything  $i \in [0, n - 2]$ ,  $p''_i(x_{i+1}) = p''_{i+1}(x_{i+1})$ .

The first and second derivatives noted  $(f'_i, f''_i)_{i \in [0, n-1]}$  are expressed as a function of the second derivative  $(f''_i)_{i \in [0, n]}$  because containing known variables. The final equation is then given by the following formulas:

$$f_i = f(x_i), \forall i \in [0, n - 1] \quad (2)$$

$$f'_i = \frac{f(x_{i+1}) - f(x_i)}{h} - h \left[ \frac{f''_i}{3} + \frac{f''_{i+1}}{6} \right], \forall i \in [0, n - 1] \quad (3)$$

$$f'''_i = \frac{f''_{i+1} - f''_i}{h}, \forall i \in [0, n - 1] \quad (4)$$

$$f''_i + 4f''_{i+1} + f''_{i+2} = \frac{6}{h^2} [2f(x_{i+1}) - f(x_{i+1}) - f(x_{i+2}) - f(x_i)], \forall i \in [0, n - 2] \quad (5)$$

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