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Oil Exploration Economics: Empirical Evidence from Indonesian Geological Basins[☆]

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Abstract

Oil exploration has been subject to economic research for decades. Earlier studies of exploration models are mostly discussed the behavior of exploration at the macro-level analysis such as field, firm, region, and continental. This paper then focuses on the geological and economic factors that determine the well-drilling decision at the micro-level using disaggregated panel data of 32 geological basins in Indonesia over the period of 2004–2013. This study shows that the number of drilled wells is determined significantly by the lag of success rate, lag of discovery size, lag of global oil price, and regional location of geological basin.

Keywords: Drilling; Geological Variables; Economic Variables; Exploration

Abstrak

Eksplorasi migas telah menjadi subyek ekonomi dalam beberapa dekade. Studi-studi sebelumnya dengan model eksplorasi, kebanyakan mengembangkan model Fisher (1964), secara umum dikelompokkan oleh persamaan yang menjelaskan respons eksplorasi pada tingkat makro menggunakan lapangan, perusahaan, wilayah, dan kontinental. Paper ini fokus pada analisis faktor-faktor geologi dan ekonomi yang menentukan tingkat sumur pemboran pada tingkat mikro menggunakan data panel dari 32 basin di Indonesia dalam periode 2004–2013. Hasil empiris menunjukkan bahwa tingkat sumur pemboran ditentukan secara signifikan berdasarkan tingkat keberhasilan pemboran, ukuran temuan dan harga minyak pada tahun sebelumnya serta lokasi basin geologis.

Kata kunci: *Pengeboran; Variabel Geologi; Variabel Ekonomi; Eksplorasi*

JEL classifications: L71; Q35

1. Introduction

Petroleum exploration has been subject to economic research for decades, but many studies have been concentrated in the US with some studies conducted for the United Kingdom and Norway. Earlier studies of exploration models, which are mostly based on Fisher (1964), have been generally characterized by equations describing the behavior of exploration at the macro-level analysis using various levels of empirical analysis including field (Attanasi & Drew 1986), firm (Ghouri 1991; Forbes & Zampelli 2000), region (Fisher 1964; Erickson & Spann 1971; Pindyck 1978; Kolb, 1979), and continent (Mohn & Osmundsen, 2008).

On the other hand, some studies have been dissatisfied with macro-level analysis in explaining the exploration behavior, as Mohn & Osmundsen (2008) reported that many exploration articles except Ghouri (1991) and Iledare (1995) fell into this category. An alternative approach is to view exploration behavior from the company's perspective and the base the econometric models on micro data. In fact there is a specific impact of geological basins on the drilled wells. However, highly aggregated data relating to exploration behavior at the geological basin have been limited due to availabil-

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[☆] This present paper is developed based on an academic thesis at the Faculty of Economics and Business, Economics Program, Universitas Indonesia , which was nominated as the best thesis in 2015.

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ity of geological data. Thus, little attention has been focused on addressing this specific issue into a micro analysis at the geological basin level.

There has been less number of empirical analyses that use the geological basin level, which is considered more representative to explain the pattern of exploratory (Managi et al. 2005; Mohn & Osmundsen 2008). Moreover, empirical studies on Indonesia's exploration have been relatively few in number, which is probably caused by unavalability of data. Nasir (2011) regressed the drilling decision using time series data consisting of seismic survey, discovery rate, exploration cost, oil price, and level of consumption. However, those parameters have insignificantly explained the drilling decision and recommended further researches using disaggregate analysis which include region and offshore area. In fact, there is a specific impact of geological basin characteristics on well-drilling decision.

The purpose of this paper is to examine the impact of natural geology on exploration decision, using Indonesian basin as a case study. The Indonesian exploration is an interesting case since Indonesia has been facing a new paradigm due to the shift of exploration drilling from mature fields in the west to emerging fields in the east prone in terms of increasing national oil reserves. After the oil period ended in 2001, many discoveries of natural gas have been developed. These are largely dominated by offshore fields at the eastern region including South Makassar, Tomori, Arafura, Salawati, and Papuan Basin, with several of them consisting of offshore and deep water development. Moreover, USGS (2007) reported that the number of wildcat wells drilled each year in Indonesia had been the largest among Asian countries, with 3,794 of 13,036 wells drilled over the period of 1961–2001, 36 mil2/well of current growth in delineated prospective area per wildcat, and 0.149 of richness of total oil discoveries of total delineated prospective area (USGS 2007).

Here we investigated the second paradigm of shifting onshore to offshore drilling, in which the exploring companies are assumed to choose a level of investment that maximizes the firm's value after balancing expected revenues against the risks involved in exploration and the corresponding costs. Combining the investment characterization, the study continued to an expression of the total amount of wells drilled in each geological basin in terms of estimates of anticipated returns and anticipated risk. Finally, we completed our analysis with geological-economic variables into an empirical model.

This study makes two contributions towards understanding the economics of oil and gas exploration. First, this study shows how the geological nature significantly affects drilling decision more than economic variables. This result has a similar conclusion to IPA's (2012), which stated that the number of exploration wells drilled had been relatively stable during the fluctuation of oil prices which only changed the number of drilling projects. Second, our empirical analysis explicitly takes account of offshore percentage and basin's region concerning the success rate and discovery size to explain the new exploration paradigm of "West to East Prone" and "Onshore to Offshore Drilling".

The paper is systematically organized as follows. First, the background and objective are briefly described. Section 2 provides an overview of earlier literatures. An explanation of theoretical framework is offered in Section 3, before an empirical method of well-drilling decision is derived in Section 4. Furthermore, Section 5 consists of the research data. Econometric results are presented and discussed in Section 6 before several concluding remarks are offered in Section 7.

1.1. Stylized Facts

To focus the discussion, this paper presents the main stylized facts for a model of oil and gas exploration. **Figure 2** shows the geological and economic data of east prone on the left side and west prone on the right side. Geological data consist of success rate (S_c), oil discovery size (D_O), gas discovery size (D_G), and offshore percentage (off). Economic data consist of oil price (p), spending per well (S_p), and value per well (V_w).

US Geology Survey (2007) reported that the first basin was discovered in North Sumatra in 1885. Since the first discovery, exploration drilling has significantly increased, most of which takes place in western Indonesia such as East Java Basin, South Sumatera Basin, Central Sumatra Basin, Northwest Java Basin, Sarawak Basin, and Malay Basin; while drilling in eastern Indonesia has been conducted in Kutei Basin, Pamusiman Tarakan

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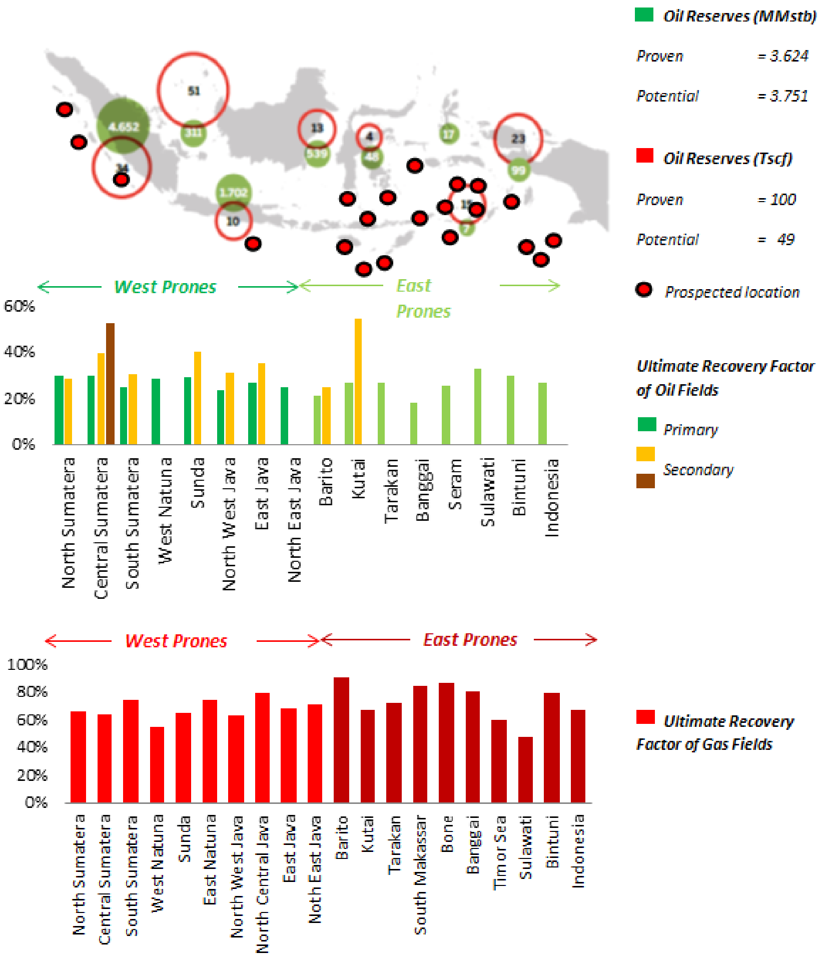


Figure 1: Ultimate Recovery Factor of Oil and Gas and Prospective Locations in Indonesia
Source: SKK Migas (2015) and Indonesian Petroleum Association (2014)

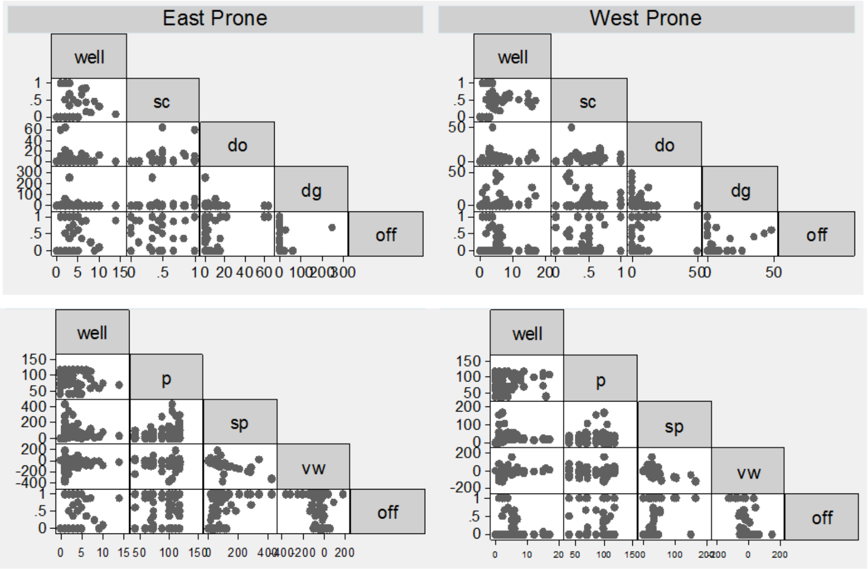
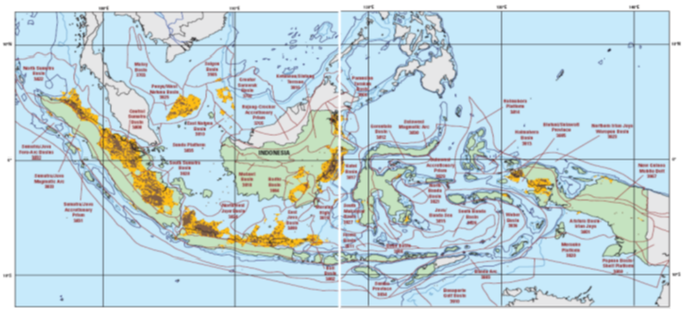


Figure 2: Geological and Economic Data of Indonesian Geological Basins
Source: Author, using Stata 13.0 for the unpublished data of Indonesian exploration, accessed through the author' account in SKK Migas in February 2015



Basin Name[2]

1	Bengkulu	9	Northwest Java	17	Biliton	25	Papuan
2	Central Sumatra	10	East Natuna	18	Bintuni	26	Pasir - Asem
3	East Java	11	South Java	19	Bonaparte	27	Salawati
4	Java Sea	12	South Sumatra	20	Buton	28	Seram
5	Kai - Aru Trough	13	Sunda	21	Irian Arafura	29	South Makassar
6	Malay	14	West Natuna	22	Kutei	30	Tarakan
7	Nam Con Son	15	Arafura	23	Lariang	31	Tomori
8	North Sumatra	16	Barito	24	North New Guinea	32	Unc. Basin

Figure 3: Indonesian Geological Basins in Western and Eastern of Indonesia
Note: Bengkulu to West Natuna are located in the western part of Indonesia (west prone), while the rest of the basins are located in the eastern part of Indonesia (east prone).
Source: US Geology Survey (2007)

Basin, Bintuni Basin, and Sulawesi Basin. The Indonesia Geological Basins consist of 2 (two) main parts of geological region. Western Indonesia is relatively underlain by mature fields and mainly consists of oil discoveries. On the other hand, the eastern region has been largely dominated by emerging fields and mainly consists of natural gas discoveries.

The diversity of geological regions qualitatively indicates the impact of natural geology to well-drilling decision. Mature basins such as Central Sumatra, South Sumatra, North West Java, and East Java are characterized by well-established exploration models, minor technical challenges, and maximized existing infrastructures. Therefore, expected discovery rates are often relatively high for such areas. However, the average discovery size is usually limited due to natural declining effect. On the other hand, emerging basins such as South Makassar, Tomori, Salawati, and Papuan Basins are distinguished by poorer comprehension of the geology, technological challenges, and limitation of installed infrastructures. Thus, the exploration risk is higher as indicated by relatively lower success rates, but the expected rewards are often relatively high in discovery size.

In the model, oil prices influence exploration drilling decision, which leads to discovery. On the other hand, gas price is represented by oil price for some reasons. National gas prices are generally comprised of pipe gas and liquefied natural gas (LNG) prices. LNG prices, as a trading commodity, are generally regulated based on world oil price. Since LNG has been mostly exported to Japan, contracted prices are determined by Japan Crude Cocktail (JCC) in the equation of $LNGPrice = \alpha \times JCC + \beta$, wherein Îś represents a slope of price and Îš cost of transportation. On the other hand, prices of pipe gas in certain fields may be different, which are subject to government regulation. Therefore, world oil prices are more appropriate in explaining the profit return in short- and long-term investment.

This study uses an assumption of fixed traditional inputs which consist of labor, capital, and interest rate. Existing literatures show that exploration models have used this assumption, excluding the impact of labor, capital, and interest rate (Dahl & Duggan 1998; Iledare et al. 2000; Mohn & Osmundson 2008). Exploration companies have employed exploration staff for the long term (Mohn & Osmundson 2008). A standby capacity has been maintained over the business cycle, almost independent of fluctuations in the oil price and exploration activity from year to year. From the exploration companies' side, exploration activities are moderately capital-intensive, as all capital equipment is hired for specific acitivities. I therefore hypothesized a subordinate role for traditional inputs such as capital and labor in decisions concerning exploration activity. This means that fluctuations in exploration activity from one year to another are driven mainly by the oil price, as well as the availability and quality of exploration opportunities (Mohn & Osmundson 2008). Moreover, the role of traditional inputs has not been well explained in the empirical studies of exploration behavior (Dahl & Duggan 1998). Attempts have been made to include interest rates and user cost of capital (e.q. Pindyck 1978; Peseran 1990), but their role is generally not justified by econometric evidence. Interest rate variables are therefore normally not included in modern empirical exploration studies (e.g., Iledare et al. 1999; Farzin 2001). The strongest argument for this simplification is that dynamic optimisation is not well supported by previous attempts to explain the economics of oil and gas exploration.

2. Literature Review

The combination of geological and economic variables in empirical models of exploration dates back 40 years, with Fisher (1964) claimed to have opened this field of research with his seminal econometric studies of US oil and gas exploration. Fisher (1964) used a three-stage model with estimating equations for total wildcat wells, success ratio, and the average size of discovery for different US Petroleum Administration Defense Districts (PADD) over the period of 1946–1955. The explanatory variables include oil prices, seismic crews, and proxy variables for drilling costs. His contribution is important to explain how economic variables affect well-drilling decision. When economic incentives increase, not only the total number of wells drilled goes up, but the average characteristics of the drilling prospects change because it now becomes worthwhile to drill wells with poorer prospect.

Since the pioneering work of Fisher (1964), a substantial literature on oil and gas exploration has developed. In the 1970s, empirical analyses were mostly based on the aggregate level. Since the mid-1980s, a growing number of studies have used state, regional, or firm-level data. There are clear advantages to using micro-level data, since aggregation of data across distinctive geologic provinces may obscure the effects of economic and policy variables on the pattern of exploratory activities (e.g. Pindyck 1978). Concentrating on gas exploration, Pindyck (1978) estimated a similar model on a broader data set, with quite different results from those of Fisher (1964) and Erickson & Spann (1971). Kolb (1979) focused on oil-prone districts in a slightly more disaggregated approach. These early Fisher models had a simple structure that largely could be justified based on economic fundamental principles.

A growing number of studies have used state, regional, or firm-level data since the mid-1980s (Managi et.al. 2005). However, the most common perspective has been based on aggregate data for regions, countries, or groups of countries. Moreover, there are clear advantages to using micro firm-level data, since aggregation of data across distinctive geologic provinces may obscure the effects of economic and policy variables on the pattern of exploratory activities (e.g., Pindyck 1978). Although the lack of data at the field level has been viewed as a major obstacle to carrying out disaggregated analysis, field-level behavior has been considered too erratic to model successfully in empirical model (Attanasi 1979).

Exploration models have been mostly developed on oil price rather than natural gas price for some reasons (Kolb 1979; Ghouri 1991; Dahl & Duggan 1998; Forbes & Zampelli 2000; 2002; Mohn & Osmundson 2008). Most studies found that natural gas price was insignificant to explain the well-drilling decision (Dahl & Duggan 1998; Kolb 1979; Mohn & Osmundson 2008; Boyce & Nostbakken 2011). Moreover, natural gas prices in Indonesia have been regulated by the government instead of representing its real production costs. For some cases, we would even find different prices of natural gas sourced from the same region. Differentiation of natural gas price in the same region may create error in determining which natural gas price to be selected to represent the basin. Thus, this paper prefers to select oil price over natural gas price.

2.1. Theoretical framework

Petroleum exploration aims to find new reserves through comprehensive process that consists of Geology & Geophysics Study (G&G) and wildcat drilling in potential areas[1]. The present framework of petroleum exploration is developed based on theoretical economics. My theoretical point of departure is a simple model of geological and economic variables associated with petroleum exploration. Based on the pioneering work of Fisher (1964) and recent literatures, I developed a theoretical framework to explain the impact of dependent variables that generally consist of geological variables: success rate, discovery size, region, and location. On the other hand, the economic variables were defined as cost of production (spending per well) and oil price. Those dependent variables were used to explain the impact on the number of wells drilled in certain basins. Adopting previous literatures to define the geological and economic variables, the framework is simply illustrated in **Figure 4**.

This paper modified a block diagram of the econometric model of Challa (1974) by emphasizing on petroleum exploration and maximizing the expected return considering the estimated risk of expected return. Adopting the work of Mohn & Osmundsen (2008), it formulated a production function $Y = F(Z, W) = W^{\alpha} Z^{\beta}$, wherein W is defined as number of wells drilled, Z represents geological variables with an assumption of decreasing return to scale, $\alpha + \beta < 1$. Eventhough the theoretical model present an analogy of Cobb-Dauglass, however α and β cannot be indirectly interpreted by a concept of degree of substainability. In this specific formula, Îś represents a level of drilling intensity of an exploration company while β represents a level of intensity of geological variables which are purely

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[1] Petroleum drilling consists of 3 (three) types classified based on the objectives and stages of drilling: wildcat drilling, delineation drilling, and development drilling. Wildcat drilling aims to ensure petroleum reserves in geological basins. Wildcat drilling becomes an essential stage due to its higher investment and risk compared to the subsequent stages. Delineation drilling tends to determine the reserves based on reservoir characteristics. Development drilling aims to increase the production rate and enhance the recovery factor.

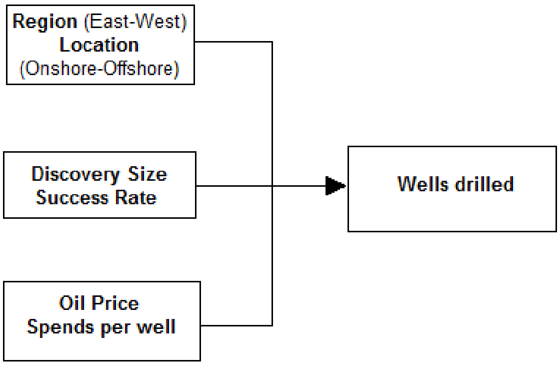

Figure 4: Conceptual Framework for the Indonesian Exploration Model
Source: Author

exogenous as given as per geological basins. As oil prices are determined by global supply and demand, its characteristics become more exogenous.

The net benefits of finding reserves is the expected (E) discounted present revenues of oil and gas production minus total cost of exploration. Subsequently, total revenue is formed by both oil price and production funtion. Furthermore total cost of exploration is explained by the function of $C = \phi_w W + \phi_w Z$, wherein ϕ_w is the specific cost of well exploration. The choice of number of exploration wells to drill depends upon the future prices expected price at time, given price $p(t)$ is $p^e(s) = p(t)e^{(s-r)t}$.

The objective is then to maximize the corresponding profit function:

$$\pi = \sum_{i=1}^{n}[pF(Z_i, W_i)e^{(s-r)t} - \phi_w W_i e^{-rt} - \phi_w Z_i e^{-rt}] \tag{1}$$

The objective subsequently to maximized by differentiation of equation (1) as follows:

$$\frac{d\pi}{dW} = \sum_{i=1}^{n}\left[p.e^{(s-r)t}\frac{dY}{dW} - \phi_w e^{-rt}\right] \tag{2}$$

In terms of maximizing profit, the first order condition is given by:

$$\sum_{i=1}^{n}\left[p.e^{(s-r)t}\frac{dY}{dW} - \phi_w e^{-rt}\right] = 0 \tag{3}$$

$$p.e^{(s-r)t}\frac{dY}{dW} = \phi_w e^{-rt} \tag{4}$$

Substituting $\frac{dY}{dW} = \frac{\alpha.Y}{W}$ into equation (4):

$$p.e^{(s-r)t}\left[\frac{\alpha.Y}{W}\right] = \phi_w e^{-rt} \tag{5}$$

$$p.e^{st}\alpha.Y = \phi_w W \tag{6}$$

Rearranging the equation, the final equation is given by:

$$W = \frac{pe^{st}.\alpha.Y}{\phi_w} \tag{7}$$

Substituting $Y = f(Z, W) = W^\alpha Z^\beta$ into the equation:

$$W = \frac{pe^{st}.\alpha.W^\alpha Z^\beta}{\phi_w} \tag{8}$$

Therefore, the corresponding a number of wells drilled is explicitly given by:

$$W^{1-\alpha} = \frac{pe^{st}.\alpha.Z^\beta}{\phi_w} \tag{9}$$

Then, the final equation of wells drilled given by:

$$W = \left(\frac{pe^{st}.\alpha.Z^\beta}{\phi_w}\right)^{\frac{1}{1-\alpha}} \tag{10}$$

With regard to the final equation, $\frac{dW}{dP} > 0$ indicates that the expected price of oil has a positive impact on the number of wells drilled, whereas $\frac{dW}{d\phi_w} < 0$ indicates that the cost of exploration has a negative impact on the number of wells drilled.

3. Method

3.1. Empirical method

This section elaborates the empirical method to analyze the well-drilling function. Adopting Fisher (1964), method used in this study provides geological variables that consist of success rate, average discovery size of oil, and average discovery size of gas. To specifically address the impact of geological basin maturity in Indonesia, I constructed several proxies as per region and offshore, while the economic variables consist of oil price and exploration cost as denoted by spending per well. By integrating those geological and economic variables, the corresponding well-drilling model is specifically notated by:

$$\begin{aligned} W_{it} =& \alpha_i + \underbrace{\beta_{2i} D_{O_{i,t-1}} + \beta_{3i} D^2_{O,t-1} + \beta_{4i} D_{G_{i,t-1}}}_{\text{Geological Variables}} \\ & \underbrace{+\beta_{5i} D^2_{G,t-1} + \beta_{6i} S_{C_{i,t-1}}}_{\text{Geological Variables}} \\ & \underbrace{+\beta_{7i} Of_{i,t-1} + \beta_{8i} Reg_i}_{\text{Geological Variables}} \\ & + \underbrace{\beta_{9i} \ln P_{t-1} + \beta_{10i} \ln Sp_{it-1} + e_{it}}_{\text{Economic Variables}} \end{aligned} \tag{11}$$

W_{it} represents the number of wells drilled and $D_{O_{i,t-1}}$ and $D_{G_{i,t-1}}$ represent the lag of discovery size of oil and gas, respectively. The geological variable of $S_{C_{i,t-1}}$ indicates the lag of success rate. Moreover, the proxies of lag of offshore exploration and region are represented by $Of_{i,t-1}$ and Reg_i, respectively. The economic variables consist of lag of oil price P_{t-1} and spending per well $S_{C_{i,t-1}}$. Therefore, β_{2i} to β_{8i} represent the coeffcient of geological variables for geological basin i, whereas β_{9i} and β_{10i} represent the coeffcient of economic variables, α_i and e_{it} indicate respectively the intercept and error of empirical model.

This paper developed lag variables on exploration model as well as expected to handle the potential endogeneity. Those variables consist of dependent variables, wells drilled, where geological and economic variables are actually exogenous. However, providing lag variables at different year has not yet represented the field drilling decision. For some cases, firms can response on monthly basis to change their drilling plan. When the existing drilling has found only dry holes with lower success rate, at certain level they could reconsider their decision to prevent higher cost and risk.

This paper provides panel data that combine both cross sections and time series. The cross sections are represented by 32 geological basins in Indonesia over the last ten years as time series data. Annual data for the model variables of 2003 to 2013 were obtained directly or derived from the official datasets of (i) Woodmac, and (ii) the Task Force for Upstream Oil and Gas of Republic of Indonesia (SKK Migas). For qualitative analysis, descriptive statistics of those data are presented in **Table 1**.

The exploration model can be estimated by econometric methods, taking proper account of characteristics of the data-generating process. Each well drilled is an integer, while discovery the explanatory variables are non-integer data, continue and categorical. Theoretically, one of regression models in this specific case is Poisson regression. The regression model analyzes the distribution with intensity paramete μ that is determined by explanatory variables. One of assumptions that should be sufficient is equidispersion, wherein the variance value of response variable Y at $X = x$ should be equivalent to the mean value, formulated as $Var(Y|x) = E(Y|x) = \mu$.

With regard to the descriptive data, wells drilled have a variance of 8.2737 and mean of 1.5770. The same value of discovery size, oil price and spends per well. Consequently, the characteristics of data will potentially create an overdispersion. The overdispersion can cause standard error for each parameters tend to be lower. For example, if we keep using the Poisson regression, the insignificance variable could be interpreted as significance one. As the implication, result summary could be inappropriate. In this overdispersion case, negative binomial is the appropriate method of Poisson model.

Poisson and negative binomial models are designed to analyze count data. The "rare events" of the nature of wells drilled are controlled in the formulas of negative binomial regression. Furthermore, Poisson and negative binomial regression models differ in terms of their assumptions of the conditional mean and variance of the dependent variable. Poisson models assume that the condi-

Table 1: Geological and Economics Data of Indonesia during 2004–2013

Variable		Mean	Standar Deviation	Minimum	Maximum
Wells drilled	W	1.5771	2.876407	0	17
Discovery size of oil	D_O	1.4003	5.531158	0	60
Discovery size of gas	D_G	2.3485	16.17237	0	248.89
Success rate	S_c	0.1500	0.250464	0	1
Offshore variable	Off	0.1833	0.360601	0	1
Oil Price of ICP	P	91.4696	19.69355	58.015	118.39
Spends per well	Sp	70.50353	76.5068	0.156694	423,769

Source: Author, using STATA 13

Table 2: Statistic Descriptive of Geological and Economic Variables of Petroleum Exploration in Indonesia during 2004–2013

Variable		Mean	Variance	Skewness	Kurtosis
Wells drilled	W	1.5771	8.273717	2.713073	11.53123
Discovery size of oil	D_O	1.4003	16.48744	5.257498	44.76493
Discovery size of gas	D_G	2.3485	262.7516	8.789477	88.25679
Success rate	S_c	0.1500	0.0627326	1.730904	5.366517
Offshore variable	Off	0.1833	0.1300334	1.612934	3.806472
Oil Price of ICP	P	91.4696	387.836	-0.3371503	1.775671
Spends per well	Sp	70.50353	5853.29	2.530098	10.63421

Source: Author, using STATA 13

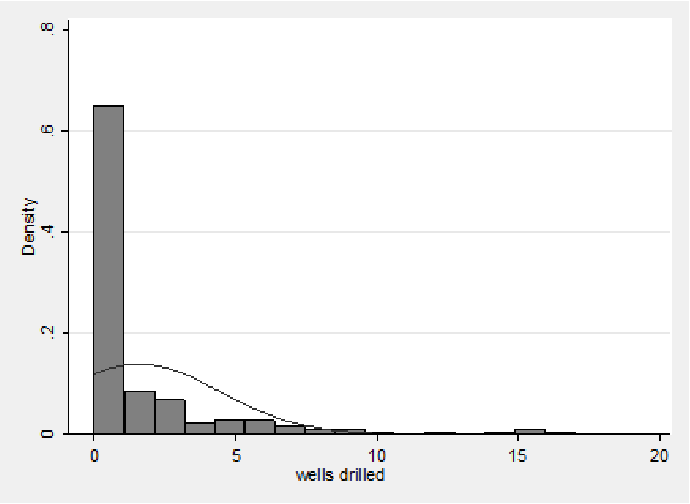

Figure 5: Wells Drilled Data in Indonesian Basins
Source: Author, using STATA 13

tional mean and variance of the distribution are equal. Negative binomial regression models do not assume an equal mean and variance and particularly correct for overdispersion in the data, which is when the variance is greater than the conditional mean. Due to the nature of the distribution of dependent variable, I chose the negative binomial models. For the result, generally negative binomial models are interpreted by an incident rate ration. It is a ratio based on the rate or incident of counts.

3.2. Empirical model

This section elaborates the result and discussion in determining the explanatory variables of exploration decision. The model was estimated by negative binomial regression both fixed effects and random effects in order to check the model stability. All results were interpreted through coefficient value and significance of explanatory variables. This section explores the comparison between result estimation and hypothesis in theoretical model. To support the result, this section was completed by supporting data and information to compare the result estimation and its real condition.

The empirical model was developed to identify the depletion effect on oil exploration to represent the maturity of geological basins in Indonesia. The depletion effect was identified by a square of discovery size of oil. In addition, I also completed a square of discovery size of gas in order to compare the results. Furthermore, I constructed an interaction variables consisting of region proxies and spending per well. For oil prices, I completed the model with local and global oil price as expected price released by OPEC to identify which one that should be selected as the main reference in drilling decision. Integrating all modification, the empirical model is mathematically given by:

$$
\begin{aligned}
W_{it} = & \alpha_i + \underbrace{\beta_{2i}D_{O_{i,t-1}} + \beta_{3i}D^2_{O,t-1} + \beta_{4i}D_{G_{i,t-1}}}_{\text{Geological Variables}} \\
& \underbrace{+\beta_{5i}D^2_{G,t-1} + \beta_{6i}S_{C_{i,t-1}}}_{\text{Geological Variables}} \\
& \underbrace{+\beta_{7i}Of_{i,t-1} + \beta_{8i}Reg_i}_{\text{Geological Variables}} \\
& + \underbrace{\beta_{9i}\ln P_{t-1} + \beta_{10i}\ln Sp_{it-1} + e_{it}}_{\text{Economic Variables}}
\end{aligned}
\tag{12}
$$

W_{it} represents the number of wells drilled and $D_{O_{i,t-1}}$ and, $D_{G_{i,t-1}}$ represent the lag of discovery size of oil and gas respectively. Meanwhile, other geological variable of $S_{C_{i,t-1}}$ indicates the lag of success rate. Depletion effects for oil and gas are respectively represented by $D^2_{O,t-1}$ and $D^2_{G,t-1}$, while the proxies of lag of offshore exploration and region are represented by $Of_{i,t-1}$ and Reg_i respectively. Economic variables consist of lag of oil price P_{t-1} and spending per well $S_{C_{i,t-1}}$. Therefore, β_{2i} to β_{8i} represent the coeffcient of geological variables for geological basin i, whereas β_{9i} and β_{10i} represent the coeffcient of economic variables. α_i and e_{it} indicate respectively the intercept and error of empirical model.

4. Results and Analysis

The estimation results for discovery size of oil and gas showed positive coefficients and were statistically significant with respect to number of wells drilled. The coefficients for lag of discovery size of oil and gas were statistically significant for all regression models, both fixed and random effects. Thus, those results were quite stable for all regression models. Those coefficients had a positive sign as I would expect in the hypothesis and theoretical model. Furthermore, I obtained similar results that supported the existing literatures on exploration model (Fisher 1964; Kolb 1979; Mohn & Osmundson 2008)[2]. The significance contributes to explain why Nasir's study (2011) was not significant with respect to the number of wells drilled in Indonesia. Thus, the disaggregate analysis at geological basin level can explain the effect of discovery size in determining the number of wells drilled.

The result is consistent to represent the real condition where exploration companies review the previous geological data such as discovery size and success rate for future investment decision. In terms of analyzing depletion effect, the coefficient of square discovery size of oil indicates the significance with respect to number of wells drilled.

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[2] Detail summary of exploration models can be seen in **Table 5**.

The results support the real condition where oil exploration has entered a mature stage since it has been exploited for decades. Thus, it has an inverse relation with respect to wells drilled. On the other hand, the discovery size of gas tends to be higher than the discovery size of oil. Consequently, it has positive relation with respect to wells drilled. The result is supported by the fact which cumulative recoverable gas discoveries in **Figure 1**. Cumulative recoverable for gas is higher than oil in terms of increasing gas discoveries in Indonesia.

The estimation result for success rate indicated positive coefficient and was statistically significant with respect to number of wells drilled. The coefficients for lag of success rate were statistically significant for all regression models, both fixed and random effects. Thus, those results were quite stable for all regression models. Those coefficients had a positive sign as I would expect in hypothesis and theoretical model. I obtained similar results that supported the existing literatures on exploration model (Boyce & Nostbakken 2011). The significance contributes to explain why Nasir's study (2011) was not statistically significant with respect to the number of wells drilled in Indonesia. Thus, the disaggregate analysis at geological basin level can explain the effect of success rate in determining the number of wells drilled.

In addition to being consistent with respect to hypothesis and theoretical model, the result represents the real fact in petroleum exploration. Exploration companies tend to invest in proven fields which have higher success rate and discovery size. Geological data show that exploration drillings which consist of 2 wells drilled in Nam Con Son in 2011, 1 well drilled in North New Guinea in 2007, 2 wells drilled in Pasir-Asem Asem in 2006, and 2 wells drilled in West Natuna in 2005 had found no significant discoveries, or generally known as dry holes.

The estimation result for offshore variable indicated positive coefficient but was statistically insignificant with respect to the number of wells drilled. The coefficients for lag of success rate were statistically insignificant for all regression models, both fixed and random effects. Thus, those results were quite stable for all regression models. Those coefficients had a positive sign as I would expect in the hypothesis and theoretical model. The insignificance is caused by distribution of data in offshore wells being lower than in onshore wells. The result is in line with the fact that offshore wells have been dominated by emerging fields in eastern part of Indonesia, whereas onshore wells have been dominated by mature fields in western part of Indonesia. SKK Migas (2015) reported that offshore drilling had been developed intensively in eastern areas of Indonesia such as Arafura Basin, Kutei Bain, Bintuni Basin, South Makassar Basin, Tarakan Basins, and Pasir-Asem Asem Basin. Indonesia has developed deep water development in East Kalimantan which has relatively high gas reserves. In western areas, Indonesia had developed offshore drillings in areas such as Northwest Java, West Natuna-Penyu Basin, and East Java Basin. Therefore, I concluded that even though the lag of offshore had a positive coefficient with respect to the number of wells drilled, the coefficient was statistically not significant for all specification models.

The estimation result for region proxies indicated positive coefficient and was statistically significant with respect to the number of wells drilled. The coefficients for lag of success rate were statistically significant for all regression models, both fixed and random effects. Thus, those results were quite stable for all regression models. Those coefficients had a positive sign as I would expect in the hypothesis and theoretical model. The result is illustrated with distribution of data in **Figure 6**. The result is in line with the fact that those emerging and mature fields are mostly located respectively in eastern and western part of Indonesia. Exploration companies tend to drill intensively in eastern Indonesia, which has relatively had higher success rate and discovery size.

Meanwhile, region proxies show that eastern areas have become more interesting than western areas for exploration companies. Eastern areas consist of emerging basins which have higher discovery size and success rate than mature basins mostly located in western areas. However, offshore variables are not statistically significant to well-drilling decision due to onshore development having been established longer than offshore development. Furthermore, offshore exploration tends to have higher risk in terms of exploration cost. The results show the impact of spending per well and region on interaction variable for emerging basins which are mostly located in the eastern part of Indonesia. This indicates that interaction variable has an inverse relationship with respect to wells drilled.

Table 3: Estimation Result of Wells Drilled Model

Variables		Wells drilled			
		Fixed Effects		Random Effects	
		(1)	(2)	(3)^a	(4)^b
Lag of discovery size of oil	mmboe	0.0226*	0.106***	0.0243**	0.110***
		(0.0125)	(0.0295)	(0.0117)	(0.0282)
Lag of discovery size of oil2	mmboe		-0.00164**		-0.00170***
			(0.000646)		(0.000623)
Lag of discovery size of gas	mmboe	0.00842**	0.0262**	0.00907**	0.0269**
		(0.00391)	(0.0125)	(0.00386)	(0.0123)
Lag of discovery size of gas2	mmboe		-0.000115		-0.000118
			(7.79e-05)		(7.74e-05)
Lag of success rate	%	1.191***	0.746**	1.186***	0.744**
		(0.294)	(0.330)	(0.288)	(0.320)
Lag of offshore variable	%	0.174	0.149	0.144	0.141
		(0.245)	(0.244)	(0.242)	(0.236)
Region proxies	east = 1	0.537***	1.021***	0.556***	1.018***
		(0.202)	(0.280)	(0.201)	(0.275)
Lag of spending per well	M USD/well	-0.00200	-9.46e-05	-0.00226	-0.000213
		(0.00171)	(0.00159)	(0.00171)	(0.00158)
Region* Lag of spending per well	M US$/well		-0.0121**		-0.0121**
			(0.00595)		(0.00588)
Lag of Oil Price OPEC	USD/barrel	0.00711**	0.00703**	0.00690**	0.00681**
		(0.00307)	(0.00300)	(0.00303)	(0.00294)
Lag of ICP	USD/barrel		0.00390		-0.00128
			(0.0129)		(0.00679)
Constant		-2.439***	-2.556**	-2.171***	-2.101***
		(0.587)	-1.003	(0.424)	(0.585)
$\ln\_r$				18.55417	17.01599
$\ln\_s$				19.8389	18.11373
r				1.14e+08	2.45e+07
s				4.13e+08	7.36e+07
Observations		279	279	279	279
Number of t		9	9	9	9
Log-likelihood		-377.96878	-366.18769	-412.48106	-399.7523

Note: Interpretation of result using incident rate ratio can be seen in attachment.
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
[a] Likelihood-ratio test vs. pooled: chibar2(01) = 2.5e-05 Prob>=chibar2 = 0.498
[b] Likelihood-ratio test vs. pooled: chibar2(01) = 2.9e-08 Prob>=chibar2 = 0.500
Akaike's information criterion (AIC) = 841.5047
Bayesian information criterion (BIC) = 917.7601
Source: Author, using STATA 13

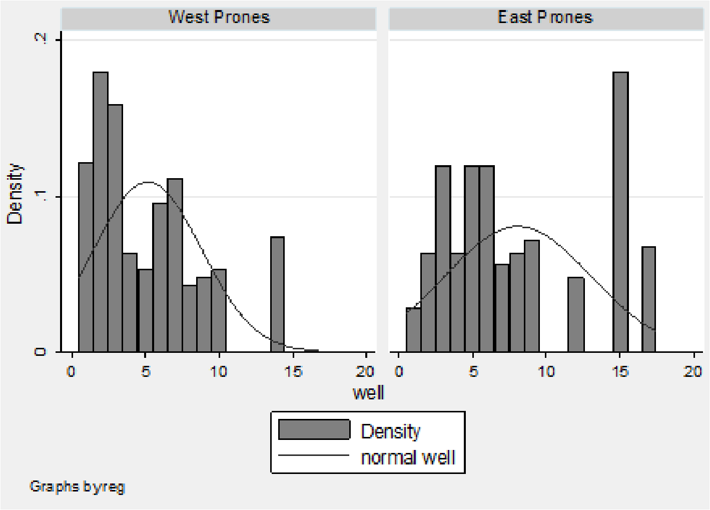

Figure 6: Distribution of Wells drilled in Eastern and Western Part of Indonesia
Source: Author, using STATA 13

Estimation result for oil price indicated positive coefficient and was statistically significant with respect to the number of wells drilled. The coefficients for lag of global price were statistically significant for all regression models, both fixed and random effects. However, the coefficients for lag of local price were statistically insignificant for all regression models, both fixed and random effects. Thus, those results were quite stable for all regression models. Those coefficients of global oil price had a positive sign as I would expect in the hypothesis and theoretical model. However local oil price failed to explain the wells drilled in Indonesia. In reality, exploration companies exercise the profitability of investment using the global price. On the other hand, local price does not purely represent market price because it has been regulated by the government. Government tends to regulate oil price by considering various factors such as subsidy and economic condition. Therefore, global price is the main reference for many exploration companies in considering the number of wells to be drilled.

Estimation result for exploration cost, spending per well, indicated negative coefficient and was statistically insignificant with respect to the number of wells drilled. The coefficients for lag of spending per well had an inverse relation with respect to wells drilled in all regression models, both fixed and random effects. Thus, those results were consistent for all regression models. Those coefficients had a negative sign as I would expect in the hypothesis and theoretical model, representing the fact that exploration companies actually consider exploration cost in terms of the profit return. The results show the impact of spending per well and region in interaction cost for emerging basins which are mostly located in the eastern part of Indonesia. This indicates that interaction variable has an inverse relationship with drilling cost, although the relationship was not statistically significant in their estimations.

Estimation result for interaction cost of spending per well and region had an inverse relation and was statistically significant with respect to the number of wells drilled. Those coefficients were statistically significant for all regression models, both fixed and random effects. Those coefficients had an inverse relation as they consist of region and spending per well which had an inverse relation with respect to the number of wells drilled. In reality, the result is in line with the trade-off that exploration companies have in terms of drilling in the frontier or emerging fields with higher exploration cost or drilling in mature fields with lower exploration cost.

5. Conclusion

This paper developed an empirical model of exploration economics for oil and gas at geological basin level in Indonesia during 2003–2013. The results showed that geological and economic variables had significant impact with respect to the number of wells drilled. Wells drilled were explained significantly with positive sign by lag of success rate, lag of discovery size of oil, lag of discovery size of gas, and region of geological basin. On the other hand, offshore proxies were statistically insignificant to determine the number of wells drilled due to the fact that onshore drillings have been intensively drilled longer than offshore drilling. As a main contribution, I find those significant variables to determine the number of wells drilled in Indonesia and explain why Nasir's study (2011), which as far as I know is the only exploration study in Indonesia which uses time series data, has failed to find geological variables that significantly determine the number of wells drilled. This occurred because of the different level between the aggregate and disaggregate data.

For the economic variables, wells drilled were explained significantly with positive sign by the global oil price. The spending per well even had an inverse relation as the expected hypothesis and theoretical model, although it failed to explain the wells drilled. The interaction cost of spending per well and region had an inverse relation and was statistically significant with respect to the number of wells drilled. The results support the fact that exploration companies have a trade-off in terms of drilling in frontier or emerging fields with higher exploration cost or mature fields with lower spending per well.

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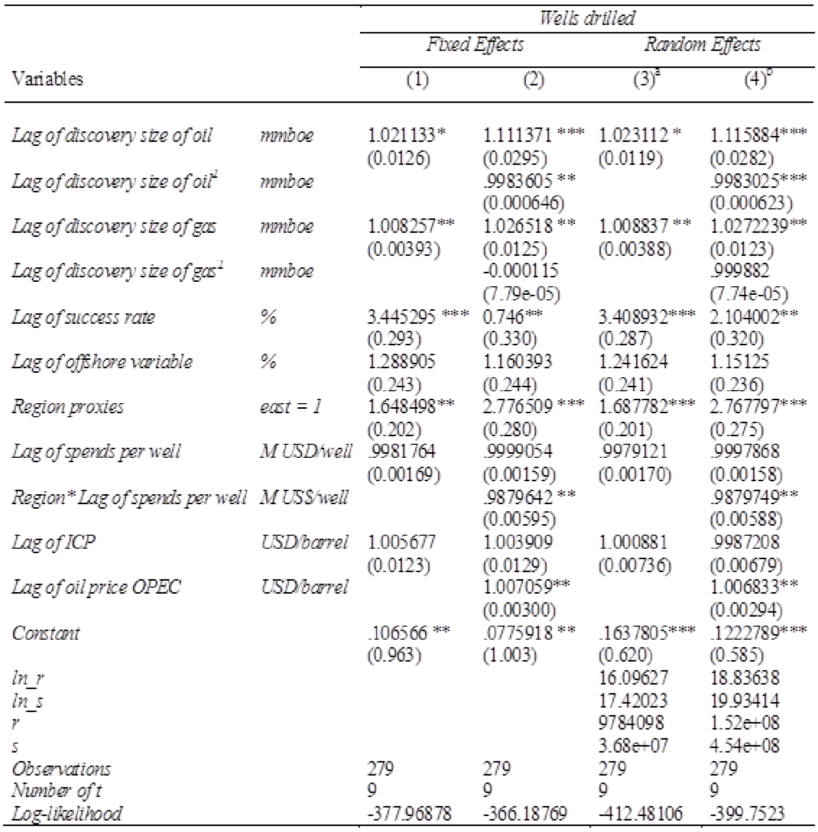

		Wells drilled			
		Fixed Effects		*Random Effects*	
Variables		(1)	(2)	$(3)^a$	$(4)^b$
Lag of discovery size of oil	*mmboe*	1.021133*	1.111371 ***	1.023112 *	1.115884***
		(0.0126)	(0.0295)	(0.0119)	(0.0282)
Lag of discovery size of oil^2	*mmboe*		.9983605 **		.9983025***
			(0.000646)		(0.000623)
Lag of discovery size of gas	*mmboe*	1.008257**	1.026518 **	1.008837 **	1.0272239**
		(0.00393)	(0.0125)	(0.00388)	(0.0123)
Lag of discovery size of gas^2	*mmboe*		-0.000115		.999882
			(7.79e-05)		(7.74e-05)
Lag of success rate	*%*	3.445295 ***	0.746**	3.408932***	2.104002**
		(0.293)	(0.330)	(0.287)	(0.320)
Lag of offshore variable	*%*	1.288905	1.160393	1.241624	1.15125
		(0.243)	(0.244)	(0.241)	(0.236)
Region proxies	*east = 1*	1.648498**	2.776509 ***	1.687782***	2.767797***
		(0.202)	(0.280)	(0.201)	(0.275)
Lag of spends per well	*M USD/well*	.9981764	.9999054	.9979121	.9997868
		(0.00169)	(0.00159)	(0.00170)	(0.00158)
Region Lag of spends per well*	*M US$/well*		.9879642 **		.9879749**
			(0.00595)		(0.00588)
Lag of ICP	*USD/barrel*	1.005677	1.003909	1.000881	.9987208
		(0.0123)	(0.0129)	(0.00736)	(0.00679)
Lag of oil price OPEC	*USD/barrel*		1.007059**		1.006833**
			(0.00300)		(0.00294)
Constant		.106566 **	.0775918 **	.1637805***	.1222789***
		(0.963)	(1.003)	(0.620)	(0.585)
ln_r				16.09627	18.83638
ln_s				17.42023	19.93414
r				9784098	1.52e+08
s				3.68e+07	4.54e+08
Observations		279	279	279	279
Number of t		9	9	9	9
Log-likelihood		-377.96878	-366.18769	-412.48106	-399.7523

Figure 7: Empirical Results Incident Rate Ratio

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Source: Author, estimated using Stata 13 and Woodmac Data (2015)

Table 4: Summary of Exploration Model - (Part 1)

No	Referensi	Dep. Variabel	Independent Variables			R^2
			Geological	Economic	Additional/Proxies	
1	Fisher (1964)1	Ww	SEISMIC +*, O/Wws(-1)+*, Wws/Ww(-1)-*, G/Wws(-1)-*	Poil deflated WPI+*		0,84
	Sample: 46–55 PADD 1-5, CT	Wws/Ww	Wws/Ww(-1)+*, O/Wws(-1)-*, G/Wws(-1), Dept(-1)-*, Seismic+*	Poil deflated WPI		0,71
		O/Wws	O/Wws(-1), Wws/Ww(-1)+*, G/Wws(-1)+*	Poil deflated WPI-*		0,85
		G/Wws	O/Wws(-1), Wws/Ww(-1)+*, G/Wws(-1)	Poil deflated WPI-*		0,32
		Ww	Seismic+*, O/Wws(-1)+*, Wws/Ww(-1)-*, G/Wws(-1)-*, Depth(-1)-*	Poil deflated by drill cost+*	D*TXshut down, D*nonTxshutdown +*	0,91
		Wws/Ww	Wws/Ww(-1)+*, O/Wws(-1)+*, G/Wws(-1), Depth(-1), Seismic+*	Poil deflated by drill costs		0,72
		O/Wws	O/Wws(-1)+*, Wws/Ww(-1)+*, G/Wws(-1)-*	Poil deflated by drill cost-*		0,86
		G/Wws	O/Wws(-1), Wws/Ww(-1)+*, G/Wws(-1)	Poil deflated by drill cost-*		0,23
		Seismic	Seismic(-1)+*		4D*PADD some*, D*Txshut down on Tx, D*TXshutdown+*	0,97
2	Erickson & Spann (1971) 1	Wwp	Depth(-1)+*, Wwps/Wwp(-1)-*, Wwlarge/WwUS+*,	Deflated Poil+*, Deflated Pgas	D*PADD some*, D*PADD some*, D*TXshutdown, D*NonTXshutdown	0,97
	Sample: 46–55 PADD 1-5, CT	Wwps/Wwp		Deflated Poil, Deflated Pgas	D*PADD, D*TXshutdown, D*NonTXshutdown	0,8
		O/Wwps	Wwps/Wwp(-1)	Deflated Poil, Deflated Pgas,	D*PADD some*, D*TXshutdown-*, D*NonTXshutdown	0,89
		G/Wwps	Wwps/Wwp(-1)	Deflated Poil, Deflated Pgas,	D*PADD some*, D*TXshutdown-*, D*NonTXshutdown	0,6
		G/Wxs	Wxs/Wx(-1)	Deflated Pgas+*, Deflated Poil	3 D*Dist some *	0,27
3	Attanasi (1979) 1 Sample: Denver Basin 49–73	Ww	$\sum$Ww	Expeceted gross profit not discounted+*, $value of discoveries(0), and (01) to (-10)+*		0,92
4	Kolb (1979) 1	O		Pgas(nr), Poil(nr), WPI(nr)	D*regional land input+*	0,70
	Sample: 46–69	Gna		Pgas(nr), Poil(nr), WPI(nr)	D*regional land input+*	0,78
	8 US Gulf Regions 46–58 7 Dist, CT	Ww	Wws/Ww(-1), O/Wws(-1), G/Wws(-1)-*, Depth-*, Seismic+*,	Poil deflated WPI+*		0,75
		Wws/Ww	O/Wws(-1), Wws/Ww(-1)+*, G/Wws(-1)+*, Depth, Seismic+*,			0,65
	48–70 7 Dist, CT	O/Wws	O/Wws(-1)+*, Wws/Ww(-1), G/Wws(-1)	Poil deflated WPI-*	Poil deflated WPI+*	0,5
		G/Wws	O/Wws(-1), Wws/Ww(-1)+*, G/Wws(-1)+*	Poil deflated WPI, Pgas deflated by WPI		0,30
		Ww		Poil deflated WPI+*, Pgas deflated WPI+*, capacity utilization, drill cost-*,	4ma WWS/WW-*, Ro plus Rg. 7D*dist*	0,88

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Table 5: Summary of Exploration Model - (Part 2)

No	Referensi	Dep. Variabel	Independent Variables			R^2
			Geological	Economic	Additional/Proxies	
		Wws/Ww		Poil deflated WPI, Pgas deflated WPI+*, capacity utilization, drill cost+*	Ro plus Rg. 7D*dist*	0,67
		O/Wwos		Poil deflated WPI, Pgas deflated WPI, capacity utilization, drill cost	4ma WWS/WW-*, Ro,7D*dist*	0,57
5	Ghouri (1991) 1	Wx		Deflated Poil+*, Poil(-1), Poil(-2), Poil(-3), Poil(-4), Exploration costs-*		0,90
	Sample: ARCO US 74-89 TS	Wx		Deflated Poil+*, Poil(-1)+*, Poil(-2), Poil(-3)+*, Poil(-4)+*, Exploration costs-*		0,94
	Mobil 70-88 US TS	Wx		Deflated Poil+*, Poil(-1)+*, Poil(-2), Poil(-3)+*, Poil(-4) +*, Exploration costs-*		0,96
	Philips 70-88 US TS	Wx		Deflated Poil+*, Poil(-1), Poil(-2)+*, Poil(-3)+*, Poil(-4) +*, Exploration costs-*		0,94
	Shell 70–88 US TS					
6	Forbes & Zampelli (2000) 2 Sample: US EIA FRS 10 firms 1978-1998 CT	Wws/Ww	Depth+*, Wwgs/Ww+*	Poil+*	ln(unexplored acreage)+*, Technological proxies+*	0,85
7	Mohn & Osmundsen (2008) 2	W	O+G(-1)-***, ∑O+G(-2)+*, Wd(-1)-***	P+**, P(-1)+**	acreage(-1)+*	0,51
	Norwegian Continental Shelf 1965–2004 CT	Ww	∑O+G(-1)-***, Wd(-1)-***	P+**, P(-1)+**	acreage(-1)+*	0,5
		Wa	∑O+G(-1)-***, ∑O+G(-2)-***, Wd(-1)-**	P+**, P(-1)+*	acreage(-1)+*	0,61
8	Boyce & Nostbakken (2011) 2	W	Wxs/W***, Offshore+**, O, G, depth, EOR+*, new CBM	Poil***, Pgas, Drillcost, real interest rate+**	Year-***, Land-**	-
	US State 1955–2002	Ww	Wxs/W ***, Offshore+**, O, G, depth, EOR+*, new CBM	Poil***, Pgas, Drillcost, real interest rate	Year-***, Land-**	
		Wdev	Wxs/W***, Offshore+***, O -*, G +***, depth, EOR+*, new CBM	Poil-***, Pgas-***, Drillcost-**, real interest rate	Year-***, Land-**	-
9	Nasir (2011) 2 Time Series 1980–2009 Indonesia	W	Seismic+*, ∑O+G(-1)	Exploration&Development cost-, worldPoil+*, OilConsumption+*		0,78

Note: 1 estimation results were reported by Dahl & Duggan (1998)
Note: 2 estimation results were taken from relevant reliteratures
Source: Authors' calculation

Table 6: Description of Variables

(-1)	=	Lag of year	Pgas	=	Gas price
CT	=	Cross section time series data	Poil	=	Oil price
D*	=	Dummy variable	Seismic	=	Seismic crews
D*dist	=	District dummy variable	TS	=	Time series data
depth	=	Kedalaman sumur	TX shut down days	=	The number of days a Texas was shut down
G	=	Gas reserves discovered	W	=	Totals wells drilled
O	=	Oil reserves discovered	Wds	=	Successful developoment wells
ma	=	A moving average	Gas	=	Associated gas
Ga	=	New associated gas reserves found	Ww	=	New field wildcat wells drilled
Gna	=	New nonassociated gas reserves found	Wwgs	=	Successful gas wildcat wells drilled
PADD	=	Petroleum administrative defense district	Wws	=	Successful wild cat wells drilled
Wx0s	=	Successful oil exploratory wells drilled	Wg	=	Total gas wells drilled
Wo	=	Total oil wells drilled	Wxs	=	Successful exploratory wells drilled
WPI	=	Wholesale price index	Wx	=	Exploratory wells drilled
Ws	=	Total successful wells drilled	Wxgs	=	Successful gas exploratory wells drilled

Source: Dahl & Duggan (1998)

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