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Application of Structural Equation Modeling in Petroleum Science and Technology Research

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Abstract

This work intends to optimize research and development performance processes in the field of oil and gas academia/industry derived from a case study, based on theoretical framework on the principles of structural equation modelling (SEM). We define the basis of the model by six different structural constructs derived from literature and their interdependence in the form of hypotheses. The constructs consist of one latent exogenous variable and five latent endogenous variables. Furthermore, five independent operational variables were established with respect to the latent exogenous variable while 20 dependent operational variables were also established with respect to the latent endogenous variables. The evidence of interdependence among the constructs and their respective operational variables were provided by five different hypotheses carried out on the path diagrams. As a result, the interaction between each construct and its variables defines its individual measurement model, which translates into some sets of linear equations. Having obtained the measurement for each construct, the interaction can then be applied to define other sets of linear equations that represent the behaviour of the organisation of the entire process which is expected to yield the proposed research and development programme. The developed model can easily be adopted by interested parties for application on similar projects.

Keywords: Structural Equation Modeling, Petroleum and Gas, Research, Nigeria Inland Basins

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INTRODUCTION

A significant value of the entire world economy, mostly in industrialised nations like China, United states, Germany etc. depends on oil and natural gas to meet there industrial needs. As a result, the oil and gas industry operates at high intensity all over the world. The industry consists of two different segments, the upstream including exploration and production (E&P) and the downstream consisting of pipeline transport, A significant value of the entire world economy, mostly in industrialised nations like China, United states, Germany etc. depends on oil and natural gas to meet there industrial needs. As a result, the oil and gas industry operates at high intensity all over the world. The industry consists of two different segments, the upstream including exploration and production (E&P) and the downstream consisting of pipeline transport, Research and development activities are primarily geared at providing the best concepts and methodologies to all levels within the Petroleum industry in a bid to ensure overall efficiency at a lower cost. The twin relationship is critical for the survival of the industry and in ensuring commercial success and development in general (Gaskins et al. 1995). For example, in multinational joint petroleum exploration and production agreements, both the host country and a foreign investor should benefit from both intellectual and cultural exchange. One major area of increasing popularity is for more developed countries which are endowed with technical expertise and superior educational facilities to train personnel from less developed countries where there is a potential investment opportunity (Baunsgaard and Emil, 2001). Similarly, this training can also be earmarked to facilitate apprenticeship and internship opportunities for both partners. In many cases, the method of cooperative training is preferred where people are employed to work alongside personnel from the investor country, not only for the obvious reason of technological and intellectual transfer but also to provide a more enabling relationship between both.

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In joint exploration agreements, both the hosts country and incoming partner must benefit from educational investments. One major area of increasing popularity is for more developed countries which are endowed with technical expertise and superior educational facilities to train personnel from the less developed countries where the minerals are located. Similarly, this training can also be earmarked to facilitate apprenticeship and internship opportunities for both countries (partners). In many cases, the method of cooperative training is preferred with the graduates employed to work alongside personnel from the foreign country, not only for the obvious reason of technological and intellectual transfer, but also to provide a more enabling relationship between both.

The Chinese policy on joint mineral exploration (both on a country to country basis, country to private basis, or a private company agreement) contain all elements of this sort of reciprocal educational agreement (Paul et al., 2008). Many universities in China such as the China University of Geosciences, Wuhan in Hubei Province provides training to many international and Chinese students in various areas related directly and indirectly to the mineral and petroleum industry worldwide. Of the over 620 international students in that university from over eighty different countries, approximately eighty (80%) percent are involved in such training (Bally, 2012). Most of these countries are important trade partners for China in the mineral industry or countries where China has interest indirectly related to the mineral exploration industry.

This paper identified Federal University of Technology (FUT) Minna (http://www.futminna.edu.ng/), as a potential partner to China University of Geosciences (CUG) Wuhan (https://www.cug.edu.cn/), for a proposed research cooperation, basically on the petroleum prospectivity of the Inlan Basins of Nigeria. FUT Minna, is one of the leading Nigerian Universities that evolved to be one of the leading research institutions in the country. Currently, it admits over 15000 students annually from around the globe, majoring in variety of specialized areas of study. As one of the country's best research institutions, FUT contributes greatly to the development of Nigeria's Petroleum and Mineral resources which form the back bone of the country's economy. On the other hand, China University of geosciences (CUG) Wuhan is a leading University in China that produces some of China's best earth scientist. The University which was selected as one of the country's best in the year 2006 (https://www.cug.edu.cn/) enjoys the ownership of a dedicated tectonics and petroleum resource center as well as national key laboratories in the areas of geology, geological processes, petroleum systems and engineering and geological engineering. This paper therefore identified CUG Wuhan as a suitable research partner for FUT Minna.

In order to make a significant contribution, this paper identified China University of Geosciences as a potential research partner in any successful Mineral or Petroleum exploration and development around the world. It also went ahead to identify the Inland Basins of Nigeria (Natural Resource) as a clear Petroleum and Gas exploration target that is in need of research and development together with a potential research partner in the resource home country. The paper went ahead to make contribution by developing a conceptual model that will aid identified research partners to evaluate the viability of a possible research partnership and or co-operation.

PROBLEM STATEMENT

The Federal Republic of Nigeria is a federal constitutional republic comprising 36 states and its Federal Capital Territory, Abuja. The country is located in West Africa and shares land borders with the Republic of Benin in the west, Chad and Cameroon in the east, and Niger in the north. Its coast in the south lies on the Gulf of Guinea on the Atlantic Ocean. Nigeria is Africa's most populous nation with a teeming population of over 170 million people having an approximate surface area of about 924,000 square kilometers with abundant natural resources (Ogbonna, *et al., 2002*). The most exploited natural resource in Nigeria is Petroleum which has the largest industry and main generator of GDP.

Nigeria's current national petroleum reserves asset (proven), put at 32 billion bbl of oil and about 170 trillion standard ft3 of gas (Nexant, 2003), derives solely from the Niger Delta onshore and offshore. Some exploration campaigns have been undertaken in the inland basins with the aim of expanding the national exploration and production base and thereby add to the proven reserves asset.

The inland basins of Nigeria (Mukhtar and Xie, *2012)* (Figure 1) constitute one set of a series of Cretaceous and later rift basins in central and west Africa whose origin is related to the opening of the South Atlantic (Figure 2). Commercial hydrocarbon accumulations have recently been discovered by the China National Petroleum Corporation (CNPC) in Chad republic and Sudan republic which also lies on this rift trend. In the inland basins of Nigeria, the Nigerian National Petroleum Corporation, through its frontier exploration services arm National Petroleum Investment Management Services (NAPIMS), has drilled some wells in the Nigerian sector of the Chad basin, and only gas shows were encountered. The first well in the Benue trough region, Kolmani River 1, drilled by Shell Nigeria Exploration and Production Company to a depth of about 3000 m (9850 ft) in 1999, encountered some 33 billion standard ft3 of gas and little oil, that has been the only well drilled by that company in that area to date (**Obaje, *et al., 2004***). Two other wells, Kuzari 1 and

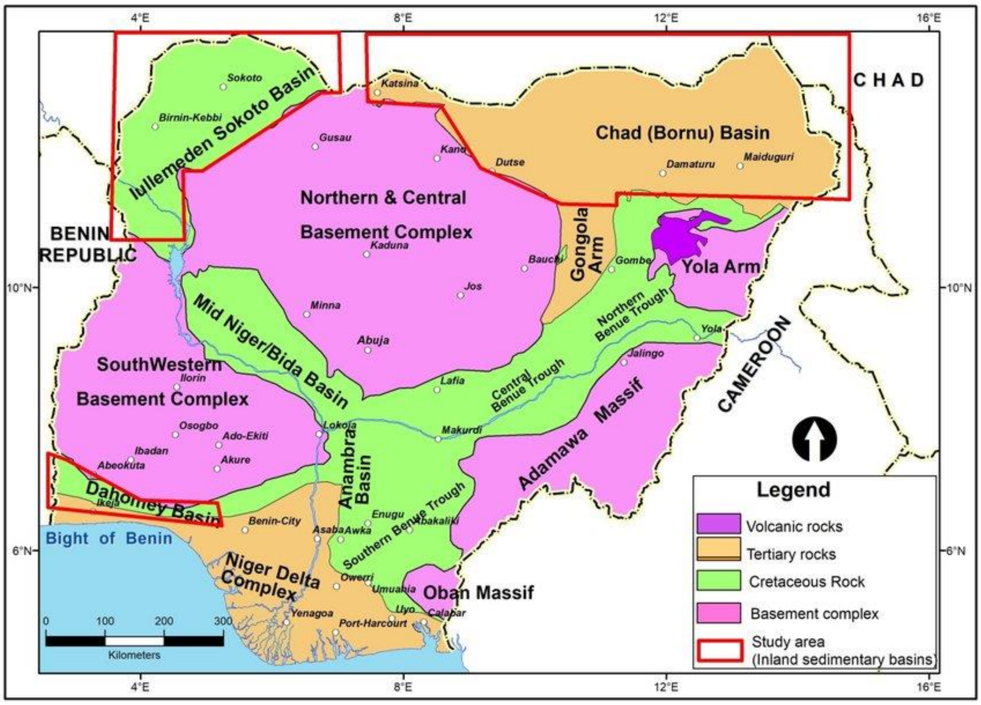

Figure 1 Geological map of Nigeria showing the inland basins and sample localities. (Adopted from Mukhtar Habib and Xie Congjiao, 2012)

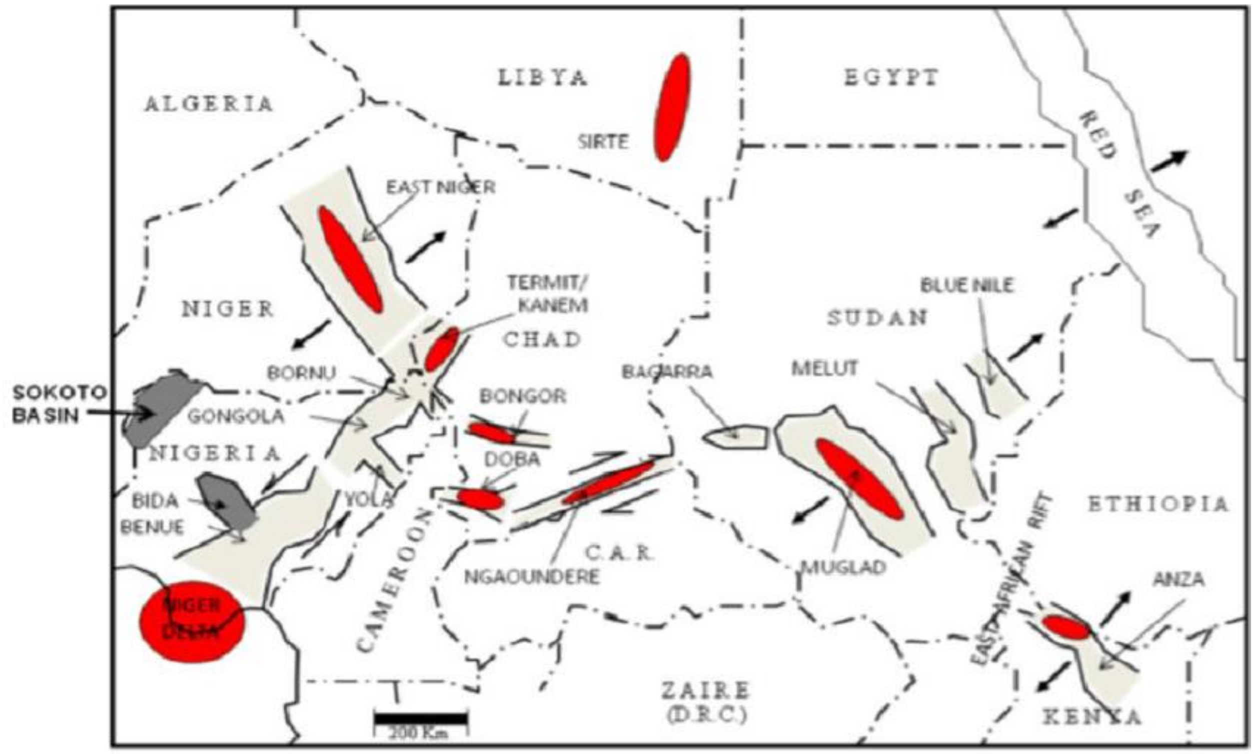

Figure 2: Regional tectonic map of western and central African rifted basins showing the relationship of the Muglad, Doba, and east Niger basins to the Benue trough/Gongola basin. Locations of regional shear zones (marked with half-arrow) and major zones extension (complete arrow) are shown. (Adopted from Mukhtar Habib and Xie Congjiao,2012)

Nasara 1, drilled by Elf Petroleum Nigeria Limited (TotalFinaElf) in 1999 to a depth of 1666m (5465 ft) and Chevron Nigeria Limited (ChevronTexaco) in 2000 to a depth of about 1600 m (5250 ft), respectively, were reportedly dry.

With this development, it has become necessary to evaluate the prospectivity of this frontier region, especially the availability or otherwise of favorable petroleum systems. At the core of any petroleum system is a good-quality source rock (total organic carbon [TOC] > 0.5%, hydrogen index [HI] > 150 mg HC/g TOC, liptinite content > 15%, Tmax _ 430jC, and Ro 0.5–1.2%, biomarker validation). However, other petroleum system elements must also include, apart from established source rocks, reservoir and seal lithologies, establishable trapping mechanisms, and favorable regional migration pathways.

RESEARCH METHODOLOGY

The method followed in this study is based on the objective of developing a theoretical structural and measurement model that is capable of evaluating the effects of some key variables in respect of an FUT – CUG research co-operation towards exploring the hydrocarbon prospects of the inland basins of Nigeria. The following stages were followed in order to achieve result;

- *Definition of FUT-CUG cooperation*
- *Defining the cooperation model*
- *Defining model constructs and path diagram*
- *Hypotheses of the path diagrams*

3.1 conceptual model definition

The model is a theoretical construct of a structural and measurement parameters. It consists of a set of latent variables, operational measurement and hypotheses depicted in path diagrams (**Fig 3**). This model intends to provide some relationships in the form of mathematical equations that will serve as tools for measuring effects of some defined key parameters that have great influence on the proposed FUT-CUG research cooperation.

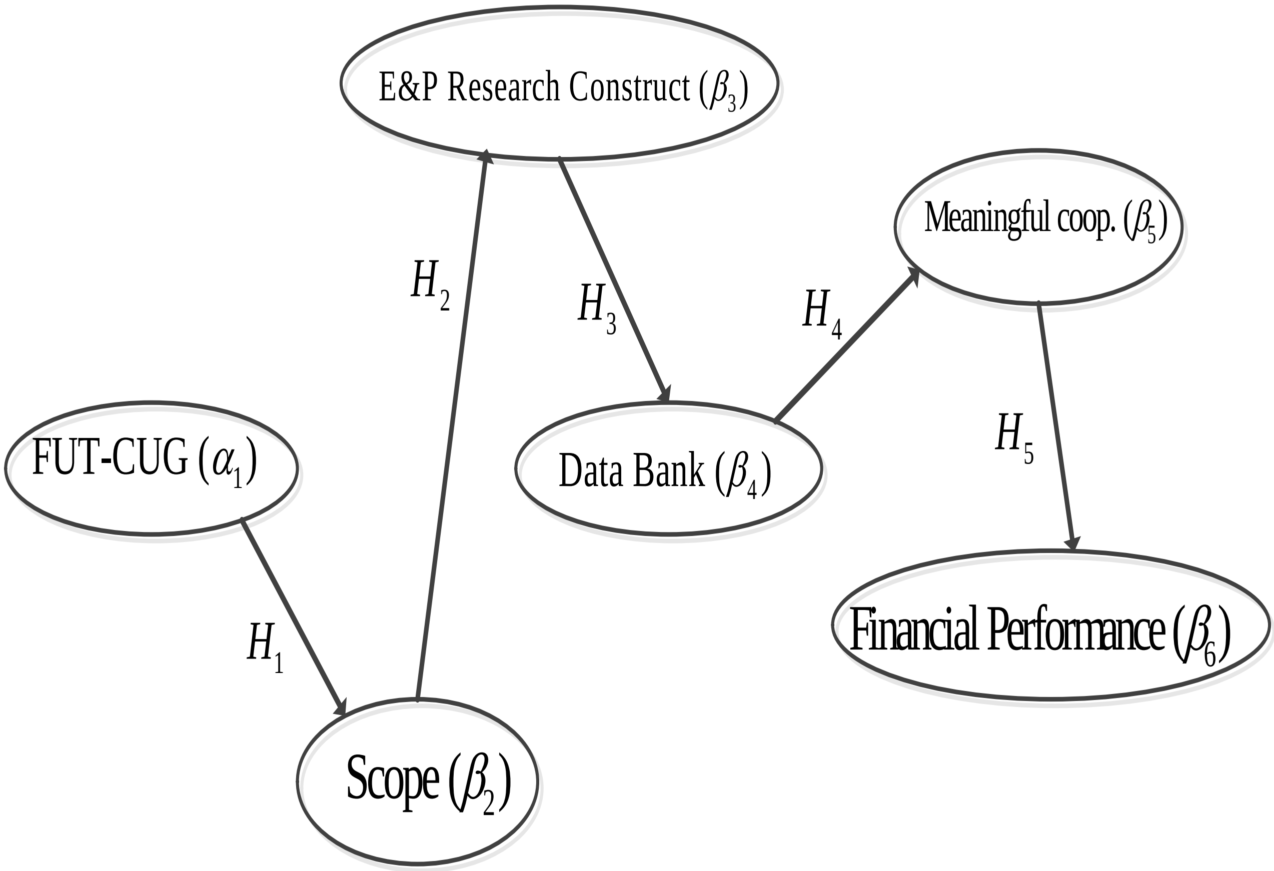

Figure 3: The structural model in path diagrams

Defining key parameters and hypotheses of the path diagrams

We established the basis of this model on six structural constructs and their interdependences in the form of a hypotheses as shown in **Fig 4**. These constructs consist of one latent exogenous variable and four latent endogenous variables. Furthermore, five independent operational variables were

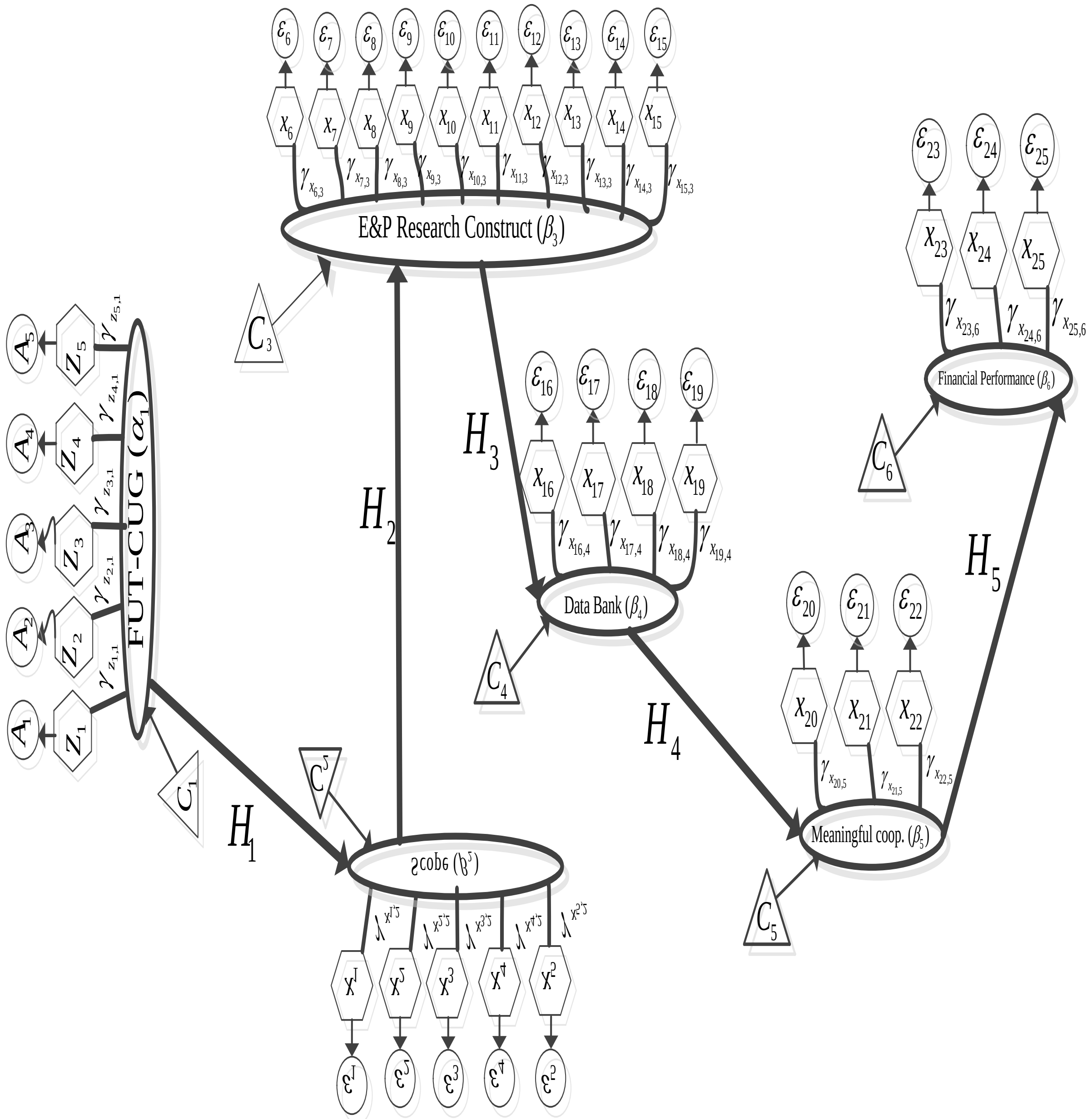

Figure 4: Depicts the Structural constructs and their respective measurement variables. A latent exogenous Construct (α_1), controlled by five independent operational Variables (Z).

Five latent endogenous variables ($\beta_2, \beta_3, \beta_4, \beta_5, \beta_6$), Controlled by twenty five dependent operational variables (X). Independent variable errors are represented by letter A while dependent variable errors are represented by E. C represents errors associated to each construct as a whole. Structural coefficient (H) and factorial weight (alpha) represents causes and effect order.

established in respect of the latent exogenous variable while twenty five dependent operational variables were also established in respect of the latent endogenous variables as shown in **table 1** and **figure 3**. The evidence of interdependence among the constructs and their respective operational variables were provided by four different hypotheses carried out on the path diagrams.

Hypotheses 1 (H1). *Relationship between cooperating partners with scope and quality.*
Scope definition and management forms the very foundation of any successful project. This is typically applied in a case where two institutions of higher learning are coming together in respect of an advanced research co-operation. In accordance with several authors, (**Close, 2006 and Souder et al, 1997**), without this conceptualization, it becomes impossible to adequately determine cost, time line and processes which may mutate during the execution phase. Once the scope is defined, detailed planning and execution can be carried out with much reduced risk for error. All necessary requirements such as

Table 1: Construct and Measurement variables for the proposed model

Construct	Codes	Observed Variables	Reference
FUT-CUG(α_1)	Z1	Policies	Raghavendra (2000)
	Z2	Experience	Christoforos and Dario (2010)
	Z3	Coodination	
	Z4	Budget	
	Z5	Communication	
Scope (β_2)	X1	Accurate definition of scope	
	X2	Quality control	Souder *et al.* (1997)
	X3	Schedule	
	X4	Response ability	Risik *et al*. (2010), Wejermars (2009)
	X5	Other requirements	
E&P Research (β_3)	X6	Technique	Souder *et al*. (1997), Chan *et al.* (2004), Li *et al.* (2007)
	X7	Data Gathering methods	Rocca (2009)
	X8	Personel Welfare	Modenesi *et al*., (2012)
	X9	Personel Health	Gu (2012)
	X10	Laboratories	Babadagli , (2007)
	X11	Machinaries	Doublet (1995)
	X12	Hardwares	Pam (2013)
	X13	Softwares	Pam (2013)
	X14	Transporation	N.G.Obaje etal. (2004)

	X15	Security	Raghavendra Rao, 2000
Data Bank (β_4)	X16	Quality	Christoforos and Dario (2010)
	X17	Coverage	Babadagli (2007)
	X18	Stability	Babadagli (2007) Cosentino (2001)
	X19	User friendly	
Successful Cooperation (β_5)	X20	Within Budget	
	X21	Desired Output	Cosentino (2001)
	X22	Timely Completion	Lewis (2000)
Financial Performance (β_6)	X23	Rate of return	Kaplan and Norton (1992)
	X24	Operating Merging	Yang *et al.* (2011)
	X25	Payback Period	Jahn *et al.* (2008)

identification of specific research directions, data gathering methods, equipment's, application methods, output requirements, welfare of research personnel and supporting staff, health requirements and others are to be clearly stated in the scope, thus, leading to a proper cost evaluation, personnel requirements and other specifications that will provide the required result.

This hypothesis established that a successful FUT – CUG co-operation on this subject matter requires a well-defined scope and quality.
Hypotheses 2(H2). *Relationship between scope and quality, with Research Construct (Team, research directions, tools and environment).*

Different scientific and technological activities are required for a successful E&P research cooperation. The key identified by this work include; Geography, Geology, Geophysics, Geochemistry, Petro-physics, Environmental sciences and management, Engineering and resource management and policy. These areas form the building block of any successful scope in respect of oil and/or gas exploration research for the Inland Basins of Nigeria.
In order to realize this multidimensional and sophisticated research, some key factors have to be considered which can serve as measurement variables to the performance of each of the research direction. Firstly, Data gathering and analytics, which requires high technological laboratory equipment's, sophisticated computing systems and more importantly, skilled personnel.

Other issues are; software and hardware requirements usually applied for observing and manipulating the processed data. In recent years, the increase in performance as predicted by

Laura, et al., (2013), and particularly, the advent of parallel computing has enabled exploration and production to effectively use larger data. With decrease in the cost of CPU and an increase in performance, parallel computing has made this easy to most E&P researcher's, thereby easing the process of this proposed co-operation.
Again, consideration must be given to external environment, because the co-operation itself will have to exist because of it. Therefore, it is essential for this co-operation to recognize that it has to be responsive to it. Environment includes; people, target market, geographic location, climate, social, economic and political settings, in fact, anything that can affect the success of a full campaign. All factors mentioned above, from data gathering through equipment to environment, are capable of affecting planning, organizing, staffing and directing. As a result, should be further scrutinized in a series of meetings.
This hypothesis concludes that, a well-defined scope and quality, that considers all necessary research components, their respective tools and environment, will positively influence this proposed co-operation.

Hypotheses 3 (H3). *Relationship between research direction and data bank*
Organizations imperatives towards sustainability, efficiency and operational challenges to meet regulatory competitive and economic pressures have forced exploration and production researcher's to rely more on the knowledge base and operation intelligence. This increases the need to move data towards decision, improved operational efficiency and overall performance so as to implement tightly integrated solutions. The key to converting data into actionable, valuable insights lies primarily on the working team's innovative approach which is based on experience and correct understanding of the task at hand as well as the data itself. With recorded progress, more data is continuously generated which adds to the original data bank. This data bank forms the backbone upon which any decision making will be guided by. With these developments, this hypothesis has come to the conclusion that, a well experienced team, with good communication skills, knowledge and continuous training positively influence the field's database management (Data bank).

Hypotheses 4 (H4). *Relationship between data bank and successful cooperation*
The underlying question regarding the value added through data to exploration models and successful field development plan should be clearly visible when one considers that large fields worldwide have seen tremendous exploration success and/or production decline reversed by intervention or operational improvements (**Doublet, et al., 1995**). China National Petroleum corporation exploration research institutes program record of an un imaginable success, in Niger republic, Chad republic and Sudan republic was a classical textbook example of a successful drilling campaign, from concept to exploration and development, in an untested, remote, high-risk, and high-cost area (**Obaje, et al., 2000**). With relentless and rejuvenated geological and geophysical studies, particularly with respect to the data evaluation targeted towards potential petroleum systems, commercial success may also be achieved in the Nigeria's inland basins.

There are many examples of initial success of tapping into data to improve petroleum and gas exploration as well as reservoir performance models. Therefore, this hypothesis has come to the conclusion that, a qualitative data, with adequate coverage, stable (not subject to changes), in a user-friendly format and language will positively influence the success of FUT-CUG research co-operation, in respect of the inland basins of Nigeria.

Hypotheses 5 (H5). *Relationship between successful cooperation and financial performance*

Acoording to many authors (Yang *et al*., 2011; Jahn *et al*., 2008; Kaplan and Morton, 1992), research and development have evolved into a business process. Therefore, success in research can now be measured in terms of financial indicators which translate into organizational performance measurements. As a result, the main financial indicators proposed here are rate of return on capital employed, net operating merging and payback period.

With this in place, there is no doubt that a successful FUT-CUG cooperation in respect of oil and gas exploration in the Inland Basins of Nigeria will positively influence their respective financial performance.

RESULTS

Converting path diagrams to measurement and structural models

The constructs represent latent variables that can only be measured indirectly through some observations. These observations can only be carried out by establishing the key variables controlling the effectiveness of each construct. As a result, the interaction between each construct and its variables defines its individual measurement model which translates into the set of linear equations as shown in figure 5.

Having obtained the measurement for each construct, their interaction can then be applied to define the set of linear equations represented in figure 6. These equations represent the behavior of the organization of the entire process that will yield the viability of the proposed FUT-CUG cooperation.

FUT – CUG Measurement Equations		Scope Measurement Equations
$Z_1 = \gamma_{Z_{1,1}} C_1 + A_1$ $Z_2 = \gamma_{Z_{2,1}} C_1 + A_2$ $Z_3 = \gamma_{Z_{3,1}} C_1 + A_3$ $Z_4 = \gamma_{Z_{4,1}} C_1 + A_4$ $Z_5 = \gamma_{Z_{5,1}} C_1 + A_5$		$x_1 = \gamma_{x_{1,2}} C_2 + \varepsilon_1$ $x_2 = \gamma_{x_{2,2}} C_2 + \varepsilon_2$ $x_3 = \gamma_{x_{3,2}} C_2 + \varepsilon_3$ $x_4 = \gamma_{x_{4,2}} C_2 + \varepsilon_4$ $x_5 = \gamma_{x_{5,2}} C_2 + \varepsilon_5$
E&P Research Construct Measurement Equations		Data Bank Measurement Equations
$x_6 = \gamma_{x_{6,3}} C_3 + \varepsilon_6$ $x_7 = \gamma_{x_{7,3}} C_3 + \varepsilon_7$ $x_8 = \gamma_{x_{8,3}} C_3 + \varepsilon_8$ $x_{10} = \gamma_{x_{10,3}} C_3 + \varepsilon_9$ $x_{11} = \gamma_{x_{11,3}} C_3 + \varepsilon_{11}$ $x_{12} = \gamma_{x_{12,3}} C_3 + \varepsilon_{12}$ $x_{13} = \gamma_{x_{13,3}} C_3 + \varepsilon_{13}$ $x_{14} = \gamma_{x_{14,3}} C_3 + \varepsilon_{14}$ $x_{15} = \gamma_{x_{15,3}} C_3 + \varepsilon_{15}$		$x_{16} = \gamma_{x_{16,4}} C_4 + \varepsilon_{16}$ $x_{17} = \gamma_{x_{17,4}} C_4 + \varepsilon_{17}$ $x_{18} = \gamma_{x_{18,4}} C_4 + \varepsilon_{18}$ $x_{19} = \gamma_{x_{19,4}} C_4 + \varepsilon_{19}$
Meaningful Cooperation Measurement Equations		Financial Performance Measurement Equations

$x_{20} = \gamma_{x_{20,5}} C_5 + \varepsilon_{20}$	$x_{23} = \gamma_{x_{23,6}} C_6 + \varepsilon_{23}$
$x_{21} = \gamma_{x_{21,5}} C_5 + \varepsilon_{21}$	$x_{24} = \gamma_{x_{24,6}} C_6 + \varepsilon_{24}$
$x_{22} = \gamma_{x_{22,5}} C_5 + \varepsilon_{22}$	$x_{25} = \gamma_{x_{25,6}} C_6 + \varepsilon_{25}$

Figure 5: Measurement equations for each construct

Structural Equations
$\beta_2 = \alpha_1 H_1 + C_2$
$\beta_3 = \beta_2 H_2 + C_3$
$\beta_4 = \beta_3 H_3 + C_4$
$\beta_5 = \beta_4 H_4 + C_5$
$\beta_6 = \beta_5 H_5 + C_6$

Figure 6: Model Structural equations

CONCLUSION

The aim of this paper is to contribute towards cooperation among institutions in respect of Petroleum and or gas exploration research.The paper provides a platform on which institutions can collaborate not only on petroleum and or gas development but also on other various areas of research with a view to testing and validating the viability of their intended cooperation

The case applied in this paper, as deduced from literature is expected to yield successful economic results for a viable investment potential which will create jobs and reduce youth restiveness and insecurity in the region. In order to support the partnership, a conceptual model was developed in which key constructs for cooperation were identified together with their respective measurement variables.

These constructs and variables translated into simple mathematical equations that can be applied to capture different operating conditions, therefore creating room for evaluation. It is evident that there is a growing evolution of research into the business world; as a result, this proposed cooperation is a wake up call.

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