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In honour of Prof. Ekhaguere at 70

A materclass on stochastic modelling in finance and economics with a focus on current and emerging research directions

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Abstract. There is a dense literature on stock market analyses, including research themes from investment analyses, time series analysis and forecasting, empirical finance issues (market efficiency, bubbles, anomalies, volatility, predictability and valuation), financial derivatives, quantitative risk management, and macroeconomic modelling, for example. These works cover individual firms, market sectors, national, cross-national and international remits. This paper notes that there is a dearth of literature that pulls these ligaments of theoretical and practical works together, in a way that provides a systematic characterisation of a stock market akin to the mapping of DNA genome in modern biology. The paper, therefore, presents current works along this line in the Nigerian Stock Market (NSM), based mainly on doctoral research topics supervised by the author. The Systematic Stock Market Characterisation and Development (SSMCD) research theme was enunciated as a key part of the Statistics, Information Modelling and Financial Mathematics (SIMFIM) research at Sheffield Hallam University, UK, from about the onset of the global financial crisis in 2008. This paper aims to stimulate the mathematical and financial sciences research communities in Nigeria to undertake this SSMCD work through: a) the Nigerian Mathematics Finance Statistics and Economics Research Consortium (NIMFSERC), which the author convenes as an enabling research hub; b) spokes comprising of special Doctoral Training Centres (DTCs) in selected Nigerian universities, in which collaborating academics will jointly supervise an army of PhD students and post-doctoral research scholars; c) innovative research exchanges amongst myriad NIMFSERC groups, supported by a rich ecology of research grants and consultancies at local, national, continental and global perspectives; and d) special focus on research-teaching excellence and high-impact economic development.

Keywords: stochastic modelling, time series analysis, forecasting, empirical finance, quantitative financial risk management, macroeconomic modelling, derivatives, SSMCD, 'practification', global economics, economic development.

1. Introduction

In the paper 'Secrets of the Masters: Model-Based Hyper-Performance in the Corporate-Academic Business of Life', I noted: a) that Contemporary Mathematics is 'applicable mathematics that addresses itself to significant real-life problems', and b) that 'Professor Ekhaguere is an archetypal contemporary mathematician and Global Corporate Academic (GCA)'. The intellectual and practical puzzle I was attempting to resolve therein was how academics can work in a contrarian way, by living almost equally in the 'classroom' and 'the street of hard knocks', continually 'practifying' their knowledge, and translating such knowledge to significant enterprises.

In this paper, I continue this line of reasoning, but with a focus on how different streams of mathematical and statistical finance research, should be flexed into a DNA-style and deep-mind systematic stock market characterisation and development (SSMCD) framework. The aim is to develop a set of economic and investing principles which will help investment analysts, fund managers, and economists to manage financial assets in a country more successfully, for example Nigeria. For this, the Nigerian Stock Market (NSM) is a focal point, with linkages to the wider economy. It is apposite that Professor Ekhaguere and most of our colleagues at the UI Mathematical Finance research group have significant stakes in this quest (Ezepue & Ekhaguere 2016).

The key gap in knowledge addressed in this paper is that academics research economic and finance themes within specialist silos, without sufficient integration among the fieldas of specialisation and strong focus on applying resulting combined insights on identified challenges in research, theory, practice and policy-making. Take, for example, the different themes explored in the above reference Proceedings of the 1st International Symposium on Mathematical and Statistical Finance, held

1-3 September 2015 at the UI Mathematics and Statistics Complex and co-edited by Professor Ekhaguere and I. The key words in this paper echo those themes. The question is: when shall we as academics defy the mystique of the 'classroom' to: connect salient knowledge from such themes into working frameworks and rules of thumb, for intelligently managing the gorgeous perpetual motion machine (Dalio 2017), which describes the complexly uncertain (daily, monthly, annual, yearly, and period) fluctuations in the stock market; and balance out the see-saw of risk and returns across portfolios of asset classes, to continually create wealth?

Analogically, how can we chance upon a 'Holy Grail' in stock market characterisation and investing, much the same way as the human genome facilitates gene therapies for curing diseases? What nature of this SSMCD imprint helps us to automate lived experiences of stock market fluctuations, and improve economic and investment decision-making, at overall and sectorial levels of the market? How, through this deeper and automated system, do we resolve conflicts between street economic realities as observed by investment analysts, economists and policy makers?

The underpinning methodology is a meta-analysis of the spectrum of ideas in Ezepue & Ekhaguere eds. (2016), related research I have undertaken since about 2008, and more recently what I regard as the best exponent of such characterisation and automation, Dalio (2017).I will presume an elite audience of mathematical and statistical finance experts (not lay persons), so that given the immediacy of the above evidence bases, I simply tell the story of the techniques, results, and discussions, which weave out the SSMCD web from the different research themes summarised in 'Key words' to this paper.

The rest of the paper is as follows. Section 2 periscopes the theoretical background through selected literature. Section 3 presents the empirical base for SSMCD from the contributing themes. I may dip into important frameworks mainly, for want of space, and refer the reader to the key references involved. Section 4 develops related SSMCD tenets in form of key research directions for realising the Holy Grail in view. Section 5 summarises and concludes the paper. Again, a suitable mode of communication of ideas here is story telling about the mechanisms and merits of SSMCD work, which synthesises advanced research in the themes with developments in computational modelling and 'algorithmic' trading.

2. Theoretical background

Ezepue & Solarin (2009) explore the metaheuristics of the 2007-09 global financial crisis in a three-part paper system presented as a keynote paper at the 2008 International Conference on Mathematical Modelling of Global Challenging Problems, National Mathematical Centre (NMC), Nigeria. Part I on the causes and research implications of the crisis clearly notes that the crisis was not predicted by economists and policy makers, even though the mortgage costs of securitised homes sold to low-income American households by banks and federal housing institutions had started from end of 2006 to weaken the economic and credit systems. The paper recommends the need for early warning signals to be developed through a thorough historical analysis of past financial crises, their encompassing contexts of policies and reforms, and their consequences. This is the seedcorn of SSMCD which I hinted on for further work, and started implementing through follow-on PhD topics, results from some of which are presented in Ezepue & Ekhaguere (2016). Part II of the paper applied the insights from Part I to some topics in investment and financial risk management, including advanced quantitative risk management elements discussed in McNeil et al. (2005).

Part III provided a rejoinder to Professor Charles Soludo's inaugural lecture as Professor of Economics at the University of Nigeria (when he was the Central Bank of Nigeria Governor). In that part, I outlined the nature of research that would connect developments in financial mathematics sketched out in Parts I and II to the wicked problems in macroeconomics and development economics, which the lecture foregrounded. I believe that such spectrum of ideas in the three parts indicate the nature of SSMCD in mind. In the appendix to this paper I list out such research topics, to bring them to the fore as we attempt to match them to prospective PhD students.

In 2009, shortly after the NMC conference, I commenced supervision of Omar (2012) entitled Stochastic Modelling in Financial Markets: Case Study of the Nigerian Stock Market. This thesis explored in intimate details six key issues in empirical finance (also known as financial economics) which underpin stock market characterisation, namely market efficiency, volatility, bubbles, anomalies, predictability, and valuations, at overall market levels, using the All Shares Index (ASI) of the NSM. It was noted, though, that predictability and valuations are sector-based phenomena which apply also to individual firms, asset classes, and investments. Ezepue & Omar (2012) publish the efficiency results which show that the NSM (not counting in additional insights from the torque exerted on the NSM dynamics by oil prices and transaction costs) was weak-form inefficient. This result hints that there are enough signals in the market for agile investment strategies that will make monies for concerned investors.

The range of volatility results in Omar (2012) show that three key volatility models with the symmetric GARCH (1,1) model dominating and some concatenating asymmetric models, were best-choice models for tracking insipid volatility dynamics of the ASI, across different epochs of the study period determined by the 2004 bank reforms and the 2007-09 global financial crisis. These periods are: before the bank reforms, between the reforms and start of the crisis (2005 and 2006), during the crisis proper (2007-09), and after the crisis (2010 upwards). The implications of these results for SSMCD is that investment strategies for managing the risks associated with these shocks to the NSM and the economy generally, could be structured and computationally programmed to use these models involved, building in knowledge of the impact of reforms and the crisis. This, for the 2007-09 crisis which was unforeseen by the entire fraternity of global economists and investment researchers will be 'medicine after death'. If, however, such dynamics and effects were observed, documented and built into an early warning system from past crises (Asian crisis, 1987 stock market crash in developed economies, the crisis associated with World Wars I and II which culminated in the Marshall Plan, and the Japanese stagflation of the 1990s, also the 1990's dot com bursts), we would have had an SSMCD-like system that will help the investment community to figure out what to do before the 2007 crisis.

It was noted that such systemic links among investment objectives of households, firms and governments, and the system of monetary and macroeconomic policies which obtain in different regions of the world, will generate a globalised SSMCD framework for effective global economics and capital management; see more details of the remits of the global economics research in the School of Global Economics at www.oseluxworldhero3e.com.

Interestingly, an attempt to elicit bubbles from the same data that informed the efficiency and volatility effects in Omar (2012) and Ezepue & Omar (2012) failed to detect the bubbles. This result, which was recently published in Ezepue & Ekhaguere (2016) by Omar & Ezepue (2016), was explained by the fact that bubbles across the overall market could be masked by cross-sector effects, whereby gyrations in the banking and finance sector may be cancelled out by opposing ones in other inversely correlated sectors, for example oil and gas, agriculture, telecommunications and manufacturing. This realisation prompted further work in specific sectors, also to enable us to investigate predictability and valuation in those sectors. For this, a system of NSM sector-focused PhD topics and related publications was instituted for banking sector(Ezepue & Raheem 2016; Raheem & Ezepue 2016; Mbama & Ezepue 2016), derivatives, investment theories and portfolio optimisation using all NSM trading firms (Urama & Ezepue 2016), oil and gas (Awidan 2017), bank financial management models (Ochinanwata & Ezepue 2016), and integrated business modelling (Ezepue & Ochinanwata 2017). The key results in these papers are summarised in the different force effects of market features within different sectors involved, not to talk of the different configurations of theoretical approaches used, including advanced time series modelling of the Box-Jenkins, ARCH-GARCH volatility modelling, Vector Autoregressive (VAR) and Vector Error Correction (VEC) flavours, and combinations of these for time series-macroeconomic modelling (Awidan 2017; Raheem 2017).

Again, the upshot of these ramifications of empirical finance, derivatives, random matrix correlation analyses which support effective derivative pricing and portfolio optimisation work in the NSM, is that without inputting their insights into a master SSMCD framework, imbued with algorithmic investment decision making system of the kind elucidated in Dalio (2017), say, investment managers and policy makers will typically suboptimise the decisions. Given the centrality of efficient markets theories and the pervasive randomness of financial market returns, a well-oiled SSMCD system that anticipates crises and reckons with the past events, mostly historically recurrent cause-effect relationships amongst the crises, policy responses, and investment results, will better support economic, investment and policy making in the economy (Dalio 2017).

A question is: why do we not train students on the possibilities that such a system creates? Why do we not institute experimental economics and electronic investment markets that enable such a system to be practised by researchers, students and practitioners in the global economics and capital management space? We know that most successful fund managers like Dalio (2017)'s Bridgewater Associates Inc. in the US use variations of such a system, built through painstaking research on the economic history of different financial crises, investment models, and computerised decision-making systems.

Would it not be advisable for mathematical finance and applied economics research teams to create a small investment company with equity owned by academics and PhD students, with experimental portfolios across different market sectors? Such sectors could first be the twelve main sectors into which NSM trading firms are categorised or more globally classifications used by, say, The Times UK newspaper, namely banking and finance, investment companies, construction and property, consumer goods, health, engineering, industrials, leisure, media, natural resources (including oil and gas), professional and support services, retailing, technology, telecoms, transport, and utilities (The Times Monday December 4 2017, pp. 50-51).

Is it not clear that this level of detail is required in progressive education of mathematical scientists devoted to the business of global economics, taken broadly as noted in www.oseluxworldhero3e.com? Even if this is in form of departmental consulting units, we need to create such opportunities for real-life practical problem-solving, to innovate traditional pedagogy (Ezepue & Ochinanwata 2017, Ezepue 2016 mainly).

So far, regarding the range of mathematical sciences tools and techniques deployed in global economics and investing research and practice, we recall such techniques as time series and forecasting, empirical finance analyses frameworks, quantitative financial risk management, macroeconomic modelling, financial engineering including derivative pricing and products, theoretical physics models including Random Matrix Theory (RMT), which we feel is central to SSMCD in ways we will clarify below. We are aware that so much work has been achieved in these approaches taken one item at a time, but the knowledge connectedness amongst the different perspectives that they warrant, and which drives SSMCD work, is still not well-developed, especially in the teaching of global economics and their mathematical sciences underpinnings in developing countries.

We agree with Dalio (2017) that developing algorithmic rules that automate economic modelling and investment decision-making (aligned with expert judgment amongst domain experts) is a royal road to mastery in SSMCD work, even though the author does not use this acronym. Hence, profound mastery of applied computing, special coding and techniques such as simulation, neural networks, AI, genetic algorithms, decision trees, logistic regression, hybrids of these, and how they are informed by advanced multivariate statistics (principal components and factor analyses, for example) is required (Ezepue & Ekhaguere eds. 2016). See also the remits of the School of Integrated Business Analytics which cover such applied computing techniques in www.oseluxworldhero3e.com.

For this, Professor Ekhaguere provides requisite leadership through the International Centre for Mathematical and Computing Sciences (ICMCS), www.icmcs.org. In all humility, I have founded related platforms in forms of the African Higher Education and Research Observatory UK (www.afrihero.org.uk) in 2005. And recently this year 2017, I established the global face of this organisation, Oselux World Higher Education and Research Observatory 3E (www.oselucworldhero3e.com), which seeks to redress the key triad of lacks in higher education curricula, namely entrepreneurship, enterprise development and employability education (Egwuatu 2013; Sadik 2017).

Again, the reader may browse through indicative programmes of work in the Worldhero 3E Schools of Integrated Business Analytics which encompasses all the computing technologies outlined above, and the School of Global Economics which expands the scope of modern global economics and capital management research along the lines discussed in this paper, anchored on SSMCD thinking. Further remits of business education that covers these needs and other results achieved in different Worldhero 3E Schools, are provided in the School of Global Business and the Oselux International Business School in the website www.oseluxworldhero3e.com. The question again is why should such structures be established outside the classroom environs? This lack of deep applications bases denies our graduates the requisite knowledge to apply their learning meaningfully (Ezepue 2016; Dalio 2017).

In section 3 of this paper, we reinforce the evidence base for research-informed SSMCD work, using the range of meta-analytic studies indicated in the introduction. We take opportunity this way to explore the implications of some publications in Ezepue & Ekhaguere (2016). We further illuminate these SSMCD connections with recent research on RMT (Urama et al. 2017) and signal the need to explore modern investment strategies explored in Dalio (2017), Silver (2012), Tetlock & Gardner (2016), Buffet & Munger (2017) and Berkin & Swedroe (2016), and macroeconomic management (King 2016; Greenspan 2008; Sharma 2016). New SSMCD thinking from this mosaic of ideas will be published in the near future.

3. Empirical supports for SSMCD

Ezepue & Omar (2016) in Ezepue & Ekhaguere (eds) (2016, pp. 408-427) 'examine the nature of multidisciplinary stochastic-time series and control engineering' underpinnings of SSMCD, financial policy and macroeconomic management, especially focused on ARCH-GARCH volatility modelling of the NSM ASI for 2000-2010. It is recalled that stochastic processes and modelling encompass a wide range of time-dependent probabilistic systems, including time series, Markov chains and processes, Poisson process, Brownian motion and associated Levy processes, martingales, and derivative pricing models. The gist of the paper is recalled below in smaller print to show the kind of knowledge connectedness evoked by SSMCD research. In this paper, we do not replicate the referent papers in the summary vignette in the references.

3.1 *Overview and strategic importance of SMCD research*

Research in quantitative finance and economics is generally underpinned by some form of expertise in statistics including stochastic processes, time-series modelling and applied econometrics. The SMCD research programme explored in this paper therefore requires adequate understanding of these fields by collaborating academics and research supervisors. A stochastic process generally refers to a family of random variables (r.vs.) indexed by a time parameter and governed by a specified or underlying probability law. For example, if a random phenomenon is such that the behaviour at different time points is time-dependent, but the phenomenon generally follows a Gaussian (or normal) distribution, then such a stochastic process is said to be Gaussian. Typically, time-dependence in a stochastic process is reflected in the fact that the process parameters are now functions of time t instead of being fixed constants across time. Hence, if a sequence of r.vs. $\{X_1, X_2, \cdots\}$ follows a normal distribution with mean and variance parameters μ and σ^2 we write that

$$\{X_1, X_2, \cdots\} \cong N(\mu, \sigma^2) \equiv \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^2\right\}, \qquad -\infty < \mu < \infty,\, \sigma^2 > 0.$$

The stochastic version of this representation will be something like

$$\{X_1, X_2, \cdots\} \cong N(\mu, \sigma_t^2) \equiv \frac{1}{\sigma_t\sqrt{2\pi}} \exp\left\{-\left(\frac{x-\mu_t}{\sigma_t}\right)^2\right\}, \qquad -\infty < \mu_t < \infty,\, \sigma_t^2 > 0.$$

Special time-dependent stochastic processes, apart from time series, which could be used to model the dynamics of a financial system include Markov chains and processes, Poisson process of rare events, Brownian motion and associated Levy processes, Markov chains and processes, branching population processes, queuing processes, martingales, and renewal theory.

It is sometimes essential in SMCD research to combine tools from different fields, for example stochastic-time series and control engineering models, in order to more richly explore the timevarying dynamics of key characteristics and features of stock markets, at both overall and submarket levels. For example, in the case of the NSM, we may wish to characterise the overall market as well as key submarkets such as banking and financial services industry, telecommunications, energy, agriculture, and manufacturing sectors. Doing this across time epochs that accommodate different government policy and global financial scenarios will provide insights into the effects of the scenarios on stock market development and performance (Ezeoha et al., 2009; Ezepue & Omar, 2012).

The focus of SMCD research is on six key issues known in financial economics (also called empirical finance) to capture different aspects of market behaviour, namely efficiency, predictability, valuation, bubbles, anomalies, and volatility. These market features are to some extent intertwined with the fundamental concept of market efficiency. Market efficiency simply looks at how effective the market is in transmitting market information transparently and speedily to all market participants, in order to facilitate the determination of correct prices of market assets, and thereby enable sensible valuation of the assets and related investment strategies in the market, within the space allowed by overarching financial and macroeconomic (monetary and fiscal) policies (Ezepue & Omar, 2012). Bubbles, anomalies and volatility collectively deal with abnormal movements in market data, for example interest rates, asset prices and returns, and market indices, which may be traceable to policy and economic factors such as 2004 bank reforms in Nigeria and the 2007 global financial crisis.

The gist of multidisciplinary research into stochastic-time series models associated with these market characteristics is that new results on the model structures are obtained, especially results that relate the emerging market dynamics to control engineering ideas, which could lead to better ways of managing the dynamics from the point of view of different market participants. Some candidate time series topics of interest in SMCD research programme are: autoregressive (AR), moving average (MA), mixed autoregressive-moving average (ARMA), autoregressive integrated moving average (ARIMA) models, vector autoregressive (VAR); vector error correction (VEC) models which simultaneously model the effects of different economic variables on each other; and other specialised models such as (Generalized) Autoregressive Conditional Heteroscedastic (ARCH/GARCH) models typically used to model volatility of financial data, as in this paper.

The strategic importance of SMCD research has been emphasised in different works (Ezepue & Solarin, 2008/9 a, b and c; Ezepue & Omar, 2012; Omar, 2012). We summarise the key points below based on the schematic representation in Figure 1.

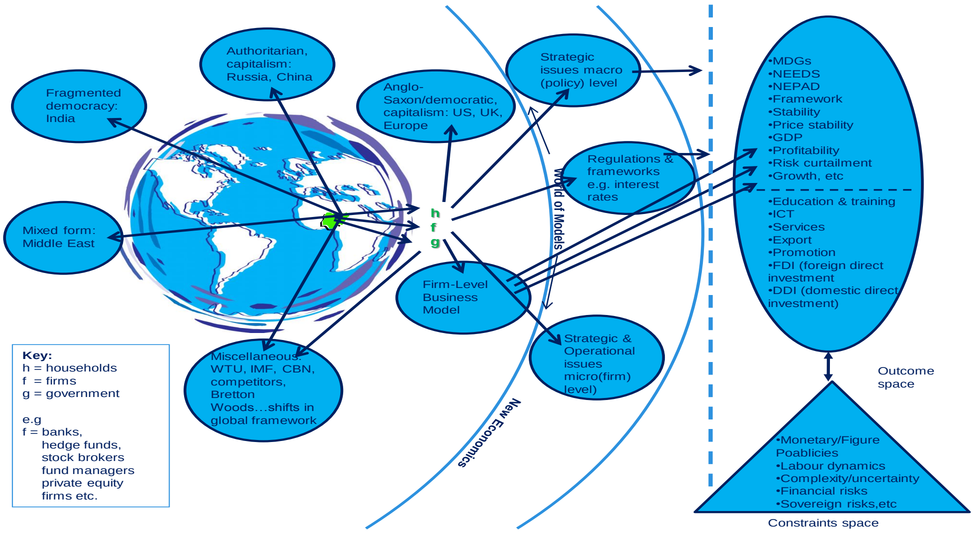

Figure 1. Policy analysis and decision spaces for economic agents in a globalized financial world (adapted from Ezepue & Omar, 2012, Figure 5, p. 218)

The schematic depicts the local and global financial investment, policy, risk management, and related decision-making contexts, facing households, firms and governments (h, f and g). In the schematic, the World of Models which market participants use in optimising their financial decisions is circumscribed by the macroeconomic status quo, financial and institutional regulations set by central banks and securities and exchange commissions, for example, and firm-level strategic and operational issues. The overall outcomes of the market moves, as depicted in the outcome and constraints spaces, are subject to controls set by monetary policies, labour dynamics, and financial risks, including sovereign risks. These financial risks are in turn determined by the extent of bubbles, anomalies and volatility in the financial systems, hence the need to more robustly characterise the stock markets in light of the six key market issues mentioned above, and key market data on interest rates, exchange rates, share prices, price/earnings ratios, inflation indices, consumer price index, asset returns and indices, domestic and foreign investments, national economic growth, capital market, capital formation, and other macroeconomic indicators (Barucci, 2003; Fama, 1991; Ezeoha et al., 2009). The research agenda also encompasses fundamental analyses of firm performances, meta-analyses of empirical finance studies on concerned economies, and their implications for national economic development, competitiveness, profitability, portfolio management of investment assets, and stock market development, market capitalization, value of traded securities, stock market liquidity issues (Ezepue & Solarin, 2009; Osinubi, 2004; Okpara, 2010, Ezeoha et al., 2009).

We extract further from the paper some aspects of volatility modelling and results which show the best-fit volatility models for sub-periods of the study duration. We include the volatility model equations for the understanding of scholars working outside financial mathematics.

3.2 *SSMCD research and volatility modelling of overall market returns in the NSM*

This section uses ARCH/GARCH models to explore the volatility of NSM All Shares returns in light the plausible effects of the 2004 bank reforms in Nigeria and the 2007 global financial crisis on the returns over the period 2000-2010. Volatility quantifies the errors made in modelling stock market returns, asset prices and other financial quantities. It is linked to market efficiency and performance and has applications in risk management, portfolio analysis, derivatives and valuation, for example. It is shown that the NSM has excessive volatility associated with some significant variables and that the volatility varies subtly across sub-periods determined by the bank reforms and financial crisis. The results are important to domestic and international security analysts, investors, management of the Nigerian Stock Exchange and Central Bank of Nigeria, in their investment, stock market development and policy making decisions. The example therefore supports an agenda for SMCD research which embodies these applications and is discussed later this paper.

3.3 *Brief notes on GARCH (p, q) models*

Let r_t denote NSM return from time $t-1$ to t. Given investors' knowledge of all relevant variables for determining returns up to time $t-1$, including the values of past returns, the expected return and volatility to the investors are the conditional return and volatility given this information set, denoted by $(\mu_t \,|\Omega_{t-1})$ and $(\sigma_t^2 \,|\Omega_{t-1})$ the unexpected return at time t is $\epsilon_t \equiv r_t - \mu_t$. In this paper, this error term is conceived of as a collective measure of news at time t. A positive value of the error term connotes the arrival of good news, while a negative value equivalent connotes the arrival of bad news. Also, a large absolute value $|\epsilon_t|$ signifies 'big news' in any direction, in the sense that it yields a large unexpected change in return. Hence, in general GARCH models incorporate effects of current and recent news and previous volatilities (older news) in their measurement of conditional means and variances of financial quantities of interest in a study. Volatility persistence in ARCH/GARCH models measures how long these effects last and volatility asymmetry measures the differential impact of bad news versus good news on the quantities.

A GARCH (p, q) model is defined as

$$r_t = \mu + \sqrt{h_t}\epsilon_t;$$

$$h_t = \sigma^2 = \omega + \sum_{i=1}^{q} \alpha_i (r_{t-1} - \mu)^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$$

$$\equiv \omega + \sum_{i=1}^{q} \alpha_i \epsilon^2 + \sum_{i=1}^{p} \beta_i h_{t-i}.$$

The GARCH (1,1) process produces multi-period volatility forecasts and when $\alpha_1 + \beta_1 < 1$ the unconditional variance of ϵ_{t+1} is $\omega/(1 - \alpha_1 - \beta_1)$.

If we rewrite the GARCH (1,1) process as

$$h_t = \omega + \alpha\epsilon_{t-i}^2 + \beta h_{t-1}$$

$$\equiv \omega + \alpha(\epsilon_{t-1}^2 - h_{t-1}) + (\alpha + \beta)h$$

we see from the equation below that the sum coefficient measures the rate at which the volatility effect reduces over time

$$E_t(h_{t+j}) = (\alpha + \beta)^j \left[\frac{h_t - \omega}{1 - \alpha - \beta}\right] + \left[\frac{h_t - \omega}{1 - \alpha - \beta}\right].$$

The dependence of the volatility process on both the sign and size of lagged residuals enables the EGARCH (1,1) model to better capture thick tails and volatility clustering in returns. This model is specified thus:

$$\ln h_t = \omega + \beta \ln h_{t-1} + \gamma \left(\left[\left| \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} \right| - \left(\frac{2}{\pi}\right)^{1/2} \right] + \delta \left[\frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} \right] \right).$$

The model yields a positive conditional variance h_t for any choice of ω, β, γ so that there are no restrictions on these parameters, but the restriction $-1 < \beta < 1$ applies to the model. Importantly, the model captures asymmetries in ϵ_t since it contains both absolute and ordinary errors normalized by the standard deviation, and for negative δ it manifests higher volatility for large negative errors. Hence, the EGARCH model captures asymmetric shocks in NSM returns from, say bank restructuring (financial reforms), global financial crisis, and oil price volatilities.

A GARCH-M (1, 1) model incorporates an autoregressive conditional heteroskedasticity. It links or integrates returns with volatility and is specified with ARCH-M return and GARCH-M volatility components thus:

$$h_t = \omega + \alpha\epsilon_{t-i}^2 + \beta h_{t-1} \equiv \omega + \alpha(\epsilon_{t-1}^2 - h_{t-1}) + (\alpha + \beta)h$$

and ARCH-M

$$r_t = \psi h_t + \epsilon_t$$

where $\epsilon_t = v_t\sqrt{h_t}$, $v_t \sim N(0, 1)$ and $h_t = \omega + \lambda + \alpha\epsilon_{t-1}^2$. The returns can be expressed as

$$r_t = \psi(\omega + \lambda + \alpha\epsilon_{t-1}^2) + \epsilon_t.$$

The GJR-GARCH model links mean returns and volatilities and is an alternative to the GARCH-M model. It serves similar purpose in NSM returns modelling as we have stated in the case of the

GARCH-M model. The GJR-GARCH model is specified as follows:

$$r_t = \mu + x_t^T b_i + \epsilon_t;$$

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i(\gamma s_{i-1})\epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sqrt{h_{t-i}}.$$

The path to conditional volatility effects in this model is through squared residuals and as noted earlier the model is suitable for capturing asymmetries based on the parameter γ, which, when positive, accentuates the effects of negative residuals even more compared with positive residuals. Importantly, the returns component in the equation justifies the use of external predictor and dummy variables in GARCH models, which is the approach we take in this paper. That is, we use dummies for days, weeks, months and years, as appropriate, to try to gauge the effects of these variables on NSM returns, which, though not directly associated with the volatility component, will enable us identify which of the variables have significant effects on returns, and may therefore account for the observed volatilities.

The Power GARCH (PGARCH) model of Ding et al. (1993) is specified as follows:

$$h_t = \omega + \sum_{i=1}^{p} \beta_i h_{t-i} + \sum_{j=1}^{2} \alpha(|\epsilon_{t-i}| + \omega\epsilon_{t-i})^2.$$

A consequence of volatility persistence is that the sample autocorrelation function for absolute returns and squared error terms are significantly positive for very long lags. Also, the pattern of the sample autocorrelation varies for differentstockreturns and differently from theoretical autocorrelations given by the GARCH (p,q) or EGARCH (p,q) models. Consequently, Ding and Granger (1996) propose a two-speed PGARCH model in stated in the equation below

$$h_t = \frac{\omega}{(1-\beta_1)(1-\beta_2)} + \sum_{i=1}^{p} \alpha_1 \beta_1^{i-1} \epsilon_{t-i}^2 + \sum_{j=1}^{q} \alpha_2 \beta_2^{j-1} \epsilon_{t-j}^2.$$

The model uses two variance components with exponentially decreasing autocorrelation patterns to model the long-term and short-term variations in volatility.

The PGARCH model is suitable for studying NSM returns volatility even at the overall market level as in this chapter, because it captures long- and short-term volatility effects due to myriad movements in the NSM caused by different market events for example news, policy uncertainties, financial reforms and global financial crisis.

Aggarwal et al. (2001) adopt the augmented (or dummy variable) approach in estimating the volatility equation; we illustrate the volatility equation of this kind for a GARCH (1, 1) model thus

$$h_{t+1} = \omega + \beta_1 h_t \epsilon_t^2 + \beta_2 h_t + \sum_i d_i D_i + \sum_j m_j M_j + \sum_k y_k Y_k.$$

where D_i, M_j, Y_k are dummy variables for days, months and years with corresponding effects on the volatility denoted by the coefficients in lower-case letters. In this paper, we use the dummy variables in the returns equation as:

$$r_t = \mu + x_t^T b_i + \epsilon_t \equiv \mu + \sum_i d_i D_i + \sum_j m_j M_j + \sum_k y_k Y_k + \epsilon_t.$$

3.4 *Empirical results and interpretations*

A stock index and return can be computed by comparing the current total market value of the issued shares of the constituent stocks in a particular day t with the corresponding value on the previous day $t-1$ as follows:

$$I_t = \frac{\sum MC_i}{\sum MC_{t-1}} \times 100;\ R_t = \ln\left(\frac{I_t}{I_{t-1}}\right) \times 100,$$

where MC is the market capitalization of constituent stocks on different dates with base date $t-1$. Hence, the stock index measures the rates at which the market changes in value from day to day. The stock market return measures the relative change in stock market index from the observed data on returns for the entire study period.

3.5 *Which models fit the data best?*

To examine which of the five models fit the data best across the five periods, we use the Akaike information criterion (AIC) (or the Schwartz criterion (SC) and the Hannan-Quinn criterion (HQC)), together with the log-likelihood (Log-L) statistics, Shin (2005, p. 35-41), Rousan and Al-Khouri (2005, p. 105-115). The AIC, SC and HQ statistics are similar across the models and periods. We use the AIC and Log-L statistics (standard formulas for which are not stated in this paper) to set up a model-fitness contest for the different periods and present results in Table 2 below.

Table 2: Best-fit volatility models and results for different modelling epochs

Period	**Best model**	α	$\beta\,(\gamma)$	$\alpha+\beta$ $(+\gamma/2)$	**Interpretations**
Overall 2000-2010	GARCH-M(1,1)	0.5248	0.4313	0.9561<1	Reliable model, persistent volatility, strong impact of current and old news on volatility, no asymmetric effects
Pre reforms 2000-2004	GJR-GARCH(1,1)	0.6189	0.3837 (−0.2876)	0.8588<1	Reliable model, fairly persistent volatility, strong impact of current and old news, significant asymmetric effect of the news
Post reforms 2005-2010	GARCH-M(1,1)	0.4725	0.5128	0.9853<1	Same as above, but far more persistent volatility, no asymmetric effect of current versus old news
Post reforms-pre crisis 2005-2007	GJR-GARCH(1,1)	0.4838	0.5284 (-0.2254)	0.8995<1	Strong impact of old and new information, much lower volatility persistence than before, significant asymmetric effect
Post reforms-post crisis 2007-2010	GARCH-M(1,1)	0.5781	0.4041	0.9822<1	Model a bit more unreliable, strongly persistent volatility, no asymmetric effects

Having sketched out the character of SSMCD research in this paper, we present an understanding of how some of the papers in Ezepue & Ekhaguere eds. (2016) potentially contribute to the research.

Ayinla (2016) compares short- and long-term Brownian motion-based simulation of NSM stock prices of Okomu Palm Oil trading. The paper shows that the geometric Brownian motion is very accurate for the long-term and far less accurate for the short term. This kind of understanding means that developing an SSMCD framework that could automatically compute investment decisions needs more attention on the reliability of selected stochastic models for different investment periods.

Raheem & Ezepue (2016) use a three-state Markov chain to predict asset prices for a Nigerian bank, including perspectives on expected lengths of different trading runs and cycles. The paper (now published in the CBN Journal of Applied Statistics 2016) shows that for five years including the 2004 post-banking reforms and 2007 global financial crisis, 'there are no significant asymmetric or leverage effects' on bank returns. In SSMCD parlance, we view such results as revealing of sector-based NSM dynamics which have implications for investment decisions in portfolios that include bank assets. You can imagine that such results could be explored in the other twelve (12) key sectors of the NSM to begin to map such dynamics across the entire market. Also, as noted earlier in the paper, more work can be done on possible predictability and valuations in these different sectors, for entire sectors (probably using market indices) and individual firms in the sectors, say specific banks. Given that investment decisions are really about market signals and valuations, SSMCD-based trading algorithms should include these insights, depending on the investment objectives and portfolio structure.

As summarised before, Omar and Ezepue (2016) explore the presence of bubbles in the NSM ASI and their possible links with recent bank failures in Nigeria. Curiously, the statistical evidence of no bubbles in the market contradicts the near bank crashes saved by CBN funding interventions. It is clearly noted in the paper that this calls for sector-based examination of bubbles in SSMCD research which another PhD topic by Raheem has investigated.

Obinichi & Ekhaguere (2016) present a 'sensitivity analysis of model parameters in a G-S Model for the energy market'. Using simulations and Kalman filter approach they investigate how to minimise model uncertainties for the long-run yield. We know that portfolio risk in investment theory is fundamental to effective investment management. Hence, building an SSMCD framework that exploits knowledge of the NSM energy market needs such insights. For a derivates spin in the papers under review, Fadugba & Nwozo (2016) study the 'Melling Transform Method for the Valuation of European power options', focusing on integral representation of the options, linked to Black-Scholes-Merton-like valuation formula. The results show that 'the Mellin transform method is a good alternative approach for valuing European options'. We argue that this implies the need for detailed research into the relative merits and computational schemas for using derivatives to inoculate investment portfolios against risks, for example structuring risk-neutral portfolios and the drivers of value in such portfolios (Urama 2017, Dalio 2017). Again, sound SSMCD-focused computational trading models involving derivatives require such mastery on the part of academics, students and collaborating investment professionals. See also other derivatives and stochastic models of stock prices, interest rates, CBN bank reforms and bank return volatilities (Adeosun et al. 2016; Adenegan & Ayoola 2016; Urama & Ezepue 2016; Agwuegbo et al. 2016; Ezepue & Raheem 2016).

We are intrigued by a panoramic review of the 'impact of contemporary technological tools on financial mathematics and financial management services' offered by Aro-Gordon & Uppin (2016). They explore emerging computational tools and financial technology products with a real estate investment case study. The paper recommends curriculum innovations which equip academics, students and practitioners in global economics, investment and finance with computing technologies that enhance 'sustainable corporate productivity and national prosperity'. The following Table 1 from the paper captures the key areas of financial mathematics where such computing technologies are germane. The main idea in SSMCD is precisely the use of computing technologies to automate investment decision-making in these 27 areas of financial mathematics, in a way, also argued in the paper, that connects Basic Financial Mathematics (BFM), Applied Financial Mathematics (AFM) and Financial Computational Technology (FCT), for the benefit of direct users, financial institutions, financial market analysts, indirect or proxy users, and learning community (academics, students, and professionals).

We add to these remits the need for pervasive training of the Nigerian learning community in mathematical sciences and global economics generally, in key forms of computational coding summarised in the Worldhero 3E School of 3E Technologies (or Information Technology Management) and recalled below (www.oseluxworldhero3e.com):

- The 3E International Coding Schoolis devoted to advanced computer programming education

Table 1: Application/professional scope of financial mathematics

▪ Asset/Liability Management	▪ Liquidity Modeling	▪ Risk Governance
▪ Alternative investments	▪ Market Risk Modeling	▪ Securitization
▪ Behavioural Finance	▪ Risk Management	▪ Valuation
▪ Capital Budgeting	▪ Modeling Techniques and Tools	▪ Time Series Modelling
▪ Credit Risk Modelling	▪ Operational Risk	▪ Data Analysis
▪ Econometrics	▪ Portfolio Construction	▪ Trading Systems
▪ Board Governance	▪ Quantitative Trading (Buy-side)	▪ Market Microstructure
▪ High Frequency Trading	▪ Quantitative Trading (Sell-side)	▪ Interest Rate Modeling
	▪ Risk/Performance	▪ Management Technology

for millions of academic- and technical-minded academics, young school leavers, university students, and professionals interested in furiously effective personal professional development in core and emergent applied computing work;

- Hence, intense immersions in key coding systems and business analytics platforms like SAS, R, SPSS, C++, Advanced Excel/Visual Basic, Python, Agile, Business Objects, Hadoop (SAS and R versions, for example), QlikView, and Tableau;
- Primarily to cascade advanced coding and application development skills to millions of next-gens, in parallel with advanced use of all key software systems and techniques in applied statistics, statistical computing, mathematical finance and engineering, business analysis and data science.

The following vignette provides additional perspectives from the Worldhero 3E School of Integrated Business Analytics.

3.6 *School of Integrated Business Analytics & Development*

In this School, we implement world-leading Full-Spectrum Integrated Business Analytics and Development (FIBAD), including such perspectives as:

- Underpinning Business Analysis to scope a project fully;
- Suitable Data Analytics of either Data Science or traditional BI/Data Mining persuasions;

- Advanced Artificial Intelligence, Neural Networks, Genetic Algorithms, Decision Trees, Logistic Regression, Advanced Time Series, Econometrics and Macroeconomic Modelling; Hybrid Models; Insight Development, including
- Detailed Insight Development and related Business Development, focusing possibly on Customer/Stakeholder marketing pitches, based on pen portraits of who they are;
- Business Geography and its applications, linked to Geodemographics, Applied Business Analytics and Big Data, Personalised, International and Ecological Marketing, Hospitality and Tourism, and Social Media Research;
- Formal market access and development, to link resulting new offerings to key customers, clients and stakeholders, across industry sectors, public services and academia, if need be;
- Follow-on training of hands-on staff to bed in the novel techniques; and
- Follow-on consulting to further develop related prospects, for example
- Profitable growth and revenue management,
- Strategic partnerships, integrated business modelling;
- Business Networks; and
- Social media strategies for fanning related fanbases for an offering.

Importantly, we present in the below vignette the entire gamut of global economics research and enterprise development work which these technologies support and which SSMCD insights particularly reinforce.

3.7 *Oselux School of Global Economics and Capital Management*

In Oselux Global Economics and Capital Management, simply referred to as the School of Global Economics, we conduct deep PhD-level theoretical and applied economics research, to provide robust evidence base for effective decision making under conditions of uncertainty and complexity. This is hinged on broad and deep characterisations of key sectors of an economy to elicit fundamental and contingent predictors of value in the sectors, and for the wider economy. An example is Systematic Stock Market Characterisation and Development (SSMCD), which links key empirical market features (efficiency, anomalies, bubbles, volatilities, predictability and valuations) to macroeconomic factors like interest rates, inflation, consumption, investments, growth, and unemployment.

Mapping the DNA of overall financial markets and key sectors this way (energy, banking and finance, health, telecommunications, retail, and industrials, for example), combines with related applied statistics, financial mathematics, investing, applied economics, computational modelling, and business analytics knowledge, to produce a multiple-lensed view of economic and investing phenomena.

Key perspectives of work in the School are:

- Innovating leading university curricula in Economics, for instance Nottingham, Oxbridge, Warwick, Harvard, Princeton, MIT, and LSE;
- Financial Mathematics, including derivatives research and investment applications in global financial markets;
- Researching and investing in different asset classes equities, bonds, currencies, commodities, real estate, and derivatives;
- Links with business and finance;
- Advanced time series and econometric analyses;
- Bank financial management (retail banking, investment and wealth management, for example);
- Applied economics, including economics of strategy, financial economics, monetary policy;
- Experimental and behavioural economics linked to the social-psychology of investments;
- International private equity and valuations;
- Understanding and doing business with global central banking e.g. US Federal Reserve, UK Bank of England, Central Bank of Nigeria;
- Street-Wise Economics: Case Studies built from emerging and typically multidisciplinary hot topics;

- Other emerging perspectives from daily general cultural literacy work in Worldhero 3E, which generate valuable wisdom of the crowds, surveys of experts, and financial journalism;
- Applied Economics Newsletter, practical financial journalism which digests and creatively extends critical reads, blogs and informed conceptual articles from journals and financial broadsheets such as The Times, The Economist, using Worldhero 3E research and businesses as case illustrations;
- Regular international symposia, schools and workshops in global economics, mathematical and statistical finance, in collaboration with experts from academia, industry and government, linked to national socio-economic development goals and challenges.

Related research and enterprise development perspectives:

- Worldhero 3E Centre for Advanced Research and Enterprise Development, linked to related disciplinary research in mathematics, statistics, computing, information modelling, applied economics, and financial mathematics;
- Organising national cross-sector multidisciplinary support networks like Nigerian Mathematics, Finance, Economics and Statistics Research Consortium (NIMFSERC);
- Linking these consortia to a global Centre for Mathematical Modelling in Finance, Insurance, Economics, Banking and Business (CEMMFIEBB), which the School of Global Economics coordinates;
- Founding Mathematical Sciences Research Groups (MSRGs) in affiliate universities, to cross-fertilise research in mathematics, statistics, computing, finance, and economics;
- World-leading undergraduate and postgraduate tuition in the contributing subjects;
- PhD Research on the topic: The Pedagogy of Selected Global Economics Disciplines: Entrepreneurship, Enterprise Development, and Employability Perspectives, with specific focus on, say,
- Financial Mathematics, Investing, Fund Management, Econometrics, Applied Economics, Experimental and Behavioural Economics, International Private Equity and Valuations, Bank Financial Management, Wealth Management, Mergers Acquisitions, Entrepreneurial Finance, and Financial Journalism

Again, work in this school produces outstanding corporate academic PhD theses, MSc dissertations, and advanced project outcomes, which can be spun-off as social enterprises, and for-profit born-global firms that are powered by the Internet.

When Aro-Gordon & Uppin (2016) talk about the need for serious curriculum innovations, we agree completely with such views, hence the above Worldhero 3E programmes. It is satisfying that the Worldhero 3E initiative is a fulfilment of the calls for such curriculum innovations in Ezepue (2016), which is devoted to Part II of Ezepue & Ekhaguere eds.(2016). To complete our understanding of the nature of challenges in African HE and their indicative solutions through SSMCD programmes and Worldhero 3E training sketched out above, we present in Table 0 in Ezepue (2016) that almost says it all. Ezepue & Ochinanwata (2017) develop these solutions further using insights from integrated business modelling for born-global firms, which are firms based mainly on the internet just like Google and Amazon, with the potential to reach global audiences from inception.

We note that the Corporate-Academic Model (CA Model) mentioned in the table is the subject of Invited Paper 3 in the Proceedings of the 2017 International Conference on Contemporary Mathematics in the Real World, which this paper belongs to.

4. Tenets and vistas of the Holy Grail in SSMCD work

In this section, we summarise the paths to practice in SSMCD research and enterprise development, especially indicating the way SSMCD as a DNA map of a stock market, indeed a national financial system as the Global Economics programmes reveal, automates economic and investment decision-making for investors (households, firms and governments) and policy makers. We present the pertinent literature to save space.

Urama et al. (2017) present a detailed analysis of the cross-correlations of traded assets in the NSM

Table 0: A summary matrix of identified challenges in African HE and indicative solutions

No.	Challenges	Description	Indicative responses
1	Faculty shortage and development	Acute shortage of teaching faculty and world class research scholars, especially senior faculty at PhD level; inability to retain qualified research scholars; amplified by brain drain, retirements, and unattractive working conditions	National and Continental Doctoral Training Centres aimed at using pooled expertise to train word-leading PhDs; creative ways to train lecturers as corporate academics (CAs), who live in the class and street, and thereby generate funding that enhances their research, teaching, learning, assessments, consulting, and community services (RETLACCS) engagements and earnings; similar opportunities to benchmark CAs' working conditions on best practices in world-leading universities e.g. MIT, Harvard, and Oxford.
2	Governance, leadership and management	Weak leadership, management and governance due to inefficiencies, underutilized facilities, duplicative programmes, low staff-student ratios, allocation of large share of budget to non-academic activities, poor HE leadership development in strategic planning, market research and advocacy, research management, financial planning and management, HRM, performance management, and partnership building and networking skills	Setting up a global WORLDHERO 3E born-global firm, with mainly virtual presence and physical presence in partner HEIs, special focus on strong institutional leadership, management and governance, and a radical 3E (entrepreneurship, enterprise, and employability education) ethos, which forces resource efficiencies, mission-critical strategic planning, marketing, research management, financial planning and performance management; supported by research-based spin-offs and teaching companies, which execute Triple Helix collaborations in relevant HE and commercial marketplaces. The WORLDHERO 3E simply expands current Afrihero thinking globally to accommodate other regions of the world; regional 'franchises' include Afrihero, Amerihero, Indiahero, Chinahero, Asiahero generally, and Mehero for Middle East, for example.
3	Problems of quality and relevance	Mismatch between curricula and labour market requirements, education obsolete and disconnected from the economy, over-emphasis on theory and less on practice and technical competencies, poor generic, entrepreneurial, enterprise and employability skills, and lack of effective national and continental research and teaching excellence frameworks	With CAs that live in the class and streets where knowledge is directly applied to cogent societal problems, disciplinary curricula are regularly renewed in line with changing labour market requirements; case studies and mixed pedagogies are used to link theory to practice in all disciplines, in a way that recognizes that every discipline is sufficiently 'professional' if taught the right way; fervent focus on 3E education imbued with radical RETLACCS innovations gleaned from original research, best practices, and Triple Helix collaborations; condensing all these experiences into a Global Research and Teaching Excellence Framework (GLORETEF) adapted specially to an African Research and Teaching Excellence Framework (ARETEF), based on a meta-analysis of similar frameworks in UK, say, relevant HE and business performance league tables, Six-Sigma methodology, and excellence frameworks such as the European Foundation for Quality Management (EFQM)
4	Weak research and innovation capacities	Inadequate research facilities; poor translation of knowledge to practice through adaptation, innovation and problem solving; slow expansion and development of innovative postgraduate programmes; low impact of HE research on national innovation systems, productivity, and 'dynamic university-industry linkages'	Training workshops on **Translation Academic**s, which is a common trait of CAs and academic entrepreneurs; training on 3E skills (about 58 core skills) which nurture adaptation, innovation and problem solving mindsets among knowledge workers, see for e.g. the Skills for Students Graduates and Start-ups (SSGS) programme of Afrihero (www.afrihero.org.uk); addressing national economic and global sustainable development goals (SDGs) through innovative teaching of HE curricula, and Triple Helix collaborations (3E RETLACCS innovations) (Ezepue and Ojo, 2012)

5	Financial austerity and lack of capacity for diversification	Lack of adequate finance, competing public service priorities; weak support from international community; need to diversify revenues, but very limited experience; poor competitiveness in knowledge generation and adaptation; poor integration in global knowledge systems	Operating entrepreneurially through 3E and value-adding RETLACCS innovations means that academics, PG students and external industry-government collaborators can generate enough funds and diversify their programmes, products and services competitively and *glocally*; Capacitating academics with smart CA model-based PhD research supervision skills which turn PhD theses into born-global firms similar to Google, Amazon, Alibaba, SoftBank and Microsoft, for example – this amounts to a radical innovation in cutting-edge theoretical and applicable research, which mimics the Silicon Valley in the streets of Nigeria, Africa and developing countries.
6	Poor physical facilities and infrastructure	Little or no infrastructure improvements in the last few decades; widely deficient learning infrastructure e.g. internet access, library, textbooks, equipment, laboratories	Again, a CA model-based 3E education approach uses the above strategies to generate sufficient funds to improve the learning environment along all these lines. For textbooks and research monographs, training Nigerian and African author syndicates by disciplinary clusters on the Afrihero STELLARTEXT © system for writing bestsellers and related ARETEF and GLORETEF motifs, will enable them to produce world-leading learning resources, with a good mixture of local and international examples and case studies. But this requires academics that operate the CA model and therefore have enough street wisdom to develop such texts, including laboratory manuals and library resources for specific disciplines.
7	Inability to meet increasing demand for access and equity	Too many students seeking admissions compared to available HE capacities; small graduate level (MSc and PhD) enrolments, especially in core STEM and health fields vital for science-based innovation and national competitiveness, with less than 30% of Sub-Sahara African students in agriculture, health sciences and STEM subjects	Researching and implementing signature RETLACCS learning systems and strategies which work with large classes; creating a WORLDHERO 3E Research and Enterprise University System that uses online programmes and modified Massive Open Online Courses (MOOCs) to role out deep theory-deep praxis courses, certificates, UG and PG degrees, jointly awarded with leading universities in Nigeria, Africa, and other parts of the world; special focus on STEM subjects and quantitative business disciplines; with advanced studies institutes that catalyse cutting edge RETLACCS excellence in all HE offerings

using Random Matrix Theory (RMT), which exploits the eigenstructure of the correlation matrices to determine the relative noisiness or informativeness of the correlations. More detailed applications of the RMT techniques to modelling bank returns and implied volatilities in the NSM are presented in the embodying thesis, Urama (2017). We do not have enough space in this paper to present the models. The thesis describes an heuristic approach for using RMT results, and other insights on extensive stochastic calculus and derivative pricing modelling useful for creating NSM derivative products, to achieve this. It uses the stylised facts of NSM assets, implied volatilities of presumed derivative products to be built on them (not yet existent) and benchmark JSE products which exist. We summarise the heuristic here as guides tofuture work.Again, we note that the references in the summary vignettes in smaller font are not replicated since they are already in the indicated source reference.

4.1 *Some notes on heuristic modelling of JSE-NSM asset and derivative price dynamics*

The management of the Nigerian Stock Exchange (NSE) indicated in a meeting with the researchers in 2014 that: the NSM was interested in using derivative products to deepen the markets; enable such products to play traditional roles in risk hedging, speculation and arbitrage; and successfully benchmark its performance on existing JSE derivatives, given the relatively more advanced status of the latter. Hence, the heuristics aims to combine JSE derivatives data with broader NSM stylized facts and characterisations, especially based on Random Matrix Theory (RMT), to simulate plausible derivative models and prices that will fit the Nigerian stylized facts and RMT results better. For example, to cover the essential scope in this initial modelling of derivatives in the NSM, we will look at key sectors and products that will be more useful for achieving the stated derivative modelling objectives risk hedging, speculation and arbitrage especially those which the NSE management mentioned that major NSM investors are interested in.

These products include currency options, cross-currency swaps, deliverable and non-deliverable forwards. Also, important market sectors in these considerations are banking and financial services, energy and (agricultural) commodity derivatives such as futures, because of the strategic relevance of energy and agriculture sectors in the Nigerian economy. For instance, banking and financial services are fundamental sources of development finance for investors (households, firms and government). Oil and gas provide the energy inputs into manufacturing and production of goods and services, and revenues for Nigeria, and agricultural products support other industries.

The ingredients for the derivative pricing heuristics are the correlation structures from RMT analyses and Black-Scholes derivative pricing models, observed stylized facts of underlying asset prices, and implied volatility dynamics in the JSE. These facts will be categorised as Generalised Stylised Facts (GSFs) and Implied Volatility Stylised Facts (IVSFs). Sequential modelling in form of models M1, M2, M3, for example, will exploit the JSE data, based on comparative analysis of the performance of selected derivative models against the standard BS model, for suitable derivative products mentioned above. The reason for this approach is to understand which BS models or extensions of the BS model are typically used in the JSE for specific asset prices, and whether the derivative prices from competing models are more accurate than the ones used.

This knowledge will be very useful to NSE management, as they optimise the decision choices facing them in introducing derivative products and models in the NSM. It will also be useful to the JSE management, if they become aware that existing models used in pricing JSE derivatives are not as good as alternative models revealed by this research. This, therefore, will be a crucial contribution of the heuristics to knowledge.

We, however, recall that the underlying asset prices are available in Nigeria, but not derivative prices. Given that derivative models are common theoretical knowledge across the two markets, we represent the Nigerian information as NBS for BS model, NGSFs for General Stylised Facts (GSFs), NUAPs for underlying asset prices. We use the known NGSFs in Nigeria to estimate the unknown Nigerian implied volatility stylised facts (NIVSFs). Similar notations are adopted for JSE by replacing N by S. The key research question now is: How do we overcome the lack of research data on the IVSFs which underpin derivative pricing in the NSM?

In brief, the following steps are involved: a) compare the stylised facts (GSF information) on underlying prices for JSM and NSM, to gauge how close the two data sets are in behaviour (using, say, the first four moments and distributions of the data sets); b) explore the correlation or heuristic links between the full data on SGSFs and SIVSFs in South Africa, and across Nigeria and South Africa; c) infer therefore the likely range of values for the unknown Nigerian IVSFs; d) run RMT analyses on asset prices from key market sectors in NSM and JSM (for example selected banks, oil and gas, commodities), to characterise mainstream tendencies in the markets, and further refine the initial correlational and heuristic links in b) above; e) using knowledge of the RMT comparisons, simulate plausible data that fits the Nigerian modelling scenarios and repeat the sequence of modelling M1, M2, M3, ..., on the data (Voss, 2014). This will produce indicative results which will inform possible decisions on the models and projected prices that could obtain in the NSM, under different modelling scenarios.

In an absorbingly interesting account of how the management of the investment firm (Bridgewater Associates) conducted a detailed analysis of the economic history of all past financial crises in the world and their consequences, Dalio (2017) offers practical ways to implement the SSMCD ideas explored in this paper. The principles for automating investment decision-making compared to their expert but manual judgements are the focus of the text. Though Dalio and team do not use the SSMCD acronym in the text, it is clear to us that they are presenting a good way to implement such a systematic framework. This opens up remarkably interesting research directions for using SSMCD and Dalio's Principles to implement the above Global Economics programmes.

In doing this, just as Dalio was heavily consulted by policy makers in the US Federal Reserve and other parts of the world because he used the system to correctly predict the 2007-09 global financial crisis, we need to map the minds and understandings of central bank players and global financial institutions most of whom could not predict the crisis. We recommend therefore a thorough read of Mervyn King (2016)'s The End of Alchemy: Money, Banking and the Future of the Global Economy, Alan Greenspan (2008)'s The Age of Turbulence with a New Chapter on the Credit Crisis, and Ruchir Sharma (2016)'s The Rise and Fall of Nations: Ten Rules of Change in the Post-Crisis World. I also suggest that a reread Professor Soludo's Inaugural Lecture at the University of Nigeria and my rejoinder to the lecture in Part III of Ezepue & Solarin (2009) provide useful additional theoretical understandings of the macroeconomic ilk.

For additional perspectives on the nature of (super)forecasting methodologies which could augment Dalio (2017)'s Principles, we need to review Tetlock & Gardner (2016) and Silver (2012). For complementary investment perspectives by successful investors and researchers, we recommend also a critical reading of Berkin & Swedroe (2016) and Pecaut & Wrenn (2017).

Finally, Ezepue (2016) in Part II of Ezepue & Ekhaguere (2016) summarises the nature of research and training which are related to higher education curriculum innovations, and pervasive SSMCD-like capacity building across academia, industry and government sectors. We present relevant excerpts from these initiatives in the appendix to this paper, including some of the PhD research topics developed from Ezepue & Solarin (2009) and its Part III rejoinder to Professor Soludo's inaugural lecture.

5. Summary and conclusion

This paper provided insights into SSMCD research, training, curriculum innovations, and national economic development, from many perspectives depicted in the Key words, namely Stochastic Modelling; Times Series Analysis; Forecasting; Empirical Finance, Quantitative Financial Risk Management; Macroeconomic Modelling; Derivatives; SSMCD; 'Practification' of these ideas; Global Economics; and Economic Development. Of these, we say more now about Practification. In a related paper 3 on Secrets of the Masters, we note that:

'Practification, as opposed to formal practice which it includes, requires continual rethinking of contexts, situations, problems, and challenges facing significant stakeholders in society – individuals, organisations, and government – using everyday situations obtained from wide readings, referred to as General Cultural Literacy (GCL) in the Corporate Academic career self-management model (CA Model). This lends a sense of holistic realism to the quest for meaningful knowledge, not typically encountered in traditional case studies within a technical field, or end-of-programme theses and dissertations'.

Take financial mathematics for example. A thorough exploration of this field as in this paper shows its immense applications in different global economics programmes. The point is: do we research, teach and apply this beautiful subject, in such integrated and analytical SSMCD ways that encourage aspiring learners to see the systemic connections among different asset classes, sectors, national and global markets? Do we run SSMCD and global economics laboratories or collaborate with stakeholders in the emerging research results, such that students are immersed in deep learning of these possibilities, thereby continually practising financial mathematics on all manner of problems amenable to such solutions? Hence, is the subject connectedly 'practified', with students continually exposed to case stories of its applications, the way narrated in this paper, and subjected to creative problem-solving of unstructured problems in economics and investment decision-making?

The paper suggests that we innovate higher education curricula accordingly to achieve this goal. We are satisfied that this is happening in Oselux World Higher Education 3E (www.oseluxworldhero3e.com). The appendices to this paper remind us of the nature of capacity building work and technical subject-matter research which Worldhero 3E will lead and facilitate among all Nigerian universities, and in partnership with global universities it mobilises for sustained innovations in research, teaching, learning, assessments, consulting and community services, of which SSMCD work is a cardinal part.

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Appendices (from Ezepue 2016)

Appendix 1: Remits of the Nigerian Mathematics Finance Statistics and Economics Research Consortium (NIMFSERC)

Founded by the African Higher Education and Research Observatory (Afrihero, UK www.afrihero.org.uk) in partnership with the National Mathematical Centre Abuja Nigeria (NMC), and selected universities in Nigeria, the NIMFSERC programme covers research collaborations and consulting among experts in selected mathematical, business and social sciences, for example mathematics, statistics, computer science, physics, finance, economics, marketing, sociology and psychology. Using Nigeria as a case study, it interfaces these disciplines within problem contexts and explores how they combine to produce new knowledge and new practices that address existing and emerging skills shortages in the financial services sectors of many African countries.

The core aims of NIMFSERC are to:

- To facilitate cross-disciplinary academic developments and research collaborations among the constituent disciplines
- Characterize and calibrate Nigerian (and African) financial markets for effective investment approaches and decision making
- Facilitate strategic cross-disciplinary collaborations among experts in the above fields, based on audits of financial industry needs, and talent pools, research and teaching statuses of partner higher educational institutions in Nigeria
- Examine the implications of the recent global financial crisis for research and practice in the subjects, possibly within in a new global financial architecture, and in light of corporate governance, and new accounting/regulatory frameworks
- Explore the nature of innovations in the pedagogy and practice of the disciplines required to produce new kinds of graduates, who are able to it the ground running in the financial services industry.
- Map project ideas and related studies to strategic national and regional economic development agenda facing Nigerian and other African countries, for example the Millennium Development Goals (MDGs), Nigerian Vision 2020 (NV2020), Nigerian Financial Services Strategy (FSS2020), and develop a fitting training programme for a new cadre of cross-disciplinary professionals in these fields of immense strategic importance
- Establish a state-of-the-art multidisciplinary Doctoral Training Centre covering the key topic areas mentioned in these notes, to be jointly supervised by Nigerian, African and international scholars in these fields
- Develop specialist academic resources in the areas, including textbooks, research monographs and case studies, which are adapted to contemporary Nigerian and African pre-emerging markets experiences and needs
- Use experiences from the programme to undertake contract research, consultancies, and training workshops for specific industry sectors and institutions in Nigeria and Africa, and sell related services to global client publics, as appropriate

Related MSc/MBA/PhD Research Topics to be jointly supervised by Home and Diaspora-Based Nigerian, African and Global Academics mainly

- Characterisation of Nigerian Financial Markets: Stochastic Modelling Perspectives
- Characterisation of Nigerian Financial Markets: Functional and Stochastic Analyses Perspectives
- Characterisation of Nigerian Financial Markets: Empirical Finance Perspectives
- Characterisation of Nigerian Financial Markets: Financial Engineering Perspectives
- Characterisation of Nigerian Financial Markets: Risk, Volatility and Financial Practice Perspectives
- Characterisation of Nigerian Financial Markets: Implications for Financial Reforms and Policy Making
- Stochastic-Time Series Modelling for the Telecommunications, Energy, Agricultural and Manufacturing Sectors of the Nigerian Stock Market
- Stochastic Analysis and Financial Engineering in the Nigerian Financial Markets
- Financial Time Series, Extreme Value Theory and Quantitative Financial Risk Management
- Stochastic Modelling, Financial Engineering and Market Movements in [Nigerian and UK—European] Energy Markets
- Limit Theorems and Stochastic Volatility Modelling in the Nigerian Financial Markets
- Research directions and workshops in credit and interest rate analytics
- Research directions and workshops in Extreme Value Methods and copula methods in quantitative finance
- New product development, financial engineering and advisory services for banks, stock exchanges and other financial institutions
- Studies in Quantitative Finance, Financial Risk Management and Change in Global Financial Markets with a Focus on Emerging Markets of Sub-Saharan Africa
- Customer Analytics and Strategic Marketing Management in Bank Financial Management: Case Study of XYZ Bank in Nigeria
- Topics in Nonlinear Mathematics and Complexity Theory: Applications to Investment Behaviour in Emerging Markets
- The nexus among deep characterization and calibration of financial and stock markets, financial reforms and policymaking (may be specialized to monetary and fiscal policy),
- Pathways for Extending Asset Ownership among Nigerian Citizens: Experiments in Financial Product Engineering, Risk Profiling and Investment Advising
- On the Social Contagion of Ideas: Financial Bubbles, Market Efficiency, Information Cascades and Experimental Economics in Emerging Markets: Case Study of the NSM
- Fundamental Analysis of Economic Activity Versus Speculative Bubbles-Related Economic Prosperity in Sectors of the Nigerian Financial Markets (for example banking, communications industry)
- Rational Versus Irrational Bubbles in Economic Analysis of Financial Markets: Links with Fundamental Analysis
- An Event-History Analysis of the Global Financial Crisis and Foreign Capital Flows into Emerging Markets: Any Lessons for Effective Statistical Warning Signals?

Examples of integrated multidisciplinary NIMFSERC research projects which incorporate some of the above doctoral topics:

(1) Studies in Quantitative Finance, Financial Risk Management and Change in Global Financial Markets with a Focus on Emerging Markets of Sub-Saharan Africa (up to 100-200 students across the country to cover key market niches, capital and financial, as requested in Project FINE).
(2) Stochastic Modelling in Emerging Financial Markets: A Case Study of the Nigerian Stock Market (up to 10 students to cover key market sectors)
(3) Consistent, Sequential and (Dis)Aggregated Information Databases for (Near) Perfect Modelling Methodology in the Nigerian Financial System (again up to 10 students for the satellite projects)

(4) Constrained Optimization for Firm-Level Investing and Financial Risk Management under Conditions of Uncertainty and Complexity (up to 10 students similarly as above)
(5) On the Approximate Resolution of the Trilemma Problem of International Monetary Economics within the Fleming-Mundel Open Economy Framework: A Subordinated Mathematical Optimization Approach (2-3 students)
(6) Prospecting for a Unified Monetary Theory that Does Almost Everything in Financial Policy Making: Theoretical Physics to the Rescue? (at least 2 very strong PhD students)

Related nationally coordinated programme of actions on new thinking in financial education and research

(1) Series of MSc/MBA/PhD Symposia, Seminars and Training Workshops (SSTWs) on complexity theory and decision making under uncertainty, to be held at the National Mathematical Centre and also rolled out to universities in different geopolitical zones of the country
(2) Similar SSTWs on empirical finance and quantitative financial economics in emerging financial markets analyses
(3) Similar SSTWs on stochastic modelling foundations of (advanced) financial risk management
(4) Week-long MSc/MBA/PhD training courses on (advanced) financial risk management, building on the stochastic modelling foundations
(5) Development funding for new MSc/MBA/PhD curricula and training the trainers (supervisors) on the curriculum entailments, prior to commencement of supervision
(6) Related workshops at the NMC/African HEIs on a new pedagogy for the mathematical sciences contributory to effective economic development of the country
(7) Mass-specialist education of an effective middle-level finance and economics academics and professionals, as envisioned in the MSc/MBA/PhD
(8) National funding of Project FINE and the Doctoral Training Centre which underpins the NIMFSERC programmes
(9) National launching of NIMFSERC
(10) Project funding for research and design of the Integrated Financial Database for (Near) Perfect Modelling Methodology for the Nigerian Financial System, at both macro- and micro-economic levels.

Appendix 5: Related mathematical sciences projects earlier submitted for possible implementation at the National Mathematical Centre, Abuja, Nigeria and within Nigerian universities

On 3 September 2012, I chaired the Working Group on Postgraduate Programmes at the Second Meeting of Professors of Mathematics and Heads of Mathematics Departments in Nigerian Universities held at the National Mathematical Centre, Abuja FCT, Nigeria. Professor Charles Chidume FAAS of the African University of Science and Technology Abuja FCT chaired the Undergraduate Programmes and Professor G O S Ekhaguere FAAS of the University of Ibadan, Nigeria, chaired the Research-oriented Programmes.

In preparation for the session, I had related needs assessments discussions with some mathematical scientists including Dr Nnamdi AGWUEGBO, Acting Head of Department of Statistics at the Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. In response to the discussions and the call for projects to support the Communiqus action plans to foster academic excellence in mathematical sciences research, teaching and applications, I produced and submitted to Professor SOLARIN, Dr AGWUEGBO and other mathematical scientists in the country the following list of projects:

(1) Learning, Teaching and Assessment (LTA) Workshop on Addressing Economic Development Needs through Effective Teaching of Mathematical Sciences: Case Study of Statistical Theory and Practice (with Dr Nnamdi Agwuegbo, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria)
(2) LTA Workshops on the Pedagogy and Practice of Different Statistical Topics: Entrepreneurial Perspectives (with Dr Nnamdi Agwuegbo FUNAAB, Professor Polycrap Chigbu UNN, Pro-

fessor Iwueze FUTO, Dr E Nwogu FUTO, and Dr Umoren UNIUYO)

(3) Research and LTA Workshop on Statistical Leaening and Research as Entrepreneurial Practices: Perspectives from Stochastic Processes and Time Series Modelling (with Dr Nnamdi Agwuegbo FUNAAB)

(4) Research and LTA Workshop on Mathematical Learning and Research as Entrepreneurial Practices: Perspectives from Functional Analysis, Stochastic Calculus, and Financial Mathematics (with Professors J Oguntuase FUNAAB, Chika Moore UNIZIK, G O S Ekhaguere UI, Dr Eric Ofoedu UNIZIK, Dr I Igbokwe UNIUYO, and Dr M Wodu, Sheffield Hallam University, UK (SHU))

(5) Foundation Postgraduate Course (FPGC) on Topics in Stochastic Analysis and Mathematical Finance: Theory and Applications (with Professor G O S Ekhaguere)

(6) FPGC on New and Multidisciplinary Research Directions in Financial Time Series and Exreme Value Theory (with Dr Nnamdi Agwuebo FUNAAB)

(7) FPGC on Limit Theorems in Probability, Stochastic Processes and Statistical Inference: Mathematical Foundations and Applications (with Dr Nnamdi Agwuegbo FUNAAB and Dr Eric Ofoedu UNIZIK)

(8) FPGC on Branching Stochastic Processes and Mathematical Demography (with Dr E Nwogu FUTO)

(9) FPGC on Stochastic-Time Series and Empirical Finance Modelling for the Banking Sector of the Nigerian Stock Market (with Dr Nnamdi Agwuegbo FUNAAB and Dr M A T Omar, Libyan LIBYA, to be repeated over time for other key sectors of the economy, for example telecommunications, oil and gas, agriculture, and manufacturing, with assistance from industry professionals

(10) FPGC/industry-focused CPD Training on Stochastic-Time Series Forecasting Models for Strategic and Operational Business Performance Improvement (with Dr Nnamdi Agwuegbo FUNAAB and Dr M A T Omar LIBYA)

(11) FPGC on Topics in Nonlinear Mathematics, Complexity Theory and their Applications in Investments, Financial Engineering and Quantitative Financial Risk Management (with Professor G O S Ekhaguere UI, Professor Oguntuase FUNAAB, Professor Stephen Onah FUNAM, Dr Eric Ofoedu UNIZIK, and Professor B Oyelami NMC)

(12) FPGC on Topics in Stochastic Processes and Biomathematics (with Professor J A Ogidi NMC)

(13) Joint NMC/NIMFSERC Research Programme, including FPGCs, seminars, writing research grant proposals, and PhD student supervisions on the research theme Characterisation of the Nigerian Financial Markets: Perspectives from Stochastic Modelling, Functional Analysis, Stochastic Calculus, Empirical Finance, Financial Time Series, Financial Engineering, Monetary and Macroeconomic Policies, Financial Reforms and Policy Making.

(14) Facilitating graduate research seminars in selected areas of PhD research interests to academic staff, for example advanced econometrics, stochastic processes, time series analyses and forecasting, applied multivariate analysis and multi-level modelling

(15) Topics in Stochastic Analysis, Mathematical Finance Theory and Applications, for example Stochastic Differential Equations in Hilbert Spaces, Levy Random Fields, Measure and Integration Theory, Stochastic Optimisation Models, and Mathematical Foundations of Investment and Risk Theory

(16) Statistical Aspects of Data Mining and Big-Data Science-Based Applications. Including Neural Networks, Logistic Regression, Decision Tress, Cluster Analysis, Multivariate Analysis, Time Series and Forecasting in Finance, Health and Key Economic Sectors

(17) Mounting strong FPGCs and bridging workshops in topical areas of theoretical and applied statistics, for example stochastic modelling in finance and business, data mining techniques with novel applications to systems exposed to very large data sets

(18) Using a Balanced Corporate Academic Scorecard to Achieve Excellence in Teaching, Research and Community Service: Case Studies in Mathematical Sciences. This can also be extended to all the disciplinary groups discussed in this lecture

(19) Pathways and Global Best Practices for Establishing World-Class Interdisciplinary Research

Groups, Centres, and University-Industry Consortia: Case Studies in Mathematical Sciences.

(20) Enterprise Teaching and Curriculum Innovations in Mathematical Sciences: Theory and Paths to Practice (Target audience: all academics, staff of Centres of Entrepreneurial Studies in universities and HEIs in Nigeria and Africa: 3-day workshop)

(21) Mathematical Sciences Academics, Graduates and Professionals as Entrepreneurs: Models and Strategies for Entrepreneurial Career Self-Management (Target audience: academics, graduates and professionals with very ambitious career goals: 2-day workshop)

(22) Repositioning Mathematical Science Departments as Small Businesses in Nigeria: What Currently Obtains and What Works? (Target audience: deans, HODs, academics, and support staff: 1-day workshop)

(23) Linking Mathematical Sciences Knowledge to Society: the Development of Higher-Order Skills in the Disciplines (Target audience: academics, students and professionals: 1-day workshop, with follow-on subject-based workshops facilitated by selected teams of staff)

(24) Research Methods for Young Mathematical Scientists: Laying Bare the Success Tricks that Are Not Taught in Standard Research Methods Texts (Target audience: senior undergraduate students, trainee staff of companies: 2-day workshop)

(25) Advanced Research Methods for Mathematical Sciences Graduates and Professionals: Laying Bare the Success Tricks that Are Not Taught in Standard Research Methods Texts (Target audience: postgraduate students, middle-level research professionals from other organisations: 3-day workshop)

(26) Advanced Research Methods and Graduate Supervision Methods for Senior Academics: Laying Bare the Tricks that Drive Quality Research Design and Supervision (Target audience: senior academics in different disciplines: 3-day workshop)

(27) Innovative and World-Beating 21st Century PhD Research Supervision in Different Disciplinary Clusters: Global Best Practices, Tools and Techniques (Target audience: senior academics who are qualified to supervise PhD students: 3-day workshop, with experienced supervisors drawn from the different disciplines)

(28) International Conference on Innovative and World-Beating 21st Century Graduate Supervision for High-Impact Research Excellence, Enhanced National Economic Development, and Graduate Employability in Different Disciplinary Clusters (Target audience: all universities, polytechnics, research institutes, in collaboration with NUC, NBTE: 3-day conference)

(29) Stitching Up the Nigerian Mathematical Scientist: Model-Based Reflections on High-Impact Academic Research, Teaching and Community Service (Target audience: academics in HEIs and research centres: 2-hour seminars)

(30) Writing Winning and High-Impact Research Proposals and Highly Publishable Academic Papers: International Best Practices and Enabling Frameworks (Target audience: academics in HEIs and research centres: 2-day workshops)

(31) Writing Excellent Texts and Research Monographs in Different Disciplinary Clusters: Exceeding the NUC BMAS Standards and Developing Critical Thinking and Entrepreneurial Skills among Graduates (Target audience: academics: 2-day workshop)

(32) Building Research Capacities in Higher Educational Institutions in Nigeria Using an Innovative African Research and Teaching Excellence Framework (ARETEF) (Target audience: academics and research centres: 2-day workshop)

(33) Building Research Capacities and HEI-Industry Linkages in Nigerian HEIs Using Models of Engaged Scholarship (Target audience: academics and research centres: 2-day workshop)

(34) Proactive Customer Relationship Management for Enhancing University-Industry-Government and International Partnerships and Third-Stream Income Generation in Nigerian and African HEIs (Target: academics, research centres and relevant directors: 2-day workshop)

(35) Linking up staff with international academics, research centres, and universities for quality academic work, PhD supervision (Full Time, Part Time, and Split modes), staff research exchanges, opportunities for bench-work to complete vital aspects of a PhD research already in progress, post-doctoral research work, joint publications for funding, research collaborations, and joint authorships of papers in leading journals (ongoing work as and when the

need arises)

(36) Research seminars and FPGCs on the pedagogy of mathematical sciences and other disciplinary clusters aimed at equipping academics and students with the skills, tools and techniques for translating disciplinary knowledge to practice, and linking their knowledge bases to national development. In these seminars, academics will be stretched to consider how some topics they research and teach on are mapped to economic development themes explored in strategic development blueprints, for example the Nigerian Economic Empowerment and Development Strategy (NEEDS), Nigerian Vision 202020, the Nigerian Financial Services Strategy 202020 and the Millennium Development Goals (MDGs).

Closing remarks

The NMC communique under reference stated that the NMC should:

(1) Establish a robust programme of activities aimed at strengthening existing and building new teaching and research capacities at the undergraduate and postgraduate levels

(2) Organise training programmes, such as Foundation Postgraduate Courses and bridging workshops in emerging areas of knowledge, in collaboration with the NUC, for postgraduate students and lecturers in the mathematical sciences in the six geopolitical zones, especially in the endangered areas of mathematics such as classical analysis, geometry, differential equations, and algebra

(3) Facilitate collaborative authoring, by identified experts, of textbooks in the core courses of the mathematical sciences; this has the potential of saving the nation substantial foreign exchange, as well as making relevant textbooks available in the nations universities

(4) Create and maintain a database of experts in the mathematical sciences in the nations universities, complete with the experts areas of specialization

(5) Develop and implement a selection process, with well-publicised selection criteria, for approving proposals of high quality, which the NMC will receive from time to time, whether solicited or unsolicited, for organising research-related courses

(6) Set up and operate a diversity of fellowship schemes, including: a postdoctoral fellowship scheme, aimed at deepening the research skills of new doctoral graduates; a postgraduate fellowship scheme, that will support students on short or extended research visits to the NMC; a staff fellowship scheme, that will support staff from Nigerian universities on short or extended research visits to, or sabbatical leave at the NMC

(7) Ensure gender mainstreaming in its diverse activities, in order to continually increase the number of women in the mathematical sciences in the country

(8) Facilitate the establishment of credit transfer systems in the mathematical sciences in Nigerian universities, as this has the potential of eliminating gaps in learning and ensuring optimal use of available human capacity

(9) Persuade the National Universities Commission (NUC) to allow the body of mathematicians in Nigerian universities to be in charge of developing the NUCs proposed Minimum Benchmark for MSc courses in the mathematical sciences

(10) Nigerian universities should: partner with the NMC in its Herculean task of improving the quality of teaching and research in the mathematical sciences; ensure that only those candidates who are genuinely prepared for careers in the mathematical sciences are admitted into the programmes of study; enter into collaborative arrangements with recognised universities around the world for split-site supervision of doctoral research in the mathematical sciences, as this strategy has the potential of improving quality and saving costs; promote the development of the mathematical sciences, through attractive incentives, as well as provision of funds for prizes, fellowships, conferences/workshops participation, and textbook writing; encourage mathematics departments to establish linkages with the private sector as sources of real-life problems and potential research collaborations; and establish credit transfers in order to eliminate gaps in learning, ensure optimal use of available human capacity and enable students to receive instruction and be examined in courses which are unavailable in their universities, in any approved institution in the country which possesses the requisite

expertise, with the freedom to transfer the credits earned to their home universities

(11) The Nigerian industry and organized private sector should: sustain and expand their ongoing support for the development and application of the mathematical sciences to real life problems, through the award of fellowships, funding of research projects, and multi-year resource assistance to departments in Nigerian universities that provide training in the mathematical sciences; partner with the NMC and departments of mathematical sciences in Nigerian universities to organize conferences, seminars and workshops that focus on the mathematical modelling, simulation, statistical analysis and scientific computing of industrial and development-related problems; encourage and promote research visits and internships by staff and students of the mathematical sciences to various sectors of the industry

(12) The various governments of the Federation should: sustain and expand their support for manpower development in the mathematical sciences, through the award of scholarships/bursaries to both undergraduate and postgraduate students who enrol in programmes of study in these sciences; foster academic-industry collaborations through the establishment of a special fund to support visits/internships by staff and students of the mathematical sciences to Nigerian industries, and encourage young Nigerians to pursue careers in the mathematical sciences by operating an appointment policy that places a graduate of the mathematical sciences, upon first appointment, on an enhanced salary scale that is two grade levels above that of his/her counterpart with a degree in a different field of study