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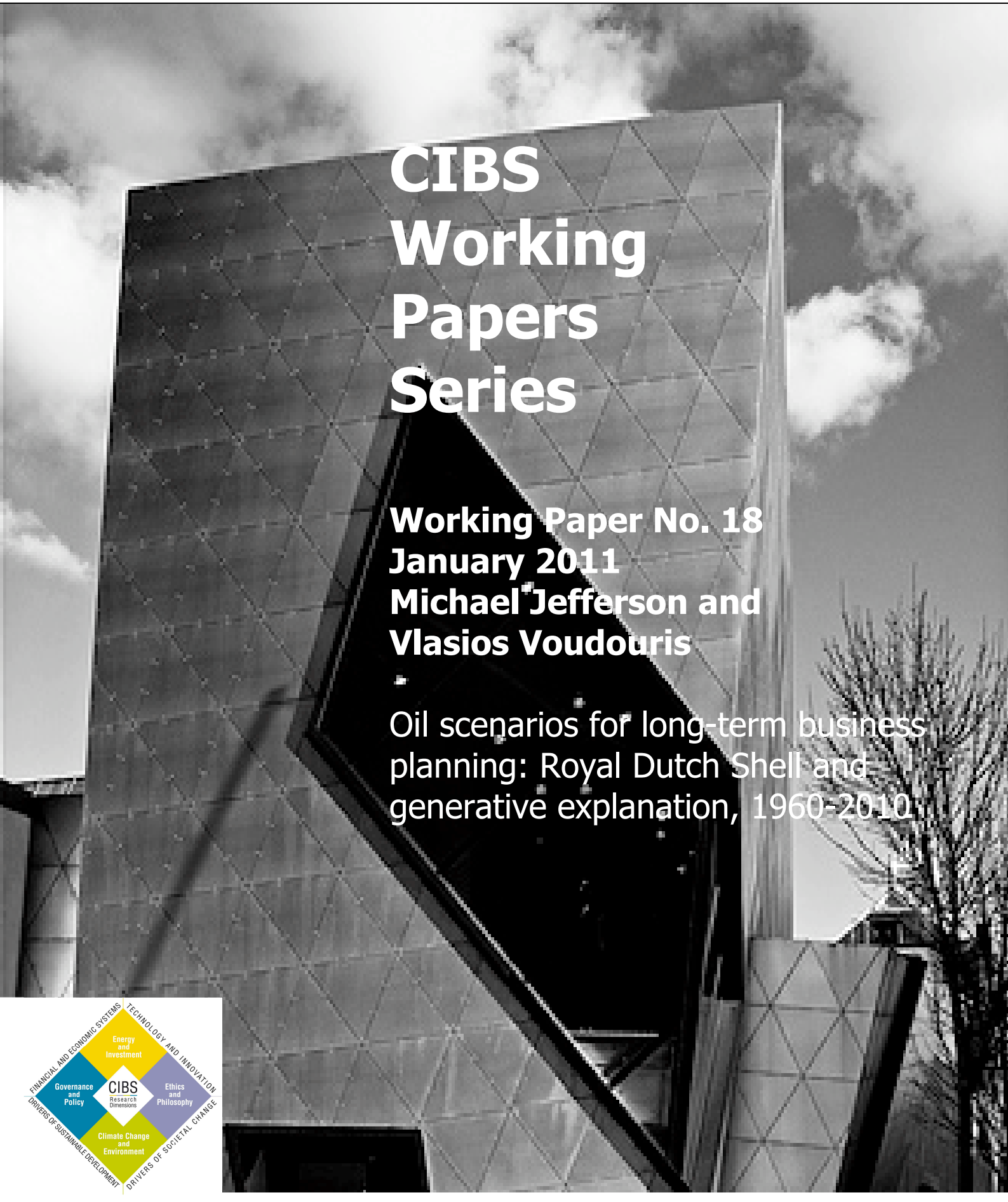

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Oil scenarios for long-term business planning:

Royal Dutch Shell and generative explanation, 1960-2010

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Abstract

Most executives know that overarching paints of plausible futures will profoundly affect the competitiveness and survival of their organisation. Initially from the perspective of Shell, this article discuses oil scenarios and their relevance for upstream investments. Scenarios are then incorporated into generative explanation and its principal instrument, namely agent-based computational laboratories, as the new standard of explanation of the past and the present and the new way to structure the uncertainties of the future. The key concept is that the future should not be regarded as 'complicated' but as 'complex', in that there are uncertainties about the driving forces that generate unanticipated futures, which cannot be explored analytically.

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1. Introduction

In seeking to explore indirectly an uncertain, and in some respects unknowable, future, the use of scenarios can be traced in the writings of some early philosophers, including Plato. Scenarios, as we understand them today, have been developed since the 19th century by military strategists, particularly by von Clausewitz and von Moltke – two Prussian military strategists[1]. In this article, we will present a historical review of the 'intuitive logics' approach for corporate scenarios, advanced by The Royal Dutch/Shell Group (hereafter Shell) since the late 1960s, and a way of incorporating scenarios into 'generative explanation'[2] and its principal instrument, namely agent-based computational laboratories, which have been primarily advanced since the early 1990s based upon the early work of the mathematician John von Neumann.

From the mid-1950s, the development and application of scenarios portraying possible futures emerged, with two main geographic centres: the USA and Europe. In the USA, in the 1950s, the RAND Corporation developed scenarios for the US Department of Defence; and then in the 1960s Herman Kahn's Hudson Institute developed scenarios for social and public policy. In Europe, the leading exponent was Gaston Berger who founded the Centre d'Etudes Prospectives or La Prospective. In the mid-1970s Michel Godet developed scenarios for French national institutions by advancing the La

[1] U. von Reibnitz, Scenario Techniques, McGraw-Hill GmbH, Hamburg, 1988

[2] Joshua Epstein, "Agent-based computational models and generative social science", *Complexity* 4, no. 5 (1999): 41-57

Prospective methodology through the development of his own mathematical and computer-based probabilistic approach[3].

With the growing uncertainties and threats facing the international oil companies by the late 1960s Shell had begun to turn its attention to using scenarios as a critical planning and decision-support tool. Although RAND, Hudson Institute and La Prospective were leading exponents of scenarios for military, social and public policy, it was Shell that was the key corporate exponent of scenarios. Therefore, Shell's scenario development approach became the gold standard of corporate scenario generation[4], although for several members of the then scenario team not above serious criticism.

Scenarios, as critical planning and decision-support tools for business megatrends - a term popularised by the businessman and author John Naisbitt in 1982 - work well when the business world is best characterised by 'morphogenesis' rather than 'stasis' – this is when the business environment is populated by 'resting points' rather than 'fixed point attractors' that can be forecast. The acceptance of the world of morphogenesis requires acceptance and inclusion of uncertainty in the decision-making process and a focus on how the constituent components of the business world work and interact. Although Shell's decision scenario development process strongly acknowledged the need to understand relevant past history, especially in economic and political areas, the approach can be augmented with the recently introduced 'generative explanation' paradigm. This

[3] Bradfield, Ron, et al. "The Origins and Evolution of Scenario Techniques in Long Range Business Planning", *Futures* 37, no.8 (2005): 795-812

[4] S. Millett, "The future of scenarios: challenges and opportunities", *Strategy and Leadership* 31, no.2 (2003): 16–24

augmentation can help scenario planners better understand the challenging outlook of the business environment by means of a morphological analysis for scenario building - to paraphrase Michel Godet, former head of the Department of Future Studies at SEMA. The fundamental foundation of generative explanation and decision scenarios is the core concept of 'organic' development. In the words of Pierre Wack, "the art of scenarios is not mechanistic but organic" - this is also applicable in the case of generative explanation where our understanding of i) how the constituent elements of the business environment work and ii) how the business environment as a coherent whole evolves, growing organically from bottom-up. The latter will support executives to think about where their organisation may be out of alignment with the emerging business megatrends – incipient societal, political, technological and economic shifts.

In this article we first outline Shell's scenario planning process and results as they applied to the production of conventional oil, and the threats then perceived to that production. This is followed by a brief discussion of 'generative explanation' as a scenario-oriented bottom-up approach to i) 'explanation' of the past and the present and ii) the new way to structure the uncertainties of the future. This bottom-up approach defines and argues for a new standard of explanation; for a 'generative standard'[5] and highlights a new tool – the agent-based computational (co-) laboratory - that facilitates the construction of scenarios as critical planning and decision-support tools satisfying the 'generative standard'. This bottom-up generative approach is fundamentally different from the top-down approach of 1960's Cross-Impact Analysis (CIA) of RAND , the 1970s Trend-Impact Analysis (TIA)

[5] According to Joshua Epstein, 'generative standard' is encapsulated by the motto: if you didn't grow it, you didn't explain it

of Futures Group, and the 1970s suite of tools (Micmac, Mactor and Smic) of Michel Godet.

2. Shell's decision scenarios: A historical review

The origins of scenario planning in Shell can be traced back to 1966, and curiously enough in the organisation's Exploration & Production (E&P) function, where some considered that it was desirable to try and assess the political risk of upstream investments by seeking to understand the forces at work. Jimmy Davidson, who had been Head of Economics & Planning in E&P, moved to head Shell's Group Planning in 1967 and later became Group Planning Co-ordinator. At that time a formalised, single-line business forecast five years ahead – the Unified Planning Machinery (UPM) system – had been in place for two years and was already raising concerns about its flexibility in a fast changing world – a world of morphogenesis. In January, 1971, the first formal document heralding the introduction of scenarios appeared, to be followed by more developed ones.

In January, 1973, "Scenarios for 1973 Planning Cycle" appeared, with three of the six scenarios outlined based upon the "impending energy gap" and possible ensuing "crisis". In May, 1973, the perspective was narrowed to emphasis upon a scenario which "involves a threat to the economic well-being and progress of the industrialised world" (page 1). Even then, however, the perspective was relatively optimistic: crude oil prices rising to US$ 5 per barrel f.o.b.Arabian Gulf in 1975/76, and to US$ 7 by 1985. On the basis of this crude oil price projection inflation prospects for the OECD were raised to

5% (page 26). There was almost paranoid fear that OPEC member countries would be unable to absorb the resultant 'surplus' oil export revenues. As a result of some wild optimism, which even in November, 1973, saw Shell projecting 3% Real GNP growth in the USA in 1974; 10% in Japan; and 5.6% in the EU (of which the UK was placed with 5.8%), a series of internal papers was written during 1974 by the Group's Chief Economist intended to introduce some reality and historic perspective. Real GNP change in 1974 was reduced for the USA to 0-1%; for Japan to 4-5%; and for the EU 1.5 to 2.5%% (UK -1 to 0%). Inflation possibilities were raised up to 15% for 1974. The capacity of OPEC surplus revenues to be absorbed was set out. Notions that OPEC would quickly break up as all cartels did (based on a particular view of the history of US trusts) were critiqued. In a paper: "How Quickly Do Cartels Collapse?", it was pointed out that there were many examples of cartels which had lasted for decades (in a few cases, on and off, for centuries). Examples cited included the Rhenish-Westphalian Coal Syndicate, the Newcastle Coal Vend, the London Coal Ring, the Neckar Salt Union, the Oberlahnstein Association for Nassau pig-iron, and a miscellany of examples from the chemicals, explosives, iron and steel, and electrical industries.

Although by October, 1974 there was a preference for developing two scenarios, there continued to be some flaws reflecting earlier views – not least the resources put into developing some scenarios which were clearly overly optimistic and therefore unreal. Such titles as 'Belle Epoque' and 'The (President) Carter Miracle' encapsulated this mood in some quarters, and rather damaged the reputation of those most closely associated with them. Similarly, unrealistic ideas about anticipated changes in societal values and individual lifestyles (as seen through a Californian 'mirage') took the eyes of

some key planners off the main balls in play. The central purpose of Shell's scenario work was, however, in the memorable words of its Head of Business Environment – Pierre Wack – "to shift the personal microcosms" of Shell's employees. And this it did for many in those early years. But it is one thing to move people away from 'Business as Usual' attitudes to understanding and working with the numerous forces which may cause 'perturbations'. It is not only a question of looking at future possibilities, but of understanding the past (the failure to do so has had remarkable repercussions in the financial and banking crisis of the past three years).

Speculation about the availability and price of oil has been a continual feature of the oil industry over its 150-year history. As the availability and use of refined oil products has spread, so has that speculation widened, though its nature has not changed as much as may be commonly assumed. From the sudden loss of oil production in Pithole, Pennsylvania, in 1865; through the "dearth of petrol" which caused concern during the First World War in the main participating countries; to the calls for "conservation" of a non-renewable resource in the later 1920s, the scene had been set for later worries.

Fears for oil supply security and prices were motivations behind both the rise and the fall of Dr. Mossadegh in Iran (US political and industry interests were involved in both), the creation of OPEC in 1960 and responses to regime change in Libya in 1969 – all these forces of change define a world of 'morphogenesis' which is characterised by resting points or punctuated equilibrium. At the end of the following year OPEC agreed a 55% tax rate at its meeting in Caracas, which was quickly followed by the Tehran Agreement

formalising the higher tax rate between the six main Gulf oil exporters and the oil companies. In the run-up to the October, 1973 Arab-Israeli War came numerous nationalisations of oil companies' upstream assets (a process which had begun in Mexico in 1938), and further tax rate and price rises. It was clear that fundamental changes had occurred, and would continue to occur, in the international oil industry. This fundamental changes required the use of decision scenarios to paint plausible futures that can be govern by different, heterogeneous and inter-connected forces (both in terms of direction and magnitude).

For example, when OPEC agreed to an oil embargo against "unfriendly states" on October 17, 1973, there was widespread alarm as the embargo began to bite, and this was followed two months later by announcement of an increase in the 'posted price' of marker crude from $5.12 per barrel to $11.65 from the beginning of January, 1974. This represents a significant 127.5% increase in the posted price of marker crude. There was surprise in many quarters when Shell's then Chairman, Sir David Barran, announced at the height of the crisis: "A blip, dear boy, a mere blip on the trend curve."[6]. However, Barran also had the benefit of the warnings which had begun to come from his Planning colleagues, and which were set out more formally in a planning document in January, 1971. By October 1971, Barran and some of his senior colleagues were communicating their concerns to senior members of the OECD and the European Union. This rapid change of the posted price of marker crude is just an example of the need to understand

[6] In fact Sir David felt no such thing. Those who knew him recognised that he was inclined to say one thing in private and another in public, for considered reasons. Between 1970 and 1972, in numerous conversations in, and going to and from, various parts of Europe with Michael Jefferson he had discussed his fears – drawing on the long experience of the Middle East both of them had: Sir David from his professional work, Jefferson from family circumstances going back twenty years.

the past and present driving forces of change, particularly the then incipient societal, political, technological and economic shifts, in order to paint plausible futures.

The January, 1971 document attempted "to chart the course of upstream-government take over the next 15 years, within reasonable limits of confidence." Claiming that past experience provided little indication of the future, the report stated: "For this reason the technique of scenario-writing has been adopted." Therefore, scenarios are important for the analysis of business megatrends - incipient shifts. It was stressed that the report did not yield "final and definitive forecasts" but "at least partly, as a demonstration of the scenario-writing technique"[7]. Unfortunately, with the benefit of hindsight, the range of projections of upstream government 'take' fell within the very limited figures of US$ 3.30 for short-haul producers and US$ 3.00 for long-haul, ± 30 cents! The internal 'experts' had apparently not done a great job. But their underlying logic was largely sound:

> "After a period of relative stability, even of declining levels of upstream-government take through the 1960s, the past few months have seen a rapid upsurge in the demands for increased take on crude oil exports. In the view of all the experts consulted it represents the front edge of a period of rapidly-growing upstream-government take which will only be brought under control by the impact of major competition from deep-sea oil, North American coal and other 'unconventional' hydrocarbon resources or by the extensive growth and

7 Shell Group Planning: "A Probabilistic Approach to the Forecasting of Upstream-Government Take on Crude Oil Exports: 1970-1985", PL/52, January, 1971, page 3.

penetration of nuclear energy."

It will be noticed that there was no mention of renewable energy sources as we understand the term today, and for the past forty years Shell's performance on renewables has left something to be desired. Deep-sea oil in this report was expected to come on stream by 1980. It is important to note that once any of the key driving forces, such as sharp prices movements, military conflicts and geopolitical changes, is in motion this motion can trigger the motion of a number of other key driving forces whose direction and magnitude is difficult, if not impossible, to anticipate analytically. Therefore, a framework that takes into account inter-connectedness and positive feedback loops is required. As discussed in section 3 below, generative explanation and agent-based computational laboratories provide such a practical framework to paint plausible futures - the emergent explanada - that emerge from bottom-up based upon i) the interactions of the driving forces of change and ii) causality between micro-foundations (key building blocks of scenarios), interaction patterns and emergent macro-regularities (emergent scenarios).

Over the following months of 1971 further work was done on upstream-government take, and one of four scenarios had the level at nearly $5 by 1977 (and continuing at that level to 1985 in 1970 prices)[8]. But Henk Alkema considers that although Pierre Wack mentioned the 1971 scenarios and some aspects of producer countries' strategies in his Harvard Business Review articles, "to this day the work on the initial Oil Price Scenarios

8 Wack, Pierre: "Scenarios: uncharted waters ahead", *Harvard Business Review*, September-October, 1985.

has not been reported"[9]. An important point raised by Henk Alkema, who joined Shell Group Planning in March 1971, was the heterogeneity behind the motivations for the level of production by individual producer countries. This heterogeneity is caused by difference in proved and probable reserves and expectation of new discoveries. Following from above, heterogeneity, inter-connectedness and positive feedback loops needs explicit modelling into order to test the assumptions of the scenarios, their internal consistency and their logical consequences. The important point here is that prediction is not the only goal of modelling. Modelling is also appropriate for a number of reasons such as explanation, illumination of core dynamics, illumination of core uncertainties and the challenge of prevailing conceptions (microcosms) through perturbations[10].

The Group Planning 'Interim Report': "Individual Producer Government Take/Production Strategies" of May, 1972, focussed principally on limitations imposed i) by oil reserves, discoveries and expectations and ii) by limitations to the absorptive capacity for oil revenues in 'underdeveloped' producer economies. It agreed that the first limitation was widely accepted, but internally was based upon the perception that the demands made on oil producing and exporting countries would probably be higher than new discoveries, and that those countries with low populations would seek to conserve their conventional oil resources. The second limitation was potentially present again for countries "with adequate or even very high reserves but with a relatively small non-oil economy", and perceptions of both limitations led on to consideration of "estimating the maximum absorptive capacity for 'take' as a percentage of total GDP at high economic

9 Alkema, Henk J.: "Memories and Lessons from 30 Years in Strategic Planning", Paper delivered at a seminar in Oxford, 12 February, 2008
10 Epstein, Josua, "Why Model?", *Journal of Artificial Societies and Social Simulation*, 2008

growth levels". It was in this May, 1972, report that charts gave estimates for reserves of conventional oil for Saudi Arabia, Iran, Nigeria, Iraq, Libya, Kuwait and Abu Dhabi. With the exceptions of Iraq and Abu Dhabi they all peaked by the late 1970s (with Libya already in free fall).

In September, 1972, Shell's Committee of Managing Directors had been introduced to the six scenarios which were issued in January, 1973, as "Scenarios for the 1973 Planning Cycle". By then the 'possibility' of sharp rises in oil prices "resulting from increasing oil scarcity, which may take place at any moment in the next few years" was recognised. This perception was partly based on conventional oil reserves of producer countries "peaking out, and partly because those countries with further capacity for further growth, e.g. Saudi Arabia, are unable to absorb increasing revenues and thus do not wish to increase production". One chart in this report was the basis for Gareth Price to name the coming period "The Rapids", a period of severe turbulence which became Shell's single scenario from May, 1973, in anticipation of the events from October, 1973. But Shell also remained fixated upon the view that if there were no further discoveries of conventional oil then, based upon proven reserves figures "if freely available", there was enough conventional oil available for more than 30 years; but that if consumption continued to increase as it had been then "these reserves if producible at a constant rate would only last for 15 – 20 years" (p. 11). Again, the willingness of oil exporters to supply when they had limited 'absorptive capacity' was seen as a tremendous hurdle at the time.

This view was at odds with that of external economic consultants Economists Advisory Group, who reported in July, 1972, that: "When seen in context, the prospective surpluses of the oil producers appear large, but by no means unmanageable"[11]. With the arrival of a new Group Chief Economist from outside Shell, with twenty years of first-hand knowledge of most of the Middle Eastern countries, this fixation on "unmanageable surpluses" came under immediate review. The reasons why he considered this Shell fixation on oil exporters' lack of willingness to produce far-fetched were set out in successive internal reports (some later ably elaborated by Larry MacMahon, another Group Planning economist), demonstrating – eventually to most people's satisfaction that - through 'primary, secondary, and tertiary' recycling routes - this would prove a 'non-problem'. Yet even in 1978 a senior figure in Shell's Middle East Regional function regarded this equanimity as: "Nonsense". This comment can be accurately dated as it was in response to a paper: "The OPEC Current Account Surplus" dated September 25, 1978). Recently, Mahmoud A. El-Gamal and Amy Myers Jaffe also argue that surpluses of petrodollars are recycled through the financial system – arguing for three key interacting building blocks, namely energy markets, Middle-East geopolitics and financial markets[12]. This clearly demonstrates that scenario requires to overcome the personal microcosm about how the business world works and the need to employ scenarios as an organic learning process which helps, in the words of Hans DuMoulin (the then head of energy and oil economics division of Shell) and John Eyre (a senior analyst in the same division), "to understand the past and the present and to structure in a

[11] Economists Advisory Group (Professor E. Victor Morgan and Graham Bannock were responsible): "Effects of Prospective Balance of Payments Surpluses of Oil Producing Countries on the International Trade and Payments, July, 1972, page 43. Coincidentally, Michael Jefferson had been Manager of Economists Advisory Group, 1986-1988.

[12] El-Gamal, Mahmoud and Myers Jaffe, Amy, *Oil, Dollars, Debt, and Crises*, Cambridge University Press, 2009.

rational way the uncertainties of the future"[13]. It also demonstrates the need for scenarios satisfying the 'generative standard' by means of explicit agent-based modelling as a way of challenging prevailing microcosms involving experts from many disciplines with different, if not conflicting, views. Using partial solutions (by fixing the other driving forces – all other things being equal) is not always the best way to challenge prevailing microcosms and analysis needs to be conducted at a higher level of complexity in order to understand the working of the business world.

What was more serious was the ongoing perception that technical constraints of manpower and equipment would impinge on conventional oil production. There had been specific references to oil shale and tar sands potential from January, 1973, in Group Planning's reports. There were also numerous presentations by Hans DuMoulin[14] on the nature of the oil 'mountain' which was not specifically discussed in the 'bell-curve' phenomenon associated with Marion King Hubbert, despite the fact that Hubbert was a long-term employee of Shell Oil in the USA. Nevertheless, "Hubbert's work was important input as were several other experts in this field."[15]. Thus in several of Group Planning's scenario reports in the 1970s there are charts showing the 'mountain' plateauing, but it is not until the appearance of: "Exploratory Scenarios for the Long Term" in January, 1977, that a clear chart of Technical Potential Development of Crude Oil Resources" for the 'World Outside Communist Areas' (WOCA) appeared as Chart 11 (page 47). The report claimed that, technically, conventional crude oil production in WOCA "could reach a peak of around 75 million barrels per day (b/d) in the early 1990s;

13 GuMoulin, Hans and Eyre, John, "Energy scenarios: A learning process", *Energy Economics*, 1979

14 Hans DuMoulin headed up the Oil Analysis Division of Group Planning, supported by Alan Clarke, Doug Wade, John Curtis and others. Their analytical contributions have never been adequately reflected in the literature on Shell's scenario planning.

15 Doug Wade, personal communication, September 15, 2010

about one-third of this production would have to come from new discoveries and supplementary recovery; and by the year 2000 their contribution would represent over half of the anticipated productive potential." The report went on:

> "If new discoveries exceed expectations significantly, it is unlikely to create higher or even earlier peak production. The more likely occurrence is an extension of the production plateau and, possibly, a more gradual decline in production."[16]

On the previous page of this report had been written:

> "The results of this appraisal (a re-appraisal conducted by Shell's E&P function) show a median forecast for ultimately recoverable oil of the order of 2000 billion barrels, of which some 350 billion barrels had been produced by 1.1.1976."

Although this projection of 2,000 billion (2 trillion) barrels of conventional oil being ultimately recoverable was the "median forecast" the same report gave a "25% chance that ultimate recovery will exceed 2,700 billion barrels" (page 45). These are figures which remain robust today – though over 1 trillion barrels have now been produced. The same scenario book considered that technological improvements would raise recovery rates from 30% to 45% within WOCA, perhaps now seen as a little on the modest side.

[16] Hans DuMoulin, personal communication, September 17, 2010

The view taken on tar sands and oil shale was that "tentatively" production could reach 2-3 million b/d by the end of the 1990s under 'Belle Epoque' conditions, with the major surge of development commencing around 1990, but there were "innumerable economic, technical, and environmental problems associated with their development". Despite the high costs and heavy environmental impacts associated with exploitation of these 'non-conventional' oil resources, to which shale gas may now be added, Hans Dumoulin believes that they will be exploited on a significant scale with the result that the steepness of the slope on the other side of the oil mountain will be considerably ameliorated. This has implications for the way we paint futures of the second half of the oil age.

The work of Shell's E&P function formed a key part of the 'Oil Mountain Study' conducted by Doug Wade, and supported by Hans Dumoulin and Gareth Price. As Doug recalls it, "the main argument centred around whether global oil production would peak or plateau, and at what level"[17]. The then going view was that annual production was expected to peak at around 80 million b/d, which is interesting considering how world output has hovered around this figure over the past seven years, although the January, 1977, Group Planning long-term scenario report put the figure at 75 million b/d, with peaking in the early 1990s. This latter figure was, however, belied by charts showing that for 'Belle Epoque – Delayed Response' and 'Consumer Logic' scenarios (though not for 'Producer Logic') oil supply from 'the World Outside Communist Areas' (WOCA) would be around 80 million b/d by the early 1990s. There was also speculation that Iraq's proven conventional oil reserves would ultimately prove greater than those of Saudi

[17] Doug Wade, personal communication, September 15, 2010

Arabia; that substantial oil resources existed in the South Atlantic; and that significant resources would be found in the Arctic[18]. However, the scenario book was less accurate in one of its conclusions: that OPEC-member countries' would "continue to represent around 90% of oil traded internationally". The figure is now around 60%. Understanding the 'petroleum market diversity' is not just a function of oil production but also of oil demand and willingness of OPEC-member countries to satisfying unmet world oil demand (to be discussed further in section 3 below).

The other topic on which the January, 1977, scenario book has so far proved to be inaccurate in its projections related to oil production in the former Soviet Union. There Shell's scenario planners projected output rising from around 20 million b/d in the mid-1970s to between 35 and 40 million b/d by 1990, to nearly 50 million b/d by the year 2000, and still climbing. The figure for 2009 was, in fact, just over 13.5 million b/d.

These issues have continued to rumble along in Shell's planning background and decision-making for the last thirty years, although explicit public statements about the coming 'peak oil' problem did not surface from senior Shell personnel until January, 2008. Then Shell Chief Executive, Jeroen van der Veer, stated that conventional oil output would be insufficient to meet demand by 2015, in keeping with the Shell Energy Scenarios to 2050 (Scramble and Blueprints) that were issued at the time.

[18] Doug Wade, personal communication, September 15, 2010

One problem in 1977 had been that there were already signs in the shorter term (except for a brief hiatus under a 'Boom and Bust' sub-scenario) that OPEC technical potential and practical oil production limits were well in excess of anticipated demand (May, 1976 report: "Scenarios for the Rapids – A Review"). Another, which some of those involved considered much more serious for the quality and relevance of Group Planning's scenario work, had been foreshadowed in the January, 1977, report: "it is becoming necessary that societal change should be incorporated in a disciplined way into our analyses of the business environment." (report, page 5) Unfortunately, these analyses became too closely linked to the work on changing societal values and lifestyles pursued by Willis Harman, Arnold Mitchell, and others at the Stanford Research Institute, California. The way forward was to prove the 'Producer Miscalculation' "Case" (not the Producer and Consumer Logic scenarios as such) presented as Charts 4 and 5 (page 23) in the January, 1977 report. Jefferson and DuMoulin had sought at a meeting the previous October, in Lurs (southern France) to focus heavily on this prospect as oil exporters worried about the coming onstream of North Sea and North Slope oil took advantage of any major 'accident' that might occur in the Middle East. Their view was not that original in Shell's thinking. There had been reference to Group Planning's scenario work to concerns that the Middle East could be likened to a 'powder keg', and in "Scenarios for the 1975 Planning Cycle" (October, 1974) it had been remarked:

> "It is thought another regional conflict in the Middle East, further serious threats to energy supplies or another major currency crisis and recession could well precipitate the world into this path (a 'World of Internal Contradictions') rather than that of the alternative scenario we have called

a ‘New Belle Epoque’.” (page 21)

Pierre Wack and other colleagues were reluctant to give the prospect the emphasis its two proponents felt was justified. The downfall of the Shah provided the accident, but Shell’s planners had failed to take full advantage of the opportunity to highlight the prospect and its consequences. Indeed, in “Exploratory Scenarios for the Long Term” (January, 1977) it was claimed:

> “The macro-economic effect of oil prices rising rapidly to levels of 20$/bbl in today’s money – as might result from a ‘Producer Price Miscalculation’ in short term boom conditions – was found to be so large as to make the scenario unsustainable and unsuitable for longer term development as a planning tool. It is a reflection of current World of Internal Contradictions conditions that the psychological impact of such price increases – starting from a base of pessimism, strain in the world’s financial system and over-sensitivity to the oil price – would have an impact far stronger than the implied ‘transfer of resources’ might otherwise indicate.” (pps. 27-28)

To the best of our knowledge this stand-off between those who had envisaged the ‘Producer Miscalculation’ scenario and its sceptics has not previously been discussed in the literature. The written evidence is clear. It is therefore not quite the case that Pierre Wack “is best known as the man who led the team at Royal Dutch/Shell that saw an oil price shock coming in the 1970s, not once but twice”[19]. Indeed for those who took the May, 1977, ‘Relapse’ scenario seriously as Shell did in its European Organisation with its

[19] Hardin Tibbs: “Pierre Wack: A Remarkable Source of Insight”, NetView, GBN Worldwide, 1998, page 5

'central' "European Relapse" scenario from December, 1979, found themselves in the real world as it was developing. For the rest:

> "The scenarios produced in the early 1980s attempted to plumb the potential downside of demand, but this continued to confound most estimates." 20

[new 20: "History and Strategy in Shell", January 6, 1986, p. 21.]

Already arguably the best assessment of Shell's Group Planning scenarios, the approach adopted, and the underlying logic had already been written by Hans DuMoulin and John Eyre and published in 'Energy Economics'[20]. A somewhat less impressive paper was published in the Harvard Business Review of November-December, 1980[21]. This paved the way for the papers which appeared under Pierre Wack's name and which are widely known. They appear in most bibliographies of scenario planning, as they should do, but the DuMoulin and Eyre paper is frequently – and unjustifiably – overlooked. Hans DuMoulin and John Eyre provided detailed assessments of all fossil fuels, including conventional oil, shale oil, tar sands, and shale gas. There is reference to the Oil Mountain, the 2 trillion barrels of recoverable conventional resources then perceived to exist and presented at the World Energy Council's Congress in 1977, and – very significantly – a discussion of "the next oil crisis – a mirage or a political accident". Although Figure 3 of the paper excluded the 'Producer Miscalculation' case which the chart originally contained in its internal Shell version, Figure 9 (entitled "The next oil crisis?", page 86) contained an outline of three possibilities – mirage, mini-crises, and supply falls abruptly.

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[20] Hans DuMoulin and John Eyre: "Energy scenarios: A learning process", *Energy Economics*, April, 1979, 76-86

[21] Producer Miscalculation' and other Shell scenario matters were discussed, quite critically, in Michael Jefferson: "Economic Uncertainty and Business Decision-Making" in Jack Wiseman (ed): "Beyond Positive Economics?", (Macmillan London, 1983). A critical view of the emphasis on societal value changes and lifestyle shifts appeared in Michael Jefferson: "Historical Perspectives of Societal Change and the use of Scenarios in Shell", in Brian Twiss (ed.): "Social Forecasting for Company Planning", (Macmillan, London, 1982)

The story of Shell's scenario planning has been largely built around the contributions of Pierre Wack. That he was remarkable as a 'packager' of ideas into coherent storylines and a brilliant presenter of them there is no gainsaying. But the diversion into societal value changes and individual lifestyle shifts was for some insiders the first sign that Shell's scenario planners were losing their cutting edge. However, two other factors proved even more telling. First, the retirement of Pierre Wack, whose scenario presentations had a magical quality for most of those exposed to them. Secondly, the abandonment of medium term scenarios in 1981, as the result of recommendations made by an internal committee headed by Guy de Wouters. These recommendations reflected discomfort in some parts of the organisation that 'pessimistic' (i.e. realistic) scenarios discouraged investment in additional capacity, and some argued that medium term which failed to link to longer-term scenarios were not useful. Yet at the time of Pierre Wack's retirement and the abandonment of medium term scenarios there had been developed in Group Planning the 'Hard Times' scenario (March, 1981) and 'Hard Times Extended' (November, 1981) which contained sound insights into what actually occurred during the remainder of the 1980s.

By the mid-1980s the repercussions could be seen in the lead then taken by Shell's Supply and Marketing function in assessing crude oil production and price prospects, key elements in sound scenario work. It is true that earlier weaknesses around the macro-economic impacts of the 1973 oil crisis and "The Rapids" (despite the internal papers being written by the house economists at the time) more generally exposed some failures

in the medium term scenarios. Additionally, an overly long fixation on OPEC oil exporters' willingness to produce because of ill-founded concerns about the global capacity to absorb 'surplus revenues' and insufficient first-hand experience of the Middle East, undermined understanding and positive impacts. Overall, therefore, although Shell Group Planning's work was highly innovative in the 1970s and possibly into the early 1980s, it was heavily dependent upon the packaging and presentational skills of a single person (Pierre Wack); and ultimately failed to make the most of the internal resources and ideas devoted to it by the scenario team. This failure to reach its full potential has not yet been recognised in the literature.

Shell used scenarios to gain a lead on its competition by seeking a clearer perception of what the future would probably hold for the oil industry and the ways its unfolding future would affect strategies and decisions in the industry. Since scenarios are developed along the axes of the ranked driving forces (most important and most uncertain), it is important to explore properly these axes in order to develop a few scenarios whose differences impact the decision-maker. Because of the increased inter-connectedness of the business world, analysing these driving forces in isolation will not do. Scenarios need to be developed at higher levels of complexity (but not complication). Generative explanation as a bottom-up approach to scenarios enables the scenario planning team i) to explain the past and the present and ii) to structure the uncertainties of the future in new ways.

3. A generative explanation approach to scenarios

Shell moved from single-line business forecasting using the Unified Planning Machinery to scenarios as a critical planning and decision-support tool. The shift in painting plausible futures rather than forecasting a single future required an understanding of the numerous forces which may cause perturbations. For Shell (and elsewhere), the key purpose of scenarios is to challenge the microcosm of decision-makers and expand their imagination to see a wider range of plausible futures emerging from business megatrends. Scenarios enable executives to think about where their organisation may be out of alignment with the plausible futures and be much better positioned to take advantage of the unexpected opportunities that come along. For example, in the 1970s and 1980s Shell's scenarios contained sound insights into what actually occurred.

Scenarios can lose their effectiveness when they do not challenge individual microcosms and enable others to understand and explain the past and the present forces of change. As the forces of change become more inter-connected, scenario planners cannot neatly decompose them into separate and isolated sub-processes of change, which can be analysed independently. Aggregation of individually analysed sub-processes by means of summation to provide scenarios of a coherent whole fails when the correct process of aggregation is not a sum. This is because of the existence of interacting and heterogeneous forces and agents such as oil producing countries. The existence of

interacting and heterogeneous forces and agents gives rise to 'emergence' – the becoming of complex (rather than complicated) structures[22].

Scenarios, as advanced by the1960's Cross-Impact Analysis (CIA) of RAND, the 1970s Trend-Impact Analysis (TIA) of Futures Group, the 1970s suite of tools (Micmac, Mactor and Smic) of Michel Godet and Shell, are primarily based on the top-down and representative agent and forces approach. In 2010, two contributions in Nature by Mark Buchanan about 'Meltdown Modelling' and J. Doyne Farmer and Duncan Foley about 'agent-based modelling' eloquently discuss the massive failure of the dominant models, and argue for the case of agent-based computational model (laboratories) - the principal instrument for generative explanation. These dominant meltdown models dominated and still dominate the scenario planners' toolbox, which has been primarily developed from the late sixties and improved in the seventies and eighties. Unlike conventional approaches that use computation, for example, for the empirical analysis of observational data and the calculation of the equilibria of systems of equations, agent-based computational models takes us in new directions that focus on computer laboratories of complex dynamical systems. In other words, the business world is conceptualised as a complex adaptive system. Agent-based computational laboratories add a new approach to the existing toolbox of scenario planners. This new tool is fundamentally different because it accepts under a single umbrella:

- A higher degree of inter-connectedness between the building blocks of the business world: from hierarchical to network structures.

[22] Shelling, Thomas, Micromotives and Macrobehavior, W. W. Norton, 1978

- A higher degree of heterogeneity: removal of "N-replication" of decisions made by representative agents/pool of agents such as oil producing countries/OPEC.
- Explicit representation of multi-layered space: physical, regulator, business and socio-economic.
- Development of data-free representations: important for business megatrends – incipient societal, political, technological and economic shifts.
- Handling of a far wider range of nonlinear dynamics than conventional approaches: the computer keep track of the many interactions in order to see what happens over time.

The key issue here is that agent-based models need not be complex or complicated because simple micro-foundations (without the assumption that the business world will move towards a predetermined state) can generate complex macro-regularities. A specific micro-foundation is a plausible explanation if it grows, or can grow, to a macro-regularity. Once the scenario planning team identifies the plausible micro-foundations, decision-makers can interactively explore an artificial business world based upon a focal point and quantitatively explore the alignment and misalignment of their organisations. Therefore decision-makers are an integral part of the scenario planning process. This is of particular significance as shown by the review of Shell's scenario planning process above, although there is some evidence of concern from within Shell's past that there was on occasion a lack of "a top-down contribution to strategy." ["History and Strategy in Shell", An Internal Report, January 6, 1986, page 55].

For example, to identify the range of possibilities for global conventional oil production, this being the focal point of the scenarios, the key driving forces of the 'inside world' need to be identified. For oil scenarios, the key forces are: i) country-specific supply patterns, ii) country-specific demand patterns, and iii) country-specific oil reserves. These key forces need to be complemented by the key driving forces of the 'outside world' such as geopolitical factors and policy settings, which affect, for example, country-specific oil trade. These key driving forces are then used to identify the essential microfoundations of the agent-based computational laboratory. An example in shown in Figure 1 below, satisfying the generative explanation standard of the past and the present and the new way to structure the uncertainties of the future.

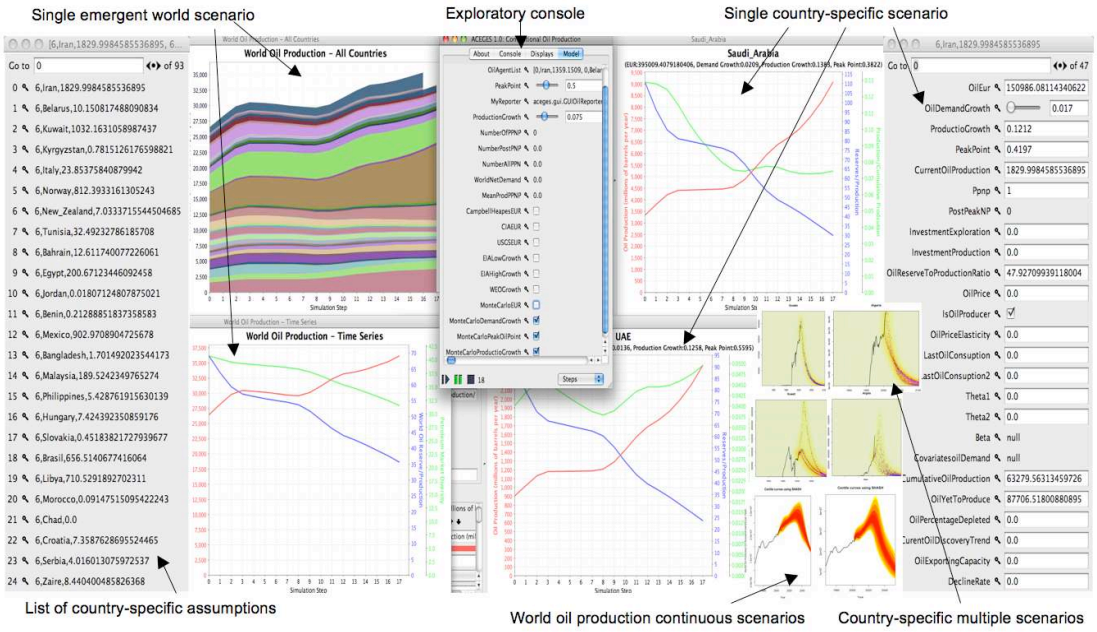

Figure 1: Agent-based computational laboratory for scenario development

In particular, the agent-based computational laboratory of Figure 1 is based upon the judgments by the scenario planning team about the key building blocks and driving forces of the oil system such as:

i. Country-specific oil demand.
ii. Country-specific oil production.
iii. Country-specific cumulative oil production.
iv. Country-specific oil trade.
v. Country-specific oil demand growth.
vi. Country-specific oil production growth
vii. Country-specific EUR estimates.
viii. Country-specific peak or Reserve/Production (R/P) point.

From these key building blocks, the last four have been identified as the key uncertainties. Note that country-specific oil trade can also be considered as an uncertainty, but this uncertainty is mainly affected by the last four key uncertainties through the country-specific 'decision rule' of oil production and trade. These country-specific 'decision rules' of production need not be homogenous. In 2008 at the Oxford Futures Forum, Henk Alkema, who joined Shell Group Planning in March 1971, noted that "our analysis showed quite different motivation levels of individual producer countries for higher production given the differences in resources and expected findings…". Therefore, heterogeneity is present not only in the oil production rules but also is the characteristics of the countries such as resources and expected findings (yet-to-find oil). Despite the observed heterogeneity, conventional models – the primary toolbox

of scenario planners – can only accept a modest degree of heterogeneity by means of pools of representative agents. The agent-based computational laboratory relaxes this restriction by including country-specific oil production rules and characteristics such as oil reserves. These decision-rules are not necessarily all in the same form of an 'oil mountain', as discussed by Hans DuMoulin, who headed up the Oil Analysis Division of Group Planning, or the 'bell-curve' phenomenon associated with Marion King Hubbert.
In fact the country-specific form of the 'oil mountain' is not predetermined as is usually assumed. The country-specific 'oil mountain' emerges because it depends on the consumption, production and export decisions of the other countries – countries interact by means of oil trade, for example.

The agent-based computational laboratory has a number of screens to set: i) the parameters of the whole scenario such as oil demand growth per year; and ii) the parameters affecting particular agents (building blocks) or groups of agents such as Iran and OPEC. The latter is important if a scenario is explored to test, for example, the export willingness of the OPEC countries given their absorptive capacity of oil revenues, although, as noted by Michael Jefferson and Larry Macmahon, through 'primary, secondary, and tertiary' recycling routes absorptive capacity would prove a non-problem despite that a senior figure in Shell's Middle East Regional function regarded this as nonsense. With an agent-based computational laboratory satisfying the standard of generative explanation, the robustness of different views can be challenged through bottom-up perturbations. Given the high degree of inter-connectedness of the agent-based model, this will also test the export potential of the non-OPEC countries as they react to

the production decisions of the OPEC countries. This cannot be done analytically because of the many different interaction patterns that emerge from positive feedback loops. Mahmoud El-Gamal and Amy Mayer Jaffe discuss another example of positive feedback loops in their 2009 book "Oil, Dollars, Debt and Crisis" where, for instance, a major oil exporting country's decision to sell its oil for Euros rather than US dollars can start a flood of diversification away from US dollar-denominated investments. This non-dollar diversification of investments can then trigger other oil exporting countries to sell their oil for Euros or a basket of currencies, which, in turn, reinforces other non-dollar-denominated investments. Mahmoud El-Gamal and Amy Mayer Jaff also note that as difficult as it is to find a partial solution to various components of the problem (while holding the other factors constant), the overall understanding of the system dynamics requires studying the system at substantially higher levels of complexity" (p.16). Agent-based computational laboratories satisfying generative explanation emerged from the need to understand the overall dynamics of a system through complexity (not to be confused with complication).

Within the generative explanation approach, the future is not be regarded as 'complicated' but as 'complex', in that there is uncertainty about the key driving forces of change that can generate unanticipated futures. The implication for executives is that to move from the perspective of top down to bottom up, the conception of the future changes, from one where we assume that all key driving forces and their uncertainties are ultimately knowable to one where this assumption is no longer tenable. Covering the

range of possibilities identified, and encompassing them in readily communicated alternative scenarios, is an art in itself. The scenario planning team will have their own views on which of the scenarios they regard as more probable. But, given the uncertainties about the future that provide the rationale for the multiple scenario approach in the first place, it is important also to recognise that some scenarios considered to have a low 'subjective probability' of occurring may have far greater consequences for the organisation than a 'mainstream' scenario. Finally, there is a need to resist the temptation to back a particular scenario too strongly because, as Shell's scenario planners and senior managers were constantly reminded in the 1970s: "Those who foretell the future lie, even when they foretell the truth".

The conventional way to foretell the future of oil production is to use line forecasts based upon historical data and a curve-fitting approach. An alternative approach is to reject the 'surprise-free' approach and introduce more than one line pathways by incorporating certain uncertainties such as three estimates of oil reserves – USGS Estimates of Ultimate Recovery. This approach, which is used by the US Department of Energy, Energy Information Administration shown in figure 2, results in a finite number of lines and in a discrete scenario approach to the handling of uncertainties. The general idea of more than one line pathways is sound as a way of communicating the inherent uncertainty around the outlook of, say, conventional oil production.

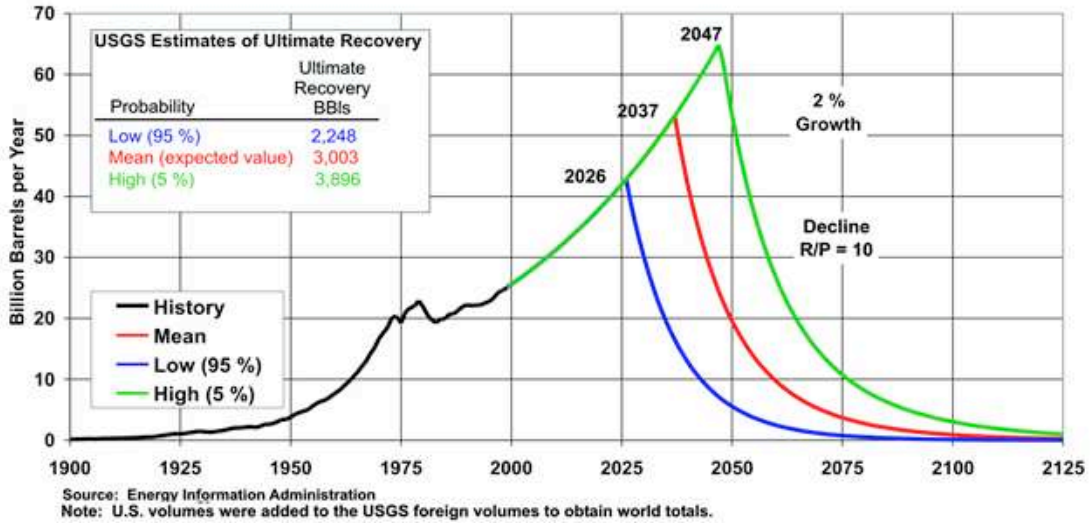

Figure 2: Discrete scenarios based on finite number of uncertainties[23]

The alternative approach is to use pathways as probability distributions, as shown in Figure 3, to guide the probabilities and risks facing executive by emphasising the inevitable uncertainties. Figure 3 depicts the scenario planner's judgement of the probability of various outcomes for oil production in the future. The colour bands, representing emergent probabilistic statements of oil production, widen as the time horizon is extended towards 2035, indicating the increased uncertainty about global conventional oil production outcomes. Because of the finite nature of conventional oil, the uncertainty decreases. The shape of the 'probability bands' represents the emergent:

- central project of oil production which determines the profile of the central darkest band;
- degree of uncertainty, which determines the width of bands; and
- skewness and/or kurtosis, which determines the probability of extreme outcomes (the light yellow bands),

[23] Wood, J., Long, G., Morehouse, D., 2004. Long-term world oil supply scenarios: The future is neither as bleak or rosy as some assert. Energy Information Administration.

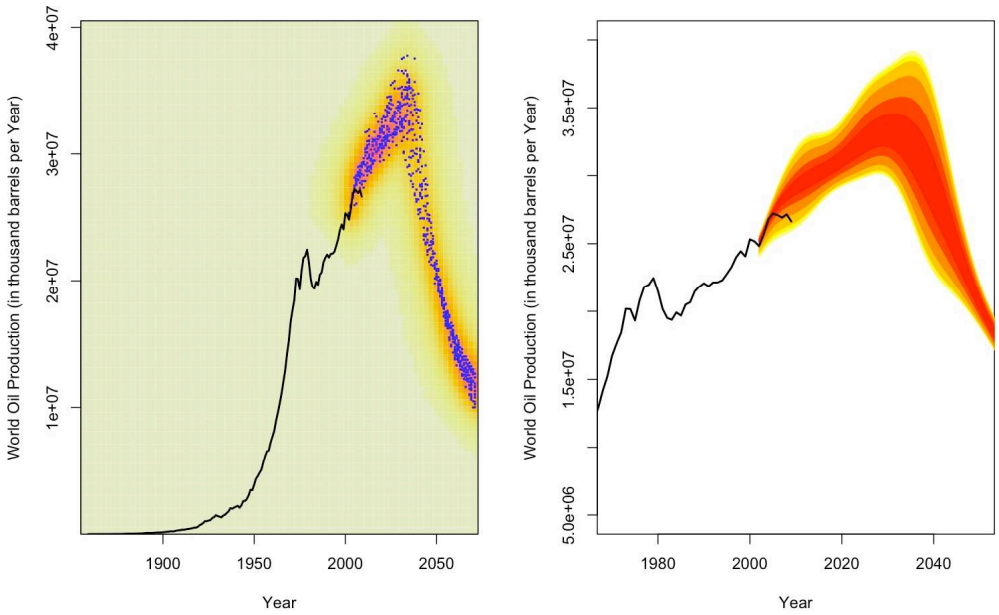

Figure 3: Continuous scenarios based on a range of uncertainties

Because figure 3 satisfies the generative explanation standard, the probability-based pathway is not a pre-determined state explicitly defined by scenario planners. The important point here is that the pathway is not modelled explicitly (by assuming that the global production follows a 'mountain-like' production profile) but the global production profile emerges from the production profiles and interactions of the individual countries (both net-oil-producing and net-oil-consuming countries). To check the validity of the assumptions (encapsulated by the building blocks) and the plausibility of the scenarios, scenario planners can compare historical out-turns against the probability bands - tilting historical data into better future scenarios. This will enable them i) to test the assumptions of the scenarios by asking whether x% of the outruns do actually fall within the

corresponding probability bands[24], ii) to detect patterns, trends and trend breaks and iii) to highlight areas of particular interest for the future of the organisation and/or the focal point of the scenario.

Given that uncertainty about the future is endemic, the scenario development process seeks to marshal the key 'building blocks' required to provide greater rationality on the nature and range of the uncertainties. Clearly the geopolitical, social and economic environment in which organisations operate or, where changing, are likely to operate is a critical area. Policies and measures that may affect the organisation, or changes thereto, are also critical. Possible shifts in the patterns of demand or supply (availability of raw materials, products or parts thereof, prices, costs) are a third area. The fourth main area is technological: what may be the pace of substitution, innovation, diffusion. Finally, there may be actual or potential competition, and its nature, to be considered. Agent-based computational laboratories satisfying the generative explanation standard are based on a litany of building blocks.

These 'building blocks' define a world of morphogenesis with positive feedback loops that literally beg organisations to be more adaptive because negative feedback loops, which tend to negate change, are not always present or in motion. The range of uncertainties can be explored in two complementary ways:

a. User-centred exploration: Scenario planners adjust interactively the key uncertainties using the GUI (Graphical User Interface) widgets of the

[24] The informal analysis can be complemented with format statistical tests to assess the scenario assumptions such as Kolmogorov-Smirnov test, Berkowitz test and/or Kullback-Leibler divergence.

'Exploratory console'. For example, scenario planners can adjust the R/P point for the whole scenario or for specific countries to explore their effect on the profile of world conventional oil production, country-specific oil production profiles and trade between countries.

b. Mathematically-centred exploration: Exploring a multi-dimensional uncertain space using the user-centred approach can be cumbersome, especially when a high degree of heterogeneity is required such as country-specific peak or R/P point. Scenario planners can select a sampling method, often called Monte Carlo methods, to explore a highly complex uncertain space. This exploration then results in 'continuous scenarios'.

Another source of uncertainty in developing scenarios is the 'decision rules' of building blocks. For example, oil scenarios can be developed based upon the late 1950's 'Hubbert model', proposed by the American geoscientist Marion King Hubbert, or any other curve-fitting or econometric model. Alternatively, scenarios can be developed using a 'mechanistic model'[25] such as the one suggested by the British petroleum geologist Colin Campbell in 1997[26]. Therefore, uncertainty also exists with the way the building blocks behave - the decision rules. Using the agent-based computational laboratory satisfying the generative explanation standard, alternative decision rules can be explored in order to identify plausible candidates. Within the generative explanation standard, plausibility is defined if a decision rule can 'grow' the historic macroscopic explanada, such as historic oil production. Once a number of 'plausible behavioral rules' are identified, fundamental

[25] The scenarios of Figure 2 and Figure 3 use a modified version of the mechanistic model suggested by Colin Campbell in 1997

[26] Colin Campbell, "Depletion patterns show change due for production of conventional oil", *Oil and Gas Journal* (1997), 33-37

shifts or perturbations can be explored using the user-centred and/or mathematically-centred exploration approaches. For example, if the thread of military conflicts with major oil producing countries, such as within the Middle East, is expected (or is explored), scenario planners can widen the range of uncertainties of the key driving forces or 'shock' the system by temporarily reducing or stopping production for the countries under consideration to explore how the dynamic interaction (by means of oil trade) between countries can widen the pathway of the scenation. This suggests that scenarios are not only about looking at future possibilities but also about understanding and working of the driving forces that may cause 'perturbations'. By means of computational experiments, scenario planners step back from details and provide a 'big picture' by deciding what to suppress and which patterns, relationships and trend breaks to show. The full narrative stories are developed using simple, clean and convincing messages to communicate an internally consistent and plausible story effectively and imply authenticity in order to shift "personal microcosms" and enhance understanding and working of the building blocks. Such an approach would probably have avoided dismissing Shell's "Producer Miscalculation" scenario in January, 1977, as "unsustainable and unsuitable".

4. Conclusion

Many of the pitfalls in developing scenarios are linked to specific failures to identify customers for the scenarios presented, users' needs, or a lack of balance between intuitive logics, as advanced by Shell since the 1970s and strongly computer-based models. Achieving a balance and proper fusion of intuitive logics and computer-based models

results in a more integrated approach to scenario development by promoting a morphological analysis approach of scenario building. Probably the main challenge is to build scenarios that enable executives to rehearse the future in a way that transforms the identified facts and key uncertainties into new perceptions – a new microcosm.

The need to develop scenarios in order to help understand uncertainties and their possible consequences, and the process of developing or 'building' scenarios, is more straightforward though sometimes complex in detail. However, it should be emphasised that scenario development is not a mechanistic process. This is because there is inevitably uncertainty around the outlook, say, of oil production. To explore an uncertain future, scenarios have been used since the post-war period for guiding executives' expectations of change. The more obvious way, by publishing a single (numbered) forecast, simply will not do as (i) single number forecasts have a high probability of being incorrect; and (ii) the distribution itself is important.

To address (i), scenario planners have used multiply pathways, say, of conventional oil production by incorporating uncertainties such as conventional oil reserves. However, the multi-pathway approach fails to take into account the distribution itself. Thus, instead of building scenarios using the multi-pathway approach, the application of generative explanation and its principal instrument – agent-based computational laboratories - demonstrates an approach to enhance the toolbox for corporate scenario planners. This approach explores better the key uncertainties, and communicates this uncertainty by enhancing the single pathway approach with its corresponding probability. This in turn

encapsulates the range of uncertainties and risks of the 'inside' and 'outside' business worlds.

Although nobody can predict the future evolution with absolute certainty, it is more realistic for scenario planners to recognise that uncertainty when describing their outlooks. Understanding of the uncertainty is important if scenario planners can describe it and communicate it in effective and efficient ways. Generative explanation and agent-based computational laboratories offer a new way that scenario planners can employ to understand and explain the past and the present, and the new way to structure the uncertainties of the future. This approach enables the scenario planning team collectively to decide on the balance of risks. The key point here is that scenario planners should not mechanically extrapolate past trends in order to calibrate the uncertainty – they should grow it from bottom-up as a way to explanation and understanding. This emphasises the importance of subjective assessments. Generative explanation and agent-based computational laboratories are not about reflecting the differences of view among the scenario planning team. Generative explanation and agent-based computational laboratories encapsulate a single view, which represents the centre gravity of opinion among the scenario planning team.

Each of the building blocks of the scenarios need to be carefully analysed, taking account of past experiences which may have relevance, as well as forces already 'in the pipeline' and possible new factors needing to be considered. Current fashions and euphoria need to be critically examined. Both quantitative assessments and qualitative assessments will be

required, and here the quality and experience of the members of the scenario team are particularly tested. Sometimes importing experience from outside the organisation has been of high value, in order to get the scenario team away from simply re-examining past organisational experience and context. This may be of particular importance where macro-economic turbulence, a major shift of pattern in an industry's supply or demand relationships, or significant governmental policy changes, are taking place. Agent-based computational laboratories provide the environment for experiments. In other words, as wind tunnels and related simulation methods work in the physical world (e.g. testing the essential aerodynamic features of scale-model bridges), then Agent-based computational laboratories can also work for scenarios by taking the scenario team away from simply re-examining past organisational experience and change. Therefore, generative explanation permits a distinctive approach to empirical-based decision scenarios by offering an environment for the study of the implications of business megatrends – incipient societal, political, technological and economic shifts.

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