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CASE STUDY

# Black Swan Theory: Applications to energy market histories and technologies

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ABSTRACT

**This article provides an overview of several key shifts in energy supply and demand within the analytical framework of Taleb's famed Black Swan Theory (BST). The BST illustrates the low probability and low predictability of highly impactful events. Through a detailed review of extant academic literature and government reports, our paper focuses on black swans in the form of historical disruptions in energy security and technological innovation (the latter of which has been a key contributor to the recent explosion in the rate of development of unconventional fossil fuel resources). The piece concludes by emphasizing the need to adopt a considerably more conservative approach to energy forecasts. Policy recommendations are provided and include the need for skepticism in long-term projections, avoiding picking specific technology winners, and the need for enhanced valuation systems for environmental externalities.**



## 1. Introduction

To an unsettlingly large extent, the world is a chaotic and random place wherein formative events are often unexpected and hugely impactful. However, few models – quantitative or qualitative – properly account for this entropy. To compensate for this recurring failure of economics, finance, public policy, and other fields, Black Swan Theory (BST) was articulated by the academic and quantitative trader Nassim Nicholas Taleb. His powerful writing is a stirring indictment of those who prescribe scientific solutions to social science issues, eschew unorthodox thinking, integrate unknowable variables into Gaussian probability curves, and attempt to label themselves (or are labeled by others) as "experts" in their specified field – even when they know little more than, to quote Taleb, "cabdrivers" ([1]. p. 14). His findings have been justifiably lauded by many leading thinkers and have been applied to a large number of fields, including health, law, engineering, and statistics.

But perhaps no field provides a greater testing ground for this theory than energy policy. At over $5 trillion dollars per annum, it is the world's largest industry – and it comes laden with idiosyncratic shortcomings of the Black Swan variety [2]. For example, security of energy supply is increasingly threatened by unpredictability in hydrocarbon recovery rates, the dwindling accessibility of inexpensive conventional reserves (historically responsible for providing high energy returns on energy invested), mounting political risk, and pervasive market failures [3]. Myopic energy decisions are often disproportionate contributors to anthropogenic climate change, major causes of public debt burdens, and a surprisingly inertial source of unequal stakeholder interest consideration [4]. From the recent disaster at the Fukushima nuclear plant to the controversy surrounding the Chinese Three Gorges Dam to questions surrounding the optimal role for nuclear energy in a robust supply mix, the world is constantly encountering difficult questions around the limitations and deficiencies of current energy practices.

## 2. Overview of Black Swan Theory

To set the context, a brief overview of BST is outlined at this juncture. Properly applied, BST enhances our ability to explain fundamental unpredictability in the energy world [1]. BST is complex and interdisciplinary, drawing from economics, mathematics, psychology, and evolutionary biology. Therefore, to simplify the analysis, only five core elements of this broad vision will be discussed herein.

First, it is important to understand the relevance of the metaphor of a "black swan" in the BST title. To do so, it is helpful to

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embrace a simple thought experiment and envision a countless flock of white swans. One observing this flock over a prolonged period of time might be tempted to assume that all swans are white, as past experience would point invariably toward this conclusion. Yet the appearance of even one black swan can invalidate years of painstaking knowledge accumulation (see Ref. [1] for a more complete description). Such a thought experiment allows one to envisage the first tenet of defining an event under the rubric of the rudimentary BST outline presented in this article: it is an entirely unexpected outlier with little or no precedent.

Second, Black Swans appear to be retrospectively predictable and anticipatable. In the case of one of the most studied Black Swans in history — the credit crisis of 2008 — the coalescing of dubious financially-related activities like predatory lending, insufficient bank capital reserves, and excessive speculation appeared "post-crash" to make a financial calamity inevitable. Indeed, many mainstream economists have conveniently taken up this theme in the post-crash period through a series of bestselling books, with only a few being capable of saying that they were actually at the vanguard of predicting the calamity [5]. Yet, at the time, such a crash seemed unthinkable for most (especially "experts").

The aforementioned "retrospective predictability" is closely linked to the third component of a Black Swan; namely, the fact that Black Swans often arise due to a human illusion of understanding. This illusion can take several forms. However, it is most succinctly summarized as "the human frailty of believing we fully comprehend a world that is far more complex and random than we realize" [6]. We tend to assume we can readily identify monocausal inputs shaping a given result when, in reality, the truth is often far more unclear.

Fourth, a Black Swan is (usually) extreme in its implications. A good example can be found in the case of new energy technologies that will allow for major breakthroughs in the generation, transmission, distribution, and consumption configurations of modern electricity systems. These systems rarely follow the expected trajectory of their proponents and tend to confound elegant theories or expectations. As noted by Hargadon and Douglas [7], "when innovations meet institutions, two social forces collide, one accounting for the stability of social systems and the other for change".

Fifth, humans are easily duped into confusing structurally similar but entirely different explanations for events. Taleb [1] uses the example of individuals confusing the two nuanced terms "no evidence of disease" and "evidence of no disease", which are wholly different ideas framed in a similar way (e.g. Ref. [8].). BST explains that humans are prone to building explanations into plausible-sounding but false narratives that make sense of how disordered events unfold. Kahneman [9] provides several examples of our irrational tendency to focus on this so-called narrative fallacy [1], whether it be in our interpretation of theater, life experiences, or assessments of other people. In the energy industry, for example, many engineers tend to hold a preference for technically complex projects that are not necessarily enduringly sound or broadly optimal [10].

## 3. Historical black swans in energy

The last forty years has hoisted a variety of energy supply and energy demand black swans into the public domain, creating enormous uncertainty in assumptions regarding energy futures. Six examples of energy-related black swans and their implications are illustrated below.

### 3.1. 1970s oil crisis — the classic example of energy-related BST

As is now common knowledge, the petroleum supply of the developed world collapsed in the seventies. The 1973 oil embargo of the Organization of Arab Petroleum Exporting Countries (OAPEC) was a punitive response to the United States and other nations for their collective support of Israel in the Yom Kippur War [11]. The following seven years saw a 500% rise in crude oil prices (after inflation), with the developed world scrambling to adjust [12]. Even the mighty United States' national policies were unable to resolve the immediate political, economic, and technological fallout that emerged in the aftermath of these unprecedented price increases. Across North America, gasoline was rationed and central banks slashed interest rates to encourage economic growth, even as industrial production costs continued to rise and exports declined. The embargo triggered a significant decline in the American auto industry and compounded its existing fiscal woes [12].

The oil crisis of the seventies is an archetypal black swan event. None of the most affected countries — Japan, France, the US — had predicted the occurrence or severity of this oil shock. Retrospectively, policy makers should have anticipated the anger that their support of Israel would provoke in the Middle East and the probability of an oil embargo in retaliation. Some developed nations managed to adapt; fuel-poor Japan, for example, deployed creative technological and economic paradigm shifts to compensate, evinced in that country's evolution from oil intensive industries to value-added consumer electronics [13].Yet the overhang of the oil crisis has loomed for decades after the original tremor, with an ongoing sense of incessant unpredictability over both fuel supply and the viability of alternative technologies.

### 3.2. Shale gas in the United States

In what could be one of the least prescient energy statements ever uttered by an American President, April 18th, 1977 saw Jimmy Carter give a public address declaring the imminent end of domestically produced natural gas [14]. Thirty two years later, America's Potential Gas Committee [15] projected natural gas reserves at 1836 trillion cubic feet, the highest estimate in 44 years and a thirty nine percent climb from just two years before. Two significant innovations in shale gas extraction methods — directional drilling and George Mitchell's recent development of hydraulic fracturing — turned previously inaccessible gas reserves into relatively easily obtainable commodities. In the past ten years, the estimated recovery of gas-in-place (GIP) grew from 2% to estimates as high as 50% [16]. The sudden promise of comparatively clean, domestically-produced shale gas has once again shifted the U.S. energy sector's paradigm from import to export, with far-reaching implications.

The shale gas boom of the last decade has proven to be one of the most important energy black swans in recent history. As Adam Sieminski of the U.S. Energy Information Administration remarked, "For 40 years, only politicians and the occasional author in Popular Mechanics magazine talked about achieving energy independence… now it doesn't seem [like] such an outlandish idea" [17]. Nevertheless, a cautious optimism must inform any shale gas forecasts. The complex geological and environmental barriers to shale gas recovery have sometimes been underestimated, as demonstrated in a recent study that found a strong correlation between elevated methane levels in water wells and local shale-gas drilling [18]. Another study by the United States Geological Survey [19] has "almost certainly" linked natural gas drilling operations to a recent spate of earthquakes from Alabama to the Northern Rockies. These unforeseen consequences have caused some states to push for a prohibition of fracking [20], and future development may force American energy commentators to, once again, reverse some of their rosy predictions.

### 3.3. Emergence of oil sands development in northern Alberta, Canada — major recent supply shift #2

It may be hard to reconcile with the vast megaproject sites now dotting northern Alberta (Canada), but the bulk of Canada's petroleum reserves were deemed both