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A quantum derivation of a reputational risk premium

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ABSTRACT

Using quantum modeling, we propose a novel approach to reputational risk management arguing that taking care of corporate reputation can be considered a coalitional strategy framed into a quantum game theory schema. Following a stochastic mechanics approach, and assuming that the revenues of a firm can be modeled as an Ornstein–Uhlenbeck process represented by the well-known Langevin equation for the diffusion of a particle with unit mass under non-linear friction, we offer a mathematical derivation for the discount rate of a firm that does not manage its reputational risk and for a company that optimally manages its reputational risk. By comparison, we derive an analytical expression for the reputational risk premium. Our approach provides useful managerial and financial implications, suggesting that the use of the quantum ideology may result useful in enlarging the body of knowledge of corporate management.

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1. Introduction

Quantum finance is an interdisciplinary branch of research that uses analogies from quantum mechanics to describe and explain financial issues. It is an emerging part of the prolific field of econophysics, which shows that theories, concepts and methods originally developed for the explanation of physical phenomena can be successfully applied to the understanding of social-economic problems (Chen & Li 2012; Haven & Khrennikov 2013). Some remarkable results in this subject include the proposal of economic analogs for basic physical quantities such as economic mass and economic Planck's constant, or financial applications for the Heisenberg's uncertainty principle (Soloviev & Saptsin 2011) or the quantum anthropic principle (Piotrowski & Sładkowski 2001).

The purpose of this paper is to offer a novel approach to reputational risk management based on quantum modeling, something that to our knowledge has not been done yet. Framing the analysis into a quantum market game schema, and following the Nelson's stochastic mechanics approach (Nelson 1966), we use differential equations, as well as remarkable results from stochastic calculus and dynamic programming, with the aim of acquiring an explicit expression for a reputational risk premium. Ultimately, our contribution enlarges the current knowledge in the branch of corporate social responsibility, encouraging the addition of the quantum ideology and formalism in further investigation about corporate governance and business management.

The rest of the investigation is structured as follows. The second section provides a literature review about financial applications of stochastic partial differential equations and quantum modeling. The third section relies on the link between the stochastic basis of diffusion processes and quantum mechanics. The fourth section argues about the suitability of a quantum approach for the analysis of reputational risk and derives a reputational risk premium. Finally, the fifth section concludes and points out the managerial and financial applications of the results of this research.

2. Literature review

The Black–Scholes formula for the valuation of a European option is one of the most prominent applications of stochastic processes in financial research (Black & Scholes 1973). Further developments have resulted in a generalization of this methodology so that it can be used to value a wide set of financial derivatives (Hull 2006; Poitras 2002; Wilmott 2007), capital structure (Bensoussan, Crouhy, Galai, Wilkie, & Dempster 1994), financial responsibilities (Longstaff & Schwartz 1995; Merton & Samuelson 1990), corporate securities (Black & Cox 1976), corporate liabilities (Brealey, Myers, & Allen 2006; Merton 1974), investment opportunities (Abel, Dixit, Eberly, & Pindyck 1996; Amram & Kulatilaka 1999; Brennan & Schwartz 1985; Copeland & Antikarov 2001; Dixit 1994; McDonald & Siegel 1985; Smit & Trigeorgis 2012; Trigeorgis 1993; Trigeorgis 1996), and even a whole company (Bowman & Hurry 1993; Copeland Thomas, Koller, & Murrin 1994; Koller, Goedhart, & Wessels 2010; McDonald & Siegel 1985; Sanchez 1995) or the issue of business failure (McGrath 1999).

At a more general level, the same approach has been successfully applied in construction and technology projects (Benaroch 2002; Ford,

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Lander, & Voyer 2002; Kumar 2002; McGrath 1997; Schwartz & Zozaya-Gorostiza 2003; Zou & Zhang 2009), research and development (Eckhause, Hughes, & Gabriel 2009; Huchzermeier & Loch 2001; Paxson 2001; Schneider et al. 2008), production (Gamba & Fusari 2009; Xu, Lu, & Li 2012), manufacturing (Kogut & Kulatilaka 1994), supply chains (Cucchiella & Gastaldi 2006; Tang & Nurmaya Musa 2011; Wong, Potter, & Naim 2011), joint ventures (Chi 2000; Kogut 1991), budgeting (Costa & Paixão 2010; Meier, Christofides, & Salkin 2001), corporate social responsibility (Husted 2005) and risk management (Cruz 2002).

These models are developed under the assumption that a certain financial magnitude can be represented as a stochastic process. Among other examples, the modeling of interest rates offers a wide range of motivating results (Handhika 2012; McLeish & Kolkiewicz 1997; Nowman 1997). In this sense, it is worthwhile mentioning the Merton model (Merton 1973), the Vasicek model (Vasicek 1977), the Cox–Ingersoll–Ross or CIR models (Cox, Ingersoll, & Ross 1980; Cox, Ingersoll, & Ross 1985), the Dothan model (Dothan 1978), the Courtadon model (Courtadon 1982) and the Brennan–Schwartz model (Brennan & Schwartz 1980). In addition, some comparison has been carried out, showing that a general formulation with the appropriate parameters selection can include all of them, leading to the Chan–Karolyi–Longstaff–Sanders or CKLS model (Chan, Karolyi, Longstaff, & Sanders 1992).

It is worth to note that these financial stochastic models are usually based on variations of the well-known Ornstein–Uhlenbeck process, which has numerous applications in physics, usually cited as the Langevin equation (Caceres & Budini 1997; Lindner 2010; Wilkinson & Pimir 2011). This similarity opens the path for a shared knowledge between researchers in financial theory and physics. Thus, the financial field has benefited from different mathematical tools coming from physics and quantum mechanics, usually referred to the analysis of non-linear dynamics, uncertainty, stochastic calculus and dynamic programming. Therefore, there are notable results concerning financial applications of quantum games (Piotrowski & Śładkowski 2002; Piotrowski & Śładkowski 2004; Piotrowski & Śładkowski 2008) and quantum financial modeling (Baaquie 2013; Ilinski 2001). In particular, a quantum approach for the diffusion of prices and profits has been offered (Piotrowski & Śładkowski 2005) and a quantum model for the stock market has been proposed (Bagarello 2009a; Bagarello 2009b; Cofas 2013; Zhang & Huang 2010). In addition, the valuation of financial derivatives has been enriched by the use of path integrals (Dash 1989; Linetsky 1997) and Hamiltonian operators (Baaquie 2004; Baaquie 2013). As a consequence, we find some notable results like a derivation of a quantum Black–Scholes equation (Accardi & Boukas 2007) and the proposition of a Black–Scholes–Schrödinger equation (Haven 2002; Haven 2003). Also, a quantum extension of a European option valuation has been derived (Piotrowski, Schroeder, & Zambrzycka 2006) and a quantum harmonic oscillator framework has been considered for option pricing (Cofas & Cofas 2013). Finally, a quantum reconsideration of the Cox–Ross–Rubinstein binomial model has also been offered for option valuation (Chen 2001).

3. Quantum modeling and stochastic processes

There is a prolific branch of academic research that establishes deep connections between well-known results of stochastic calculus applied to the theory of diffusion processes and quantum modeling (Davidson 2006). In particular, it is worth mentioning the approach proposed by Nelson (1966), who hypothesizes that any particle can be modeled by a Brownian motion with no friction, using analogies from the Ornstein–Uhlenbeck theory of macroscopic Brownian motion with friction. Under this assumption, he is able to derive the Schrödinger equation into a stochastic mechanics framework, based on stochastic differential equations and remarkable results from stochastic calculus (Bacciagaluppi 2005; Nelson 1985).

The approach proposed by Nelson is typically referred through academic literature as a stochastic version of the pilot-wave theory of

de Broglie (1928) and Bohm (1952a, 1952b), which is one of the most famous approximations to the basis of quantum mechanics. In fact, it is remarkable pointing out that the pilot-wave theory has been already suggested as an accurate framework for the analysis of different financial phenomena (Choustova 2004; Khrennikov 2014). In particular, this methodology has been successfully applied for the description of stock markets (Choustova 2008b), as well as the dynamics of stock prices (Choustova 2008a). Also, it has been used for offering a wave-equivalent equation for the Black–Scholes equation (Haven 2004). At a more general level, but with deep implications in the field of behavioral finance, this framework has been also proposed for the explanation of decision processes (Aerts & Aerts 1995).

In this paper we follow an approach similar to the one adopted by Nelson (1966) based on stochastic mechanics. Thus, the mathematical reasoning relies on stochastic partial differential equations, as well as other notable results from stochastic calculus and dynamic optimization.

4. A quantum model for a reputational risk premium

The public relevance acquired by recent reputational scandals, especially in the banking industry, has forced corporate managers to put a special focus in social and reputation related issues (Fiordelisi, Soana, & Schwizer 2013). Thus, in so far as the compromise with reputational risk management and corporate social responsibility is mediated by the attention given to this subject by stakeholders and society as a whole, there is a connection between observer and observed phenomenon that suits well with the quantum ideology and, as a consequence, research on the field of reputational risk can take advantage of the quantum formalism.

Actually, the aforementioned analogy has been already used to explain several social concerns, with some remarkable applications of open quantum systems to decision making processes, either generally considered (Busemeyer, Wang, & Townsend 2006) or framed into specific scenarios, like a political context (Khrennikova, Haven, & Khrennikov 2014) or a game theory framework (Asano, Ohya, & Khrennikov 2011). That is why we hypothesize that the analysis of reputational risk can be also framed into a quantum market game schema (Piotrowski & Śładkowski 2002). In fact, previous researchers have tackled corporate social responsibility related issues from a game theory point of view (Lambertini & Tampieri 2011; Sacconi 2004; Sacconi 2006; Shaw 2009). So, as an extension of this analysis that benefits from the ideology and formalism of quantum modeling, we argue that reputational risk management can be conceptually framed into a quantum market game. Given that corporate social responsibility and reputational management require taking care of relations with stakeholders, as well as cooperation with the environment (Castelo Branco & Lima Rodrigues 2006), a company that does not intend to manage its reputational risk is assumed to hold a non-coalitional strategy within a quantum game theory scenario. Otherwise, if the company is willing to deploy an active reputational risk management, this attitude can be thought of as a coalitional strategy between the company and its environment.

Adopting an approach based in stochastic mechanics that is close to the one proposed by Nelson (1966), we assume that the revenues of a firm follow an Ornstein–Uhlenbeck type process (Vizcaíno-González 2010). In particular, and focusing in the non-coalitional scenario where a company does not manage its reputational risk, the revenues can be modeled as the following Langevin equation for the diffusion of a particle with unit mass under non-linear friction (Lindner 2010):

$$dR = -\mu R dt + \sqrt{2\mu k_B T} dW \quad (1)$$

In this equation:

- μ represents the friction coefficient
- R stands for the revenue

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