"Financial Risk and Crisis Management after
the Global Financial Crisis" Series No.2 (11/2015)

New Movements of Financial Risk Analysis in Post-Financial Crisis[1]

Hisashi Nakamura[i]

Associate Professor, Graduate School of Commerce and Management,
Hitotsubashi University

[1] This document is an English translation of the original Japanese, which appears in the Nov. 2015 edition of The Japan Economic Research Institute Monthly Report, published by The Japan Economic Research Institute.

Overview

Over the past quarter century, financial markets have witnessed remarkable growth in financial techniques, including securitization and the development of derivative products. The free use of these techniques allowed for subdividing individual business risks and diversifying as well as disseminating those risks into an enormous capital market. This led to the thought in the mid-2000s that financial markets and real economies had succeeded in constructing an iron-clad system to manage risk. However, in 2007 and the years that followed, the subprime mortgage crisis and the bankruptcy of Lehman Brothers revealed the obfuscatious nature of diversified risk when absorbed into the capital market, and unprecedented losses were inflicted on financial markets and real economies. Given the experience of this world financial crisis, the previous standard arbitrage-free pricing approach alone is insufficient to completely analyze recent movements in financial markets and the financial risks found therein. This has prompted the construction of a new asset valuation (asset pricing) model that can appropriately explain financial risk in the post-global financial crisis period, which is an urgent issue for both academics and those working in the financial field. Outlining a brief review of the fundamentals of the asset price research theory, this study presents new movements in the post-financial crisis financial risk analysis and provides a guide toward future research.

1. Introduction

Financial techniques have significantly evolved over the past quarter century, including securitization and derivative product development. The free use of these techniques allowed for subdividing individual business risks and diversifying as well as disseminating those risks into an enormous capital market. This led to the thought in the mid-2000s that financial markets and real economies had succeeded in constructing an iron-clad system to manage risk. However, in 2007 and the years that followed, the subprime mortgage crisis and the bankruptcy of Lehman Brothers revealed the obfuscatious nature of diversified risk when absorbed into the capital market, and unprecedented losses were inflicted on financial markets and real economies.

Given the experience of this world financial crisis, the previous standard arbitrage-free pricing approach alone is insufficient to completely analyze recent movements in financial markets and the financial risks found therein. Most notably, the presence of asymmetric information (moral hazard, adverse selection, monitoring), transaction costs, defaults, psychological causes, network effects, and other sources of financial friction render markets incomplete, thus making the analysis of asset pricing a troublesome affair. Considering these points, the construction of a new asset valuation (asset pricing) model that can appropriately explain financial risk in the post-global financial crisis period has become an urgent issue for both academics and those working in the financial field.

This study serves the following purposes: first, it provides a basic review of the asset pricing theory; second, it presents new movements in the post-financial crisis asset pricing theory and financial risk analysis; third, it suggests the direction of future research in this area. However, the construction of a universal asset pricing model in an incomplete market wherein various sources of financial friction exist is a difficult matter. Considering this, this study introduces new asset pricing and valuation models with respect to numerous specific financial friction sources. Specifically, this study presents nine pieces of research conducted with grant funding from Japan's MEXT, which comprise the "Construction of new Interest/Exchange Valuation Models After the Global Financial Crisis" (Class B, general, headed by Eiji Ogawa, reference number 25285098), focusing on the financial friction sources of network effects and moral hazard in introducing three pieces of research on asset valuation and pricing from theoretical, demonstrative, and numerical analytical perspectives. The first piece of research is a numerical analysis of network effects-related asset pricing models based on the study by Kobayashi and Nanpo (2016), considering a financial market model incorporating causes from behavioral finance and investment behavior. The second piece of research, based on the study by Takamizawa (2015), explores demonstrative research on interest rate volatility forecasting using data found in the yield curve. The third piece of research, based on the study by Misumi et al. (2015), provides theoretical validation for the distorting effects of moral hazard on prices in the financial market. Significant focus is placed on the third area of research as it is based on my research.

The remainder of this paper is structured as follows: Section 2 reviews fundamental theory on asset pricing analysis and financial risk analysis.

Section 3 presents new trends in asset pricing analysis and financial risk analysis as they have unfolded in recent times. Section 4 presents an overall conclusion and suggests directions for future research.

2. Frameworks for Asset Pricing Analysis: Arbitrage-Free and Equilibrium Approaches

Here, we provide a low-level review of the framework that supports asset price analysis based on the textbooks of Duffie (2001) and Cochrane (2005); specifically, we address arbitrage-free and equilibrium methods and related topics.

2.1 Basic Assumptions

Let us consider a one-period two-date economic model ($t \in \{0, 1\}$).[2] This economy is exposed to uncertainty, and a finite set of scenarios $\{1, \cdots, S\}$ is possible. Though which scenario will occur is unclear at date 0, it is revealed at date 1. The chance of each scenario occurring is indicated by $p_s > 0$ $(s \in \{1, \cdots, S\})$, $\sum_{s=1}^{S} p_s = 1$. Also, N securities exist within this economy's financial market, with security structures reflected by an $N \times S$ matrix, indicated by $D = \{D_{is}\}$ $(i \in \{1, \cdots, N\},\ s \in \{1, \cdots, S\})$. In other words, D_{is} represents the payoff of security i in scenario s at date 1. The security price at date 0 has N elements, represented as q, and the security portfolio purchased at date 0 has N elements, represented as θ. Security portfolio θ's market value is $q \cdot \theta$, and payoff is $D^{\top}\theta$. In other words, an economic entity purchases security portfolio θ at date 0 for the price of $q \cdot \theta$ receiving $D^{\top}\theta$ at date 1 depending on the scenario. Here, we utilize two presumptions.

Given (1): Payoff space X is $X := \mathrm{span}(D) := \{D^{\top}\theta : \theta \in R^N\}$.

This presumption relates to market transaction opportunities, which implies that an economic entity may freely purchase or sell securities at date 0 to form a portfolio.

Given (2): The price for payoff $x \in X$ is represented as q_x, and a π exists that satisfies $q_x = \pi(x)$ at which $x_1, x_2 \in X$ and $a, b \in \mathbf{R}$ (note that R represents the set of real numbers) can be constructed as

$\pi(ax_1 + bx_2) = a\pi(x_1) + b\pi(x_2)$.

This is known as the law of one price and implies the linearity of pricing

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[2] For more details, see Duffie (2001) and Cochrane (2005)

and guarantees that all portfolios with the same payoff also have the same price; that is, rearranging payoffs will result in no gain.

In the asset pricing theory, we validate what properties π will have when security structure D is observed with security price q. In particular, we may find the state-price concept useful in applying characteristics to π . A state-price security (or Arrow–Debreu security) is defined as one that pays off a unit of a numeraire if a particular state occurs, with no payoff in other states with price vector $\psi = (\psi_1, \cdots, \psi_s, \cdots, \psi_S)$. Therefore, $\psi_s = \pi(\mathbf{1}_s)$ exists. Here, only the s^{th} element results in 1, whereas other elements result in zero in an s-dimensional column vector, which represents the Arrow–Debreu security's payoff in state s. We may notate this as $q = D\psi$ based on our two given conditions.

2.2 Arbitrage-Free Opportunities and Incomplete Markets

However, we cannot simply utilize π, ψ to assign characteristics in an analytical or numerically analytical fashion to asset pricing and financial risk movements for all security structures and market transaction opportunities. Actual financial operations will analyze asset pricing under more realistic restrictions on security structures and the market transaction environment. Arbitrage opportunities are defined as $[q \cdot \theta \leq 0 \ \cup D^{\top}\theta > 0]$ and $[q \cdot \theta < 0 \ \cup D^{\top}\theta \geq 0]$ for portfolio θ. In general, this refers to the opportunity of realizing a gain by the simple act of holding portfolio θ. Therefore, the nonexistence of arbitrage opportunity (arbitrage-free opportunity) means that there is no free gain to be made (stochastically). This is a more stringent restriction compared with our second given condition. Here, we posit

Theorem 2.1: In the absence of arbitrage opportunity, and only in such an occasion, a positive state price must exist. However, though this positive state price exists in this situation, it does not necessarily follow that it is the only possible state price.

Yet, another classic restriction is that of a complete market. A complete market means that any payoff pattern may be replicated within the market. In particular, when the number of states is limited, a market is complete when the number of market assets is equal to the number of states. This restriction is more stringent than our first given condition. Here, we posit

Theorem 2.2: When the market is complete, if and only if there is an absence of arbitrage opportunity, a single positive price state vector will exist.

Since a single positive state price vector exists in this situation, this can prove useful in analyzing financial market asset pricing. However, the restriction of a complete market is stringent in practice. For example, transaction costs, asymmetric information, defaults, etc. may render the market incomplete.

In actual financial risk and asset pricing analyses, these and other restrictions provide the basis for analyzing state price characteristics. More specifically, analysis methods are largely categorized into arbitrage-free and equilibrium methods. As these are complementary approaches, they must be utilized under different circumstances. The following is a simple explanation of these two approaches and their reciprocity.

2.3 Arbitrage-free Method

The arbitrage-free method presumes the absence of arbitrage opportunity in a complete market, extracting π , ψ from an existing security structure/price regardless of whether it is explicit or implicit, valuing other securities through replication based on risk-neutral probability. A classic example of this is the Black–Scholes option pricing model. Arbitrage-free pricing models are characterized by their convenience in price valuation for securities through replication, whereas their applicability in incomplete markets is restricted. The existence of corporate bankruptcy, imperfect information (moral hazard, adverse selection, monitoring), transaction cost, and other sources of financial friction will render markets incomplete, making it difficult to directly apply an arbitrage-free approach.[3]

2.4 Equilibrium Method

A second analytical method is the equilibrium approach. Based on our fundamental assumptions, when a representative economic entity accesses a securities market characterized by (D, q) , it will optimally allocate assets for optimal consumption to achieve maximal expected utility. The equilibrium approach seeks out a price function π (or ψ) in which this optimal allocation allows for market equilibrium in the economy. Although arbitrage-free methods also take a particular view on equilibrium, the

[3] There have naturally been significant attempts to apply arbitrage-free pricing approaches to incomplete markets in academia and in the field; however, wide-ranging mathematical limitations outside of arbitrage opportunity-free scenarios are often imposed.

“equilibrium” in the equilibrium approach refers to (1) maximization of a given value (here, expected utility) by an economic entity within its budgetary restrictions, given the use of consumption/investment/asset allocation, and (2) the state of complete market clearance in financial assets.

If we work through these problems of optimization under the appropriate mathematical conditions, then we realize that for optimal consumption, state price is comparable with marginal utility. Consequently, a security’s price may be characterized as a function of the potential economic environment (output in this scenario). Moreover, even in an incomplete market, asset pricing becomes possible as long as an optimal solution can be discerned. Thus, we may build upon these fundamental presumptions by introducing information problems (moral hazard, adverse selection, monitoring), transaction costs, and other sources of financial friction in using the equilibrium approach to seek out a state price, thereby being able to structurally analyze the effects of movements in financial friction sources and outputs (market conditions and company performances) on asset pricing and market risk. If a state price is found through the equilibrium method when the market is incomplete, then this particular state price is considered to be one of the multiple appropriate state prices that could be derived and does not exclude the presence of other state prices. The equilibrium approach can be characterized by having the advantage of structurally deriving a state price without presupposing a complete market while being easily exposed to model risk due to the state price’s dependence on the model structure.

Overall, arbitrage-free pricing and equilibrium approaches have limitations imposed on their application. If we then consider that the assumption of incomplete markets for risk analysis is inevitable after the financial crisis, then it is conceivable that a more preferable stance may be to apply either one approach or the other in a complementary fashion depending on the situation.

3. Analysis of Post-financial Crisis Asset Pricing/Financial Risk Using the Equilibrium Approach

This section presents recent research on the equilibrium method in relation to asset pricing and financial risk movements under restriction from sources of financial friction; specifically, three new analyses of asset valuation/financial risk are presented. These analyses are based on the research conducted with grant funding from Japan's MEXT, "Construction of new Interest/Exchange Valuation Models After the Global Financial Crisis" (Class B, general, headed by Eiji Ogawa, reference number 25285098). The first piece of research is a numerical analysis of network effects-related asset pricing models based on the study by Kobayashi and Nanpo (2016), considering a financial market model incorporating causes from behavioral finance into investment behavior. The second piece of research, based on the study by Takamizawa (2015), explores demonstrative research on interest rate volatility forecasting using data found in the yield curve. The third piece of research, based on the study by Misumi et al. (2015), provides theoretical validation for the distorting effects of moral hazard on prices in the financial market. Significant focus is placed on the third area of research as it is based on my research.

3.1 A Price Fluctuation Model for Financial Markets Constructed from Investment Behavior

The complex mixture of credit and liquidity problems during the global financial crisis revealed peculiar price fluctuations in financial markets. As such, studies thus far have proposed numerous models to tackle the question of the nature of price variation in stocks and other such items. However, the greater part of existing models was created *ex post facto* with stochastic items to apply to actual price movements; thus, this stochastic format does not provide a clear explanation beyond statistical effects.

In contrast to the models proposed thus far, we do not presuppose that movements that may appear random are of exogenous probability. We instead utilize the structure created by a swath of investors engaged in deterministic investment behavior to produce a model and reproduce market price fluctuations among investor interdependence (networks) with numerical calculations. In other words, we do not engage in stochastic estimation based on the financial market's output (price movements) but construct a financial market model whereby price is determined through equilibrium between total sales and purchase volumes across all investors in the market, given that those investors base deterministic investment strategies on past price movements. Investor behavior has some interdependence in the market, which leads to network effects. Therefore, we can increase the number of investors and conduct numerical analyses to validate the network effects of investor behavior.

The results indicate that regardless of the absence of random elements in investor decision making, deterministic investment behavior feeds onto itself in the market and deteriorates into a chaotic phenomenon whereby seemingly random price fluctuations are generated. The results of this study imply that the act of presupposing a probability model, as in models proposed thus far, is not the only method for modeling financial markets.

3.2 Predicting Interest Volatility via Information Extracted from the Yield Curve

Takamizawa (2015) constructed and verified time series models to explain (1) interest rate time series behavior and (2) a cross-section of risk premiums demanded by investors with respect to interest rate variation factors, thus clarifying the key conditions necessary for constructing an interest rate model. In previous studies, a problem of contradiction between time series and cross-sections was found, and time series analysis did not completely consider cross-sectional information in the yield curve. In contrast, this study utilizes the US interest rate data comprising LIBOR and swap rates and empirically explains interest rate volatility using cross-sectional information inherent to the yield curve. Specifically, it expounds that interest rate volatility has a uniformly non-linear function across all interest rate factors (three were used in the proof) versus yield curve information.

The following three items represent the major results of that analysis. First, (the non-linear function of) interest rate factors suffice well to explain the volatility of the yield curve's "slope." Second, (the non-linear function of) interest rate factors can explain the volatility of the yield curve's "curvature" when combined with volatility factors. Third, though interest rate models that satisfy arbitrage-free conditions have been said to face troubles in simultaneously explaining the data's cross-sectional directionality and time series directionality, discoveries here reveal that resolving the mutual exclusion problem of time series and cross-sectional areas without needlessly increasing the number of factors is possible. Though this study does not absolutely presuppose an equilibrium approach, its demonstrative uniform explanation of both cross-sectional and time series areas in a reduced form conceivably implies the construction of a financial model based on the equilibrium approach.

3.3 Distortion Effects of Moral Hazard on Financial Market Prices

Misumi et al. (2015) formulated equilibrium asset price valuation when moral hazard is present. Moral hazard is considered to be one of the most serious problems in finance, and the moral hazard in investment banks that caused the recent financial crisis reminded the world once again of its potentially disastrous effects. A significant body of research has examined moral hazard in the corporate finance world (e.g., Tirole, 2006, Section 3.2). As an example of moral hazard, if an investor is unable to observe the management effort made by the firm in which they invest, then the firm's management may neglect maximizing corporate value and instead prioritize personal gain, causing a loss to the investor. To mitigate the threat of loss by moral hazard, investors engage in loans/investments through contracts meant to incentivize efforts by the firm's management to maximize value. Consequently, we understand that moral hazard may distort optimal risk sharing and/or optimal allocation.

However, not all these distortions on the most micro levels of firms and investors in the financial world lead to possible moral hazard in the market. If risk sharing or allocation were to be altered, then investor marginal utility (or state price [density]) would be altered as well, thus exerting influence not only on corporate value but also on all financial asset pricing on a macro level. Considering the recent financial crisis, investment banks would sell off loans via securitization, lowering oversight incentives. Moreover, hedge funds would induce strategic insolvency through selfish investment behavior. These and other examples of microdistortions from many different forms of moral hazard at corporations and financial institutions accumulated across the market create instability on a macro level.

Considering this, recent years have witnessed a rapid proliferation in research analyzing the market's unstable macroenvironment due to moral hazard. However, moral hazard asset pricing valuation models in the past have not been well established in the areas of asset pricing theory and financial engineering. How much return on investment would be demanded in reality by investors to manage the loss from moral hazard faced by company management? For example, how much return would be demanded by an investor when selfish investment behavior by a hedge fund facing moral hazard may distort the investment return? Moreover, how much would that accumulate and distort the total investment return across the entire market? Answers to these questions are yet to be revealed either academically or in the financial field.

Moral hazard may take many forms in financial operations; recent macro research broadly classifies moral hazard into three major categories. He and Krishnamurthy (2012, 2013) posited the existence of diversion, whereby a financial institution neglects asset management and misappropriates revenues for personal benefit. More specifically, their study investigated the addition of limitations on capital holdings to curtail moral hazard and determined how asset pricing is distorted therein. Brunnermeier and Sannikov (2014) explored the effect of financial institutions' financial positions on asset pricing under a similar scenario, particularly analyzing the volatility paradox noted by Kocherlakota (2000). These bodies of research take continuous-time optimal restructuring contract models developed by Biais et al. (2007), DeMarzo and Fishman (2007), and DeMarzo and Sannikov (2006) and develop their premises in support of the construction of asset pricing models.

Ou-Yang (2005) also posited that while a firm's efforts toward on-demand production increase (a drift item) adds cost burden to the firm, an investor entity will not be able to directly observe the level of the firm's efforts. Moral hazard can then be characterized by changes in drift. This applies the continuous-time contract models of Holmström and Milgrom (1987) and Schättler and Sung (1993) in an asset pricing model framework and develops a weak mathematical formulation for a company's stochastic control problems. Similar to Ou-Yang (2005), Nakamura (2016) also categorized moral hazard as related to drift control but sets a strong formulation for a company's stochastic control problems. This study applies the study by Nakamura and Takaoka (2014) in an asset pricing model framework. The differences between these weak and strong formulations are not solely mathematical; they have implications for economics and financial theory as well.[4]

Myerson (2012) posited a third scenario whereby the success probability of a firm/financial institution's investment project is influenced by the management's efforts, which then incur costs that are directly unobservable by investors. Myerson (2012) analyzed the effects of moral hazard on

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[4] Please see Misumi et al. (2015) and Nakamura (2016) for more on the economic and financial implications. In addition, for definitions of strong and weak solutions in stochastic differential equations as well as strong and weak formulations for stochastic control, see Karatzas and Shreve(1991), Yong and Zhou (1999), and other related works.

macroeconomics. A significant amount of in-depth analysis has been performed on this type of moral hazard in areas such as corporate governance and optimal contracting theory, with everything from textbooks to research literature analyzing this classic model of moral hazard (see Tirole, 2006, Section 3.2 and other related literature). More recently, Biais et al. (2010) analyzed optimal contracting considering moral hazard whereby a firm may make efforts and expend funds to decrease jump probability, although an investor cannot observe the level of effort made by the firm. This indicated that based on shareholder limited liability systems and bankruptcy laws, company management is less motivated to reduce jump probability for major negative jump risks that could exceed the firm's asset value, therefore suggesting that the contractually stipulated threat of reducing compensation during poor performance periods was an optimal practice. Furthermore, the study indicated that if the threat of reducing compensation was only marginally effective due to extremely low performance, then the threat of reducing the scale of investments made in poor performance situations would also serve such a function in optimal contracting.

Myerson (2012) applied this form of moral hazard to a macro-level analysis. Myerson (2012) indicated that without long-term financial assets and even with a simple, non-stochastic, constant model, granting long-term employment incentives could curtail moral hazard. In particular, given that financial institutions established for different numbers of years will have accumulated different levels of trust based on the economic conditions they have experienced, a situation whereby multiple financial institutions coexist with differing qualities as such will lead to variations in employment states across each generation in accordance with changes in economic conditions. Myerson's (2012) study indicated that the effect of moral hazards could therefore induce complex cyclical variations in the economy on a macroeconomic scale.

Our study, Misumi et al. (2015), aligns itself with this third classification. It specifically focuses on moral hazard when the stochastic distribution of success chances has a sizable downside in a scenario where both Brownian-based normal distributions and overall probability measures (including negative jump probability) can be modified. Although this study simulates jump probability controls much like in the study by Biais et al. (2010), neither shareholder limited liability systems nor corporate bankruptcy will be seen under the setting of the most appropriate contract.

This study establishes a formula for how this nature of moral hazard exerts distortive effects on asset pricing in the macro market, indicating in its analysis that moral hazard reduces the Sharpe ratio, which decreases the appeal of investing in risk assets. It also indicates that this moral hazard increases risk-free interest rates as it plays a "hedge" role in shifting market risk prices opposite to investor marginal utility. We therefore understand that the risk-free rate puzzle, initially explored by Weil (1989), is further exacerbated by moral hazard. Finally, we understand that the distortions in actual resources borne of moral hazard may be alleviated by investor access to financial markets.

4. Conclusion

This study presents new analytic trends that incorporate experience from financial crises to supplant more traditional financial risk analyses. However, though we present theory, proofs, and numerical analyses of new individual segments while specifically focusing on various identification problems involved with financial friction, we have not yet arrived at a point of practical application of these concepts. In going forward, investigating actual implications for risk management as practiced by firms and financial institutions will be necessary.

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i [Profile: Hisashi Nakamura]

Graduate School and Faculty of Commerce and Management,
Hitotsubashi University
Naka 2-1, Kunitachi City, Tokyo
Tel：042－580－8826. Fax：042－580－8747.
Email：hisashi.nakamura@r.hit-u.ac.jp.

Dr. Nakamura obtained a Ph.D in Economics from the University of Chicago in 2005, taking on the assistant-professor position that same year at the University of Tokyo and holding said position until 2011. He then joined Hitotsubashi University and has held his position there since. Dr. Nakamura was also on the main career track at the Bank of Japan from 1994 to 2001. Recent research fields include risk management and asset pricing under asymmetric information – more specifically, given a common real-life scenario whereby a firm holds propriety information not available to external investors, theoretically and mathematically analyzing said risk management and financial asset valuation while securitization and the financial derivatives market continue their rapid growth, then deriving implications for financial system stability.