COMPLEXITY IN FINANCIAL MARKETS

Markus K. Brunnermeier
Princeton University

Martin Oehmke
Columbia University

CURRENT DRAFT: Septermber 10, 2009
FIRST DRAFT: September 15, 2008

Abstract
Should we regulate complex securities, subject them to an FDA-style approval process, or limit who can invest in them? To answer these questions, one first needs to establish why complexity matters, and what defines a complex security. Complexity is an important concept in financial markets with boundedly rational agents, but that finding a workable definition of complexity is difficult. For example, while CDOs are viewed by most as highly complex, equity shares of financial institutions, whose payoff structures are even more complicated, are often seen as less complex. We point out three different ways in which boundedly rational investors can deal with complexity: (i) by dividing up difficult problems into smaller sub-problems or by using separation results, (ii) by using models – simplified pictures of reality, (iii) through standardization and commoditization of securities. Importantly, simply increasing the quantity of information disclosed to investors does not resolve complexity, since in the presence of bounded rationality it leads to information overload.
(JEL: G10, D03)

Markus K. Brunnermeier
Princeton University
Department of Economics
Bendheim Center for Finance
26 Prospect Avenue
Princeton, NJ 08540
markus@princeton.edu

Martin Oehmke
Columbia Business School
3022 Broadway
420 Uris Hall
New York, NY 10027
moehmke@columbia.edu

We thank Viral Acharya, Sanjeev Arora, Philipp Hartmann, Stephen Morris, and participants at the 2009 EEA Meetings and the 2008 ECB-Chicago Fed Conference for helpful comments.

1. Introduction

During the recent turmoil in financial markets, so-called high-risk complex securities were particularly affected. Examples of such assets are tranches of CDOs, CDOs squared, and a variety of other structured credit instruments.[1] This raises the question whether the complexity of a financial security is an important determinant of its price dynamics and the efficiency with which it is traded, particularly during times of crisis. In fact, in response to the current credit crisis many commentators have argued that financial innovation may have made the financial system too complex, and policy makers are exploring ways of dealing with this complexity of modern financial markets and, in particular, with complex financial securities. The prescribed answers often call for more regulatory intervention, for example in the form of an FDA-style regulatory security approval process for securities, investor restrictions or disclosure requirements. One example is the recent proposal for a consumer protection agency for retail financial products.

In this article we comment on the role of complexity and complex securities in financial markets. We focus on three main points that are central to a well-informed debate about complexity. First, we point out that, at a theoretical level, complexity only becomes important in financial markets when agents are boundedly rational. This means that in order to tackle issues relating to financial market complexity, economists have to step outside of the rational paradigm, which most of classical asset pricing theory is based on. Importantly, we point out that in the presence of bounded rationality more information *per se* does not help investors make well-informed investment and risk management decisions. This is because simply increasing the quantity of information disclosed can lead to *information overload* – a boundedly rational investor who receives an entire truckload of documents will be overwhelmed by the amount of information he needs to distill. Consequently, the way in which information is disclosed becomes crucial. This has important implications for designing disclosure requirements for consumer protection.

Second, we argue that finding a workable definition of the complexity of a financial instrument is surprisingly difficult. We illustrate this through an example: a CDO tranche – an instrument that most observers would regard as highly complex – is, in fact, not necessarily more complex than a seemingly very simple financial instrument: equity in a financial institution. This difficulty defining complexity poses a challenge for policy proposals that target complex securities.

Third, we discuss ways of dealing with complexity in a world of bounded rationality. We first highlight how complexity can be dealt with by dividing up difficult problems into smaller sub-problems, or by using

[1] For a summary see Brunnermeier (2009).

separation results. We then highlight importance of models – simplified representation of reality – to deal with complexity. However, since models ignore certain aspects of reality, they are subject to modeling pitfalls. Finally, we discuss the use of a regulatory approval process and/or investment restrictions for complex securities. We argue that it is not clear how effective these measures would be in dealing with complex securities.

2. Why Does Complexity Matter?

Classical asset pricing theory has not seriously explored the implications of the complexity of a financial security on its price dynamics and the efficiency with which it is traded. The reason is that most of asset pricing theory, like much of economic theory, relies on a rational framework – investors are able to conduct even the most complicated calculations at lightning speed. Naturally, this framework leaves little room for complexity as a determinant of asset prices.

To see this, consider the following example. A complex and a simple asset trade in a rational world. While the simple asset's payoff is easily determined, in order to value the complex asset, the investor has to read and process a vast amount of information. Only after reading and processing this information the investor understands the complex asset as well as the simple asset. In a rational world, this would not matter. Since the investor can process an unlimited amount of information instantaneously, he can reduce complexity instantly if only he has the right information at hand. What matters to the investor is thus access to information, but not how much information he needs to be process, or how complex that information is. Within the rational paradigm, reducing complexity is thus only a matter of information provision or acquisition. Once the relevant information is available to the investor – in whichever form – the agent can reduce complexity at no cost.

Now introduce bounded rationality. To fix ideas, consider an investor who is limited in his ability to process information. For example, the investor may be subject to computational limitations, or limited in the number of variables that he can keep track of. In any of these cases, complexity clearly matters to the investor.[2] While in the rational setting described above providing a sufficient amount of information about the complex asset allowed the investor to make an informed decision, in a bounded rationality world this is not the case. Rather than reducing the complexity of an asset, disclosing more

[2] The classic reference in bounded rationality is the work of Herbert Simon (a good starting point is his Nobel Prize lecture, Simon 1978). Sims (2003) provides a framework modeling information processing constraints using tools from information theory.

information may now lead to *information overload*.[3] Consequently, in the bounded rationality setting more information may *not* necessarily lead to more informed investment decisions or risk management by the investor. Rather than simply the quantity of information, the way in which information is presented and how an investor reduces complex interdependencies becomes crucial. In addition, information release may introduce information asymmetries if some market participants are better at processing information than others, potentially leading to market breakdown due to a lemon's problem. Or, alternatively, when complexity is so high that no investor finds it in his interest to collect information, information is still symmetric among investors, but a large amount of hidden information may build up in the background, leading to large and sudden price adjustments when this pent-up information is finally released.

In summary, except for benchmark case of perfect rationality, complexity matters in financial markets and investors need to find ways to deal with it.[4]

3. Defining Complexity

If complexity matters, the next step is to determine which financial instruments should be considered 'complex.' Unfortunately, this classification is much less clear cut than one may suspect. As an illustration, consider first an asset that most people would regard as complex, a tranche of a collateralized debt obligation (CDO). The reason why this asset is considered complex is its complicated cash flow structure. A CDO is created by first bundling and then tranching the cash flows from a pool of loans. In other words, the CDO takes the cash flows from a debt claim on a firm, mortgage, or project, bundles these cash flows with similar cash flows from other firms or projects into one large pool, and then divides up the cash flows from this pool into different tranches. Tranching essentially gives this pool of assets a capital structure: The most junior tranche, like equity, suffers the first losses. The mezzanine tranche suffers losses once the equity tranche is depleted, while the most senior tranche only suffers losses after all other tranches have been wiped out.

Hence, while each of the initial individual loans may be considered a simple claim on a project, the CDO adds two layers of removal: it is a claim on

[3] A classic example of information overload is the terms and conditions window that pops up when installing a new software program. Not many people ever read it – in most cases the terms and conditions are ignored and users decide whether to install the program without learning about the terms and conditions.

[4] Note that we do not discuss what necessitates complexity in financial markets. One interpretation is that more sophisticated instruments that allow more risk sharing are inherently more complex. Another interpretation is that complexity emerged from financial institutions' desire to sidestep regulation.

a claim on a pool of a number of projects. The payoff to the holder of the CDO thus depends on the performance of all loans in the CDO, and, in particular, the correlation of defaults among these loans. It is well known that this correlation is notoriously hard to estimate.

From this example, one may want to conclude that the number of layers of removal from the simple underlying project could be a natural measure of complexity. Or alternatively, one may be tempted to posit that the more complex security is the one whose cash flows are more difficult to describe, for example using a measure of complexity from computer science theory, such as the minimum description length of a given set of data.[5]

However, by this line of argument also securities that many investors would view as less complex fall into the complex category. Consider for example the equity of an investment bank, say Goldman Sachs. If one were to value Goldman Sachs "bottom-up", i.e. by considering each of Goldman Sachs's businesses, their positions, projected cash flows and their risk profile, the resulting exercise would likely be *at least as complex* as coming up with a price for the tranche of a CDO. In fact, since an investment bank like Goldman Sachs holds a multitude of complex financial securities, including CDOs, on its balance sheet, finding a bottom-up price for Goldman's equity is arguably even *more* complex than finding a value for a single CDO tranche. Note that this argument pertains not necessarily only to financial firms. A similar logic holds for valuing companies outside the financial sector. Coming up with a bottom-up valuation for General Electric, for example, would involve modeling all of GE's businesses, their projects, the resulting cash flows, cash flow risks, and correlations. For a conglomerate like GE this is a similarly formidable task and, once again, not necessarily simpler than valuing a CDO.

What, then, is the difference between valuing a CDO tranche and determining the value of Goldman Sachs's or General Electric's equity? One possible answer is that in the case of valuing Goldman equity it may be easier for the investor to deal with the complexities at hand, because he can rely on certain building blocks rather than performing a full bottom-up valuation. This suggests a third approach of defining complexity – one that incorporates how investors can deal with complexity. In order to do this, it is useful to first take a step back and think about how investors can deal with complexity in abstract sense.

4. Dealing with Complexity

4.1. Subtasks and Building Blocks

---

[5] For an introduction to computational computer science see, for example, Arora and Barak (2009).

One way to deal with complexity is by dividing up a larger, complex task into smaller, more manageable subtasks. This process of subdivision can be compared to the proof of a complicated theorem – rather than proving the whole theorem at once, often researchers divide up the proof into different lemmas, which, taken together, deliver the proof. In other words, one may arrive at D, by taking a number of smaller steps, from A to B, B to C, and then, finally, from C to D.

In doing this, an investor may even realize that he does not have to perform all of these steps himself. This is the case when the investor can use certain building blocks for his valuation. To return to the above example, one reason why investors may consider valuing Goldman Sachs to be less complex than valuing a CDO is that, for a liquid stock like Goldman Sachs or GE, most investors do not feel the need to value every part of the firm separately, i.e. they do not need to conduct a full-fledged bottom-up valuation exercise. Active trading in Goldman stock ensures that there is a liquid market with an informative price that signals a consensus view of Goldman's current equity value, providing investors with an accurate signal. As Bray (1982) shows, prices may accurately reflect information even when individual agents are boundedly rational and do not understand how exactly information aggregation is achieved.

The investor can then use the information summarized in the stock price, add to it his incremental private information, and then take a view on whether he wants to buy or sell the stock. This is arguably much less complicated than aggregating all public information and synthesizing it with private information to arrive at a 'bottom-up' view on Goldman's equity value. Goldman's stock price may thus serve as a useful building block for the investor.[6] In a similar manner, an index like the ABX can facilitate valuing structured products without performing a full bottom-up analysis. The price of the index can be used as a starting point for valuation, and can then be adjusted to reflect differences between the composition of the index and the actual security being valued. However, as recent experience has shown, once an index like the ABX becomes illiquid and ceases to be an informative signal, investors have to revert to valuing the security without the help of a building block. In the case of CDOs they would revert to starting with the individual loans and aggregating up, a much more complex task.

4.2. Separation

[6] This point is also emphasized in a recent report by the Counterparty Risk Management Policy Group (CRMPG 2008), which states that "[i]t is possible that an instrument which would otherwise be high-risk and complex is not regarded as such because of its liquidity and price transparency."

However, even if a complex problem can be divided up into a number of more tractable sub-problems, the sheer number of sub-problems one has to solve may not be manageable. For example, an investor may know which ingredients he would need to price a particular asset, but it may still not be possible for him to synthesize all these ingredients such that he can arrive at a valuation. In cases like this, rather than mere subdivision, actual simplification of the problem is needed. One way of doing this is to use separation or independence results. Separation means that certain dimensions of the problem may not matter. Knowing that these dimensions can be disregarded makes the remaining problem much simpler.

In finance there are a number of theorems that allow us to do just that. Fisher Separation, for example, tells us that a firm's investment objective should be to maximize value, regardless of its investors' risk preferences. The Modigliani-Miller theorem allows us to value a firm without having to consider its capital structure. Both of these theorems tell us that, under certain assumptions, we can disregard certain dimensions, leading to significant simplifications and insights. In these cases, rather than doing A, B, and C to get to D, separation theorems simplify the analysis by telling us that, say, A and B are irrelevant for the problem.

4.3. Models – A Simplified Picture of Reality

Even if a problem cannot be separated through the use of a separation theorem, it can usually be simplified by using a model. In contrast to separation theorems that allow us to disregard certain aspects because they are irrelevant, models focus on first order effects while blocking out second order effects that are quantitatively less important. Models thus provide us with a simplified picture of reality; they are tradeoffs that sacrifice real-world detail for analytical tractability. The art of modeling is to recognize which effects are of first-order, and to capture those well.

A good example of how models can help investors deal with complexity is the Black-Scholes formula in option pricing. Before discovery of the Black-Scholes formula, there was no standard agreed-upon option pricing model. Traders had to rely on their own intuition or a non-standard model to price options. With arrival of the Black-Scholes formula, traders could suddenly use a simple equation to price options using only a small number of inputs.

While the price derived using the Black-Scholes formula relies on a number of simplifying assumptions (constant volatility, for example), it turns out that in many cases the practical difference between the value of an option and the price given by the formula is small enough to make the Black-Scholes price a very useful benchmark to price options. The Black-Scholes model thus captures the first-order determinants of options prices well, at least under normal market conditions.

Summary statistics work in a similar manner to models. Summary statistics convey certain dimensions of a complex security, while leaving out others. One prominent example is the use of credit ratings. Credit ratings provide an estimate of the default probability of a security. Ratings only focus on a subset of dimensions because, for example, they do not convey any information about the expected loss given default, or correlation of defaults with the wider economy. Risk measures are another example of the use of summary statistics. Risk measures reduce a complex loss distribution to a single number. Value-at-Risk, for example, summarizes downside risk of a risky asset or portfolio in the form of a quantile of the loss distribution. If the 95% daily VaR is $100 million, for example, this means that 95% of the time a daily loss will not exceed that amount. The VaR gives no indication, however, how the losses that exceed the 95% VaR are distributed or what the expected loss conditional on exceeding the VaR are. Thus, while summarizing some dimensions of the loss distribution in an intuitive manner, the VaR leaves out other relevant dimensions. Of course, summary statistics should be designed to communicate the information that is of first-order relevance. In the case of risk measures this means that the appropriate risk measure will depend on the question at hand.[7]

Since both models and summary statistics disregard certain dimensions, they naturally have limitations and are prone to *modeling pitfalls*. They describe a simplified version of reality and thus should be interpreted accordingly by those who use them. While the Black-Scholes formula greatly facilitated the growth of derivatives markets – and thus our ability to share risk through financial markets – the model's shortcomings have been made apparent a number times. For example, during the stock market crash of 1987 and the LTCM crisis of 1998, the failure to trade without moving prices led to a breakdown of the formula. In 1987 this meant that portfolio insurance strategies exacerbated the drop in the stock market, while in 1998 this contributed to the demise of the hedge fund LTCM. Similarly, relying exclusively on Value-at-Risk as a risk management tool can lead to pitfalls. For example, as is well known, VaR can discourage diversification.

However, while these examples remind us of the limitations of models, they do not imply that those models are obsolete. Rather, these episodes show that users of models should take into account that, on occasion, one or several of the model's underlying assumptions may fail to hold. Moreover, often these breakdowns in modeling assumptions will occur during extreme market conditions.

---

[7] A similar problem arises in the design of accounting rules. Financial statements should convey all the relevant information in a simple manner and without excessive footnotes that may obscure information.

4.4. Standardization, Security Approval, Investment Restrictions, and Disclosure

Finally, complexity can be reduced via standardization or regulation through a third party. *Standardization of contractual terms* reduces complexity by clearly defining the 'rules of the game' to market participants. A good example of this type of standardization is the set of rules outlined by the International Swaps and Derivatives Association (ISDA) for the swaps and derivatives markets. These contractual standards reduce complexity since they can be fixed for an entire set of securities (leading to *homogenization*) and do not have to be agreed upon every single time two parties want to trade (leading to *commoditization*).[8] In fact, securities that adhere to such clear and simple standards of this type are often referred to as *plain vanilla.*[9]

In addition to direct standardization of contractual terms, standardization can also occur when a number of investors use the same or similar models to price securities. We call this effect *standardization through (commonly used) models*. Once a model becomes popular enough to be considered standard by market participants, it also becomes easier to sell the security *before* expiry. This standardization happened quickly in the case of the Black-Scholes model, partly because the formula was available on programmable calculators. Being able to sell an option contract before expiry is valuable in the presence of liquidity shocks. A trader who at time t enters into an options contract with expiry at time T may be forced to liquidate his position at time $\tau < T$. Standardization of valuation models facilitates the liquidation of a position before maturity, because the valuations of potential buyers using similar models are likely to be relatively close to the seller's valuation. In other words, standardization reduces the potential for mispricing before expiry.[10] This standardization effect of models is in addition to the direct effect, which allows investors to price options assuming that they will hold them until maturity, independently of whether other investors use the same pricing model.

Another way to deal with complex securities is to require approval of novel, potentially complex securities, or to limit the set of investors that can invest in these securities. The hope is that security approval may be able to screen out securities that, for example, would increase systemic risk. Restricting the number of investors, on the other hand, may be a way to make

---

[8] For a more formal treatment of the standardization of securities, a good starting point is Gale (1992).

[9] It may be important to have such standardization be implemented by a third party like ISDA, since investment banks may not have an incentive to push for standardization if it reduces profits.

[10] This is similar to the effect in Froot, Scharfstein and Stein (1992).

sure investors know which risks they are exposed to when purchasing a particular security.

Security approval could be done in a process similar to the FDA approval process for new drugs.[11] A regulatory body, for example the SEC, would assess the risk characteristics, potential benefits and potential pitfalls of a financial security. The approval process may require a financial security to adhere to certain standards or disclosure rules. The resulting degree of standardization and transparency may in turn reduce information processing requirements for investors. Moreover, both contractual standardization and a centralized approval process of this sort may also reduce the duplication of effort that would occur if each potential investor would screen the asset individually.[12]

However, a regulatory approval process of this kind would not be without problems. In particular, given the difficulty of classifying securities as complex, it is likely that an FDA-style approval process would be a highly subjective process. It may thus be considerably harder to find common, consistent approval standards for financial securities than it is in the process for drug approval. Moreover, since potential benefits of introducing a particular security may be highly uncertain and not immediately obvious (and since no controlled trials can be performed), regulatory approval may considerably stifle financial innovation, possibly causing substantial costs in the long run.

Rather than restricting the set of securities available to investors through an approval process, another approach is to restrict the set of investors that can buy certain securities. In particular, investments in complex securities, however defined, could be restricted to 'sophisticated' market participants, e.g. financial institutions (and potentially individuals) that have the necessary expertise and risk management systems. In addition to sophistication, one could imagine that investors may also have to demonstrate sufficient financial resources to invest in high-risk, complex securities.

However, it is an open question how effective such investor restrictions would be in promoting financial stability. In fact, the current crisis suggests that they may not be effective, since many of the financial institutions that incurred large losses were presumably sophisticated investors. If not Lehman Brothers, Merrill Lynch or UBS, who then should have invested in these securities? Thus, while there may be other good reasons[13] for security approval or investor

---

[11] New drugs are approved by the FDA through the New Drug Application (NDA) process. Upon approval the drugs are initially available only on prescription. Approval for over-the-counter distribution is a separate process that follows the NDA.

[12] Another reason to limit complexity, not discussed in this paper, is the ability of consumer ignorance to raise market power. See Scitovsky (1950) or Carlin (2009).

[13] For example, one could imagine that financial institutions may have an incentive to design contracts that lead to systemic risk, maximizing the chances of a bailout.

restrictions, complexity per se does not seem to be a compelling reason for either.

Well designed disclosure rules, on the other hand, may help the boundedly rational investor to deal with complexity. However, because of potential information overload, the key is that disclosure requirements are designed in an appropriate fashion. For example, some financial securities could be issued with a standard, one-page term-sheet that summarizes key properties and risks of the investment.[14]

5. Conclusion

Financial innovation has over the last few decades allowed us to share risk more effectively than before. At the same time, however, it has introduced a large number of often complex securities, which investors and risk managers have to deal with. We argue that while complexity is an important concept in financial markets with boundedly rational agents, it is surprisingly hard to find a workable definition of complexity, posing a challenge for policy proposals that target complex securities. We highlight three ways in which boundedly rational investors can deal with complexity: (i) by dividing up difficult problems into smaller sub-problems or by using separation results, (ii) by using models, but keeping in mind potential modeling pitfalls, (iii) through standardization and commoditization of securities or investor restrictions. We also point out that, simply increasing the quantity of information disclosed to investors does not resolve complexity, since in the presence of bounded rationality it leads to information overload.

Bibliography

Arora, Sanjeev, and Boaz Barak. *Computational Complexity: A Modern Approach.* Cambridge, UK: Cambridge University Press, 2009.

Bray, Margaret M. "Learning, Estimation, and the Stability of Rational Expectations." *Journal of Economic Theory*, 1982: 26(2), 318-339.

Brunnermeier, Markus K. "Deciphering the Liquidity and Credit Crunch 2007-08." *Journal of Economic Perspectives*, 2009: 23(1), 77-100.

[14] Requiring this kind of disclosure may also limit the ability to increase market power through complexity.

Carlin, Bruce Ian. "Strategic Retail Complexity in Financial Markets." *Journal of Financial Economics*, 2009: 91, 278-287.

CRMPG. *Containing Systemic Risk: The Road to Reform.* www.crmpolicygroup.org, 2008.

Gale, Douglas. "Standard Securities." *Review of Economic Studies*, 1992: 63(2), 169-198.

Kenneth A. Froot, David S. Scharfstein and Jeremy C. Stein. "Herd on the Street: Informational Inefficiencies in a Market with Short-Term Speculation." *Journal of Finance*, 1992: 47(4), 1461-1484.

Scitovsky, Tibor. "Ignorance as a Source of Oligopoly Power." *American Economic Review*, 1950: 40(2), 48-53.

Simon, Herbert A. "Rational Decision-Making in Business Organizations." *Nobel Prize Lecture*, 1978: http://nobelprize.org/nobel_prizes/economics/laureates/1978/simon-lecture.html.

Sims, Christopher A. "Implications of Rational Inattention." *Journal of Monetary Economics*, 2003: 50(3), 665-690.