The development of Model Risk Management: a Luhmannian perspective

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Abstract

In the wake of the subprime crisis, several criticisms have been addressed to the way in which financial institutions model risk: the underlying assumptions generally accepted to estimate the economic worth of financial instruments would give a false sense of confidence to financial actors by underestimating the probability of extreme events. In response, and under pressure from regulators, these institutions are now being led to integrate the danger of being fooled by methodological options – the "model risk" – into their risk management. Our contribution proposes to account for this evolution, in its possibilities and limits, based on a major sociological theory: Niklas Luhmann's social systems theory.

Keywords: financial model, risk, social systems, Luhmann

JEL Classification: A14 , B26 , C52 , G01

1 Introduction

The massive transformations of the financial landscape between the 1970s and the 1990s have made its functioning more complex: technical and conceptual innovations [1] and the relaxation of regulation [2] have allowed the appearance and diffusion of new, more elaborate derivative products. This evolution has implied a parallel modification of the techniques of risk apprehension for the main financial institutions (banks and investment funds): this has resulted in the importation of modelling techniques already used in other domains, in particular in physics. The best known example - and undoubtedly the most triumphant in the effects it had on financial practices - is the Black-Scholes model, which revolutionized the way option products are valued by mobilizing the famous differential equations describing, in the field of statistical physics, the heat diffusion process.

As some sociologists and historians have well traced [3, 4], these conceptual imports were determined by practical requirements and constituted more an *ad hoc* "bricolage" than a coherent and unified set: financial products too original to benefit from a liquid market *had to* be valued (for accounting reasons, but also for the calculation of remunerations based on daily P&L). Some of these modelling techniques have been criticized in the wake of the subprime crisis, both by academics and by actors involved in the financial system [5–7]. The reason for this is that their underlying assumptions have allegedly biased the perception of the value of certain products and therefore of the risk they entailed. More specifically, they would have given a false sense of confidence by underestimating the probability of catastrophic events such as the one that occurred in the fall of 2008. In particular, the cross-sectional use of the normal distribution would have led to the neglect of the risk of colossal losses (since known as "fat tail risk"). These criticisms did not go unnoticed and led to reactions, both from the regulator and from financial market professionals.

An important, yet little studied, manifestation of these reactions was the appearance - or rather the reinforcement [8, 9] - of "Model Risk" in the perimeter of the risks that financial institutions must integrate into their management policy. At first sight, we can define "Model Risk" as the risk incurred by the use of a model: either by a misuse, or by an erroneous model. In this article, we propose to analyze this evolution by putting on the "glasses" of Niklas Luhmann's sociology. In doing so, we will realize that this evolution - remarkable in many ways - may still seem insufficient. In terms of the criteria of Luhmann's theoretical framework, it does not address the essence of the shortcomings pointed out by critics: the lack of translation of extra-financial codes into the language of the financial system, that is into a language that integrates the human nature of its object.

The contribution of our article is threefold. On the theoretical level, the fruitfulness of Luhmann's systems theory in its mobilization to grasp the evolution of the financial subsystem is made fully apparent. While some authors have already paved the way for such an approach [10–12], no work has developed this point via the in-depth examination of a case study such as the development of Model Risk. Empirically, this article provides a first documentation of the emergence of Model Risk within the departments of financial institutions. On this second aspect, we base ourselves on fieldwork carried out by one of the authors within a large European bank, including dozens of interviews with traders and risk managers and a three-month "participant observation" in the trading room. Finally, on a more normative level, we highlight some of the limitations of the contemporary approach and conclude with some suggestions for improvement.

The rest of this article is structured as follows. In section 2, we present the concepts of Niklas Luhmann's systems theory that will be useful for our further analysis. This part is intended to be accessible to non-sociologists and can therefore be skipped by readers familiar with Luhmannian sociology. The main axes of risk modelling techniques in finance will then be exposed, and related to the uses to which they have been put historically in the natural sciences (section 3). This will allow us to grasp the gap between two types of phenomena - physical and financial - that have been apprehended using the same techniques. In Luhmann's terms, this ambition stems from an insufficient translation, by the financial subsystem, of codes that are exogenous to it - and this helps to explain the relative blindness to the risks taken before 2008. Section 4 documents a "reflexive leap" that allows the system to be stabilized: the emergence and contemporary treatment of "Model Risk". In the discussion (5), we will identify the possibilities - some of which already exist - for affirming this evolution in financial risk management.

2 Luhmann's systems theory

Niklas Luhmann's sociological theory first proposes a characterization of the evolution of human societies [13]. According to Luhmann, this evolution is not characterized by the succession of modes of production (Marx) or by the transformation of the nature of the link between humans (Durkheim), but by a *functional differentiation*: the functions ensured within a society - producing wealth, reaching agreements, providing meaning to life, deepening our understanding of the world, etc. - are progressively ensured by different instances - respectively, the economic, political, religious, and scientific subsystems. On the contrary, in premodern or undifferentiated societies, these different dimensions were intermingled: a single authority (not necessarily centralized) provided intellectual, political, artistic references. The complexification of relations - amplified by the entry into modernity (globalization of exchanges) - is the source of differentiation: specialization is necessary to deal with such a volume of stimuli.

To illustrate this point of view and its explanatory force, let us mobilize it to analyze counter-trends, that is "de-differentiation" projects in which several functions that had already been separated are brought together under a single authority. From a Luhmannian point of view, the failure of totalitarian regimes is not surprising: the common ambition of the USSR and National Socialism to submit to the political system (the State) cultural (prohibition of certain works and promotion of others), economic (planning) and religious (cult of personality) issues was not compatible with the growing complexity of our societies. For example, economic stimuli have become too numerous to be managed by a sub-system that is not exclusively devoted to this task. Luhmann goes further: as social relations become more complex, the subsystems must themselves differentiate in order to be able to manage the increase in stimuli; the economic subsystem thus tends to differentiate into several *sub-subsystems* (financial, industrial, commercial...).

This fate of modern societies is not inescapable: it is permanently threatened by the imperialist tendencies of certain subsystems. In the case of totalitarian experiments, it was the political system that was the most threatening. Today, certain phenomena can lead us to identify the economic system as the main danger to functional differentiation [14]: the way American political campaigns are financed or the possibility for certain wealthy people to buy a visa can be interpreted as invasions of certain segments of the political system. But why should this modern fate - functional differentiation - be preserved? According to Luhmann, it should be preserved because it is the guarantor of individual freedom. Modernity has freed individuals from the grip of a single system: in the past, the individual was not thinkable independently of his clan, which identified him and from which he could not detach himself (in the same way, in the USSR, his affiliation to the Party determined his identity, as a comrade). In modernity, the individual is no longer reduced to belonging to a system, but is defined by the plurality of his affiliations - always revocable - to different subsystems: since the adoption of human rights, religious conviction does not determine political opinion or purchasing power [15].

To guarantee this freedom of affiliation and disaffiliation, it is necessary to ensure that the individual is treated by a system only by the language of that system (its "code"). For example, a consumer can only be excluded from a supermarket because of insufficient purchasing power; no other criteria - whether she wears a veil (religious subsystem), is a socialist (political subsystem) or a Dadaist (artistic subsystem) - can affect how she will be judged by the economic subsystem. The freedom of individuals and the stability of societies thus require a certain autonomy of the subsystems, which in turn implies a code of its own with which each subsystem perceives reality (its "environment"): the supermarket can only discriminate its environment (individuals and other subsystems) on the basis of the monetary standard, whereas the democratic state only decides on the basis of voting. Luhmann would thus have welcomed the growing self-referentiality of the code specific to the economic system: at first dependent on the nature at the time of the gold standard (the quantity of money being limited by a non-economic referent, the stock of gold), then on the political subsystem that fixed the exchange rate, money gradually became autonomous [11].

As for the financial sub-subsystem, several authors have suggested that its particularity, compared to the rest of the economic subsystem, was its relation to time: its code would allow to make different periods commensurable monetarily [16]. We therefore propose to consider the "Present Value" as the code of this sub-subsystem (for a close position, see [17]). In other words, a reality can only be captured and understood by the financial sub-subsystem if it can take the form of a present value, that is of a net sum of discounted cash flows. This code differs, for example, from the "cost-benefit analysis" of the industrial sub-subsystem or from the "utility" that characterizes the commercial sub-subsystem; all of these codes refer to the monetary standard, but in distinct forms that lead to the capture of different realities in different ways[1]. In Luhmannian theory, we have seen that it was essential for the stability of systems that the code not depend on any external reality, that is, that it be self-referential. Just as money had to autonomize itself from nature and the political subsystem to become self-referential via the money market, so the present value, as a code, must be specific to the financial subsystem. But, as the next section shows, this code was originally heteronomous, determined by tools from other subsystems. And this is, in Luhmannian theory, a generator of instabilities and can even threaten the reproduction of the system (just as the gold standard and Bretton Woods systems threatened the stability of the economic system before they imploded).

3 The perception of risk by the present value: an insufficient translation

If the financial sub-subsystem intercepts reality through the "present value" code, its risk is expressed by a variation in this present value (PV). Indeed, financial institutions evaluate their position according to this criterion, that is, by the probability that the PV of the securities on their books will deteriorate significantly[2]. To capture this reality, they depend on models in two ways. First, the probability of PV deterioration is controlled by a tool called "ValueAtRisk" (VaR) which is - in its analytical form - a model. Second, VaR is based on the PV of the different securities in the institution's books, but in many cases this PV is not directly available and requires the use of models. In the remainder of this section, we will dive into these two types of models in order to assess whether the financial sub-subsystem code has become sufficiently autonomous to ensure a certain stability.

To do so, we will not trace the inter-organizational and interpersonal networks that enabled the arrival of these modeling techniques in the financial community (for an attempt in this direction, see [3, 4, 18, 19]). Instead, we propose to identify these modelling techniques and to situate them by recalling their original uses: what phenomena do they initially allow to be captured? It will thus appear that these techniques were initially mobilized to capture

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[1] A professor of finance used to tell us about his difficulties in getting engineers to understand that for an industrial project to be carried out, it was not enough for its profits to exceed its costs: it had to generate a sufficient margin to remunerate the providers of capital. In other words, this professor saw the project as a present value (cash flows discounted by a discount rate equivalent to the WACC), while the engineers saw it through a cost-benefit analysis.

[2] The potential causes of such a scenario are typically classified as follows: operational risk (failure of the financial institution's organization or external incident), credit risk (counterparty default) and market risk (unfavorable market evolution). In this article, we will focus on the latter type of risk, which more closely involves the issue of modeling. A similar theorization of the other types of risk would however constitute a valuable extension.

the evolution of *natural* phenomena and that their importation, often precipitated, into the financial world did not result in a sufficient translation into financial language. Several authors have already raised, in varying degrees of depth, the conceptual affinities between finance and certain natural sciences, in particular physics [20–24]. But none of them has established - as we propose to do - a more systematic parallel between the different uses, in finance and in the natural sciences, of the same modeling techniques. For this purpose, we will start from the practice of the risk departments of trading rooms to infer general types of modeling that we will then link to their original use in the natural sciences.

As we have pointed out, the most direct impact of modelling on risk management is through the VaR. This concept is now central because it is at the heart of many regulations: for example, financial institutions must explain themselves to the regulator each time the VaR is exceeded. The VaR is the daily loss that is exceeded only $x\%$ of the time (the x depends on the confidence interval chosen). The VaR-99%, for example, represents a loss threshold that is exceeded only 1% of the time. Unlike other measures, the VaR does not inform about the expected loss in the worst cases, but about a threshold that is exceeded only in the worst cases. There are several methods for calculating VaR (some of which, like the historical approach, are more economical in their assumptions), but the most widely used involves - to varying degrees - the use of Gaussian modeling [25]: the distribution of returns (calculated in PV) is assumed to be normal. This issue has already been the subject of much criticism, as it is recognized that financial returns do not present the same patterns as the phenomena usually mobilized via a Gaussian in the natural sciences, such as in a Langevin equation or a natural diffusion process.

A less frequently pointed out, but equally central issue, is the valuation models used to calculate the PV of the securities on a financial institution's book (and the sensitivity of this PV to different market parameters). The calculation of VaR implies, in addition to a distribution assumption (in most cases), to determine the PV of the institution's positions; however, for many products (especially derivatives), this PV is not directly accessible via a discounting of future cash flows. As a senior market risk manager explained to us, "*the mark-to-market often gives way to the mark-to-model*". It is therefore essential to look at the modeling techniques used to derive the PV of complex products. We will focus on stochastic differential equation within models that are commonly used and very influential on Model Risk management (mainly through the valuation of interest rate derivatives and option products). Table 1 will summarize some of the main results of this section by outlining the initial uses of these techniques in the natural sciences.

The models of evolution of interest rate as Vasicek's - used for the valuation of interest rate derivatives - can be linked to the model of relaxation of a spring in a thermal bath (where inertia is ignored). The speed of reversion of Vasicek can be associated to the spring constant on friction coefficient, and the volatility to the square root of the ratio temperature on friction. With respect

Table 1: Similar concepts used in financial modelling and in physics

Concept/properties	In finance	Mathematical form in finance	In physics	Mathematical form in physics
Ornstein Uhlenbeck process (SDE markovian, mean-reverting)	Vasicek Model, short rate fluctuations (+ CIR and others)	$dr = -\Omega[r(t) - r_0]dt + \sigma dW(t)$	Langevin equation of over-damped spring relaxation	$dx = -\frac{k}{\gamma}[x(t) - x_0]dt + \sigma dW(t)$ $\dot{x}(t) = -\frac{k}{\gamma}[x(t) - x_0] + \sigma\xi(t)$ $\sigma = \sqrt{2k_BT/\gamma}$
Markovian SDE	Geometric Brownian motion	$dX_t = \mu X_t dt + \sigma X_t dW_t$	Langevin eq. (overdamped, multiplicative noise and specific potential)	$dX_t = -\frac{\partial U}{\partial X_t}dt + \sigma X_t dW_t$ with $U = -\frac{\mu}{2}X^2$
Methods of calculus for SDE	Itô calculus, resolution of "Itô SDE"	$dX_t = \mu_t dt + \sigma_t dW_t$ $X_t = X_0 + \int_0^t \mu_s ds + \int_0^t \sigma_s dW_s$ $df = (\frac{\partial f}{\partial t} + \mu_t \frac{\partial f}{\partial x} + \frac{\sigma_t^2}{2}\frac{\partial^2 f}{\partial x^2})dt$ df not time reversal invariant	Stratonovich calculus	$dX_t = \mu_t dt + \sigma_t \circ dW_t$ $X_t = X_0 + \int_0^t \mu_s ds + \int_0^t \sigma_s \circ dW_s$ $df = (\frac{\partial f}{\partial t} + \mu_t \frac{\partial f}{\partial x})dt$ df time reversal invariant
	Feynman-Kac (solution Black-Scholes)	$\frac{\partial}{\partial t}u = -\frac{\partial}{\partial x}(\mu u) - \frac{\partial^2}{\partial x^2}(\frac{\sigma^2}{2}u) + Vu + f$ $u(x,t) = solution$	Fokker-Planck equation (distribution of SDE)	$\frac{\partial}{\partial t}p = -\frac{\partial}{\partial x}(\mu p) + \frac{\partial^2}{\partial x^2}(\frac{\sigma^2}{2}p)$ p probability density of X_t
Parabolic PDE	Black-Scholes Equation	$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0$	Heat equation	$\frac{\partial}{\partial t}u - \sigma^2 \frac{\partial^2}{\partial x^2}u = 0$

to option valuation models, the geometric brownian motion (GBM) can also be reached by a Langevin equation, but in a quite specific form. The noisy term is multiplicative, and the potential to fit GBM needs to be an inverted harmonic oscillator (tend to exit X_0). The drift of GBM is here the opposite spring constant (for what the analogy is worth). Let's remind that this model, on which Black-Scholes is based, has constant volatility and continuous path, which is of course a strong assumption - and the same is true for rate fluctuation models. Black-Scholes equation is then obtained by applying Itô's lemma to GBM. With some change of variables and initial conditions we can give to Black-Scholes equation the form of a heat equation. In general, the solutions of the heat equations are interpreted as the evolution of Brownian motion's probability distribution.

At the end of the day, what is wrong with the fact that the modeling techniques used in finance were originally designed to capture natural phenomena? Luhmannian theory warns us that the dependence of a system's code can generate instability - as was the case when money depended on nature or on the political subsystem. The reason for this is that the system's mode of perception (its code) must be adapted to the nature of the objects apprehended by the system: the legal subsystem would be greatly weakened if jurists began to appreciate the value of legal texts in terms of their relation to reality (as scientists do) or of their aesthetic contribution (as artists do), rather than in terms of their compatibility with existing law (the self-referential code of the legal subsystem). Similarly, in the case of PV, the mobilization of models from the natural sciences does not capture the human dimension of financial reality. Each model carries assumptions about the behavior of the object being modeled; however, the humans whose actions determine PV and its movements do not behave like the stars. In particular, their reflexivity allows them to react to the use of a model - unlike stars who are impassive to astronomical models. This well-known human singularity implies that this import of models into the financial world constitutes a violation of the epistemological principle of ontological continuity (a methodological borrowing requires a translation if the nature of the object treated is not the same).

This point is more central than it appears. The need to integrate the human dimension of financial reality is not a romantic desire to restore the centrality of the human. It is a condition of survival for the financial sub-subsystem. In many respects, the blindness experienced by many financial market professionals during the subprime crisis is rooted in the inadequacy of the models: unable to convey the precariousness of the regularities of human behavior, these models spread a dangerous sense of confidence. This is what is underlined in different ways by the criticisms - internal and external - that have emerged since autumn 2008 [5–7]. To understand this issue in more detail, the concepts of "performativity" and "counter-performativity" are particularly useful [26]. As Donald MacKenzie's various studies have shown [19, 27], increasing confidence in a model leads, *in human societies*, to an increase in its validity: it is from the moment when the Black-Scholes model was sufficiently widespread and reputed that the gap between option prices and theoretical prices was reduced to a trickle. As long as this confidence holds, the model does not disappoint and gives the impression of capturing an unwavering regularity. But, like the sword of Damocles, counter-performativity always threatens financial models: when a doubt becomes a crisis of confidence, actors turn away from its predictions, or even act in the opposite direction (contributing to invalidating the model). MacKenzie demonstrated the power of this phenomenon in the 1987 crash [27]. The subprime crisis is further evidence of this.

What should we do then? Abandon all the ingenuity of the physical sciences? Of course not. Following Luhmann, we should make the financial code more autonomous, that is, more sensitive to the human dimension of financial phenomena. In systems theory, this evolution of the code, which constitutes a learning process for the system, takes place by means of a "reflexive leap": the system succeeds in singularizing its code by observing it from within the same code. This is the case, for example, of the Judicial Code, which, by reasoning *about* other legal texts *through* a legal text, has made it possible to systematize legal language and to increase its autonomy (vis-à-vis the political subsystem in particular). As far as the financial subsystem is concerned, the appearance of "Model Risk" corresponds to an analogous evolution: it is a matter of singularize the modeling of PV by observing the model and the risks it implies *through* a model. The next section develops this new practice, which is still too little discussed in the literature.

4 The reaction by the "Model Risk": a reflexive leap

Following the subprime crisis, financial institutions were led to further include several new risks in the scope of risks to be managed, including "Model Risk" [28]. Theoretically, the latter targets two types of risk: that incurred by an erroneous model (which underestimates risks) and that incurred by a model misuse (by someone who misinterprets it) [29, 30]. In practice, this translates into the appearance, within the risk departments of financial institutions, of an autonomous team exercising control over the "quants" producing the models.

Before developing the content of this team's activities, it is worth mentioning another regulatory measure which, although not formally included in the "Model Risk" framework, shares its philosophy: VaR backtesting [31]. As mentioned, a VaR is based on a confidence interval: it informs of the loss that can be exceeded only five or one percent of the time. In other words, a financial institution's daily loss can exceed the VaR-99% only twice in the course of the 250 annual business days. If this happens more than twice, it is a sign that the model is underestimating the risk and the financial institution is penalized by the regulator. Regarding the management of "Model Risk" itself, a few works have proposed calculation methods (in addition to those already mentioned, see [32]), but none has traced how this issue was addressed within financial institutions. Based on extensive fieldwork (numerous interviews with risk managers and participant observation in a trading room), the remainder of this section attempts to begin to fill this gap.

As regards the management of “Model Risk” itself, it concerns “*all models impacting the valuation of the trading book*” (extract from an interview with a senior model risk manager). A team of quantitative experts therefore receives the models designed by the quants and used to value the positions of traders (and of the financial institution). This concerns the valuation models of derivatives, in particular those we studied in the previous section (options, interest-rate derivatives and structured credit products). The activity of this team can be classically broken down into three stages. First, they will challenge the model on the *theoretical* level, by evaluating its various sensitivities and by comparing it with alternative models[3]. Second, they will check the consistency of the model's calibration with market data: are the parameters consistent with what the market is telling us today? Thirdly, they will “*capture the materiality*” of the methodological options taken through “stress tests”. These tests capture the variation of the model's outcome (that is the PV of a position) to variations of its parameters. Variations in parameters of what magnitude? “W*e try to make reasonable choices based on data, but there is always an uncertainty in the model risk, an element of judgment*” (interview extract). Therefore, as we shall develop, this new reflexive practice introduces, through its own evaluation, a new risk: that of miscalibrating the evaluation of the model risk or, if you like, the “model risk model risk”.

According to our observations and interviews, the reports of this team have led to refinements of the models, but “*the frameworks are well established: Black-Scholes for options and so on...*” (interview extract). In the last section of this article, we propose to assess whether this development of Model Risk Management makes up for past shortcomings. If not, it will be a matter of identifying, by returning to Luhmann's systems theory, certain avenues for deepening this reflexive leap.

5 Discussion

At first glance, the introduction of “Model Risk” constitutes an effective response to the criticisms that have been levelled at financial models in the wake of the crisis: in a way, stress tests are an acknowledgement of the precariousness of any model and of the uncertainty that remains [33]. They thus limit the sacredness of the models that had been criticized. They also make it possible to reduce the dependence of the perception of risk on the model that is currently authoritative: they require that this perception is robust to marginal changes in models [34], i.e. that it is compatible with an alternative model that would supplant the existing one. However, this last point must already be tempered: the usual scope of stress tests is insufficient to capture the gap between theoretical prices and actual prices during crises of confidence.

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[3] Since these alternative models are often drawn from the literature, this first step constitutes one of the channels of influence from the academic world to professional finance.

More fundamentally, the types of risk covered by Model Risk do not include the typically human risk of counter-performativity. Yet it is this risk that is at the heart of panic phenomena, and it is its integration into risk management that would have allowed the financial code to be singularized definitively. By recognizing the possibility of error, the introduction of "Model Risk" departs from the physical sciences and does justice to the incompressible uncertainty of human phenomena. Nevertheless, by not addressing the possibility of counter-performativity, this evolution does not go deeply enough into the *translation* of financial models[4].

That said, is it not technically impossible? Is it possible to integrate these "model risks" into risk management? It would seem that certain avenues do exist, but that their sphere of influence has not yet extended beyond the academic subsystem... Certain works in the field of econophysics - such as those of Jean-Philippe Bouchaud - aim to amend financial models so that they integrate the possibility of chaotic events, such as the feedback loops that formally characterize the reflexive action of humans on the model that is supposed to capture their actions [36]. Closer to the sociological perspective, some interdisciplinary research projects, such as the AlgoFinance research project conducted at the Copenhagen Business School, aim at integrating into models phenomena attested by the sociological literature on financial markets [37]. The authors of this article are also collaborating on a similar project aimed at modeling contagion phenomena, in order to capture the impact on prices of a massive adherence to a financial model or of a crisis of confidence. These perspectives are still young and their results limited, but they demonstrate that it is possible to broaden the range of "model risks" considered, and thus increase the autonomy of the financial code with respect to its context of birth.

To conclude this discussion, let us note that these reflexive leaps always open up new problems. As Luhmann pointed out, it is logically impossible to close the chain of reflexive leaps: the observation of the code (the first leap) could itself be observed by a third-order observation (the second jump), which itself can be observed, and so on. This movement must therefore be grasped as an open process allowing a stabilization of the system, rather than as an end in itself. Thus the Judicial Code, which "observes" the other legal texts, is itself observed by the Constitution... which institutes itself: the chain of jumps is cut by the arbitrary. Similarly, the integration of the "model risk" by modeling raises the question of the risk incurred by the validity of this new second-order model, that is to say, introduces a "model risk model risk". This new risk can only be apprehended by a third order observation, etc. In the

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[4] The models underlying some high-frequency trading algorithms have already taken this step by taking into account their own impact on prices, that is their performativity. For example, the new version of the Citi Group's algorithm "Dagger" launched in 2012 was notably intended to integrate the impact of the algorithm itself on its expectations: "*many liquidity-seeking algorithms in the market fail to take proper account of the impact their own trading is having on a stock price (. . .). This is increasingly a problem in the current liquidity environment and Dagger has been specifically designed to help avoid this*" (Takis Christias, Citi's Head of Algorithmic Products, quoted *in* [35]).

Luhmanian perspective, such movements - although vain - are necessary to capture a growing complexity and to stabilize the systems.

Conclusion

This article aims to shed light on a recent evolution of risk management in financial institutions, based on a major sociological theory: Niklas Luhmann's systems theory. It appeared that the blindness of many market professionals during the subprime crisis could be understood as a problem of perception: the code specific to the financial sub-subsystem - the Present Value - had not been sufficiently autonomous from the physical sciences, whose modeling techniques were hastily imported. By recognizing the possibility of error and persistent uncertainty, the appearance of "Model Risk" provides an answer, but a partial one. From a Luhmannian point of view, a more thorough translation of the models used into the language of financial reality (which is a human reality), for example via the introduction of the risk of counter-performativity, would be desirable in order to stabilize the financial sub-subsystem.

At the end of this journey, we can also evaluate the fruitfulness of this theoretical grid. One of the strengths of Luhmannian sociology is that it fully grasps the phenomena of internal regulation - unlike many theories of regulation centred on the state. Luhmann allows us to understand the operational constraints specific to each sphere of society and the reactions that the management of uncertainty calls for. This seems particularly relevant for understanding the evolution of the financial sphere. However, this focus on self-regulation is certainly excessive and tends to underestimate the weight - albeit central - of interventions by public authorities, such as the Fed or the ECB: the introduction of Model Risk, in particular, is largely dependent on measures adopted by the regulator (in other words, it is not a spontaneous reaction by the financial sub-system). In the end, however, it seems to us that the balance remains in favor of Niklas Luhmann's systems theory. It would therefore undoubtedly be relevant to mobilize this theoretical framework to grasp other modellings of uncertainty, such as those that underlie the macroeconomic forecasts of the Central Banks or the climate scenarios of the IPCC.

References

[1] Bernstein, P.L.: Capital ideas: the improbable origins of modern Wall Street. Simon and Schuster (1993)

[2] Schenk, C.R.: Regulatory foundations of financialisation: May day, big bang and international banking, 1975–1990. Financial History Review **27**(3), 397–417 (2020)

[3] MacKenzie, D., Spears, T.: 'a device for being able to book p&l': The organizational embedding of the gaussian copula. Social Studies of Science **44**(3), 418–440 (2014)

[4] MacKenzie, D., Spears, T.: 'the formula that killed wall street': The gaussian copula and modelling practices in investment banking. Social Studies of Science **44**(3), 393–417 (2014)

[5] Derman, E., Wilmott, P.: The financial modelers' manifesto. Available at SSRN 1324878 (2009)

[6] De Pracontal, M., Walter, C.: Le virus B. Crises financières et mathématiques. Le Seuil (2009)

[7] Salmon, F.: Recipe for disaster: the formula that killed wall street. Wired Magazine **17**(3), 17–03 (2009)

[8] Izquierdo, A.J.: Reliability at risk the supervision of financial models as a case study for reflexive economic sociology. European Societies **3**(1), 69–90 (2001)

[9] Ignacio Crespo, P.N. Pankaj Kumar, Taymans, M.: The evolution of model risk management. McKinsey & Company (2017)

[10] Esposito, E.: The future of futures: the time of money in financing and society. Edward Elgar Publishing (2011)

[11] Hessling, A., Pahl, H.: The global system of finance: scanning talcott parsons and niklas luhmann for theoretical keystones. American Journal of Economics and Sociology **65**(1), 189–218 (2006)

[12] Konings, M.: How finance is governed: reconnecting cultural and political economy. Distinktion: Journal of Social Theory **19**(2), 135–151 (2018)

[13] Lee, D.: The society of society: The grand finale of niklas luhmann. Sociological Theory **18**(2), 320–330 (2000)

[14] Dias Minhoto, L.: Notes on luhmann, adorno, and the critique of neoliberalism. Thesis Eleven **143**(1), 56–69 (2017)

[15] Verschraegen, G.: Human rights and modern society: A sociological analysis from the perspective of systems theory. Journal of Law and Society **29**(2), 258–281 (2002)

[16] Esposito, E.: Predicted uncertainty: volatility calculus and the indeterminacy of the future. In: Uncertain Futures. Imaginaries, Narratives, and Calculation in the Economy, (2018)

[17] Muniesa, F., Doganova, L., Ortiz, H., Pina-Stranger, Á., Paterson, F., Bourgoin, A., Ehrenstein, V., Juven, P.-A., Pontille, D., Sarac-Lesavre, B., *et al.*: Capitalization: A Cultural Guide, (2017)

[18] MacKenzie, D.: Models of markets: Finance theory and the historical sociology of arbitrage. Revue d'histoire des sciences, 407–431 (2004)

[19] MacKenzie, D.: An engine, not a camera: How financial models shape markets. Mit Press (2008)

[20] Farmer, J.D.: Physicists attempt to scale the ivory towers of finance. International Journal of Theoretical and Applied Finance **3**(03), 311–333 (2000)

[21] Weatherall, J.O.: The physics of wall street: a brief history of predicting the unpredictable. Houghton Mifflin Harcourt (2013)

[22] Dash, J.W.: Quantitative finance and risk management: a physicist's approach. World Scientific Publishing Company (2016)

[23] Bouchaud, J.-P., Potters, M., et al.: Theory of financial risk and derivative pricing: from statistical physics to risk management. Cambridge university press (2003)

[24] Lux, T.: Applications of statistical physics in finance and economics. In: Handbook of Research on Complexity, (2009)

[25] Mehta, A., Neukirchen, M., Pfetsch, S., Poppensieker, T.: Managing market risk: Today and tomorrow. McKinsey & Company McKinsey Working Papers on Risk **32**(1), 24–36 (2012)

[26] Danıelsson, J.: The emperor has no clothes: Limits to risk modelling. Journal of Banking & Finance **26**(7), 1273–1296 (2002)

[27] MacKenzie, D.: The big, bad wolf and the rational market: portfolio insurance, the 1987 crash and the performativity of economics. Economy and society **33**(3), 303–334 (2004)

[28] Glasserman, P., Xu, X.: Robust risk measurement and model risk. Quantitative Finance **14**(1), 29–58 (2014)

[29] European Central Bank: ECB guide to internal models (2019)

[30] Federal Reserve: Supervisory guidance on model risk management. Board of Governors of the Federal Reserve System, Office of the Comptroller of the Currency, SR Letter, 11–7 (2011)

[31] Zhang, Y., Nadarajah, S.: A review of backtesting for value at risk. Communications in Statistics-Theory and methods **47**(15), 3616–3639 (2018)

[32] Bernard, C., Vanduffel, S.: A new approach to assessing model risk in

high dimensions. Journal of Banking & Finance **58**, 166–178 (2015)

[33] Boucher, C.M., Danielsson, J., Kouontchou, P.S., Maillet, B.B.: Risk models-at-risk. Journal of Banking & Finance **44**, 72–92 (2014)

[34] Breuer, T., Csiszár, I.: Measuring distribution model risk. Mathematical Finance **26**(2), 395–411 (2016)

[35] Finextra: Citi sharpens dagger algo (2012)

[36] Blanc, P., Donier, J., Bouchaud, J.-P.: Quadratic hawkes processes for financial prices. Quantitative Finance **17**(2), 171–188 (2017)

[37] Hansen, K.B., Borch, C.: Alternative data and sentiment analysis: Prospecting non-standard data in machine learning-driven finance. Big Data & Society **9**(1), 20539517211070701 (2022)

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