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'I "ham" a good egg.'

– Roberto, in *Down by Law* (1986)

Abstract

In Science and Technology Studies, performativity has been debated and used to question economic governance, the role of explicitness, the creation of signification and the enactment of theories, investigating the influence of language on social reality. Based on Wittgenstein's concept of language game, we explain that even if algorithms were designed, induced and justified by a particular rational language (theoretical framework), their implementations (their particular use in a specific context) can potentially generate unthought (irrational) outcomes: flash crashes that were not conceptualised in the original framework, generating a new form of performativity of computerised effects – these unthought consequences of flash crashes are a new phenomenon and with new implications for financial practices and financial knowledge. Algorithms as languages illustrate what the first Wittgenstein describes as a linguistic framework structuring the world that could lead, as the second Wittgenstein explained, to a complexity and multiplicity of language games. Our contribution to the literature is twofold. First, we determine that the implementation of the performativity of theory provoke new unthought effects. Second, we demonstrate that these unthought effects can become a material reality, contradicting the theory that originated these effects, which we call 'performability of effects.'

Keywords: performativity, science and technology studies, Wittgenstein, trading algorithms, flash crash.

Introduction

On October 7, 2016, the pound sterling unexpectedly dropped its value from 1.26 to 1.18 against the dollar and closed at 1.14 on October 11, 2016. This sudden drop was reminiscent of the behaviour of financial markets during the flash crash of May 2010 – an impromptu and deep drop in the market's value – when the Dow Jones lost suddenly 1000 points in a day. However, a flash crash is still not a well-understood event, and the value destruction caused by a flash crash differs from other financial crisis narratives: in financial crises, the value destruction occurs because investors have been unable to value the asset (Muniesa, 2014), whilst in the flash crash there is no human intervention nor error. Instead, a flash crash is the result of actions taken by algorithms reacting to a collection of events not only inside but also outside of the financial markets.

In the case of the drop of the British pound, an article by *The Economist* (Buttonwood, 2016), suggested that value's drop was not caused by human intervention, but it might be due to a reaction of the algorithms to the speech held by the British Prime Minister, Theresa May, at the annual Conservative Party conference. It is not surprising that the financial market reacted to a political speech because the financial algorithms are designed to track any key information that relates to the markets. They are programmed to sell an asset if they perceive an increase in the potential risk associated with that asset or if the asset's market price significantly drops. In the case of a flash crash (and of the pound's drop), algorithms reinforced each other's decisions and initiated a selling trend that became contagious on assets that were not necessarily considered risky a priori. Therefore, if all algorithms sell, and if a selling trend is initiated, we could eventually observe a flash crash in a matter of seconds (algorithms need only milliseconds to take action). This phenomenon has been seen in other instances. For example, in the research of Karppi and Crawford (2016), some hackers have entered the Twitter account of Associated Press and tweeted a piece of fake news, creating a flash crash, creating a broader social debate about the relationship between different human and algorithmic spaces, social media systems and financial market systems. This 'hack crash' episode was caused by a piece of fake news on Twitter.

In the case of the pound's drop, after the vote for Brexit, May promised she would create State interventions to defend capitalism, and she suggested that she would put British companies behaving badly on warning (including those who were hiring foreigners rather than training young British people). The speech was interpreted by the algorithms as a State's decision to influence the market, therefore creating an uncertainty. Plausibly, some algorithms interpreted the speech as if the pound, generally stable, was a risky asset, and they automatically reacted by selling it. Considering the British market risky, algorithms operating on the Asian markets frantically sold the pound, which action generated a flash crash (the pound plunged by 6% against the dollar in less than two minutes of trading activities). Therefore, we can assume that the conference speech influenced the algorithms in their trading of the British Pound, thus creating a performative effect, which was not intended.

In the case of automatic trading, algorithms are designed to act accordingly to human behaviour, working without human intervention. Algorithms are designed to be rational and to detect all possible potential situations of profits on the markets instantaneously, although, on occasion, they can be manipulated (Arnoldi, 2016). Market institutions create political controversies, made visible through the description of devices providing support to the expression of multiple points of view, which are regulated through practices involving devices and their representations (Lenglet, 2011). However, it is not established what the unintended consequences of the performativity of algorithms could be.

Therefore, a challenging query appears here: in a financial world that is becoming increasingly automatised and defined by algorithmic decisions, why are unintended consequences generated, and how are they provoked? Using the Wittgensteinian concept of the 'language game,' we suggest that algorithms have a particular language use, and they create performable actions into which the language is woven.

Wittgenstein's notion of language-game provides a flexible conceptual framework to examine how language is related to the world and how language can generate different forms of realities. We analyse the computerisation of financial markets according to the first Wittgenstein (referring to the theories on the *Tractatus*) and the trading algorithms using the theories of the second Wittgenstein in *Philosophical Investigations* (1951). The evolution from the first Wittgenstein to the second one consists in a shift from analysing language logically to doing so contextually. However, Wittgenstein is well-known for his radical switch between his positivist (logical) and his relativist way of thinking language without necessary offering a conceptual bridge between these two moments. In this context, we mobilise Rorty's pragmatism (Rorty, 1991; Rorty, 1997) to investigate further the way the connection between the first and second Wittengstein is meaningful, developing a new approach to the concept of performativity. Understanding this approach to performativity and performability would be the starting point for investigating how regulators can make interventions in the market, should a flash crash arise.

We contribute to the epistemological reflections on financial markets to advance the critical understanding of the conceptual nature of algorithms' performativity in order to provide practical suggestions to market regulators. In this paper, we demonstrate that the algorithms' performative epistemic dimension is developed in a language game. In this game, first, 'performativity of theory' is manifested, i.e., social reality is shaped by the reification of a theoretical framework, applied by the algorithms. Second, there is a 'performativity of computerised actions,' in which social reality results from interaction between algorithmic and human utterances and the reification of the first performativity in the algorithms' decision making. Thus, algorithms perform a Rortian language game with particular 'performatibility.' We demonstrate that algorithms act accordingly to a performability that results from their ability to shape reality in a way that is unexpected from the existing financial knowledge, which actually generates these algorithms. This language game creates the possibility of being performative, and, consequently, algorithms make computerised decisions that are not rational and contradict their original design.

The paper proceeds as follows. First, we present a review of the literature on performativity in financial markets. We then present the philosophical method for the analysis of the performativity of algorithms, based on language games. We analyse the flash crashes and conclude the paper with a discussion on the performativity of algorithms.

Literature review: Performativity of financial markets

In Science and Technology Studies, the field of sociological enquiry has been directed towards economic sociology differently approaching the central role of economic knowledge, the performativity of economic representations, and locally situated practices embedded in forms of knowledge (Kalthoff, 2005). In this paper, we focus on performativity. In Science and Technology Studies, performativity has been widely debated and used to question economic governance, the role of explicitness, to create signification and to enact theories (Boldyrev & Svetlova, 2016a). STS has been focusing on understanding how economic ideas play a performative role in shaping or configuring the economy (Birch, 2017a) since economic theories are not descriptive but performative (Callon, 1998): theories used by economists are the economic reality that economists aim to theorise. Economic reality is emerging from the discourses. It is conceived as performatively constituted by the economic ideas or assumptions constructed by economists. Consequentially, the performativity of language has raised epistemological questions concerning the relationship between theory and reality: dialogues create a particular reality, and different forms of engagement in various communication create unforeseen events (Horst & Michael, 2011). Speeches are an act (Aggeri, 2017) enabling and restricting agency (Law, 1996), and they enact an economic reality that is complex, emergent, plural and contingent (Muniesa, 2014).

Economics is performative not on merely describing or explaining, but also actively shaping economies and societies (Callon, 1998; Mackenzie & Millo, 2005; Beunza, Hardie, & MacKenzie, 2006; Callon, 2007b), bringing into existence the sociotechnical ‘agencement,’ i.e., arrangements provided with agency: economists create norms and theories that reconfigure the markets, and at the same time they design policies from relevant cognitive socio-economic theories that assemble and shape reality (MacKenzie, 2008). Thus, the economic reality frames the infrastructure of communities and of societies in general. The infrastructures are made of hybrid actors, in which human/non-human and socio/technological domains are working together (Callon, 1986) in the struggles of performation (Callon, 2007) through utterances. Therefore, performativity is not only a linguistic operation but a contextual translation from one mode of existence to another, during which many actors (humans and non-humans) interact to embed economic knowledge into sociotechnical performations, not only reproducing but also creating social facts.

STS has used performativity to analyse the role of financial theory in constructing financial markets as a socio-technological assemblage, since markets, economic calculations, economic preferences, marginal utility, transaction costs, equilibrium prices, demand, credit risk and cost of capital are all epistemologically constructed rather than naturally occurring (Mackenzie, 2006). Thus, economists are like designers of the markets (Roscoe, 2016) enabled by the socio-material technologies, and they are managing expectations of the markets’ behaviour, which could be defined as wishful enactments of desired futures (Tutton, 2011). Expectations are included in the modelling, and economic modelling and simulations are performative in the sense they are a process of descriptions for organisations and individuals (Roscoe, 2016), as they provoke the economic reality, which is subject to elaboration and controversy (Muniesa, 2014).

Performativity has been widely studied in finance. Cooper and Konings (2016) discussed the notion of fundamental value in the context of performativity theories. Laberge (2016) analysed how speech used in the description of the credit crisis in 2008 offered a new representation of financial markets. Related to this point, King (2016) discussed the performative effect of movies on the perception of financial reality. Financial models have also been studied through the lens of performativity – models are created both by academics and practitioners, and through their performativity, they are not stable, as they are transformed into their use and structures, reconfigured, reformulated, and cognised into their epistemic communities, distributed through market devices and material practices (Muniesa, 2014). A significant example is the Black-Sholes model's analysis of Mackenzie (2006) or the one proposed by Millo and Schinckus (2016). Black-Sholes created a formula that gave an estimate of the price of European-style options, regardless of the securities' risk and its expected return. The formula became successful because it was simple enough to be understood and used by non-economists and because Black gave away the excel sheets in which the formula was already inputted; in this way, the traders could easily make calculations and take decisions. Black could have kept it secret, but he decided to give it to the public so it could actually create the reality that the formula was representing, transforming it into a sort of epistemic system (Millo & Schinckus, 2016). By making publicly available the formula, Black and Scholes changed the traders' beliefs about the other traders' beliefs, since they all were using the same formula, and they could foresee the outcome. It has been questioned whether this use of the Black and Scholes model could be a self-fulfilling prophecy rather than a performative act. Since the materiality of agencement works through all the sociotechnical devices that are brought in the market (e.g., excel sheets, beliefs), Michel Callon (2007a) the formula becomes a coordination device rather than a self-fulfilling prophecy (Clarke, 2012). However, algorithms are producing unthought effects has not been widely discussed in the literature. We will look into this aspect through the analysis of language games, presented in the next section.

Methodology: A pragmatist perspective on language games

We use the concept of language games as a method to further understand the unthought effects caused by algorithmic financial behaviour. Wittgenstein's notion of language game provides a flexible conceptual framework to examine how language is related to the world and how language can generate different forms of life; it offers an original perspective to discuss the unthought effect of language in accordance with STS theories, since STS is built on pragmatism (Muniesa, 2014).

Wittgenstein (1889-1951) writes his *Tractatus* in 1921 (Wittgenstein, 1921). In this book, he explains what meaningful linguistic propositions are and what is asserted when a sentence is used meaningfully. Being a member of the Circle of Vienna, Wittgenstein considered the language as a logical delineation, a way of defining the exact scope of a proposition. In this context, the meaning of a term is determined by what it stands for. A good example of the first Wittgenstein reasoning can be summarised through the logical analysis of the following sentence: 'The President of USA is fat'; this sentence can be analysed in its meaning by investigating what does 'President of USA' stands for. Such proposition can actually be decomposed into three logical statements, as follows,

a) There is a President of the USA
b) There is only one President of the USA
c) Whomever the President of the USA is, they are fat.

Deductively speaking, if Fx stands for 'x is the President of USA,' and Gx stands for 'x is fat,' we can write:

$$\exists x[Fx \,\&(\mathrm{y})(Fy \mapsto y = x)\&Gx]$$

There is an X such that it is the President of the USA; if Y is the President of the USA, then X and Y must necessarily be the same, and X is fat. This analysis of language assumed a logical atomism in which language has a core logical structure that helps to establish the limits of what can be formulated meaningfully and, therefore, what can be thought in a proper way.

The later Wittgenstein, also known as the Wittgenstein of the *Philosophical Investigations* (1951) (Wittgenstein, 1951), rejects the aforementioned logical analysis of language as he puts forward the claim that human language is more complex than logical representations. Wittgenstein asserts that language can actually be directly related to the world of things/objects since language is a human invention. There is no unified core logical structure, nor an essence of language, but only 'language games' that refer to a particular use of language and the actions into which it is woven (Wittgenstein, 1953, p.7). In doing so, the Austrian philosopher states that there is no single component common to all use of languages, but rather a resemblance or a familiarity that paves the way to a more complex analysis of linguistic statements. By adopting a more interpretative vision of language, the philosopher explained that 'the speaking of a language is part of an activity, or a form of life' (Wittgenstein, 1953, p. 23). Importantly, Wittgenstein (1953, p. 206) acknowledges that all forms of life are transformative and are dependent on culture, context and history. In other words, Wittgenstein acknowledged that a specific statement, in a particular context, can have a performative effect that transforms reality even though the initial formulation of the statement is logically formulated.

As evoked above, the origin of the algorithmic knowledge comes from the code (language) of the algorithms that has been derived from a particular rational/theoretical framework so that such process is directly in line with what the early Wittgenstein considered as a delineation of what can be rationally traded. However, the automatisation of these trading algorithms generated unexpected interactions whose implications show that the implementation of a language is part of an activity, a form of life in accordance with the later Wittgenstein.

The evolution from the first Wittgenstein to the second one (i.e., from a logical formulation of language to a contextual use of language) can characterise the opposition between the logical development/formulation of algorithms in rational/theoretical reasoning and their potential irrational impacts on the financial reality. One point is, however, problematic in the use of language games as a conceptual framework: no elements are common to all games. However, in our case, there is obviously a common component: the efficient market hypothesis (i.e., the idea that the market value can stand for the intrinsic value), which is acknowledged in the logical development of financial algorithms but also in their implementation (and even irrational effects).

Wittgenstein's philosophy is appropriate to identify the difference between all potential ways of formulating the language game, their complexity and their embeddedness in forms of life. However, Wittgenstein is well-known for his radical switch between his positivist (logical) and his relativist way of thinking language without necessary offering a conceptual bridge between these two moments. In this context, we mobilise Rorty's pragmatism (Rorty, 1991; Rorty, 1997) to investigate further the way the evolution above is meaningful through the concept of performativity that we reacted to Rorty's pragmatism. Precisely, Rorty's pragmatism (that, to some extent, can be considered as a Wittgensteinian extension (see Schinckus, 2007) and his emphasis on the importance of the context is very useful to show how the evolution evoked above actually took form through the appearance of two different forms of performativity: the first one being a performativity of theory and the influence of theory on the development of algorithms – while the second performativity refers to a performativity of unthought actions characterising how the implementation of algorithms un-expectedly shapes the financial reality.

The Wittgensteinian notion of language game has been well-illustrated by Rorty (1999) and his example of the way the number seventeen is defined. Specifically, Rorty explained that seventeen implies different and numerous forms of potential relations that make sense in a specific context:

> To see my point, ask what the essence of the number 17 is – what it is in itself, apart from its relationships to other numbers. What is wanted is a description of 17, which is different in kind from the following descriptions: less than 22, more than 8, the sum of 6 and 11, the square root of 289, the square of 4.123105, the difference between 1,678,922 and 1,678,905. […] None of these descriptions seems to give you a clue to the intrinsic seventeenness of 17. (Rorty, 1999, p. 54)

Thus, if a mathematician could define the set of all relationships whose result is 17, the definition would not allow us to reach the intrinsic 'seventeenness' since this collection would not embody more the number 17 than all numbers composing the collection.

Therefore, it is not possible to understand the ontology of the number 17, but only its epistemology. The only analysis we can conduct in a determined reality is an epistemological investigation of the network, which is composed of infinitely large and potentially extensible relationships between numbers. What will define the number 17 in a specific pragmatic situation will depend on its contextual elements: what can be known and said. Thus, contextual relationships serve as an actuation of phenomena beyond which there is nothing to say. In this perspective, there is no intimacy (no essence as Wittgenstein would write) with an external reality (indeterminacy of reference) but rather an epistemological 'phenomenalization' through the reification of contextual relationship actual relationships defined by a particular environment in a specific time. This relational/contextual way of defining the value of things is used to analyse the way the trading algorithms are working in the next sections.

The trading algorithms

Finance has been shaped by technology, innovation and a progressive integration of information technology and computerisation of the financial markets (Pardo-Guerra, 2019). Computerisation means that the financial marketplace has been equipped with an electronic trading platform, which is an automated market implementing some or all of the following functions:

> an electronic order routine (the delivery of orders from users to the execution system), an automated trade execution (the transformation of orders into trades), an electronic dissemination of pre-trade (bid/offer quotes and depth) and post-trade information (transaction prices and volume data). (Committee on the Global Financial System, 2001, cited in Schinckus, 2008, p. 1080)

This computerisation led to a rapid growth of e-finance and the automation of financial markets. We could divide the computerisation of financial markets into two main historical moments. The first moment refers to computerisation as a systematic recording of all the transactions that were encapsulated to compute a market price initiated in the late-1950s (Pardo-Guerra, 2014). Precisely, at that period, computers began to be widely used by brokers operating on financial markets to systematically record all financial transactions. The use of computers as 'bookkeeping machines' combined with the creation of databases containing long-term statistical data on the evolution of stock market prices allowed the development of empirical studies used to test models and theories in finance (Jovanovic & Schinckus, 2017).

The second moment (from the '90s) concerns the extension of the computerisation financial market to trading activities, during which algorithms became capable of taking decisions quicker than human beings, and therefore financial companies decided to use algorithms for a fast implementation of their own financial and investment strategies (Gode

& Sunder, 1993; Mirowski, 2002). In automated trading, the algorithms have material effects on the behaviour of other algorithms (MacKenzie, 2019). The financial markets witness an automatisation and a rationalisation of all investment decisions with the purpose of making the market perfectly efficient (Schinckus, 2017): a fast and dynamic market in which all agents (computers) rationally make their decisions to take advantage of all potential disequilibrium of the market. In such a context, all prices given by the market are perceived as the intrinsic value of the traded assets.

However, with their fast-computerised power, algorithms created an unintended consequence that the financial industry did not expect: they performed a 'flash crash,' which refers to an almost instant drop in the financial markets due to an algorithmic 'loop-effect.' In the next section, we present these two moments in detail, and discuss what constitutes their performativity in a language game that is not a zero-sum game.

Computerisation of the financial market and the performativity of theory

Although the first attempts to automatise financial transactions started in the late 1950s (Pardo-Guerra, 2012), they were accelerated after the abandonment of the gold standard in the 1970s (Preda, 2009). The financial industry gradually integrated information and communication technology, and, by the 1980s, markets were computerised (Pardo-Guerra, 2019). Almost all recordings of financial transactions were automatised (Saglio, 2009) to improve the efficiency of markets (Pardo-Guerra, 2012). However, in the '70s and '80s, the execution of the transactions still required human intervention. In the 1990s, computers were further deployed to pricing processes, and analysts began to develop computational programs to price the financial assets. This progressive evolution led, ten years later, to what we called the algorithmising of financial markets – see Mackenzie (2006) and Pardo-Guerra (2012) for an in-depth analysis of the process.

The implementation of these algorithms changed the conception of markets (Mirowski, 2002), and the dominant firms in the marketplace (as the stockbrokers) were replaced by computers, causing rapid growth of e-commerce and the automation of financial markets (e.g., Domowitz & Wang, 1994). This new way of organising exchanges revolutionised the financial industry and led all stakeholders to adapt themselves (Mackenzie, 2006). Indeed, oral negotiations were replaced by a more abstract sociability as traders only interacted via their computer screens (Godechot, 2001). Human traders need to simultaneously observe and construct the object of their attention through the screen (MacKenzie, 2019). In this perspective, a different language emerged for transactions: an electronic language, which is not a simple assemblage of codes. Precisely, algorithms and codes became a mode of existence (and exchange) for the traders: coding transforms objects, events and relations into communicable signs (Mackenzie & Vurdubakis, 2011), mediating the relations between algorithms and traders.

Algorithms were designed to be rational and to detect all potential situations of profits in the markets instantaneously by using faster systems to gain a competitive advantage. The computerised way of calculating financial prices was based on existing knowledge, which assumed the existence of perfectly competitive markets (i.e., perfectly rational agents, no transaction costs, high liquidity etc.) that algorithms need to reify (McGoun, 1997; Schinckus, 2008, 2017). This automatisation of financial transactions resulted from a materialisation of a specific assumption (perfectly competitive market) in which market value denotes the intrinsic value of the financial assets. In this context, algorithms were designed to have a perfect rationality to identify the arbitrage opportunity and make the 'right decision' quicker than human beings, exploiting all arbitrage opportunities and bringing equilibrium to financial markets (Jiang, Tang, & Law, 2002). The conceptual background above is the linguistic framework in which key concepts/variables structuring the algorithmic design have been formulated and translated into trading algorithms. In other words, the development of the trading algorithms happened in accordance with the language game of the early Wittgenstein's *Tractatus,* according to which language and its articulation refers to a unique pre-existing structure. There is one logical way to estimate (i.e., to make meaningful the concept of) the real value of financial assets through the computation of the market price: the perfect market hypothesis and this theoretical frame can be reified through the implementation of algorithms. We can reformulate the aforementioned situation by the three logical statements,

a) There is an intrinsic value
b) There is only one intrinsic value
c) Whatever is the intrinsic value is given by the market value

Deductively speaking, if *Fx* stands for 'x is the intrinsic value,' and *Gx* stands for 'x is given by the market,' we can write:

$$\exists x[Fx \,\&(\mathrm{y})(Fy \mapsto y = x)\&Gx]$$

There is an X such that it is intrinsic value, and if Y is the intrinsic value, then X and Y must necessarily be the same and X is given by the market. Such a logical way of associating the intrinsic value with the market is a key reasoning in the financial mainstream: Eugene Fama, who developed the efficient market hypothesis on which the majority of the algorithmic calculations are based, won the Nobel Price in Economics in 2013. In line with the *Tractatus* objective, the computerisation of financial trading defines the exact scope of the following statement: the market value stands for the intrinsic value of an asset.

Thus, the development of a computerised system performed the concept of a perfectly competitive market (Schinckus, 2008) and the reification of this notion provides a first language game of economic performativity: the market value become the intrinsic value when it is computed and displayed by the algorithms. This computerisation adapts the financial reality to the original theoretical model ('efficient market') by reducing the possibility of having pluralism in finance (Lagoarde-Segot, 2015; Schinckus, 2017). Algorithms have been designed to perform the financial markets' reality as fairer: algorithms were initially designed to be a performative reification of the idea of a perfect market in which their instantaneous actions guarantee that the price given by the market is the fair value resulting from a generalised rational process of profit-seeking. This computerised way of structuring financial trading seemed to make markets more efficient, in line with the established theory of efficient market hypothesis (Pardo-Guerra, 2012). Therefore, they performed the theory. Even though from the literature we know that finance and financial markets necessitate a specific understanding of the reality that shapes the normative framing of processes and outcomes (Birch, 2017b), we need to further understand the evolution of this economic performativity that generated unanticipated situations – the flash crashes.

The emergence of flash crashes and the performativity of computerised actions

On May 6 2010, the Dow Jones Industrial Average crashed about 9% in less than five minutes due to 'the combined selling pressure from the sell algorithm' (SEC, 2010). More than 27,000 contracts (49% of total trading volume) were traded on the market within a few seconds (SEC, 2010), between 2.45:13 and 2.45:27. Because algorithms were created to react to news and events faster than human eyes, they performed the trades by exchanging half of the market in 15 seconds. When the Financial Authorities realised what was happening, they switched off the market. Nevertheless, a large part of the American economy (represented by the Dow Jones Industrial Average – DJIA – index) lost a significant percentage of its value in a few milliseconds. Historically, financial markets have contributed to the economy by creating equilibrium between companies in need of capital and cash holders (Shiller, 2012). In recent years, questions have been raised on whether wealth created by financial markets can really be distributed beyond its immediate recipient (the financial industry) (e.g., Stiglitz, 2010; Shiller, 2012). Finance as a science appeared more and more as a self-sufficient technological area disconnected from society, resulting in a predatory capitalism focused on short-term profit[1]. In this context, algorithms perform a language game that results in predatory practices that are inscribed by the companies' strategy, seeking profit at any cost, making the financial sphere more disconnected from its underlying economic fundamentals; whilst financial variables usually follow a power law behaviour, economic ones are rather characterised by an exponential distribution (Aoki & Yoshikawa, 2007). Therefore, this has inadvertently created a favourable setting for flash crashes to emerge. Crashes are part of the financial markets' games, whereas the flash crash of 2010 was a new event. In fact, extreme variations and crashes are common in finance (Kindleberger, 1989), but, in the past, they were the result of human behaviours, and they developed over a period of several days (Muniesa, 2017). In contrast, flash crashes appeared in a few seconds, and they did not result directly from human actions; this kind of crash was enacted from the computerised excitement of the market provoked by algorithms, which created a loop effect in buying and selling trends, generating a sharp fall in security prices (Schinckus, 2017).

The emergence of flash crashes corresponds to an unexpected shift in the rational estimation of the financial assets' market value. Although algorithms are supposed to act rationally by using the appropriate model, the work resulting from their relationships created and led to an irrational situation (in opposition with the original objective that motivated the development of these algorithms). This unexpected situation emerged from a language game aligned with the theory of the later Wittgenstein in his *Philosophical Investigations*: the diverse and multiple ways of using language that cannot be captured in a single logical structure that is a priori defined. Although the theoretical definition of the intrinsic value of a financial asset is associated with its market value, this association does not mean that the latter can logically stand for the first. All kinds of formulation associating these two words are necessarily introduced in a multiplicity of uses in relation to different contexts. There is no algorithmic (logical) reflection of the intrinsic value in the market value but a dynamic pattern of prices that imply a multiplicity of actions (trades and exchanges). Because these actions are real, they become particular forms of life, suggesting an infinity of potential relationships between prices and agents.

In line with the Rortian example of 17 evoked in the method section, we can assert that, even though algorithms' formulation derived from a specific rational language, its interactions with the contextual elements generate an infinity of potential relationships whose outcomes cannot be induced nor deduced. Thus, algorithms were affected by the performativity of the theory of efficient market that defined the rational structuration of the algorithms and their reification in the markets. However, the combination of lagged algorithmic (rational) decisions created a rolling effect leading to an irrational outcome (the market lost more than 10% of its value in a few milliseconds).

We consider a flash crash as an interesting convergence of social and material aspects coming together (Horst & Michael, 2011), influencing the interpretation of the communication and, therefore, of the reality. This is where we can identify a second level of performativity, in which reality results from an interaction between different utterances. However, this performativity generated an unanticipated situation that is in contradiction with the initial purpose justifying the use of algorithms.

To conclude, the economic literature has presented flash crashes as a technical consequence of the automatic algorithmisation of financial markets. Ironically, although these algorithms were supposed to improve the efficiency of markets and reify the short-term profit-seeking process, they generated flash crashes that are in complete opposition with the purpose that justified their implementation. The analysis of performativity of financial markets (e.g., Mackenzie & Vurdubakis, 2011; MacKenzie, 2005) has been conducted in a pre-flash crash, and they mainly deal with the first level of performativity (i.e., the performativity of a theoretical framework) on practices or algorithms. The emergence of flash crashes implies a second level of performativity related to a self-realisation of trade without any economic referent (neither theoretical framework). Such new performativity shapes reality, but it has, paradoxically, been generated in a way that is totally disconnected from reality (no economic justification) and from theory (no theoretical justification). This new level of performativity calls for a more specific analysis of the performability of the effects of a trading algorithm, proposed in the next section.

Discussion: the performability of effects of trading algorithms

Trading algorithms performativity is imbued with complexity, as their descriptions and languages not only influence the reality they generate, but they also evolve with this reality: being a form of financial innovations, they are multidetermined, instrumentally socially contingent in terms of risk mitigation and speculation, and, through their operations, they impact the wider social economy (Gammon & Wigan, 2015). Trading algorithms have been designed in a context defined by the first Wittgenstein: a rational/theoretical language defining the meaning of the algorithms' scope: to reify the intrinsic value of all assets. Paradoxically, the trading algorithms seem to exist in a context described by the second Wittgenstein referring to a plural environment in which algorithms are constantly evolving based on the contextual information they collect and co-construct by combining the original (logical) codes; the past prices, and all kinds of relevant communications coming from outside the financial marketplace. Even though algorithms were supposed to reify the perfect denotation between the market value and the intrinsic value, they actually came into existence by performing the code in which the decisions to be taken are based on the prescriptions of the company's strategy and other algorithms' behaviour. In this perspective, a different situation would lead to a different learning input and outcome from the algorithm. In fact, the new generation of algorithms can learn from data without following explicit programming (Amoore, 2019).

Such evolution also enacted a new way of organising exchanges (Knorr-Cetina, 2006; Muniesa, 2007) that changed the market environment since it increased the cooperative tensions between actors. The continuous quotations (automatic pricing process) combined with the systematic tracking of all transactions generated a competition which implied simultaneous cooperation and competition between actors, making the algorithms political, as they include and exclude actors stemming from modelling preferred relations (Neyland, 2015). Their work consists in combining relationships, data, and information that are coming both from inside and outside the financial markets. By reacting to the news, algorithms are not working to replicate the ideal concept of an efficient market; rather, they challenge this concept by challenging/questioning the episteme (Millo & Schinckus, 2016) that generated this concept. Consequently, algorithms are monitoring the market to adjust their behaviours by developing more data-oriented strategies trying to detect (or to create) the trend at its beginning rather than following it (in line with the perfect market hypothesis). As evoked above, flash crashes have emerged from the algorithmisation of financial markets that actually results from the reification of the perfect competition theory (economic performativity). Algorithms are more than performative as their unexpected consequence (flash crash) showed a new dimension: they continuously collect and co-construct contextual relationships that influence and challenge the usual financial practices by going beyond the control of the original coding and financial regulation (Schinckus, 2017). Algorithms as languages illustrate what the first Wittgenstein describes as a linguistic framework structuring the world that could lead, as the second Wittgenstein explained, to a complexity and multiplicity of language games. Therefore, the unexpected influences of what is supposed to be a reification of the idea of a perfect market can be said performable due to its ability to generate other unthought possibilities. The flash-crashes' reality cannot be induced, since it is a reified phenomenon that is created from a particular speech (theoretical framework).

In fact, even though algorithms might be based on some theoretical/rational principles, the timing of their application influences the kind of data collected and situations co-constructed for which algorithms are designed to act. In other words, despite a common theoretical background, algorithms might fail in their (theoretical) objective of replicating the idea of a perfect market. This failure influences what we know from the financial market (episteme) by creating new concepts ('flash crash') that scholars now investigate (Schinckus, 2017). When the flash crash emerges, the reality cannot be either deduced or induced, as it is not simply the result of the speech or a particular linguistic framework that is defined in advance, nor a reified phenomenon created from the speech. The contextual reification of algorithms' scope through flash crash was not inducible nor deducible from its epistemological dimension. To characterise this aspect, we suggest the concept of 'performability' of algorithms, which shapes reality in a way that is totally unexpected from the existing financial knowledge that initially shaped these algorithms. The irrational phenomena that emerge from the implementation of rational language cannot be ignored since it changes the mode of reasoning into a more abductive perspective (i.e., to find the best explanation as possible given the contextual relationships they can observe). In the case of the flash crash, for example, researchers and practitioners initially concluded that a flash crash can only appear in highly liquid and computerised markets, like the Dow Jones. However, the flash crash that happened the following year – in 2011 – in Bombay contradicted the initial conclusion, since Bombay's market is an emerging market (not highly liquid). This episode appeared as a new contextual expression of algorithms that enlarged the possible/imaginable horizon of this new concept/phenomenon. These new irrational and unexpected outcomes call for more research on the matter.

Conclusion

Based on Wittgenstein's concept of language games, we explain that even if algorithms were designed, induced and justified by a particular rational language (theoretical framework), their implementations (their particular use in a specific context) can potentially generate unthought (irrational) possibilities that were not conceptualised in the original framework, generating a new form of performativity of computerised effects. In other words, the unthought consequences of flash crashes are a new phenomenon and with new implications for financial practices and financial knowledge. Epistemologically, these implications could not have been deduced or induced from a pre-existing theory (discourse). Flash crashes as unexpected phenomena require the adoption of an abductive perspective derived from the context. This situation is suggested by the later Wittgenstein, who emphasised the absence of a unified and logical implementation of language but rather the existence of a multiplicity of contextual reifications.

We contribute to the computerisation of financial markets literature by discussing the performative dimension of flash crashes: the 'performativity of theory' is first manifested, i.e., social reality is shaped by the reification of a theoretical framework, applied by the algorithms. This is associated with the first Wittgenstein. Second, there is a 'performativity of computerised effects,' in which social reality results from different timing and interactions between all these algorithms that generate unexpected and unthought situations – we associate this second performativity with the second Wittgenstein. Flash crashes indeed show another form of performativity that actually questions financial knowledge by creating a real situation for which the latter has no conceptual tools to talk about. In other words, the contextual reification of a pre-existing knowledge (rational theory) generated a phenomenon (flash crash) that was not inducible nor deducible from this original (rational) knowledge – however, this irrational outcome really influences the financial reality in a way that was (and still is) unexpected from the existing financial knowledge. Language game (rational theory) generates performative computerised decisions, which are not rational and consequently contradict their original design – the objective of this article was to identify this new form of performativity that calls for further research.

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[1] Regarding this disconnection, Aoki and Yoshikawa (2007) observed an increasing difference between the statistical distributions characterizing the evolution of financial variables (e.g., stock returns, foreign exchange) and those describing economic fundamentals (e.g., growth of GDP).