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Trading on earthquakes – Algorithmic financialization of tectonic events at global stock exchanges

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A B S T R A C T

This paper addresses how high-frequency trading adapts to natural disasters. Stock market trades have accelerated to a rate at which shares change hands in microseconds. I examine ways in which high-frequency trading both reconfigures the dynamics of finance and changes the global financial system in different spatio-temporal ways and produces political ecologies of engagement, divergence and convergence between financial and Earth systems. Accordingly, I examine technological change and algorithmic strategies at stock exchanges. By analyzing algorithmic strategies, I investigate the connections between non-human trading and natural disasters. The analysis explains the nature of high-frequency trading strategies and market responses to three earthquakes in Japan. In the final section, I discuss how financial investment algorithms constitute a temporal informational epicenter when tectonic events are made subject to trading.

1. Introduction

Algorithms are transforming economies and politics. They support industrial production, logistics and marketing, and are said to increase productivity and influence ways in which political and public administration work (O'Neil, 2016). Also, financial institutions and security trades are increasingly handled by an algorithm (MacKenzie et al., 2012). New financial technologies and fiber optic cables connect financial centers as never before, resulting in high-frequency trading. High-frequency trading refers[1] to algorithmic technologies by which trading decisions are automated and executed by machines at a speed at which no human trader can possibly follow or intervene (Brogaard et al., 2014). Machine-driven trading performs techno-financial market strategies (Buchanan, 2015) and shares change hands in fractions of a second. According to Miller and Shorter (2016), high-frequency trading algorithms perform approximately half of the daily trading volume at the US stock exchanges.

Trading algorithms, such as high-frequency trading algorithms carry thousands of orders per microsecond. This implies that the global financial system has experienced significant spatio-temporal changes (Zook and Grote, 2017). Consequently, the temporalities of the stock exchange have accelerated to a rate at which milliseconds and microseconds are critical reaction times for a multitude of investment strategies (Menkveld, 2011). In essence, high frequency-trading is non-human trading in sequences – sequences in which algorithms make economic decisions on the timing, price and execution of orders in accordance with the interest of the owners of the means of production (Grindsted, 2016).

While geographies of environmental finance cover a vast spectrum of areas, including the circulation of climate service (Webber, 2017), carbon markets (Knox-Hayes, 2013), green debt (Bigger and Millington 2019) and financialization of the environment (Bergmann, 2017; Castree, 2003; Loftus, 2015), no research has explored relations between algorithmic economies and natural disasters. Yet, the accelerating financial systems and environmental crises are mutually constitutive in a number of ways (Cooper, 2010). This paper examines algorithmic trading at global stock exchanges in relation to earthquakes. To my knowledge, this is the first study that addresses financial technologies and their responses to tectonic events.[2]

Analyzing high-frequency trading from the perspective of economic geography's time-space analysis of socio-natural interactions (Knox-Hayes, 2013), the paper explores the nexus between natural hazards and algorithmic capitalism (Grindsted, 2016). Empirically, I draw on examples: algorithmic responses to the 2011 tsunami, two aftershocks

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[1] Algorithmic processing refers to a mathematical method or a set of rules (logic) that sequences as a step-by-step procedure, with computation from one state (e.g. linear list) to another that is not given to be deterministic. Some algorithms perform randomized input and output simultaneously (Brogaard et al., 2014).

[2] I found no literature on high-frequency trading (HFT) and natural disasters. The literature review (Science Direct, Scopus, Google Scholar) used the following search terms: 'algorithms, HFT and hurricane', 'Algorithms, HFT and tsunami', 'Algorithms, HFT and natural hazard', and so forth with 'natural disaster', 'flooding', 'Anthropocene', 'climate change', 'wildfire', 'drought', earthquake and 'typhoon'.

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and a tectonic event in 2012, all in Japan. I examine whether the trading algorithms took seismographic data and/or earthquake warnings into account and subsequently responded financially to natural hazards. In so doing, the paper links two distinct, yet related, bodies of literature.

First, this paper draws on algorithmic finance (e.g. Brogaard et al., 2014; Buchanan, 2015; Hosaka, 2014; McGowan, 2010; MacKenzie et al., 2012; Woodward, 2018). Studies on algorithmic finance, however, barely examine spatio-temporal figurations. MacKenzie et al. (2012), Grindsted (2016) and Zook and Grote (2017) are among the very few studies that spatialize algorithmic finance. Zook and Grote (2017), for instance, demonstrate how algorithmic technologies produce market information inequality and Grindsted (2016) finds that through algorithmic trading, techno-financial acceleration widens spatio-temporalities as a means for new market strategies. Theoretically, however, this body of literature needs refinement in order to adapt to spatio-temporal figurations with environmental finance.

The second strand is located within environmental finance (Bergmann 2017; Castree 2008; Knox-Hayes 2013; Loftus 2015). This body of literature analyzes complex economic, social, organizational and technological relations by laying bare the interactions among them as driving forces for environmental financialization (Bergmann 2017; Castree 2008). The aim is to explore localized consequences of algorithmic decision-making in response to natural disasters. As the financialization of nature develops at multiple spatio-temporal scales (Loftus, 2015), the rationale for this study hypothesizes high-frequency trading algorithms' ability to trade on multiple real-time environmental data, like early earthquake warnings.

The paper explores the following research questions: How does the rise and regulation of high-frequency trading constitute techno-financial acceleration at global stock exchanges? How do high-frequency trading algorithms work across time and space and make trading on earthquakes possible? How do natural disasters affect high-frequency trading and do algorithms trade on early earthquake warnings? When the high-frequency trading spatio-temporalities accelerate capital transactions, do human-environmental interactions accelerate as well?

First, I address the rise and regulation of high-frequency trading and demonstrate how the neoliberalization of stock exchanges produces techno-financial acceleration. Second, I review critical spatial studies on high-frequency trading to elaborate an economic geographical framework of algorithms in space-time. Third, I present the empirical data and brief discussions of methodology on the financialization of the environment. The results section addresses algorithmic responses to earthquakes. I address the time-spaces of transaction and examine ways in which the new spatio-temporalities employed constitute algorithmic environmental finance, which makes trading on earthquakes possible. Trading on earthquakes, I argue, constitutes environmental market information that both alienates from nature and establishes new environmental markets. Finally, I discuss algorithmic responses to earthquakes and develop the idea of temporal informational epicenters by managing risk in ever-smaller time fractions.

2. The rise and regulation of algorithmic trading

As high-frequency trading is a complex phenomenon, I first give a brief introduction to the phenomenon. It will illustrate how the rise of high-frequency trading parallels re- and de-regulation efforts. I hereby show how the neoliberalization of stock exchanges produces techno-financial acceleration by, changing the spatio-temporalities under which finance operates.

Authorized by the US Securities Exchange Commission (SEC), high-frequency trading entered the market in 1999. Electronic trading, however, is nothing new. In 1971, NASDAQ became the world's first electronic stock market and, five years later the New York Stock Exchange (NYSE) introduced the so-called DOT (Designed Order Turnaround) system that allowed securities to be traded electronically (McGowan, 2010). In just a few years, high-frequency trading turned from a niche strategy into a lucrative industry (Brogaard et al., 2014). In the early 2000s, high-frequency trading did not receive much attention among economists. Even within the financial sector, high-frequency trading was given little priority until 2007 (MacKenzie et al., 2012). The daily trading volume at the US stock exchanges accounted for less than 10 per cent from 1999 to 2004 (Miller and Shorter, 2016: 1). Three years later high-frequency trading accounted for approximately half of the trading volume (Woodward, 2018). Geographically, high-frequency trading first occurred in the US and then spread to Canada, Europe, Latin America and Asia (Buchanan, 2015). The structural importance of high-frequency trading is global in character. Registered exchanges worldwide are reconfigured by high-frequency trading algorithms, be it the Tokyo Stock Exchange (Hosaka, 2014), New York, Shanghai, Sao Paulo or London.

According to Sherman (2009), rather than technological improvements, it was deregulation that paved the way for algorithms. Minor technological obstacles needed to be solved, e.g. with data exchange between matching engines at different exchanges, until high-frequency trading developed into mass transactions. But, as MacKenzie et al. (2012) note, stockbrokers in New York and Chicago blocked these technologies as they saw algorithmic trading as a threat to their business model. Deregulation, however, has been critical for the security industry and the evolution of high-frequency trading. De- and re-regulation efforts from 1986 onwards repealed the Glass-Steagall Act (1933) and the Securities Exchanges Act (1934). This allowed commercial banking to merge with the credit and security industry, and according to McGowan (2010) and Woodward (2018), paved the way for algorithmic market regulation. Furthermore, the US Commodity Futures Trading Commission (CFTC), the Regulation National Market System (Reg NMS), the Markets in Financial Instruments Directive (MiFID) in the EU and equivalent regulation, combined led to algorithmic trading that potentially controls supply and demand simultaneously (Sherman, 2009). Finalized through the Regulation Alternative Trading System (Reg ATS) by SEC in 1998, electronic communication networks (ECNs) allowed trading outside the traditional stock exchanges (McGowan, 2010) and financial deregulation, thereby allowed investment banks, hedge funds and the security industry to use the new technologies (Wójcik, 2012). Also, the Reg NMS was an influential deregulatory factor that opened the terrains for trading in high frequency. The Reg NMS was authorized by SEC in 2005 with a pamphlet of initiatives that required market orders to be immediately electronically executed (Sherman, 2009). Whereas the pre-Reg NMS matches orders in temporalities of seconds and minutes, the Reg NMS matches orders in microseconds and conveys the structural advantages for current electronic trading (McGowan, 2010). The last element of deregulation that influenced high-frequency trading, was the so-called 'decimalization' Act from 2001. This act made algorithmic capitalization more lucrative since it changed the profitability time-ratio from 1/16th of a dollar to $0.01 per share. "Overnight the minimum spread a market-maker stood to pocket between a bid and offer was compressed from 6.25 cents (…) down to a penny. This move decreased a market-maker's trading advantage and led to increased liquidity which in turn eventually led to the current boom in algorithmic trading" (McGowan, 2010: 34). On this account, Sherman (2009: 11) notes that "in a completely unregulated market, derivatives trading expanded quickly, increasing from a total outstanding nominal value of $106 trillion in 2001, to a value of $531 trillion in 2008." Similarly, McGowan (2010) and Woodward (2018) show how financial deregulation approved algorithmic finance.

What makes high-frequency algorithms different from other electronic trading, though, is not only the astonishing speed at which trading takes place. It is also the ability to carry out thousands of orders within microseconds and to use financial news[3] and key reports before everyone else (Groß-Klußmann and Hautsch, 2011). Algorithms are

[3] "Based on past patterns, HFT firms estimate expected price changes triggered by the release of macroeconomic news, corporate announcements or industry reports with a significant impact on market prices" (IOSCO, 2011).

also able to foresee other traders' bids and limit offers before their trades are executed (Woodward, 2018). They take into consideration small variations in price of a particular share traded on different markets simultaneously (Lewis, 2014). Thus, algorithms provide an example of techno-financial activities, with seemingly discrete social and political effects (Golumbia, 2013). While finance studies provide a comprehensive analysis of the work and regulation of algorithms (e.g. Golumbia, 2013; McGowan, 2010; MacKenzie, 2014; Sherman, 2009; Woodward, 2018), they barely address the new spatio-temporalities employed. Yet, the constitutive relationship between deregulation and technology fuels the most fluid and mobile form of money capital that quickly relocates geographically.

I will now argue that space-time compression (Harvey, 1989), or what I would call 'space-time implosion', is crucial for understanding the radical new dynamics in the financial market. It is not only time, speed and distance as non-geographical studies on high-frequency trading tend to suggest (e.g. Lewis, 2014; Mackenzie, 2014; Sornette and Becke, 2011; Woodward, 2018); it is the expansion between different spatio-temporalities that is crucial to algorithmic strategies.

3. Time-space compression and the value of a microsecond

In this section I build on the concept of the annihilation of space through time (Harvey, 1989) by translating high-frequency trading studies into space-time compression algorithmically. Mackenzie et al., (2012), Buchanan (2015), Grindsted (2016), Zook and Grote (2017) are among the studies that best capture the geographies of high-frequency trading. In algorithmic finance, I argue, the expansion of spatio-temporalities constitutes risk reduction in ever-smaller fractions of time. This is significant for the spatio-temporalities of environmental finance.

As computer-based trading connects the global financial market closer than ever before, the modern accumulation-based economy enters a new era produced by different temporalities. Algorithmic technologies, along with electronic communication networks (ECNs), facilitate ultra-fast transactions (McGowan, 2010). Their changing character embodies new temporalities: to paraphrase Harvey's classic dictum concerning "the annihilation of space by time" (Harvey, 1989: 240), financial firms implode the temporal dimensions of the financial trade into ever diminishing fractions to gain ground in the market. New spatialities are also emerging because of the installation of ultra-fast fiber optic data connections between trading houses and financial exchanges (MacKenzie et al., 2012). Until 2010, for instance, the fastest route between NYSE and CHX took 13 ms (Zook and Grote, 2017). To save crucial milliseconds, algorithmic traders invested in new financial infrastructures connecting the cities in a straight line. When necessary, the route blasted its way through the Allegheny Mountains (MacKenzie et al., 2012). When the route opened, data ran three milliseconds faster between New York and Chicago (Zook and Grote, 2017). Banks, hedge funds and others can buy first-access packages to the new route, approximately ten times the price of the ordinary route.

While the general argument about market transactions across space indicates that everything is about speed (Woodward, 2018, Mackenzie, 2014, Lewis, 2014), I will now argue that the micro and macro-geographies of e.g. trader networks are equally important.

Co-location, for instance, is a strategy in which firms rent space next to an exchange engine. This has driven real estate prices up to $10,000 per 0.5 m^3 per month at certain locations (MacKenzie et al., 2012).

Let us briefly touch upon one algorithmic strategy (market-making) to get a sense of the micro- and macro-geographies of algorithmic market information. Insofar as algorithmic trader A is located 100 km and trader B is 10 m from the stock exchanges match engine, actor A is very disadvantaged. Algorithms act as buyers and sellers, e.g. trade in the same security from both sides simultaneously, and earn money because of the spread (MacKenzie et al., 2012). As actor A trades at a distance, accessing information on the market spread later than B, he is at a disadvantage for what I term locational market-making. Algorithmic trading gives a strategic advantage compared to traders operating at a lower temporality, in part through the construction of information inequality as Zook and Grote (2017) note.

In high-frequency trading, the value of speed relies on access to market information before competitors. The advantage of speed makes Michael Lewis (2014) claim that the entire existence of trading in high-frequency depends on being faster than the rest of the stock market. What is sold here is essentially speed or access to 'free market information' before the competitors. If speed is traded, it only has value to the extent that it is a scarce resource. Algorithmic capitalism (Grindsted, 2016) therefore refers to a process whereby the value of speed is essential for appropriating value out of other processes (e.g. environmental change) through the formation of spatio-temporal information inequalities (such as monopolies). Further, if it is time that is traded, then it is fundamentally contradictory to the utility value of products it relies upon (Grindsted, 2016). Now exchange value configures to spatio-temporal exchange value simply because this information only has value in milliseconds and microseconds.

When market competitors receive 'free market information' in milliseconds, microseconds or seconds from one another, it is, among other factors, dependent on the technologies used, traders' proximity to the match engines (servers), as well as distance to other traders, or simply buying 'first access packages' (MacKenzie et al., 2012). As far as traders' access to free market information is relative to geographical distance to the match engines, I develop the concept 'temporal-informational epicenters' with a particular profitability time-ratio in play, relative to speed/distance, relational location or co-location. Spatio-temporal information inequality relates to natural disasters, when the algorithms turn a tectonic event into spatio-temporal competitive advantages.

4. Methods

Empirically I assess high-frequency trading data from the Tōhoku tsunami in Japan (11 March 2011, 05:46:23 UTC) and two aftershocks. The examination of the earthquake is primarily in regard to the temporal aspects of the disaster (ultra-fast risk reduction). The rationale for selecting these specific events is due to the magnitude; it was the most devastating tsunami recorded (Hino, 2015) and hence the events had the possibility of significant market fluctuations. I examine market fluctuations during one minute after the earthquake at the Nikkei 225 index and for the Tokyo Electric Company share.[4] Japan Exchange Group (JPX) provided data from the Tokyo Stock Exchange, Nikkei 225 average futures within the first minute after the tsunami warning (11 March 14:46:23 UTC + 9). Two of the aftershocks, on 7 April 2011, 14:32:43 (UTC)[5], and 10 July 2011, 00:57:10 (UTC)[6] are included. Similarly, HFT data from the Nikkei 225 Index and for the Tokyo Electric Company share are analyzed during the minute after the early earthquake warning (see Figs. 2 and 3). Having analyzed the above earthquakes, one of my interviewees (C) suggested including the earthquake on 3 July 2012 at 02:31:03 UTC (Epicenter at Tokyo Bay, magnitude 5.4, 11.31.03 local time)[7]. This study rests on interviews with four anonymous leading high-frequency trading experts. One

[4] Time: 11/3/2011 05:46:23 UTC; position: 38.322° North / 142.369° East; depth: 24.4 km, magnitude: 9.1 M, locality: approx. 100 km from the east coast of Japan, approx. 373 km northeast of Tokyo. https://earthquake.usgs.gov/earthquakes/eventpage/official20110311054624120_30/executive.

[5] Time: 07/04/2011 14:32:43 (UTC); position: 38.276° North, 141.588° East; depth: 42.0 km; magnitude: 7.1 M. https://earthquake.usgs.gov/earthquakes/eventpage/usp000hzf6/executive.

[6] Time: 10/07/2011 00:57:10 (UTC); position: 38.034° North 143.264° East; depth: 23.0 km; magnitude: 7.0 M. https://earthquake.usgs.gov/earthquakes/eventpage/usp000j4gp/executive.

[7] Time: 03/07/2012 02:31:03 (UTC); position: 34.934° North 139.744° East; depth: 86.4 km; magnitude: 5.3 M. Approx. 120 km south of Tokyo. Source: https://earthquake.usgs.gov/earthquakes/eventpage/usp000jnhj/executive.

respondent is from DTN Company (Interview B, 2018). And three from the Tokyo Stock Exchange (Interview A, C, D). The respondents were first asked whether they were aware of high-frequency trading algorithms that trade on natural disasters. They were then asked about algorithmic trading directly on real-time seismographic data and early warning systems. Finally, interview questions centered around the specific earthquakes and the data provided. Though I do draw from interviews for direct quotations, I also use interview C and D to contextualize and verify the data provided.

Getting access to these interviews was a methodological challenge dating back to 2009. That year I first met respondent A in Boston, who introduced me to high-frequency trading. Later he became a leading representative of JPX. On the condition of full anonymity, respondent A (2018) agreed to be interviewed, and give access to two JPX employees for an interview (C and D, 2019). Interview C and D compiles HFT data in the minute after the early earthquake warning. Attempts to access data from the TABB Group and Nanex remain unsuccessful. High-frequency trading market data represents a hidden world that is not transparent to the public. As Golumbia (2013) notes, high-frequency trading concentrates power, and access to data provides profound methodological challenges.

5. Algorithmic responses to earthquakes

This section examines whether crash algorithms utilize early warning systems and/or seismographic data to trade on earthquakes and tsunamis. As economic geography has proved resistant to move beyond the nature-society divide (Bergmann, 2017), so have the representations of high-frequency trading and algorithmic economy. Even though many forms of ontological reductionism exist, "we cannot talk about the world of 'nature' or 'environment' without simultaneously revealing how space and time are being constituted within such processes" (Harvey, 1996: 263). While environmental finance (Bergmann, 2017) goes to the heart of debunking the ontological and ideological implications of valuation (e.g. the act of finding the right prices for ecosystem services), scholars like Knox-Hayes (2013) and Castree (2003) build methodological frameworks to better contextualize the commodification and valuation of nature. The commodification of nature (privatization, alienability, individuation, abstraction, valuation and displacement), they note, undertakes processes that implicitly remove assets from space and time. This, I argue, can better contextualize those terms within the more-than-human dynamics, and hence open multiple quantifications (Bergmann, 2017) associated with conceptions of algorithmic trading related to natural disasters. Accordingly, algorithmic economies embody particular representations of time and space that become constitutive for interactions between the Earth system and the financial system.

5.1. *Tōhoku earthquake*

The Tōhoku earthquake (11 March 2011) is the largest ever recorded (Hino, 2015) in Japan (9.0–9.1 [M_w]. The tsunami caused a natural catastrophe. The Tokyo electric power company (TEPCO) faced the Fukushima Daiichi nuclear disaster and the share dropped approximately 80% in the days after the event (Fig. 1, Tokyo Stock Exchange, 2019). Fig. 1 illustrates that shareholders and hedge funds sold out to reduce financial risk. The TEPCO accident illustrates the possibility of trading on natural disasters, e.g. by turning early earthquake warnings into financial risk and portfolio management. The Japan Meteorological Agency's Earthquake Early Warning System (EEW) estimates arrival times and initial movement of the first observed waves in coastal areas, and also provides information on the arrival times and scale of the highest waves observed at that time.

The Real Earthquake Bulletin System (4235 seismometers in Japan) offers real-time seismographic data to the early warning system. Japan is subject to frequent earthquakes[8] and heavy high-frequency trading (Hosaka, 2014). Insofar as algorithmic economies mark a new era of environmental finance – the valuation of environmental change produced through trading technologies, spatio-temporal-environmental figurations is fundamental to risk reduction. Hence, I intend to study whether high-frequency algorithms trade on the earthquake early warning system and hereby take into account natural disasters when trading equities.

The interview material and data from the Tokyo Stock Exchange, however, shows no algorithmic reaction to the Earthquake Early Warning System (tsunami warning) in the minute after 11 March, 05:46:23 UTC (Interview C, 2018). The expert from DTN stated that he is "not aware of trading systems designed specifically around seismographic events" neither in the US nor elsewhere (Interview B, 2018). In his database search, he found no unusual trading on the Tōhoku tsunami. Similarly, the leading JPX representative is "unaware of trading algorithms currently designed around natural disasters" (Interview A, 2018). Yet, he also says: "There is a case where the futures' price fluctuated simultaneously with the Earthquake Early Warning System. This is entirely my own personal opinion; algorithms use information on natural disasters for trading" (Interview A, 2018). While algorithms operated in the days after the event, they responded to human praxis (news and market decisions) as the tsunami reached Japan (Interview C, 2019). Additionally, interview C and D suggest that no crash algorithm links to either the early warning system for the Tōhoku tsunami or to the 7 April 2011, 14:32:43 (UTC) and 10 July 2011, 00:57:10 (UTC) earthquakes. The case, however, is different from the earthquake at Tokyo Bay on 3 July 2012 at 02:31:03 (UTC), interview C and D informed.

5.2. *The earthquake at Tokyo Bay*

On 3 July 2012, 11:31:15, the entire Nikkei 225 index went down from 9075 yen to 9035 yen within a few seconds (see Figs. 2 and 3). Algorithmic trading caused multiple micro-crises and micro-crashes in its own machine-driven environment (Sornette and Becke, 2011). The drop is not unusual in itself and thousands of micro-crashes exist (Grindsted, 2016), so it is difficult to determine direct relations with the earthquake, the epicenter of which was at Tokyo Bay. Nevertheless, within 15 s after the earthquake (02:31:03 UTC, 11.31.03 local time), algorithms from Argo Software Engineering, among others, began to trade on the event, Interview C and D suggests.

Interview person C explains as we speak of Fig. 2: "If you look at 11:31, it is a disaster. It is unlikely that a human can take 45 yen down at 30 s. Algorithms buy and sell at the same time. The algorithm does not only take advantage and trade on the natural disaster, it harnesses the catastrophe. Don't you wish for an earthquake, Argo? Tokyo Bay is a fantastic epicenter for trading. It is all about how you reduce risk and how foreign capital moves away. Earthquakes are serious. Foreign investors trade on the earthquake. It is a disaster" (Interview C, 2019). The interview suggests that algorithms trade on earthquakes. Further, those specific trading strategies await earthquakes, as Tokyo Bay is a fantastic epicenter for trading.

On July 3, 2012 (11.31.03 local time) this seem to be the case, and Fig. 2 demonstrates that the entire Nikkei 225 average future index drops 45 yen within 15 s after the early earthquake warning. Correspondence between the two events, however, does not demonstrate that algorithms trade on real-time seismographic data. They trade on the earthquake, but might harness market news and information on the event (Interview A, 2018).

It was not only the entire Nikkei 225 average future Index that went

[8] The Japan Meteorological Agency (JMA) distributes three types of information on earthquakes. http://www.data.jma.go.jp/svd/eqev/data/en/guide/info.html.

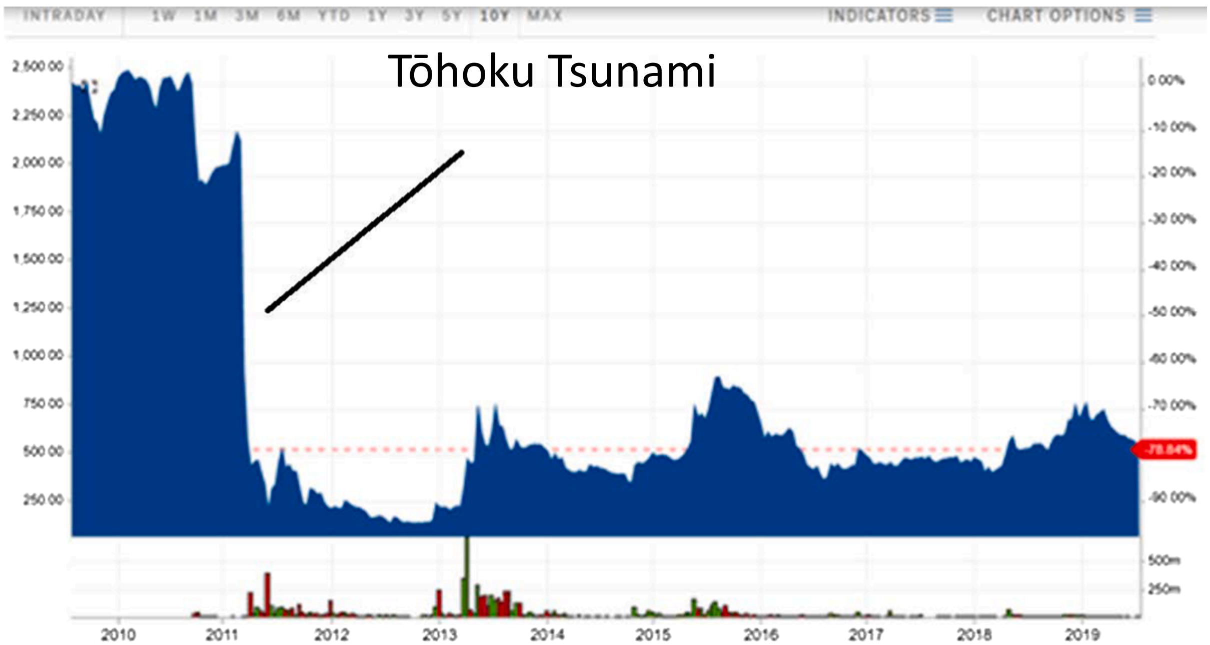

Fig. 1. Tokyo electric company share 2010–2019, Tokyo stock exchange.

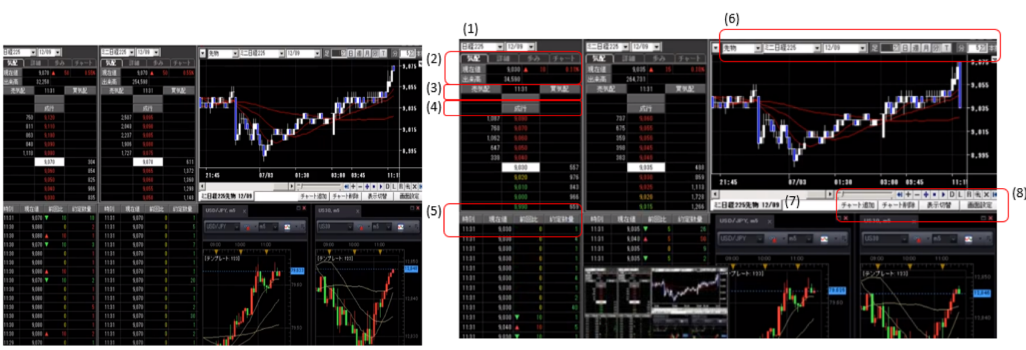

Fig. 2. Illustrates the market drop at 11.31.15 (right) compared with 11.31.00 (left) just prior to the Earthquake Early Warning. Translation: (1) Nikkei (2) Quotation/Tone of the market, Current price, Turnover/Trading volume (3) Bid price/Sell price, No offer/Buy order (4) Order without limit/Market order (5) Time, Current price, Change/Last time, Execution number (6) Future transaction, Mini Nikkei225, daily chart, weekly chart, monthly chart, five-minute chart (7) future transaction of mini Nikkei (8) Add to chart, delete chart, switch the display, screen setting..
Source: JPX 2019

down; looking also at a specific share (Tokyo Electric Power Company), it shows algorithmic responses to the earthquake (Fig. 3). This graph shows that the share price dropped 7.5% in a short fraction of time, it went rapidly up and down until the Tokyo Stock Exchange stopped trading with the equity between 12.00 and 13.30. As respondent C said: “In a few seconds the share [Tokyo Electric Power Company] drops 7.5% and swoops back to 3% before it drops again…(…). Algorithms trigger a 50-yen drop!” (Interview C, 2019).

The interview validates the data, and suggest that algorithms trigger a 50-yen drop, due to a tectonic event. Respondent D explains: “In case of an extreme and unpredictable environment, there is a safety control program disconnect switch. The earthquake warning triggers an early breakdown. It is because Argo [algorithm] acts on the buy side quickly and absorbs the sale, but it stops buying when the drop reaches a certain threshold. Argo bids are visible at the same time, and momentum drops like a stone” (Interview D, 2019).

Respondents C and D indicate that the algorithms did trade in relation to the earthquake warning and that the potential disaster caused a market drop. In the interview D, comments made about Fig. 3 also indicate that the algorithm takes advantage of the tectonic event, by establishing a microenvironment. The algorithm buys and sells simultaneously, when the share drops it send false orders, hence constructing a market situation that makes the share drop.

Further, as the earthquakes are made subject to trading, respondent D says: “In a historical context, this is a fascinating drop. I felt my personal limit. I could not think about anything when it happened. The share began to drop a few seconds before the public earthquake bulletin” (Interview D, 2019). This indicate that the algorithmic financial environment converts real-time seismographic data into market information. This is also stated by respondent C: “The earthquake warning for bulletin 254 is far too late [broadcasted via radio, TV, mobile phones, etc.]. Amateurs will never be able to compete with advanced algorithmic systems for warnings. I believe the Argo team sell earthquake news” (Interview C, 2019). Respondent C and D note that the share drops before bulletin 254, which put traders operating based on the public bulletin at a disadvantage. Further, the interviews suggest that algorithms exploit information on the earthquake before the public bulletin, indicating that algorithms trades on real-time data from the early earthquake warning systems. Hence, the earthquake information transcended into environmental finance in ways in which it is all about being the first to take advantage of changes in the physical environment and adjusting to the machine-driven financial environment. Yet, the respondent from DTN Company explains, “I am unaware of algorithms designed around natural disasters, but I know that algorithms trade on

Fig. 3. Tokyo Electric Company at the Tokyo Stock Exchange. Market fluctuation at 11.31. Translation: (1) Tokyo Electric Power Company 9501: Ticker symbol, The first section of the TSE (Tokyo Stock Exchange) (2) Display screen updating (3) Stock price chart (4) One-minute chart (5) Five-minute chart (6) Daily chart (7) Weekly chart (8) Monthly chart (9) Stock dealing on credit (10) SMA (simply moving average) (10) EMA (exponential moving average)..
Source: JPX, 2019

them" (Interview B, 2018). News articles reporting earthquakes in real time are just as important, taking into account the actions of other market participants related to such events (Interview D, 2019). According to the information participants, algorithms do not trade directly on seismographic data, but trade on the early earthquake system warnings issued, news and reports.

6. Discussion – temporal-informational epicenters: when algorithmic spatio-temporalities accelerate, do human-environment interactions accelerate as well?

Under certain environmental conditions, e.g. the earthquake at Tokyo Bay, this study indicates that algorithms trade on earthquakes at risk of becoming natural disasters. Much like algorithms trade on news, key reports and social media (Groß-Klußmann and Hautsch, 2011), the early earthquake/tsunami warning (EEW) transcends into 'environmental market information'. Hence, this study suggests that algorithms financialize the earthquake and evaluate share prices related to that event. Potentially, the warning bulletin allows prediction of the bid and offer spread before a tsunami actually happens. This creates temporal informational epicenters relative to the epicenter of the earthquake (natural disaster) that constitute new financial environments contingent on Earth system interactions. In essence, algorithmic responses to earthquakes (natural disasters, more broadly), constitute financial environments in which algorithms take advantage of environmental change before the competitors. The concept of temporal informational epicenters refines Zook and Grote' (2017) work on information inequality, as information epicenters potentially exist before a tsunami has actually happened.

The further from the epicenter of the earthquake, the longer is the reaction time. The temporality of the warning system also works as a secondary epicenter (JMA location), in contrast to the epicenter of the earthquake.

As far as traders' access to free market information is relative to the geographical distance to the match engines (Tokyo Stock Exchange), temporal information epicenters are also relative to the location of the warning system (JMA) and the epicenter of the earthquake (natural disaster). Areas near the tectonic epicenter may experience earthquakes and tsunamis before the warning is issued and financial centers and actors in the market receive the information relative to the distance from the early warning and stock exchange epicenters. Hence, we have three epicenters: tectonic epicenter, epicenter of the warning system and epicenters of match engines at the stock exchange. Insofar as TEPCO's 7.5% market drop (Fig. 3) is caused by the earthquake warning, space-locational strategies operate across multiple spatio-temporal scales simultaneously, somewhat equivalent to relativistic arbitrage (Buchanan, 2015). Temporal-informational epicenters have a particular profitability-time ratio in play, relative to the speed/distance, relational location or co-location to the 'epicenters'. Thus, temporal informational epicenters happen in cases of early earthquakes and tsunami warnings and constitute a spatio-temporal competitive advantage for financial risk management.

Crash algorithms combine market inequality (Zook and Grote, 2017) and the information rent (Grindsted, 2016) to construct temporal-informational epicenters out of natural disasters. Temporal-information epicenters become a means of financial risk management for the individual shareholder, and solely the shareholder. Risk reduction is a matter of obtaining 'data on natural disasters' before competitors, consequently being a displacement strategy that has the ability to transfer (not reduce) market risks to others. Hence, temporal-informational epicenters produce market inequality (Zook and Grote, 2017) by turning data on the disaster into a scarce spatio-temporal resource (Grindsted, 2016).

The temporal-informational epicenter is relative to the temporality of the natural disaster (earthquake to drought), the location of the epicenter of the natural disaster and the areas affected. Tokyo Bay is fantastic for trading during earthquakes, as one of the respondents mentioned. The more abrupt and the greater the geographical proximity, the better.

The occurrence of environmental crises and economic crises intersects. Algorithmic responses to natural disasters constitute financial environments (representations of process-relational contingents) so that relational economic geographies portray complex crossings of conceptual and territorial borders (numbers of flow) making natural events and finance come together. Micro-crashes (microseconds) move its (informational) crises around in physical space. Acceleration of financialization in scale and time (outwards as well as inwards) reconfigures the dynamics under which a resource or natural event is considered to be profitable or not – that is, the extent to which natural resources and environmental phenomena are valued to be profitable in any given time-scale ratio. Hence, the techno-financial acceleration of portfolio management adapts to natural disaster by aiming at minimizing risks. Thus, relational crash algorithms produce relational economic geographies, transferring market crises from one geographic spot to another at the temporality of high-frequency trading time, and at other spatio-temporal scales, they affect the geography of difference. As algorithms speed up, so does human (financial) risk management of natural disasters.

Algorithm responses to earthquakes and tsunamis can be profitable, but not productive – they produce no value. Rather, algorithms re-allocate exchange value. Technologies like trading algorithms can therefore reallocate crises by creating instruments to monitor exchange value out of environmental risks.

7. The value of spatio-temporal market information-nature decoupled?

Drawing on Knox-Hayes (2013), the remaining part (barely) opens the terrain of algorithmic valuation of natural disasters. Algorithms absorb data among thousands of orders when compiling ‘a full picture’ of all the bids and limit orders pending, and as in the case of the earthquake on 3 July 2012, crash algorithms construct and trade on tectonic information. Accordingly, assumptions of free market mechanisms seem to implode spatially inwards such that everyone can know the exact price at anytime and anywhere (Zook and Grote, 2017), e.g. in the case of a tsunami. The space of timing produces material assemblages in which high-frequency trading is constituted by and constitutive to differential geographies, not only through the scalar (and slower) process of market information accessibility, but also by the ways in which extraction alienates through the appropriate capacity of the temporal value of things/information. Knox-Hayes (2013) argues that markets divorce financial products from the material context they purport to represent. Similarly, Castree (2008) discusses the neoliberalization of the environment (deregulation) expanding markets into various aspects of nature.

Financialization, Knox-Hayes (2013) suggests, creates distortions in the representation of financial value and the application of that value to the management of environmental systems. “In particular, by removing value from its objective and spatial and temporal connotation, financialization introduces a disjuncture between the representation of value and the production of value by environmental processes […] through financialization they diminish environmental value” (Knox-Hayes, 2013: 118). Algorithmic responses to natural disaster, however, show that this is both true and untrue. Rather, it depends on spatio-temporal figurations, I argue.

Algorithms diminish environmental value by slicing time in ever-smaller fractions. Insofar as algorithms are able to act simultaneously as buyers and sellers within microseconds (McGowan, 2010), spatio-temporal market information – the multiplicity of pricing in and between time and space – elides those phenomena that are not constitutive within such timeframes. Consequently, non-human techno-financial trading not only accelerates market information[9], it also reduces information to something only affecting the immediate form of appearance. For algorithms trading in high frequency, market information is reduced to being relevant only within that particular timeframe, whereas other spatio-temporalities of occurrences are disrupted.

Algorithms, however, do not diminish environmental value, but value environmental dynamics under certain environmental conditions. Temporal informational epicenters reconfigure environmental finance from a “somewhat unchartered [sic] territory” (Loftus, 2015: 173) into financial environments whereby the algorithm turns early earthquake warning data into the core of financial risk management. Tectonic events in the physical environment may produce financial crises in high-frequency trading time (see Fig. 3) and hereby construct new financial environments. Nevertheless, nature is particularly valued under certain environmental conditions through the earth system spatio-temporalities of the tectonic event and its potential damaging character. In contrast with Knox-Hayes (2013), I argue that crash algorithms momentarily value nature (tectonic events), and thereby construct a convergent valuation of nature. The valuation is convergent as crash algorithms do not value the environment unless it produces risk relevant to high-frequency trading temporalities and hereby convert tectonic events into a matter of risk reduction before competitors.

Nevertheless, this study also aligns with Knox-Hayes’ (2013) conclusion: the “material-value divorce” (Knox-Hayes, 2013: 120) intensifies with algorithmic trading, as changes in price in a microsecond do not represent changes in the value of the environment, apart from the potential damaging effects. Hence, algorithmic trading speeds up environmental financial dynamics in sequences, while diminishing environmental value at non-algorithmic temporalities. By contrast, many environmental dynamics span from days to thousands, millions and billions of years, implying that financial acceleration further alienates and is divorced from e.g. ecosystem services. Consequently, algorithmic trading further widens the convergence and divergence between the Earth system and the financial system. As Knox-Hayes (2013) argues, finance may undervalue the rate at which the Earth system operates and reproduces itself. To pin it down, the highest form of detachment from the nature-capital relationship is founded in the acceleration of financial capital while intensifying externalities to processes (e.g. natural disasters) operating at other spatio-temporal scales.

8. Conclusion

This research indicates that high-frequency trading algorithms trade on earthquakes and thereby financialize natural disasters. Algorithmic responses to earthquakes (natural disasters), constitute financial environments in which algorithms take advantage of environmental change before competitors. This study suggests that algorithms trade on earthquakes and evaluate share prices related to that event. Tectonic events in the physical environment may produce financial crises in HFT time and hereby construct new financial environments. Hence the earthquake information transcended into environmental finance by ways in which it is all about being the first to take advantage of changes in the physical environment and adjusting to the machine-driven financial environment. This creates temporal informational epicenters. Temporal informational epicenters happen in cases of early earthquakes and tsunami warnings and constitute a spatio-temporal competitive advantage for financial risk management. The further from the tectonic epicenter, the longer reaction time. The temporality of the warning system also works as a secondary epicenter, in contrast to the epicenter of the earthquake. In essence, algorithmic responses to earthquakes (natural disasters, more broadly), constitute financial environments in which algorithms take advantage of environmental change before the competitors. Temporal informational epicenters refine information inequality as information epicenters potentially exist before a tsunami or earthquake has actually happened. Further, temporal information epicenters are mobile, and move geographically relational to the tectonic epicenter, the epicenter from which the warning was issued and the informational epicenter of the marketplace.

This study indicates that algorithms both diminish environmental value in minor fractions of time and constitute environmental value

[9] Strategies like quote stuffing, piggybacking, layering and riding on waves all generate money by the circulation of information in different spatio-temporalities (Sornette and Becke, 2011).

through peculiar forms of adaptation to natural disasters. The techno-financial revolution in scale and time (outwards as well as inwards) expand the dynamics under which the environment (processes or resources) is considered to be profitable, hence the dynamism of which material practices are valued as profitable in a given time-scale ratio. Designed to accelerate the rate of capital turnover, financial markets constitute both divergence and convergence through further expansion and widening of algorithmic spatio-temporalities (t/t) and the spatio-temporalities (t/t) in which environmental systems operate. Algorithms do not value the environment unless it produces risk relevant to HFT temporalities, while it produces divergence and alienates financialization further from the environment, e.g. long-term Earth system dynamics and the rate at which ecosystem services operate and reproduce themselves. The highest form of detachment from the nature-capital relationship is founded in the acceleration of financial capital while intensifying and producing new externalities to natural processes. Thus, algorithms seem to accelerate human-environment interactions by the ways in which they further distort environmental value that threatens the material integrity of natural systems.

While this article identifies algorithmic responses to earthquakes with temporalities constituting ultra-fast risk reduction strategies, it did not identify crash algorithms that trade on other natural disasters. It remains to be studied whether crash algorithms both in high-frequency and low-frequency trading (LFT) trade on other natural disasters, with temporalities adjusting for long-term risk reduction, such as typhoons, wildfires, flooding, landslides, volcanic eruptions drought, and famines. While the finding signals the importance of spatio-temporal figurations associated with algorithmic trading on natural disasters, methodological challenges remain. Hence, we invite studies that develop methods enabling the study of algorithmic capitalism related to natural disasters.

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