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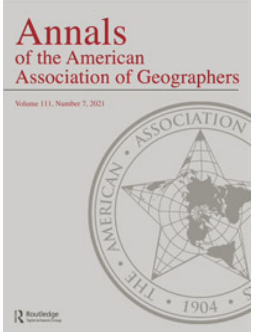

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Algorithmic Finance: Algorithmic Trading across Speculative Time-Spaces

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The speeds at which transactions are completed in global financial markets are accelerating and, in the process, connecting financial centers around the globe like never before. Algorithmic trading at high frequency is a form of automated trading in which machines, rather than humans, make the decision to buy or sell in spatiotemporal sequences. Insofar as they have agency of their own, their actions support the owners of the means of production. These techniques codevelop with new financial geographies. Accordingly, I examine technological change and speculative time-spaces of algorithmic strategies at stock exchanges. By analyzing algorithmic finance, I examine how—and to what extent—time, speed, location, and distance become critical for algorithmic finance by configuring time-spaces as competitive factors. The analysis interprets time-spaces of high-frequency trading strategies through the ways in which algorithmic finance constititutes what I term *mobile market-informational epicenters*. This article discusses the spatiotemporalities of market information and examines whether space-times of privately owned high-frequency trading infrastructures result in a juxtaposition between "public" and "private" market information across digital and physical space. It thereby responds to the questions of what role geography plays when algorithms make money in microseconds and how techno-financial time-spaces turn into competitive advantage. *Key Words: algorithmic finance, financial geographies, human–robotic interaction, time-space, stock exchanges.*

The trading of shares is increasingly being conducted at high speeds. High-frequency trading (HFT) is a financial investment execution technique that connects and accelerates trades across the world (MacKenzie 2019). This acceleration is due to electronic infrastructures linking financial centers nationally and globally, as well as the significant growth of financial instruments such as derivatives (Wójcik 2012; Sassen 2018) and deregulating factors across the globe (Woodward 2018). Electronic trading, however, is nothing new and has evolved gradually since NASDAQ (1971) and the New York Stock Exchange (1976) launched the first electronic trading platforms (McGowan 2010). HFT is also automated electronic trading. In what follows, algorithmic trading at high frequency, automated trading, machine trading, or equivalent terminologies are all referred to as HFT and are different from electronic trading because it is algorithms and not people that make economic decisions and buy, sell, and execute orders (Buchanan 2015, 161). Since their utilization, markets have accelerated rapidly. Adopted by international exchanges, HFT has become a global phenomenon and a core strategy of the financial services industry (MacKenzie 2017).

HFT takes place in a machine-driven financial environment where every microsecond counts (Brogaard, Hendershott, and Riordan 2014). For example, an HFT algorithm can execute up to 100,000 orders per second for a single client (MacKenzie 2017) and some of it operates not just in milliseconds (1,000th of a second) but microseconds (1,000,000th of a second). No person is capable of sending out thousands of orders per second or reacting to market data within these time frames. Algorithms also incorporate machine learning (artificial intelligence) and they can analyze financial news, social media, and key figures and reports (Groß-Klußmann and Hautsch 2011; Karppi and Crawford 2016). This techno-financial acceleration is institutionalized into multiple trading venues and HFT amounts to approximately 55 percent of all trades on stock exchanges in the United States (Miller and Shorter 2016), with shares held for shorter and shorter periods.

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Although financial geography covers many topics, research on the spatial and temporal dimensions of HFT remains somewhat limited. Among the studies that do exist, MacKenzie et al. (2012), Borch, Bondo-Hansen, and Lange (2015), Buchanan (2015), Karppi and Crawford (2016), Grindsted (2016), Zook and Grote (2017), Del Casino et al. (2020), and Grindsted (2020) remain the most prominent that spatialize algorithmic finance. Del Casino et al. (2020) examined the politics and governance of robotics and algorithms and demonstrated their social effects, and Karppi and Crawford (2016) analyzed algorithmic financial responses to social media tweets and hack crashes. They demonstrated how financial actors might speculate on creating social media events with the purpose of profiting from market distortions. Borch, Bondo-Hansen, and Lange (2015) exposed Lefebvre's rhythm analysis and bodily experience to HFT. Zook and Grote (2017) studied the micro- and macrogeographies of HFT and demonstrated how distance produces information inequality. HFT leads to information inequality when nonhuman machine operations work at a higher temporality than ordinary traders and receive market information ahead of those actors. In a similar vein, Grindsted (2016) illustrated how algorithmic trading widens spatiotemporalities as a means for new market strategies. Insofar as unequal access to market information is also a matter of coping with distance, financial time exploitation prevails. MacKenzie et al. (2012) researched price discovery, its materiality, and the significance of spatial location, and Buchanan (2015) emphasized the speed at which financial centers connect and their geospatial network. Grindsted (2020) examined HFT responses to natural disasters and illustrated how HFT actors trade on earthquakes when transforming early earthquake warnings into analysis of possible market crashes, for example, to the insurance sector.

This article discusses the spatiotemporalities produced by HFT and considers the theoretical and political significance of these spatiotemporalities. I argue that privately owned HFT infrastructures result in a juxtaposition between "public" and "private" market information across digital and physical space. Thus, I argue that the enormous growth of algorithmic finance produces quasi-public and quasi-private space-times, in which speed, location, and distance constitute competitive parameters in themselves. By examining how time and space become competitive parameters, I refine Zook and Grote's (2017) argument on information inequality. Theoretically, I develop mobile market-informational epicenters and related concepts explaining the speculative time-spaces of HFT. Market-informational epicenters are temporal and mobile and have a particular profitability–time ratio in play, relative to the speed and distance, relational location, or colocation to other market participants' market information. The creation of price distortion via market-informational epicenters is significant, not only because it strategically takes advantage ahead of "quasi-public space-time" but also because it conceptualizes uneven space-time configurations in global finance that create and exploit inequalities to the benefit of investors who take advantage of such spatiotemporal strategies. Thus, I examine their relational spatial strategies, discussing how multiple informational epicenters are mobile across time and space. In relating older (e.g., Schaefer 1953; Bunge 1966; Barnes 2001, 2018) and newer (e.g., Massey 1995; Leyshon and Thrift 1997; Sheppard 2002; Dixon and Monk 2014; Leamer and Storper 2014; Martin and Sunley 2015; Muellerleile 2018; Sheppard and Plummer 2020) geographical debates over why cities, towns, financial centers, nodes, and networks matter to HFT (and vice versa), this article addresses the following questions: What role does geography play when algorithms make money in microseconds? How does algorithmic finance turn time-spaces into a competitive advantage?

In this article, I first present the analytical framework and provide examples of algorithmic work across time-spaces. Thus, I examine HFT strategies (e.g., arbitrage operations) and its spatiality to understand how algorithms profit from, among others, the bid–offer "spread" and market fluctuations. It is argued that the space of timing produces material assemblages in which HFT 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 in "quasi-private space-time" reengineers "quasi-public space-time." Hence, HFT algorithms invoke location and distance, as well as speed, to temporarily create inequalities to profit from market information on spatiotemporalities. I then focus on the material geographies of HFT and discuss the theoretical implications of algorithmic strategies by demonstrating how relational algorithmic strategies produce relational algorithmic geographies and mobile market-informational epicenters. Finally, I discuss the political and theoretical implications of distinguishing between algorithmic finance based on private, public, and quasi-public market information infrastructures.

Algorithmic Work across Time and Space

Algorithmic trading at high frequency constructs a machine-driven "world where every nanosecond counts" (Zook and Grote 2017, 130). When trading between two or more stock exchanges, quick data connections between the locations of the stock exchanges' matching engines[1] reduce the time it takes to execute a trade (Buchanan 2015). It is important to distinguish between colocation and trades executed entirely within a single exchange, whether algorithmic or not (distance down to meters and their spatiotemporalities matter for HFT), and clustering trades between two or more exchanges, algorithmic or not (Zook and Grote 2017). Each strategy or combination thereof carries specific advantages in trading with and across time-spaces. This is why geography is an important aspect of the part of the financial industry that operates through HFT.

One algorithm could place up to 100,000 orders per second and potentially remove up to 95 percent of the orders again in microseconds (Woodward 2018). By screening market information on the buy and sell orders before the trade is executed, HFT algorithms are capable of buying and selling shares before regular traders (MacKenzie et al. 2012). Algorithms can both buy and sell at the same time and thereby act on the demand and supply sides simultaneously (Woodward 2018). In so doing, HFT algorithms can affect the pricing in microseconds.

As Miller and Shorter (2016), among others, emphasized, algorithmic strategies rely heavily on the speed at which HFT operates. By way of illustration, a stock market trader located close to the Chicago Mercantile Exchange's matching engines (some 66 km from the city center in Aurora, Illinois) can trade a share at the NASDAQ matching engines (located in Carteret, New Jersey, approximately 35 km from Wall Street) with a total trading distance of approximately 1,281 km (MacKenzie et al. 2012; Zook and Grote 2017). Every time the trader presses the Buy button, the price of the share goes up fifty cents and then immediately drops again. The trader is not buying the share at the market price he or she is seeing on his or her screen. The baffled trader types in a new order and the same thing happens. Even at the speed of light in a vacuum (approximately 300,000 km/s), it would, for example, take 4 ms from the time the trader hits the order button until the NASDAQ's data center in Carteret receives it (add to this the time needed to process the button press and ultimately human reaction time). "No matter how fast it could react, a system in Chicago would, therefore, be at a hopeless disadvantage compared to one closer to Carteret" (MacKenzie et al. 2012). The project begs comparison to the Chicago–New York railroad route established by the New York Central Railroad Company in 1853. The twenty-first-century link sends electrons instead of people, parcels, and assorted freight. For some types of material production, there are still locational, geographical, and transportation advantages different from the spatialities and materialities of the Internet economy (Leamer and Storper 2014). Thus, it is worth exploring the HFT infrastructural production of space, its nodes, and networks.

To save crucial microseconds, the United States has been dug up to lay down fiber optic cables between the New York Stock Exchange (NYSE), the Chicago Stock Exchange (CHX), NASDAQ, and all the other stock exchanges (MacKenzie et al. 2012). Until 2010, the fastest connection between the NYSE and CHX, for example, was 13.33 milliseconds (Zook and Grote 2017) because it had to traverse railways and highways with numerous twists and turns. To gain competitive advantages, algorithmic traders (partly in secret) laid down a new connection with fiber optic cables, a project costing US$300 million (MacKenzie et al. 2012). The new connection, unlike the previous one, did not have to zigzag along roads, infrastructure, properties, and fields. Where necessary, the route went directly through mountains (the Allegheny Mountains) to ensure the shortest possible route. With its completion, data now travel three milliseconds faster (Zook and Grote 2017). It is a widespread practice among HFT traders and hedge funds to buy first access packages. Private HFT networks convert distance and speed into trading advantage, and the new route comprises first access at a price approximately ten times what it would cost being sent along the original route. The time savings allows the firms who subscribe to the service to beat their competitors via spatial disadvantage—in this case, a market that involves the financial center's lucrative commodities and options markets (Wójcik 2012) with capital being invested in algorithmic infrastructures when it could otherwise have been invested in the hardscape infrastructure of bridges, tunnels, roads, water and sewage networks, and so on (see also Muellerleile 2018).

Nevertheless, it is not only the temporal aspect of competition that is relevant but also the integration between different markets in the real economy. As Buchanan (2015) demonstrated, declining sugar prices on the world market will, for example, have an impact on the share price of soft drink companies. It is well known that if prices in sugar and high-fructose corn syrup rose, stocks in soft drink companies would fall. HFT speeds up that process. Between 2000 and 2010, it took several minutes for share price fluctuations in one market to affect another; today, it takes seconds. The techno-financial acceleration connects areas and industries temporally and spatially in ways such that no market or sector is left alone.

Technologies compress time and space. For Harvey (1982, 1989), time-space compression is uneven and relative so that an effective distance can lengthen when another one shrinks, as formulated in Harvey's (1989) famous dictum, "time-space compression" or the "annihilation of space through time" (240).[2]

For MacKenzie et al. (2012), however, it is time that is compressed, not space. By pointing to the "annihilation of space through time," MacKenzie et al. (2012, 286) noted, "In high-frequency trading, this [time-space compression] is only half right. Time shrinks but space doesn't." It is worth noting that this echoes a longer standing emphasis on time as active (or in this case reactive) and space as passive. Examples include Laclau (1990) iterating space as ontologically separated from time, whereby dynamics reside in time, not space; Massey's (1992, 1995) critique suggesting that spatial patterns are integral with time; and Lukács (1971) suggesting space as mechanistic with structure and properties that are deduced to laws. Contingent on the quantitative revolution (Bunge 1966; Schaefer 1953; Barnes 2001, 2018; Sheppard and Plummer 2020), for Lukács (1971) objects are located in time and space and their spatialities are objectively deducible (space as passive). Smith's (1984) critique suggests space as relational with multiple space-times. For MacKenzie et al. (2012), temporal configurations result in spatial compression. Henceforth, time becomes a denominator of space, circumvented by Lukács's (1971) observation (here nonhuman): "As labour is progressively rationalised and mechanised … it reduces space and time to a common denominator and degrades time to the dimension of space" (Lukács 1971, 89). When two financial centers are connected, such as the London Stock Exchange (LSE) and the NYSE were in 2015 (with new fiber optic transatlantic cables, the so-called Hibernia Express), to MacKenzie et al. (2012) it is an expression of speed compressing space. It is a piece of physical and digital infrastructure that connects the two financial centers 2.6 milliseconds faster (Buchanan 2015, 161), with connotations of Von Thünen's concentric model (Barnes 2001) or Bunge's (1966) spatial logic of geometry.

In the following, however, I argue that MacKenzie et al.'s (2012) interpretation is lacking and that algorithmic space-times would be better analyzed as relational entities (Massey 1999) so that processes, dynamics, and flows do not operate in but actually constitute time and space (Harvey 1973). Located within the theoretical underpinnings of Harvey (1973, 1982) and Massey (1999), space is interdependent with time, so that space-times can shrink. As a result, relational spatial strategies come into play, so that the spatiotemporal figurations employed produce speculative time-spaces. Hence, the analytical framework suggests that financial processes, dynamics, and flow of market information do not operate in, but constitute financial space-times (Massey 1999). For Massey (1995), economic "geography is not just a product of social relations; it is an integral part of their development" (120), paraphrasing what has sometimes been labeled new economic geography (e.g., Gibson-Graham 1996; Leyshon and Thrift 1997; Sheppard 2002). Following Harvey (1982), neither space nor time are abstract objectives; rather, the spatiotemporalities of HFT exist as socially constructed products. By contrast, MacKenzie et al. (2012) considered space fixed as a constant (Harvey 1982), with time as the variable. Insofar as processes, dynamics, and flows do not operate in but constitute time and space, time-space "is neither absolute, relative, or relational in itself, but it can become one or all simultaneously depending on the circumstances" (Harvey 1973, 13). In accepting such a stance, it follows that multiple time-spaces exist at different scales arising from the phenomena under investigation. In accordance with such a framework, particular materialities, technologies, flows, and rhythms (Borch, Bondo-Hansen, and Lange 2015) materialize from embodied to automated space-times interconnecting with a broader (globalized) perspective of Sheppard's (2002) or Harvey's (1973, Harvey 1989, Harvey 2005) neoliberal critique. Subsequently, different materialities, infrastructures, and technologies—along with the processes, flows, and dynamics inherent in them—produce different spatiotemporalities. Massey (1999) formulated this line of thought in trying to "rethink space as integrally spacetime and to conceptualize space-time as relative (defined in terms of the entities 'within' it), relational (as constituted through the operation of social relations, through which the 'entities' are also constituted) and integral to the constitution of the entities themselves (the entities are local timespaces)" (284). MacKenzie et al.'s (2012; see also MacKenzie 2017) material political economy, in its focus on the politics of human interaction with the physics of the speed of light, therefore constitutes HFT space-time with space as definite in terms of the distance to be overcome through time. Yet statistical reasoning in economic geography around high-powered computing, data analytics, and "big" data model selection strategies similarly becomes subject to evolutionary quantifications, although more sophisticated ones (Martin and Sunley 2015), or reengagement with spatial econometric tradition(s) and self-organizing equilibria models in geography (Sheppard and Plummer 2020).

Methodology

This article builds on a literature review contemplating the spatiotemporalities of HFT. The methodological starting point is hermeneutic (Barnes 2001), which means that I do not draw systematically on all studies that might be relevant to the spatiotemporalities of HFT. Rather, I draw on papers on the space-times of HFT identified. I read the materiality as a process integral to the space-times outlined earlier (Massey 1992, 1999) and thereby impose a relational interpretation to the work of HFT in time and space. Consequently, the method does not begin from bounded geographical units but from "vantage points" around which the specific algorithmic processes both materialize in and are constituted by space-time dynamics. This, I claim, better conceptualizes algorithmic work across time and space. As each event holds its distinct spatiotemporality, I particularly juxtapose the studies by MacKenzie et al. (2012) and Zook and Grote (2017) with Massey's (1992, 1999) account and thus translate the spatiotemporalities in these studies (as well as the literature referred to in general) into a relational understanding of algorithmic strategies. Thus, I translate algorithmic strategies in the material surveyed by projecting multiple time-spaces onto the accounts given, whereby the dynamics of algorithmic market information constitute and are constituted by market participants' interwoven geofinancial networks and associated techno-infrastructures. In doing so, I define market data as issued by a trading venue, such as a stock exchange, to inform traders and investors about the latest prices of financial instruments such as shares (the latest bid and ask prices and the volume, the latest price executed and the volume, etc.; MacKenzie et al. 2012). These market data are in flux and have a temporal character often associated with a single temporality. Thus, market data constitute the market price at a given event in time (at a given location).

By contrast, I define market information as contingent on financial actors and their digitalized trading behavior. Thus, market information represents the operation through which market participants absorb and transform market data into operation of action or inaction. Market information is "analyzed" market data, including its dynamics, market participants' behavior, micro- and macrostructures, and so on. Whereas market data apply to a single event (or series of events), market information applies to the analysis of a single event (or series of events) that allows high statistical precision and so on (Woodward 2018).

Within this context, market data (as well as market information) operate with inherent spatiotemporalities—that is, the spatiality and temporality galvanized into the structuration of price formations. In the analysis I demonstrate how algorithms can transform market data into what I shall later term *financial geodata*. Methodologically, I define financial geodata as converted financial market data (or market information) from events (or series of market events) that allow the algorithm to take into consideration forthcoming market trends (dynamics in time and space, market behavior, or spatiotemporal structures) that shape trading strategies. The next section goes further in considering the material and relational spatiotemporalities of HFT.

Materiality, Technology, and Space-Times as Competitive Parameters at the Global Stock Exchanges

HFT algorithms produce financial micro- and macrogeographies (Zook and Grote 2017). The macrogeographies of algorithmic trading are illustrated by speed and connections with financial centers across the globe (Buchanan 2015). Microgeographies, on the other hand, could be illustrated by the importance of colocation. Colocation strategies are important for HFT traders and essentially mean locating your trading algorithm as close to the stock exchange's servers as possible (MacKenzie et al. 2012). Both micro- and macrogeographical techno-financial accelerations are material and physically rely on the digital infrastructures such as fiber optic cables that connect places at speeds of around 200,000 km/s and yet interconnect with traders' embodied rhythms (Borch, Bondo-Hansen, and Lange 2015). In the competition to increase these transmission speeds, HFT actors are about to hit a physical limit—the speed of light (Buchanan 2015). Even if data transactions via fiber optic cables travel at two thirds of the speed of light in a vacuum, other actors could receive market information faster by operating via other strategies or faster technologies. According to an entirely material episteme, it is a question of possessing faster algorithms or digital infrastructure (and their more than human performativity): One of the most recent technologies that has been used is the transmission of data via lasers (MacKenzie 2014). The transmission of data via the atmosphere lowers speeds but not as much as with fiber optic cables. Therefore, the air space between New York, New Jersey, and Chicago, between London and Frankfurt, and so on, has been used for new transmission corridors. Based on military technology used to date signals between airplanes, there is now a network of lasers and microwaves that can send financial market information between multiple financial centers (Patterson 2014). According to Zook and Grote (2017), fifteen to twenty private microwave networks are set up between New York and Chicago alone.

Theoretically, light travels at approximately 300,000 km/s in a vacuum. There are quite a few physical and material problems associated with lasers, microwaves, and milliwaves, however. For example, weather-related phenomena such as heavy rain, fog, or snow and dust, particles, or birds can cause problems (Buchanan 2015). Another challenge is that lasers are often located at the top of tall buildings to minimize the number of objects in the intervening landscape. High-rise buildings can cause problems, though, because they oscillate up to 3° in strong winds. Neither lasers, microwaves, nor milliwaves can be used over great distances without a network of transmitters. The signals disappear into the atmosphere, because they do not bend with the curvature of the Earth. The geodesic axis is the shortest distance between two points on the ground, and this is why HFT data engineers create a network of lasers between the stock exchanges (Patterson 2014).

As technofixes push speeds toward the physical limit (the speed of light), financial technology companies are speculating on sending balloons or solar-powered drones over the Atlantic and Pacific. Balloons or solar-powered drones can act as network transmitters. Balloon or drone stations can work with the curvature of the Earth and result in even faster transmission corridors for financial market information if placed on the geodesic line (Buchanan 2015). For satellites, the distances are too great. There is also speculation around millimeter waves and neutrinos. Neutrinos can send information at the speed of light and through physical objects (Zook and Grote 2017). Therefore, people are now working on sending market information directly through the planet itself (Buchanan 2015)—for example, via the *computational geographical axis* between Tokyo and London, which is even shorter than the geodesic one. The technology is not yet operational, however (Zook and Grote 2017). It is little wonder that a dominant theme within the HFT literature on time-space compression concerns the time it takes to travel from point A to point B. Within such studies, algorithmic space-time is predominantly one-dimensional (as in the case of MacKenzie et al. 2012; MacKenzie 2014; Patterson 2014; Buchanan 2015) and absolute in its explanation of time and distance competition. Thus, the computational geographical axis aligns with absolute space. Yet the locational variety and different notions of distance herein (e.g., Leamer and Storper

2014) invoke somewhat relational terms, as will be discussed later. Drawing on Massey (1992, 1999), I argue that multiple time-spaces are just as important as possessing the fastest technology: HFT necessarily has to immanently convert financial data into financial geodata. Converting financial market information into geodata points toward cases in which relational time-spaces shape trading strategies. The geodetic line and computational geographical axis thereby also constitute multiple geometries, among others arising from the entities inhabited by the market participants, whether human or automated. Information geometries are multiple, and the ones we choose—and thus a particular spatiotemporal frame—are relativized by the subject or by automated market dispositions. As I discuss in the next section, the dissemination of market information, its mobile and locational fluxes, as well as the location at which other market participants operate, comprise new algorithmic and strategic aspects of the digital infrastructures. This gives rise to what I term *mobile market-informational epicenters*.

Relational Algorithmic Strategies: Relational Financial Geographies

On a basic level, HFT algorithms are about executing orders automatically. Before algorithms gained ground, orders were executed manually and formed a "traditional" supply-and-demand curve for the individual securities. In contrast to supply-and-demand curves executed by manual trades, algorithmic finance supplements with curves operating at HFT temporalities (MacKenzie et al. 2012). It follows that spatiotemporalities widen between orders executed manually and orders executed by algorithms. For orders executed in the algorithmic economy, the manual supply-and-demand curve is incomplete (nothing happens in microsecond intervals). Therefore, bankers and financial institutions often point out that algorithms ensure liquidity in smaller and smaller intervals of time (Grindsted 2016). The greater difference in spatiotemporalities (human and nonhuman) expands and widens outward, so that market information expands throughout the area in accordance with the (accelerating) temporalities at which actors (human and nonhuman) trade. Moreover, the greater the distance the competitor is located from the exchange (in kilometers), the better the spatiotemporal competitive advantage for the algorithms (MacKenzie 2017). Henceforth, the temporal dimension of market information is also spatially and structurally organized via the digital network's geographical dissemination. Yet, the greater difference in spatiotemporalities (human and nonhuman) also expands inward (see Harvey 1982), whereby acceleration of financialization in scale and time reconfigures the dynamics under which a process or event is computed as profitability rates—that is, the extent to which phenomena are valued to be profitable in any given timescale ratio (Grindsted 2020). Accordingly, millisecond trades seem likewise to implode spatially inward, so that everyone can know the exact price more and more accurately according to one's (co)location. Because of the expansion between different temporalities at which actors (human and nonhuman) trade, the space of timing produces material assemblages in which HFT is constituted by and constitutive of the differential geographies of the market information they represent.

By way of illustration, a traditional investor sells in London (LSE) via smart order routing (SOR) software that divides this trade and sells it on different stock exchanges to get the best price (Zook and Grote 2017). Slicing orders (carried by humans or nonhumans) is an ordinary operation, among other reasons to avoid others gaining ground in the slipstream (orders in large quantity and within a short time span). Nevertheless, because the SOR trades over distance, it is vulnerable to other algorithmic maneuvers (e.g., relativistic arbitrage). Insofar as variation in price on a particular share traded on the different stock exchanges around the world exists, shares can be bought at one stock exchange and sold at another. In the particular example, HFT algorithms take advantage of the price differential and buy in London (LSE) while selling on the Frankfurt Stock Exchange (FWB) until the price differential is equalized. This implies that HFT traders are able to react to the executions on the LSE and send messages to cancel orders on the FWB faster than the time taken for the SOR to reach London. As a consequence, faster traders act ahead of the SOR trader. The infrastructure and traders that operate over longer distances and at a slower pace are forced to acknowledge that geography has a cost.

For algorithmic traders, the material and geographical interconnectedness results in a time–distance competition (Patterson 2014) in which the spaces of timing are crucial. It is about being faster than other competitors, who either do not have access to the technology in question or are in a poor location within the geofinancial network—or who do not know that they are trading on the basis of irrelevant and obsolete market information. Zook and Grote (2017) described such situations as information inequality. Ultrafast reaction times produce spatial inequalities where the distance between cities and the relative location among the participants is critical to the construction of these information inequalities.

In the following I open the discussion of what I term *market-informational epicenters*, *price-location*, and *relational spatial strategies* before considering them more deeply and comprehensively. The example of the price variation being traded between multiple stock exchanges has a number of implications in this respect. First, the time it takes market information to travel from point A to point B is also relational; for example, if traded at multiple exchanges simultaneously. This implies that there is an epicenter at the location of the exchange's matching engine from which market information is sent. Information moves outward. Further, as information moves outward it interacts with multiple epicenters, as each exchange constitutes a market informational epicenter. Market informational epicenters and their data transmission at high frequency connote the multiple and mobile quantification of Von Thünen's concentric model (Barnes 2001) or Bunge's (1966) spatial logic of geometry, despite its assumptions.

Algorithms can thus execute relational spatial strategies, which I term *price-locations,* within which the associated space-times of the market information (information epicenter's) flow constitute mobile and locational supply-and-demand curves. It follows that each location has a temporary supply-and-demand curve. Algorithms are unable to move around geographically; they can only position themselves within the geofinancial network. Figuratively, this relates to previous quantitative traditions in geography such as Weber's locational choice triangle or Christaller's central place theory (Barnes 2001). Yet price-location strategies absorb market information in which supply-and-demand curves are different at different locations (according to the temporality of the individual actor) and equally move around geographically. For example, the competitive advantage might be in trading on actors that react via slower spatiotemporal effects (Grindsted 2016) or that are located at the wrong places in the geofinancial network. The difference is that HFT algorithms no longer take account of the individual orders but can calculate the mobile character of the bid–offer spread. Trading strategies therefore also come about from the networks and fluxes (locational space-times) under which each market participant operates. Circumventing Leamer and Storper's (2014) re- and (de)agglomeration and new web density dynamics, HFT incurs spatial concentration and A-to-B acceleration not only between financial centers but also between dispersed geographies and networked dynamics. In a similar vein, Dixon and Monk (2014) found that frontier investors (e.g., pension funds and foundations) remain outside financial centers and discussed their long-term investment horizons, to some extent immune to accelerating financial fluxes.

Second, the place where market actors have the fastest possible market information between two stock exchanges is precisely at the midpoint of the geodesic line (or computational geographical axis), because the actor will be the fastest to receive market information from the two stock exchanges simultaneously (Buchanan 2015). Consequently, the relative distance between the actors also becomes a deciding factor. Thus, it is worth bearing in mind the infrastructural production of time-spaces and the geographic networks subsequently being calculated.

The midpoint between the LSE and the NYSE is in the middle of the Atlantic. Insofar as a ship, balloons, or drones can be located at the midpoint between the two exchanges, it is theoretically profitable to gain from the locational advantage, because you trade on a relational place-based strategy (relativistic arbitrage). The relational algorithmic strategy therefore takes advantage of the fact that it transforms place into a competitive advantage, for example, in cases where the same share is priced differently on two stock exchanges simultaneously. Hence, I develop the concept of locational trading advantages, different from colocation, because it is mobile and operates at a distance from the matching engines. From these locational trading advantages I develop the concepts of fixed informational epicenters that are in geographical proximity, because they are linked to the stock exchanges and matching engines, and of mobile market-informational epicenters with fluxes in different time-spaces. Until now, we only took into account the relation between two exchanges, but computational geographical axes also constitute multiple geometries. In cases where market information becomes available at two exchanges at slightly different times, variance between the two exchanges on the geodesic line is still prevalent, whereby price-locations move along the line. Trades between multiple stock exchanges produce multiple price-locations. Hence, market-informational epicenters are mobile and networked geometries between different actors and their spatiotemporal entities. It begs comparison with Leyshon and Thrift's (1997) and Zook's (2012) accounts of actor networks and virtual spaces, although it is codependent on material networks. From a macrogeographical perspective, this results in multiple supply-and-demand curve epicenters that move around in space and time as trade information fluxes change between multiple trading platforms. Insofar as each epicenter, whether mobile or fixed, generates locational advantage in space-times (counting hours to nanoseconds), these epicenters are a way of interpreting place-based information monopolies. Arguably, fixed and mobile informational market epicenters connote a multiple and mobile version of von Thünen's concentric model (Barnes 2001) and constitute market participants' relational strategy and spatiotemporal figuration. The location-based competitive advantages create a location rent defined by the profit that accrues solely to the location, albeit with an associated time rent (Grindsted 2016) existing for the actors competing on the spaces of timing. For instance, trading on slower temporalities conceptualizes a multiple space-time version of Weber's location triangle (Barnes 2001) as mobile and networked, whereby location rent equally moves around geographically, singaling newer hybrid quantifications (Sheppard and Plummer 2020), such as automated evolutionary thoughts (Martin and Sunley 2007, 2015) in economic geography.

From a microgeographical perspective, fixed informational epicenters produce place-based advantages through geographical proximity, whether through a colocation strategy (Woodward 2018) or strategies relative to mobile space-times; that is, strategies involving the relative location between other market participants. To take a first example of the latter, momentum ignition contains a set of strategies that places a number of orders with the manipulative purpose of indicating rises and falls in prices and then eventually profiting from them (Miller and Shorter 2016). This generates what I term *false market informational epicenters*, through which the mobile character (outward from its epicenter) signals when it is profitable to trade on competitors' market reactions due to their location. Colocation, however, proves to be one of the most lucrative marketing strategies for many HFT companies (Zook and Grote 2017). The locational flux of market information creates what I call *locational advantage monopolies* with an associated concept I term *location rent* for market information. Colocalization is about placing your algorithms as close as possible to the stock exchange's matching engine. Trading firms, for example, rent space to place their computer right next to the exchange's matching engines at a cost of up to $10,000 per square meter per month (MacKenzie et al. 2012), thereby demonstrating the renting aspect of place-based strategies (location rent) and the algorithmic financial symbiosis with space as competitive factors.

The most competitive market information is geographically connected with the market information's epicenter (the location of the stock exchange's matching engine). Therefore, colocation has become a new and important competitive parameter as it engineers and creates private informational epicenters working with spatiotemporal market information ahead of public informational epicenters. It makes a difference whether you are located right next to the stock exchange or whether you are located a block away or in another city (MacKenzie et al. 2012; Buchanan 2015). Therefore, we can empirically speak of *location as a competitive parameter* in algorithmic finance. Location as a competitive parameter can be mobile or fixed; it nevertheless explains the value-skimming algorithms performed out of multiple informational geometries, among others by the ways in which public market information becomes privatized and delayed in fractions of time (defined in terms of the entities "within" informational fluxes across space-times) and relative to other market participants' space-times (each market participant, whether human or automated, represents individual space-times). False market information (90–95 percent of all orders) illustrates why "dark market" information makes colocation a limited strategy (Woodward 2018). Similarly, the volume of actors operating at slower temporalities matters, as well as low-frequency trading, dark pools (Zook and Grote 2017), relational market strategies, and other trading dynamics that opt away from the ultrafast algorithms. Colocation is an important strategy, but close to a relational understanding, neither hegemonic nor deterministic, because it is difficult to determine boundaries in a complex system (Martin and Sunley 2007; Coe and Hess 2012). In the remaining part I argue that these spatiotemporal figurations challenge three basic market premises of neoclassical economic theory.

Discussion: Speculative Spaces in the Free Market

What different HFT strategies have in common is that share price fluctuations in milliseconds do not represent any change in the value of the company that price is supposed to represent. The company's trading value changes according to multiple spatiotemporalities; for example, when algorithms act on the supply and demand sides simultaneously (Woodward 2018).

Muellerleile (2015, 2018) discussed the formation of financial infrastructure and technologies alongside the ways in which market participants intervene, reengineer, and transform market logics—in large part due to information and knowledge management, which has its own distinct spatialities (Wójcik 2012). In a similar vein, Hau (2001) found proximity to financial centers and headquarters more profitable than for traders located elsewhere. Insofar as HFT has a transformative power, it not only reengineers and transforms market logics by accelerating them (Grindsted 2016) but it also produces new relational spatiotemporal entities integral to the techno-financial networks themselves, following Massey (1992). In addition, following the preceding account, different HFT spatiotemporalities also reconfigure three basic market premises of classical economic theory; for example, when acting on social media tweets (Karppi and Crawford 2016) to generate microcrashes. To follow Harvey's (2005) critique of neoclassical assumptions on market participants—(1) free access to information, (2) free transferability, and (3) no intrusion from others—as a prerequisite for perfect competition, I extend Zook and Grote's (2017) finding on information inequality.

My argument is that HFT creates a spatial advantage out of spatiotemporal entities. Insofar as algorithmic strategies are relational (through the constitution of relations and networks across time-spaces), different HFT strategies become integral to locational informational epicenters (the entities constitute local time-spaces). Consequently, the locational advantage, mobile market-informational epicenters and time rent, and so on, lead not only to information inequality but also to trading space-times that amount to new competitive parameters (the spatial positioning of one event [x] in relation to another [y] might not be directly caused). Different algorithmic strategies (e.g., relativistic arbitrage) transform market logics, for example, by acting on the supply-and-demand curve simultaneously, whereby relational strategies identify the space-times at which trading ahead of future demand and supply might be profitable (Woodward 2018). Henceforth, HFT produces relational strategies by the constitution of space-times that allow trading ahead of future demand and supply curves constituted by the market participants' "place" in the geofinancial network. Insofar as market-informational epicenters constitute mobile informational supply-and-demand curves, HFT reengineers and spatializes the assumption of free access to market information, transferability, and intrusion.

To gain locational advantage, algorithms might, for instance, block, slow, or disseminate "fake" market information to other actors (Karppi and Crawford 2016; Woodward 2018), or delete up to 90 to 95 percent of the orders they send (Buchanan 2015). Such strategies, whether momentum ignition, layering, spoofing, or their equivalent, are common but illegal and initiate quick increases or decreases in price with the manipulative purpose of generating delayed or false supply-and-demand curves (Miller and Shorter 2016) across the geofinancial network. Whether manipulated or not, public market information operates at a spatiotemporal scale with delayed informational epicenters compared to automated market information. Private infrastructures and algorithmic arrangements thus trade ahead of the public market information by privatizing it. As Zook and Grote (2017) noted, HFT aims to privatize public information for just long enough to profit from it. Privatized public market information from mobile or fixed market-informational epicenters arises from differential space-times being used to transform assumptions on quasi-free market logics, seeking in part to privatize them. Thus, HFT institutionalizes market logics via private infrastructure and arrangements through which the construction of different space-times makes private networks form locational informational epicenters that work ahead of public information. HFT challenges "free market information" as competitors trade on obsolete—yet public—market information, precisely because the inherent space-times have been so radically transformed.

Second, free price formation implies that market participants have full control over an asset until sold. Furthermore, it implies that they enter the market on a voluntary basis without intrusion or intervention from third parties. These assumptions are utopian in practice, Harvey (2005) noted. HFT algorithms, however, can often be said to act as a third party. Let us return to the "baffled" trader: In the space of time when the market data travels from Chicago to New York (approximately 13 milliseconds), the trader cannot cancel the order. Theoretically, he or she does not control the asset for 13 milliseconds. In the meantime, the algorithm acts as a third party that privatizes the market information as it buys a share ahead of the trader and sells the very same share to the trader at a higher price. Yet, converting financial data into financial geodata not only makes space a competitive factor but also produces locational surveillance, monitoring systems of the actors' geographical location, network, market behavior, and positions, thereby turning financial geodata into financial geoinformation that creates new algorithmic locational governing advantages. This echoes concern as algorithmic economies in high frequency refine Zuboff's theorization of surveillance capitalism into locational surveillance capitalism over codes, bits, and bytes and thereby the power over places and people as geographers have explored in virtual agglomeration economies (Graham 2005; Zook 2012; Dixon and Monk 2014; Leamer and Storper 2014; Martin and Sunley 2015). "The virtual world of the Internet has no physical neighborhoods," Leamer and Storper (2014, 79) noted. This, however, seems debatable to algorithmic economies in general and the geographies of HFT in particular.

HFT companies often correlate data to be able to identify orders executed by a human (MacKenzie et al. 2012), which enables the algorithm to systematically act as a third party insofar as the market spread is lucrative between the time and space it takes to place the order and its execution. In the same vein, Buchanan (2015) suggested that speculative spaces of timing (private market information) make public market information dysfunctional. Del Casino et al. (2020) called for geographies of algorithmic governance that envision radical democratic, postcapitalist, emancipatory alternatives. The least we could do is call for space for algorithmic market information to be openly explored.

Conclusion

In this article, I have demonstrated how algorithmic trading constitutes speculative space-times. Through speculation in time-spaces and the expansion of multiple temporalities between market actors (inward-facing) and speculating in geographical location and distance between the market actors (dissemination), HFT algorithms institutionalize market logics not only by transforming them but also by privatizing public market information in fractions of time. The greater the geographical distance to the stock exchange's match-making servers, the greater the temporal delay. The greater the difference in time, distance, or relational geographic dispersal between the actors (from colocation to actor dispersal), the better the spatiotemporal competitive advantage. HFT algorithms not only identify market changes over brief intervals of time; they also perform on the markets by creating fixed and mobile market-informational epicenters from which market information is disseminated (price formation epicenters) as described via a location rent, the privatization of public market information, and related concepts as developed in this article.

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Notes

1. A matching engine forms the core for any public exchange, because it matches buy and sell orders

that are submitted to stock exchanges such as NASDAQ. The matching engine handles the bid–offer spread, so that its order management functionalities allocate matching quantities, used when an aggressor order matches with one or multiple resting orders, and applies both to outright and implied matching.

2. "I use the word 'compression' because … the history of capitalism has been characterized by speed-up in the pace of life, while so overcoming spatial barriers that the world sometimes seems to collapse inwards upon us. … [S]pace appears to shrink to a 'global village'" (Harvey 1989, 240).

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