TRANSACTION MACHINES

THE INFRASTRUCTURE OF FINANCIAL MARKETS

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Declaration

The work presented in this thesis is the candidate's own.

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Abstract

This thesis describes financial markets as complex machines in the broader sense, as systems for organizing informational flows and performing certain functions in regards to the processing of transactions. We focus on the transaction infrastructure of financial markets, on the flow architecture that allows transactions to happen in the first place. First, in order for a financial market to function there needs to be some mechanism for aggregating and matching disparate transactional requests. Another mechanism is then needed in order to untangle and reduce the complexity of overlapping exposures between participants. The history of finance shows us that there are indeed certain patterns and regularities, procedures and mechanisms present in any system that processes financial transactions. The thesis describes this sequence of functions as transaction machines, understood as complex socio-technical systems for the execution of financial transactions. This is achieved by leveraging a specific philosophical account of technology coupled with a computational and evolutionary account of financial markets. We ultimately focus two types of transaction machines, performing the matching and clearing of financial flows, acting as the infrastructure of financial markets. We also provide a sketch for an evolutionary trajectory of these machines, evolving under the demands and needs of marker participants. From medieval fairs to the millisecond electronic platforms of today, transaction machines have gradually transitioned from human-based 'hardware' to electronic automated platforms. Moreover, we also describe the complex power dynamics of contemporary transaction machines. In as much as they are the dominant hubs of global financial markets, the thesis argues for the necessity of a more granular account of the functioning and evolution of transaction machines.

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Parts of Chapter 6 and 8 have been previously published[1].

[1] Dragos, B. and Wilkins, I. (2014) 'An ecological/evolutionary perspective on high-frequency trading', *Journal of Sustainable Finance & Investment*, 4(2), 161-175.

Table of Contents

List of Figures

Introduction

'Two hundred fifty milliseconds are hardly noticeable while talking, but it's long enough for a crowd to get ahead of you in the market' (Leinweber, 2009, p.72)

In 2010, a firm called Spread Networks unveiled a new fiber optic cable affording a 13.10 millisecond round trip between New York and Chicago. While this might seem like an unusual venture, high-speed connectivity is absolutely crucial in today's financial markets. In order to be successful today, latency must be reduced to a minimum, as argued by a recent study on the optimal geographical locations for trading (Wissner-Gross and Freer, 2010). Taking into account the distances between the major financial centers, Wissner-Gross and Freer calculated the precise strategic locations on the planet where one would have to position computers in order to optimize low-latency trading arbitrage. In any case, since the advent of electronic trading, our view of financial markets seems to be increasingly dominated by recent technological transformations. In fact, some have even suggested that finance deserves the same kind of attention as other complex technical systems, such as nuclear reactors, particle colliders or the Internet (Arnoldi, 2009). In fact, rather than allowing finance to be an enclave for economists, scientists such as Didier Sornette have offered deep insights into the working of the financial system, modeling it as a complex dynamic system (Sornette, 2003). This complements the more recent efforts in economic sociology to open up the black box of finance (MacKenzie et al., 2012). In any case, from the point of view of our contemporary situation, technology and financial markets seem to have two closely intertwined trajectories. One cannot begin to think about contemporary financial markets without being struck by their high level of technological sophistication. Nevertheless, what seems to be a recent development is perhaps better understood as a more complex long-term tendency. One could argue that finance has always been directly impacted by the latest technical developments from the streets of medieval Amsterdam and the coffee houses of London, to the millisecond electronic ecology of the 21st century. Going back in history, one can look at the impressive evolution form ancient Mesopotamia, where the venues of exchange were primarily religious temples (Swan, 2000) to the medieval fairs of Champagne (Braudel, 1982), the pits of modern futures exchanges

(Knorr-Cetina and Preda, 2005; Zaloom, 2006) and finally to the electronic low-latency data centers of today (MacKenzie, 2015). Reuters and the Rothschild Bank used carrier pigeons in the 19th century (Freedman, 2006), while the telegraph and the stock ticker transformed financial markets in their own right later in the century (Preda, 2009). Closer to our present, the adoption of information and communication technology (ICT) has allowed for the recent transition towards a truly global financial system, where more and more operation are being controlled by computer algorithms[2]. While it is certainly possible to think about the impact of technology on finance (Pardo-Guerra, 2012) or the way in which finance can be seen as a tool for achiving our goals (Shiller, 2012), it might be more interesting to think of financial markets in themselves as a series of complex technological systems processing and executing financial transactions. In fact, this constitutes the initial research question underpinning the whole thesis. Namely, is it possible to think about financial markets as being complex machines from the outset? Moreover, this initial position can actually be broken down in four different inter-connected research questions:

1. How can a broader notion of technology and machines be used to understand financial markets?
2. More to the point, can we understand financial markets as complex machines developed for the execution of specific financial transactions?
3. Does an understanding of financial markets as transaction machines offer a different perspective to some of the established approaches in the social sciences and humanities?
4. Can such an account, namely of machines designed for the processing of transactions, offer a meaningful understanding of the past and present of financial markets?

[2] Following the work done in Software Studies (Chun, 2006; Fuller, 2008; Manovich, 2013) it has become clear that algorithms guide most of our daily existence. *The Black Box Society* (Pasquale, 2015) offers a detailed account of how algorithms control more and more of our social interaction, including the financial flows of the global economy.

This thesis will attempt to answer, elaborate and develop these very questions through an interdisciplinary approach, leveraging insights from contemporary sociology, cultural theory, philosophy of technology and unorthodox economics. The first step is to understand that the term 'machines' is used in the broadest sense of the word, as socio-technical systems. But more importantly, that our understanding of machines is positioned within the trajectory of 20th century cybernetics, information theory and computer science. Current understandings of machines largely gravitate around the differentiation between a set of instructions and their material execution, that is to say, between software and hardware. Software (stored in the computer's memory) relates to instructions that cause the CPU to perform a certain set of operations. Hardware, on the other hand, relates to the actual material components of computers that run/execute the software (Kitchin, 2014). In short, any procedure or operation, which can be formalized as a set of step-by-step instructions, can also be translated or coded so that it can run on a machine. With the advent of modern computers, which essentially operate with symbols, there has been a decisive mutation in our understanding of machines as primarily information processing machines. In as much as this functional perspective can be translated into logical operations, machines are thus best understood as algorithmic structures (set of instructions) executed by specific hardware.

While all of this might seem too abstract, it is important to understand that what we mean by 'complex machines' are by no means a recent phenomenon, particularly. Following cybernetics and information theory, machines (or technology broadly) can be understood as any system that organizes material, energetic and information flows in the context of human social interaction. The history of technology thus moves from machines that required humans or animals to provide energy, then to machines that could access energy directly from nature (wind, water, combustion) and finally cybernetic machines, which achieve a higher degree of automation and autonomy through self-regulation. In fact, as Mumford understood them, the first machines were not made of bolts or cogs, but of flesh and blood, comprising human beings as component parts Mumford, 1967, 1971)[3]. This approach is similar to the work of historians of computation and technology such as Martin Campbell-Kelly, who understands Victorian data-processing institutions such as the Railway Clearing House or the Post Office Savings Bank as complex information processing machines whose 'hardware' was the Victorian clerk (Campbell-Kelly, 1998, 2010). Therefore, it is obvious that our perspective is indebted to the likes of Claude Shannon (1936), Alan Turing (1937), John von Neumann (1951) and Norbert Weiner (1965), all of who understood complex machines as information processing systems that can have a variety of material instantiations.

It was important to clarify what this thesis means by 'machines' as it allows us to differentiate from other approaches within the social sciences and humanities. As we will see in Chapter 1, within contemporary economic sociology there is a growing body of literature looking at markets in general and financial markets in particular through the lens of Actor-Network Theory (ANT)[4]. In this context, markets are understood as hybrid assemblages or associations of all sorts of elements. This thesis doesn't approach socio-technical systems as networks made up of discrete elements, either human or non-human. As we have said, drawing from cybernetics and computer science, we look at socio-technical systems in general as information processing machines with their own abstract schematic or algorithmic structure, controlling the way in which they perform certain functions. In the context of financial markets, these specific functions relate to the processing of financial transactions. For much of history, human beings and their technical artifacts have been the component parts of complex machines performing certain transactional functions. While the execution of these functions has recently shifted to electronic platforms, which an interesting development in itself, focusing too much on the composition of these complex machines runs the risk of missing their broader

[3] According to Mumford, as machines evolve they become less dependent on humans for their operation and direction (Trogemann, 2013a; Trogemann, 2013b).
[4] While these approaches are interesting in terms of offering insightful narratives of financial markets as a coming together of human beings and technical artifacts, they are less suited for giving an account of the long term evolution of financial markets as complex machines in their own right, performing certain transactional functions.

evolutionary trajectory. Namely that from the beginning, financial markets can be seen as certain types of complex machines and that it is possible to look at their operational architecture, independent of who or what executes the actual functions.

This could be an interesting approach, as financial transactions do not just occur randomly. Namely there are specific mechanisms entailing certain operations and sequences of instructions, affording the execution and settlement of financial transactions. This of course points to the fact that most transactional processes entail rule-based structures (which can thus be formalized[5]) and suggests that financial markets[6] have an algorithmic or technical nature from the very beginning. This points to the second step, namely that it is possible to model and understand even the oldest forms of financial markets as comprising precise rules and procedures that can be formalized as a series of algorithms. Moreover, the way in which humans interact with the market can also be seen in an algorithmic gaze[7]. In this sense, the thesis endeavors to understand the 'machinic' nature of financial markets as something intrinsic to their mode of functioning, rather than as a recent epochal shift disrupting a pre-established social structure (Knorr-Cetina and Bruegger, 2002). Rather than focusing too much on the recent impact of electronic trading and e-commerce, one should perhaps ask in what way have financial markets always been complex machines, i.e. socio-technical systems. In as much as one looks even at the earliest and simplest designs, one can already see the basic blueprints of machines constructed for the purpose of processing some form of financial transaction.

In order to fully grasp what is at stake in this account of financial markets as complex machines we will engage with a particular philosophy (Gilbert Simondon), opening

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[5] The formal nature of these process points to the fact that they can be described as specific algorithms.

[6] We define financial markets as the venues where buy and sell requests are aggregated and executed.

[7] The philosopher John Searle (1995) has rigorously analyzed the formal nature of social institutions, based on his understanding of language as a system of rules for the production of speech acts.

up an understanding of technology as a complex evolving system in its own right. In addition, as we engage with the detailed operations of financial markets in a more granular way, we will also leverage a specific approach to markets as formal automata, or information processing systems (Philip Mirowski). Once we have a clear understanding of financial markets as complex machines for the processing of transactions, we will attempt to read through the history of these markets from the Middle Ages to the present. At the end, through a series of interviews, we will also endeavor to analyze some of the recent developments affecting the very structure of financial markets. The overall aim is not simply to satisfy a theoretical curiosity on the topic of the technological or 'machinic' nature of financial markets. The ultimate goal is to show how this perspective can be used to offer a different understanding of the history of financial markets and shed a light on their contemporary transformations.

What is a Transaction Machine?

While most people would profess to have a clear and transparent understanding of what it means to transact, it is certainly worth distinguishing it from the broader category of exchange. Within the social sciences, the notion of exchange has long been considered as one of the most basic forms of social interaction. For Max Weber, exchange was a voluntary agreement between parties ''in the course of which goods or other advantage are passed as reciprocal compensation'' (Weber, 1978, p. 72). One basic example of this is barter, where something changes hands without any kind of monetary quantification. In the case of Georg Simmel, ''exchange is the purest and most concentrated form of all human interactions'' (Simmel, 1971, p.43). For him, this social form has a certain sacrificial nature, because in the course of exchange you have to give up something in order to gain something new. For both of them, the introduction of monetary exchange represents a major turning point in terms of rational quantification of goods, replacing personal economic ties with more impersonal formal relationships (Simmel, 2011). Once the monetary equivalent is in place, exchange fundamentally takes a transactional form whereby a buyer and a seller enter into a legal agreement to transfer an asset for a monetary payment. In this sense, transacting entails the negotiation, writing, execution and enforcement of legal contracts/agreements, with the end result of exchanging property rights over certain assets for money. Therefore the transactional form of exchange requires a certain formal institutional and technical[8] framework within which it can be executed.

At the same time, it is important to note that throughout history transactions have been performed by a variety of different means including clay tablets, metal coins, double-entry books, centralized ledgers, electronic order books, blockchains, etc. For instance, in his recent work, Michael Castelle (2014, 2015) has gone to great lengths in researching the most recent stage of the technological formalization of transactions. For Castelle, a transaction is that form of ''exchange which in its

[8]As Oliver Williamson pointed out, ''transactions occur when a good or service is transferred across a technologically separable interface'' (Williamson, 1981, p.552).

conceptual disembeddedness has been most amenable to implementation via symbolic intermediating systems'' (Castelle, 2015, p.1). While the formal nature of any transactional operation is probably as old as accounting and money itself, Castelle constructs a recent genealogy of the financial and technological innovations resulting in the current omnipresence of standardized and automated transactional capabilities. In his work, he highlights the crucial aspects of contemporary transactions: atomicity, consistency, isolation, and durability, in the context of ICT and relational databases going back to the 1970s and 1980s (Castelle, 2015, p.2). In this context, these features refer to the fact that a transaction is a discrete operation, it has a beginning and an end, it either completes or it doesn't. In addition, its execution is recordable and retrievable and it can be audited at a later point in time (Castelle, 2015, p.24). Perhaps more importantly still, a transaction is seen as a reversible operation similar to most process entailed by information processing systems. In his view, the formal nature of transactions is largely why contemporary economic exchange becomes increasingly dominated by automated electronic platforms processing global financial flows.

From a broader historical perspective, whether they are executed with a pile of blankets, as records in a ledger or as changes in electronic databases, we can understand transactions as formal procedures executed over an information-processing medium. This doesn't seem so strange once we understand the act of transacting from a functional perspective, as the execution of a step-by-step process, i.e. an algorithm. The history of markets shows us that there are indeed certain patterns and regularities, procedures and rules evident most complex machines that process financial transactions. In fact, it might be interesting to look at one example that has apparently almost no technological underpinning or financial complexity, as for instance the research done on the Kwakiutl tribe in North America (MacLeod, 1925). It is commonly held that North-American societies were non-monetary societies in the Western European sense, and that they relied heavily on a gift economy (Curtis, 1976). Few things could be more different from western financial markets then the famous potlatch, a massive exchange of gifts, the result being status gains within the community. One example regards gifts comprising pieces of metal such as copper, which were particularly valued for potlatch purposes**.** The drive and determination to pursue the ritual of potlatch posed specific transactional problems, of how to actually get hold of copper plates. As a response to bottlenecks, the tribe developed an interesting practice called ''giving-out-of-the-door'' (MacLeod, 1925). The central mechanism was a pile of blankets, which can be seen as a centralized ledger. When a certain quantity of copper would become available, the seller and the buyer would meet under the eyes of the whole tribe. The potential acquirer o copper would advance his pile of blankets but there was a risk that the quantity was not enough to cover the needs of the copper seller. In that case, the buyer would call upon some other tribe member who owed him a debt and ask him to pay his debts. If this third person could not repay his debt, he might call upon the first person (the initial seller of copper) and ask him for credit. If the seller of copper agrees, he could take some blankets from the central pile and extended them as credit to the third person, who in turn pays his debt to the second participant by putting the blankets back on the pile. What happened was, in effect, a transfer of accounts, with the ''physical handling of the blankets merely being a visualization of the transfers for the benefit of the surrounding witnesses'' (MacLeod, 1925, p.454). What is important to note is that the central pile of blankets functioned as a transactional mechanism for reducing the complexity of conflicting balances. That is to say, what we have here is a socio-technical system made up of human beings and technical artefacts whose primary function is to clear the bottlenecks of an overlapping series of transactions.

This is of course a much too simplistic example of what happens in contemporary financial markets. But it does highlight the importance of certain transactional mechanisms, which can be modelled as instructions subject to algorithmic formalization and can thus be executed on number of different physical hardware[9]. As we will see, modern financial markets entail a number of different, and quite complex mechanisms performing a number of transactional functions. First, in order

[9] We can reference here most of the literature on market design, microstructure research, experimental economics, etc. We will develop this further in the context of Philip Mirowski's theory of markets.

for a financial market to function there needs to be some system for aggregating and linking disparate transactional requests (matching). Second, the growth of trading volumes leads to complex overlapping exposures between participants. Another mechanism is then needed in order to untangle and reduce the complexity of transactional flows (clearing). This simplified sequence of functions, composed of very specific step-by-step procedures and instructions, represents a basic blueprint of the infrastructure of financial markets, which affords smooth flow of financial transactions[10].

For the purpose of this thesis we put forward the notion of transaction machines[11] as those socio-technical systems performing certain functions that maintain the flow of financial transactions, otherwise understood as the infrastructure of financial markets. In terms of their most basic formal blueprint, these machines receive a certain number of inputs (trade requests/orders), process them according to a set of rules and procedures (algorithms) and provide certain outputs. Transaction machines should not be conflated with the wider and more complex phenomenon of financial markets, but are best understood as the basic infrastructure of these markets, maintaining the regular flow of financial transactions. Moreover, looking at the history of financial markets, one can see how specialized human individuals and technical artifacts assemble together as complex machines processing and maintaining the flow of financial transactions. Different transaction machines perform different functions such as aggregation, matching, clearing, settlement, custody, order routing, dissemination of price information, reporting, etc. (Lee, 1998)[12].

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[10] We will devote a considerable part of the thesis to tracking the evolution of some of these systems for the special case of certain financial securities.

[11] Throughout the thesis we understand machines as socio-technical systems in the broadest sense. This is very much in the tradition initiated by Lewis Mumford (1934, 1967, 1971). In his account, the first machines were not made of bolts or cogs, but were very much social machines, comprising human beings as component parts.

[12] It is important to note that we do not apply this framework to the economy in general but only to the exchange of securities such as stocks, bonds, exchange traded derivatives (futures, options), over-the-counter products (interest rate swaps, credit default swaps, repos, etc.).

Over the course of the thesis we will only focus on two functions**,** namely matching[13] and clearing [14], in the specific context of specific financial markets. For instance, a matching machine would receive a number of orders to buy or sell certain quantities of financial securities at certain price levels. These disparate requests would then be matched according to a specific algorithm producing certain outputs such as the most up to date market price for that security. In a less complicated scenario, the final settlement of these requests can happen on the spot directly between participants. But in the case of financial securities such as stocks, bonds, futures, options, etc., the accumulation of complex and overlapping trading positions is inevitable. A second systems is thus required, namely a clearing machine that receives the different exposures of each market participant as inputs. Through the use of another algorithm, this second machine would reduce the complexity of trading positions by netting offsetting[15] exposures.

As we have said, the execution of these functions follows different algorithms, which have qualitatively and quantitatively different outputs and are more or less resilient. Over time, more elaborate designs emerge under the pressure of larger trading volumes and more complex financial products. Thus the daily operation of these machines transitions from human-based 'hardware' to electronic systems exhibiting ever-higher degrees of automation and standardization (Muniesa, 2003; MacKenzie et al., 2012; Pardo-Guerra, 2012; Beunza and Millo, 2013). Finally, as these transaction machines become the dominant hubs of financial flows, they are also crucial for understanding the complex power dynamics in both old and contemporary financial markets.

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[13] Matching refers to the collection of intentions to trade (orders/requests) and their subsequent execution.

[14] In economics, the standard definition of clearing refers to the convergence between supply and demand and the discovery of a price that clears the market. In financial markets, clearing can also refer to the management of trade exposures between matching and final settlement, which includes operations such as netting, novation and risk management through margining.

[15] Offsetting positions are trades that cancel each other out.

Theory, History and Empirical

The genesis of the thesis began by reading the recent of literature in the social sciences and humanities where social-technical systems are understood as hybrid assemblages, associations or networks comprising a diverse set of elements. This includes broader philosophical accounts such as Manuel DeLanda's assemblage theory and the new economic sociology of financial markets, the so-called Social Studies of Finance (SSF). Both of these strands of theory address the topic of markets in general and financial markets in particular based on what can be roughly called an assemblage view of the social and the technical. This triggered an interest for the changing landscape of contemporary financial markets, particularly in terms of the impact of information technology on the structure of finance. In this regard, the SSF literature leverages the theoretical and ontological framework of Actor-Network Theory, paving the way for an understanding of markets as assemblages comprising human beings and technical artifacts. This approach leads to detailed descriptions of the complex web of relations that make up the day-to-day existence of financial institutions, markets and actors. In addition to that, we reviewed some of Manuel DeLanda's recent work, where markets are understood as complex assemblages made up of physical, biological, social and technical components. Both of these approaches suggest that the functioning of financial markets cannot be reduced to a set of inter-personal relations, so that any account of these systems needed to seriously consider the ontological overlap between the social and the technical. Moreover, DeLanda's work also suggested that some of the recent technological transformations of financial markets are perhaps part of a more complex longer-term process, thus the importance of history and evolution in his work. The confluence of these two strands ultimately led to one of the research question of the thesis. Namely, is it possible to think of financial markets beyond understanding them as assemblages of a multitude of discrete elements (particularly human begins and technical artifacts). If the recent technologization of financial markets is part of a longer-term process, then perhaps these markets are best understood as machines from the very beginning. That is to say, drawing from an understanding of machines as information processing systems (i.e. cybernetics, computers science, etc.), one could focus on the detailed functioning of these systems rather than their composition. Perhaps a more adequate approach would be to think of these systems as transaction machines in their own right. In this context, the way in which different elements (both human and non-human) come together becomes secondary to what exactly it is that they to, the way in which a specific design performs a transactional function. The aim of the thesis thus shifted to understanding financial markets as having always been complex machines in their own right, focusing on the infrastructure that performs the execution of financial transactions.

The next step was to acknowledge that, in order to achieve this goal, it is necessary to adopt a broader inter-disciplinary theoretical framework. On the one hand, we looked for a broader perspective on technology, giving an account of machines as information processing systems. Drawing from cybernetics, information theory and the history of technology, Chapter 2 of the thesis focuses on the work of French philosopher Gilbert Simondon. Following his account of what he calls technical ensembles, we gain an understanding of machines as complex systems defined by certain operational schematics, i.e. their formal algorithmic mode of functioning[16]. While for most of history, humans have been the most important component parts of complex machines (technical ensembles), the advent of modern information processing capabilities leads to an increased degree of autonomy in relation to humans. Importantly for Simondon, the actual make up of these machines is secondary to the way in which the actual operational design or mode of functioning evolves through time. On the other hand, while Simondon looks at the evolution of machines in general, our aim was to focus on the granular details of specific machines underpinning the functioning of financial markets. In this sense, Chapter 3 focuses on the work of Philip Mirowski and his theory of markets as specific types of information processing machines. Similar to Simondon, Mirowski's perspective is heavily indebted to cybernetics and computer science. In his account, specific market functions are formal automata, understood as algorithmic structures

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[16] Their basic functioning is akin to any input/output system in that they receive a certain number of inputs, which are processed according to a set of rules and procedures/algorithms and provide certain outputs.

performing a series of functions relative to the processing of transactions. In other words, Mirowski thinks of financial markets as machines running a series of algorithms, ultimately evolving under the constraints of human culture and society[17].

Thus, leveraging both Simondon and Mirowski, the thesis began to frame financial markets as some sort of information processing machines performing a number of functions, such as processing the flows of financial transactions. It became clear that using Simondon and Mirowski (following cybernetics, computer science, information theory, the history of technology) it would be possible to give an account of financial markets substantially different form SSF as well as DeLanda's assemblage theory. As our understanding of transaction machines matured, it also became clear that history would have a crucial part to play in any kind of adequate account of the contemporary transformations of financial markets as for both in Simondon and Mirowski the present is intimately linked with past evolutions. The next logical step was thus to apply the theoretical framework to several historical examples in order to track the long-term evolution of transaction machines. Consequently, Part II of the thesis comprises three chapters where the framework of transaction machines is used in order to read through or re-interpret the evolution of financial markets from medieval times up to the present.

The first encounter with the history of financial market occurred in the context of Fernand Braudel's encyclopedic work comprising *Capitalism and Material Life 1400-1800* (Braudel, 1975) and *Capitalism and Civilization 15th-18th Century* (Braudel, 1981; 1982; 1984). Braudel's work addresses the complex history of the European economy, tracing the roots of medieval commerce, finance and their impact on modern capitalism. More importantly, his work offers detailed descriptions of market institutions and the genesis of medieval finance. From this starting point the present thesis branched out into the secondary literature looking the history of

[17] In a period when technical artifacts were more primitive, these functions had to be performed by human beings and their prosthetics. In our contemporary situation, the execution of these functions has been integrated (coded) within the internal workings of computers.

medieval finance. As we will see in Chapters 4,5 and 6, the thesis provides a review of the history of medieval merchant banking as well as the genesis of financial institution such as brokerages, exchanges and clearinghouses.

While drawing from a diverse set of secondary historical sources, this thesis is nevertheless driven by theory and the attempt to construct a framework allowing for a better understanding of past and present financial markets. While a large part of the thesis is engaged with historical narratives, this is by no means a history of financial markets in the classical sense[18]. The three historical chapters should be seen as the canvas on which the thesis attempts to paint the evolutionary trajectory of certain transaction mechanisms, of machines performing functions relative to the processing of financial flows. Throughout the thesis, it is the theoretical understanding of transaction machines that guides the reading and interpretation of medieval, modern and contemporary financial markets. Nevertheless, the reading of history also provided valuable feedbacks for the theoretical framework. The history of finance shows us that there are indeed certain patterns and regularities, procedures and mechanisms present in any system that performs certain transactional functions. Moreover, it also indicated that the thesis should focus on two distinct types of functions, that of matching and clearing as the essential mechanisms underpinning the existence of financial markets. Therefore, this led to a reading of the historical evolution of financial markets through the gradual development of these two types of transaction machines. Where the standard historical account (Ferguson, 2008) might focus on the way in which financial 'technicians' invent new products and create new financial institutions, this thesis sees the gradual evolution of specific transactional designs and algorithms. Over time, it is interesting to see how both the 'hardware' and the 'software' of these machines changes and responds to various pressures and constraints (technical, social, cultural, etc.). The table below offers a visual illustration of our understanding of the historical evolution of transaction machines:

[18] Each chapter comprising Part II of the thesis is effectively a review of the secondary literature addressing the history financial markets.

	Components		
Medieval	Bills of Exchange, Stocks, Bonds	Brokers, Merchants-Bankers	Bourses Clearing Fairs[19]
Modern	Stocks, Bonds, Futures, Options,	Brokers, Jobbers/ Specialists	Exchanges Clearinghouses
Contemporary	Stocks, Bonds, Futures, Options OTC (IRS, CDS, etc.)	Electronic Order Books Real-Time Clearing Systems	ECNs, MTFs, SEFs[20] CCPs[21]

Figure 1: Historical sketch of transaction machines

As we progressed through the theoretical and historical chapters, our initial position was reinforced, namely that the framework of transactions machines offers a different way of approaching financial markets, particularly in light of recent events such as the 2008 financial crisis. Within public discourse, the critique of the financial system has largely revolved around the moral condemnation of greed, the age-old problem of debt accumulation or the inherent contradictions of capitalism. Different to these approaches, our framework allows us to deconstruct the functional layers of financial markets and understand that the current structure of finance is part of a long and convoluted history. Moreover, it also allows us to see that there are different designs pertaining to different transactional functions and that throughout history, a certain community of users relied on complex machines for the maintenance of financial flows. It shows us that certain transactional designs are more or less efficient in processing flows, more or less resilient in the face financial shocks and thus can have a very different impact on the stability of financial markets. It finally allows us to distinguish between ways of organizing financial markets that are less robust but perhaps more profitable and other ways that are

[19] Medieval Bourses where essentially meeting places for merchants, while clearing fairs allowed them to reduce and settle overlapping exposures.

[20] ECNs (Electronic Communication Networks) are electronic trading platforms for share and bond trading in the US, MTFs (Multilateral Trading Facility) represent the European equivalent of ECNs and SEFs (Swap Execution Facility) are the new generation of electronic platforms for Over-the-Counter (OTC) derivatives.

[21] CCPs (Central Counterparties) are clearinghouses that perform central clearing, becoming the buyer to every seller and the seller to every buyer.

more resilient but are perhaps more difficult to implement, expensive to maintain and therefore less profitable. Therefore, instead of rejecting finance outright it would be more interesting to look at the long evolution of transaction machines and how it helps shed a different light recent events such as the 2008 financial crisis.

Consequently, Part III of the thesis applies the transaction machines framework to the current state of finance. This is achieved by reviewing the secondary literature within economic sociology and financial economics, dealing with issues such as electronic trading, automated market making, high frequency trading and centralized clearing. Moreover, in order to get a better grasp of current developments we began a series of interviews with professionals from the financial services industry. The aim was to focus on the current state of clearing machines, in the context of the regulatory overhaul in the OTC derivatives markets post the 2008 financial crisis. It is important to highlight one of the limitations of the research, as the results represent only a limited snapshot at a particular point in time. Nevertheless, this was an attempt to introduce a certain empirical dimension to the thesis. The semi-structured approach was complemented by open-ended questions, through which interviewees were encouraged to expand were appropriate. During the course of the interviews it became clear that the major themes emerging could be brought back and reinterpreted in light of our transaction machines framework. Namely, that the intricate details surrounding the current regulatory reforms could actually be understood as a process of redesigning a complex machine. The reform represented the transition from a bilateral to a centralized clearing design, from a more opaque and fragile to a more transparent and more resilient clearing machine. We also discovered that most of the technical details of this process of reconfiguration were also political. As we will see, the new centralized clearing design was also in the process of altering the power distribution and dynamics of these markets, shifting the centre of gravity from the dealer banks to clearinghouse. As one interviewee described it: ‘‘everything technical is political’’.

This thesis thus revolves around a theoretical account of financial markets through the interdisciplinary lens of transaction machines. Both the historical and empirical chapters function as the foundation allowing us to unfold the various layers that make up the convoluted trajectory of transaction machines. The final aim is to demonstrate that it is possible to gain a different understanding of financial markets by focusing on the actual functioning of their transactional mechanisms. Moreover, this allows us to focus on what is at stake in the current transformation of transaction machines, which is particularly important in terms of the political economy contemporary finance.

Chapters

Chapter 1 reviews the so-called Social Studies of Finance (SSF), underpinned by Actor Network Theory (ANT) and Manuel DeLanda's account of markets, according to assemblage theory. Both approaches share a common ground in thinking in terms of socio-technical hybrids (so-called assemblages or *agencements* of human and non-human elements) while highlighting the importance of materiality and technical artefacts in the shaping of markets in general and financial markets in particular. Drawing from Simondon's philosophy and Mirowski's economics, (both influenced by cybernetics and computer science), we propose a different framework by looking at financial markets as complex machines in their own right, performing a series of functions relative to the processing of financial flows.

Chapter 2 is devoted to the work of Gilbert Simondon, who understands technology as an individuation or as complex systems in itself. The most common mode of existence of technical objects is what he calls technical ensembles (made up of humans and technical artifacts) performing specific functions. For Simondon, the composition of technical ensembles becomes secondary to the technical schematic/design, i.e. the actual algorithmic blueprint. Moreover, each new generation of technical ensembles is more complex and integrates a larger umber of component parts, while also becoming less reliant on human beings for maintenance and self-regulation. While Simondon focuses on technology in general, we leverage his perspective in looking at financial markets as machines for the processing of financial flows.

Chapter 3 builds on the previous chapter by addressing the detailed operations of markets and looking at specific transactional designs. This is achieved by leveraging Philip Mirowski's theory of markomata (markets + automata). In this context, markets are seen as formal automata, as algorithmic structures performing a series of functions relative to the processing of transactions. While also being heavily influenced by information theory, computation and cybernetics, Mirowski has a more narrow focus than Simondon, looking specifically at the ways in which certain transactional functions are performed in the context of markets. Thus, leveraging both Simondon and Mirowski, the thesis can begin to frame financial markets as some sort of information processing systems performing a number of functions in regards to processing the financial flows.

Chapter 4 applies this theoretical framework to the history of financial markets. We start with medieval Europe and describe the development of two different types of transaction machines, a matching machine and a clearing machine. Both of them developed in order to service the needs of international merchant-bankers and their intricate web of transactions. The first matching machines developed around the activity of brokers and their specific matching algorithms. With the increase in transaction volumes, merchant-bankers also needed to reduce and compress the complex web of exposures accrued amongst themselves. Thus a new clearing machine developed in the context of the clearing fairs of Champagne and Piacenza. While they represented a substantial increase in transactional capability, these machines were essentially based on human beings and required extensive manual labor.

Chapters 5 and 6 shift the focus to modern financial markets, looking at some of the innovations developed in Amsterdam, London and New York. Among these, we will focus on the advent of floor trading in stocks and derivatives, and the development of specialized individuals (such as jobbers and specialists) allowing the stabilization of more efficient transaction machines, in the context of exchanges and clearinghouses. Using Mirowski, we identify an evolutionary trajectory whereby more complex and transaction machines emerge over time, evolving under the constraints and demands of users. These constraints can comprise everything from higher trading volumes, more diverse trading strategies, decrease in order size, more complex products, need for faster execution, more complex financial instruments, to more scrutiny and regulation. In this sense, the recent push for automation and efficiency has led to the development of more advanced matching machines, in the context of electronic trading. We will also construct a similar narrative for the clearing function focusing specifically on the central clearing for derivatives and the emergence of new clearing machines in the form of Central Counterparties (CCPs).

Chapter 7 engages with the most recent transformation of matching machines, in the context of High Frequency Trading (HFT) and electronic market making. Within the current ecosystem of electronic trading, HFT trading firms are at the forefront of an arms race for higher speeds, lower latency and more advanced algorithms. Being at the centre of liquidity and controlling the matching of order flow affords a crucial advantage in any market as well as substantial profits. We also offer an understanding the 2010 Flash Crash in arguing that while HFT firms are not directly to blame for the crash, such events might now be the normal output of HFT-dominated financial markets. While contemporary matching machines have reached high levels of efficiency and immediacy of execution, there are important concerns regarding market stability. We also review some of the current reform initiatives and new market designs, shifting the focus from immediacy of execution the quality of liquidity and overall market resilience.

Chapter 8 looks at the contemporary reforms of clearing machines for complex financial products such as Over-the-Counter (OTC) derivatives, following the 2008 crisis. We thus review the impact on OTC markets in the context of current regulatory reforms mandating the shift from bilateral to central clearing. The chapter also summarizes a number of interviews with professionals of CCPs, exchanges, global banks, trade associations, UK and EU regulators and independent consultants. We highlight the fact that the details of the new clearing machine are not just technical issues but directly impact the power distribution within market, shifting the centre of gravity from banks to central clearing utilities such as CCPs. While the post-crisis period has been dominated by the critique of major banks, it is the integrated financial infrastructure providers that are now the dominant transactional hubs increasingly controlling the matching and clearing of financial flows.

PART I: THEORY

Chapter 1. Markets and Assemblages

Summary:

The aim of this chapter is to position the thesis within the social sciences and humanities literature on the topic of finance. It also highlights the merits and limits of certain approaches such as the Social Studies of Finance and DeLanda's assemblage theory as applied to the topic of markets and capitalism. We review the recent sociological and anthropological research on financial markets and elaborate on some of its theoretical underpinnings, such as Actor Network Theory (ANT). In this context, financial markets are understood as hybrid assemblages, composed of both human and non-human elements. While the sociology of finance offers detailed description of markets as hybrid assemblages, it is less capable of grasping the 'machinic' nature of financial markets. Drawing from cybernetics and computer science, we propose a different framework by looking at financial markets as complex machines in their own right, performing a series of functions relative to the processing of financial flows. We also review Manuel DeLanda's assemblage theory and his history of capitalism, which is another account of markets as complex socio-technical assemblages. While providing an insightful narrative, DeLanda cannot describe market structures in any relevant detail, while contending himself with simple dichotomies (markets vs. antimarkets). While it is important to incorporate DeLanda's historical and evolutionary approach, an account of transaction machines requires a deeper engagement with the detailed functioning of financial markets, which is difficult to achieve in the context of his assemblage theory. Finally, this chapter sets the stage for the subsequent theory chapters, where we leverage Gilbert Simondon's philosophy of technology and Philip Mirowski's theory of markets as computational systems. The overlap of these two thinkers will afford a more rounded and elaborate definition of transaction machines.

1.1 New Sociology of Finance

Once could argue that there has always been a certain interest for the topic of finance within the broader social sciences and humanities (Simmel, 1978; Menger, 1892; Proudhon, 1857). Max Weber addressed the topic of financial markets early on, in his 1894 essay entitled *The Stock Exchange* (Weber, 2000*)*. In that context, he describes some of the institutional aspects of 19th century German stock and commodity exchanges. In his account, he criticizes the view that these institutions were simply ways to defraud ordinary investors. While he acknowledged that plutocratic financiers could dominate public exchanges, these institutions were necessary in order to modernize the German economy. Moreover, he saw the modern stock exchange as a promoter of the national interest as ''a means of power in the economic struggle'' (Swedberg, 1998, p.184). More recently, there has been a renewed interest in the topic of markets and finance within the social sciences broadly. This comprises anthropological and sociological analyses focusing on a variety of different financial institutions (Mark Granovetter, 1985; Granovetter and Swedberg, 2001; Abolafia, 1996; Fligstein, 1996; Callon, 1998):

> (…) In the reconstituted perspective of economic sociology, markets are not merely mechanisms for the exchange and re-allocation; they are, overall, signalling systems embedded in a wider set of social relations that allow evaluating risks, dealing with uncertainty, and stabilizing economic networks across space and time (Pardo-Guerra, 2013b, p.5).

This new avenue for social research is clearly trying to set itself apart from the more traditional understanding of financial markets developed in economic theory. Rather than looking at markets as mechanisms for the efficient allocation of resources among scares means, this literature understands financial markets as very specific social structures. More recently, a growing body of research has been focusing on the impact of technology on the structure of finance. To a certain extent, the question of technology has been a central concern in sociology for some time (Lash, 2002; Castells, 2004) but this new sociology of finance revolves around a new strand of social theory namely the Actor-Network Theory (ANT) developed by the likes of Bruno Latour (1991, 1993, 1996) Michel Callon (1998) and John Law (1992). ANT represents an important theoretical turn within the social sciences in that it entails a novel approach to age-old question of the social. To be more precise, they adopt a constructivist position whereby what exists are associations of people and things. The study of the social is no longer at the centre of sociological inquiry, but the research and mapping of various associations (Gane & Beer, 2008, p.82). In addition to human beings, these associations and inevitably made up of other objects. In this sense, ANT expands the realm of sociology beyond human interpersonal interactions. Within this new paradigm, human beings are no longer the only relevant objects of social research**:**

> For no longer is it possible to treat social relations as arising simply from human relations (as did Marx and Weber), to confine social interaction to the face-to-face interactions of human 'agents', or to talk of society in the same breath as the social (as was the trend for the majority of the twentieth century (Gane, 2004, p.1)

In this sense, ANT provides an alternative to the social theory developed in the 19th and 20th century. Following Latour's work it becomes problematic to continue to think of human beings as self-contained social agents, as 'islands' of agency within an 'ocean' of passivity. The traditional framework of social theory grants human beings an absolute monopoly in terms of agency, power and control in relation to their environment. This of course extends to technical artifacts, which only exist as expressions and extensions of human agency. In this context, the human is a tool-bearer and technical artifacts are simple means of amplifying human agency. Contrary to this tradition, ANT grants no privilege to human individuals and their motivations. Social actors have no essential nature but become what they are through their interaction in a network, where an actor can ''literally be anything provided it is granted to be the source of an action'' (Latour, 1996). Within the framework of ANT, both human and non-human elements interact in material and semiotic ways, and ultimately stabilize in coherent forms of associations or networks. Consequently, agency comes from the coordination of a diversity of elements within a network and a certain dynamic between human and non-humans (their interaction is understood as a negotiation or a translation) (Callon, 1984). While this approach was first used in the anthropology of science, thanks to the work of Latour and Callon it has also been adopted in sociology more broadly and economic sociology in particular. Rather than relying on reified notions such as the Market, or Capitalism, this new sociology attempts to describe economic institutions as complex processes of assembling and disassembling where actors, knowledge, scientific theories and technological artefacts all play a part (Muniesa and Callon, 2003; MacKenzie, 2009a; Callon and Latour, 2011). As Michel Callon understands it:

> (…) the way we are now studying social sciences is only an extension of the work done on the natural sciences. It's simply the continuation of the anthropology of science, but an anthropology of science which is concerned with economics in the broadest sense of the term, including, for example, marketing and accountancy (Barry & Slater, 2004, p.101).

One of the most famous examples of the so-called Social Studies of Finance (SSF) is Michel Callon's well-known book *The Laws of the Markets* (Callon, 1998). In that text, he introduces the crucial understanding of performativity, challenging the neutrality of economic models and showing how they actually help construct what he calls market devices. This point has also ben addressed by Donald MacKenzie and Yuval Millo, arguing against an understanding of economic theory as an accurate description of the economy (Millo and MacKenzie, 2009), and interpret it as being part of a process that creates the economy. Callon and MacKenzie shows us how economic theory can be deployed in order to induce patterns that end up converging with the initial theoretical predictions, such as in the case of the Black-Scholes formula for pricing options (Herrmann-Pillath, 2012). That being said, the use of performativity as a guiding concept can be confusing, as it can easily be understood in linguistic terms as an enunciation, a performative declaration[22]. What Callon

[22] Speech act theory has been developed by John Austin (1962) and later refined by John Searle (1969).

actually means by performativity is that when a model is adopted, endorsed by market participants this contributes to it being true (successful), which feeds back to the interactions between market participants and further normalizes its use (Callon, 2007). In this sense, performativity is much more a question of a performance in the sense of acting something out, deploying a certain process of framing and formatting. Similarly to the option pricing formula, Callon's looks at how in the wider economy, something like *Homo Economicus* (i.e. the rational economic agent) comes about through the performative effort of mainstream economic theory. Many voices have criticized Callon's performativity thesis, either for lack of proof (Fine, 2005; Santos and Rodrigues, 2009) or its neutrality towards the neoclassical tradition (Nik-Khah and Mirowski, 2007; Whittle and Spicer, 2008). Nevertheless, Callon's approach has been crucial in opening up new kinds of questions, such as understanding the impact of financial and economic theory on certain financial products or broader market dynamics (MacKenzie and Spears, 2014).

While Michel Callon has applied ANT to economic sociology and market institutions more broadly, it was Donald MacKenzie who offered a more rigorous theoretical framework for SSF. In fact, the collective work of Donald Mackenzie, Yuval Millo, Fabian Muniesa, Daniel Beunza, Karin Knorr Cetina, Alex Preda and Juan Pablo Pardo-Guerra, to name but a few (Arminen, 2010) is now considered the core of a new sociology of financial markets. All of these social scientists attempt to understand the ''hybrid, social, technical and material character of market devices'' (Mcfall, 2009). Donald MacKenzie's statement that ''all sociology should be material sociology" (MacKenzie, 2009b, p.88) highlights the fact that all sorts of elements are crucial in understanding the functioning of social institutions and financial markets in particular. His research on the LIBOR rate analyses the rate setting mechanism as a market device composed of different arrangements of humans and technical artifacts (MacKenzie, 2009b). In fact, considerable efforts have been made in exploring the way in which existing markets have reacted and adapted to the disruptions entailed by contemporary technology (Muniesa, 2003; Zaloom, 2006). Moreover, MacKenzie's percept that ''equipment matters'' means that technical artifacts are crucial in understanding the way in which economic agents and markets are assembled. One can reference here the work done by Alex Preda (2009) on the stock ticker and its influence on 19th century Chartism and the more recent influence of computer screens on market dynamics (Knorr-Cetina and Preda, 2006). Within the broader framework of ANT MacKenzie understands financial markets as necessarily collective, in the sense they are associations of human beings, tools, technological platforms, otherwise articulated as market devices or *agencements* (Callon and Caliskan, 2005; Hardie and MacKenzie, 2007; Arminen, 2010)[23].

In this sense, SSF look at how human actants mobilize alliances with non-human actors (algorithms, formula, technical artifacts, etc.) in order to construct financial markets. This ultimately begs the question whether or not human actants are absolutely necessary for these assemblages to function. Given the state of contemporary financial markets and the tendency towards electronic and automated trading, it might be more interesting to give an account from the point of view of the technological infrastructure itself. That is to say, to look at the evolution of financial markets as the gradual development of more complex technological systems. Juan Pablo Pardo-Guerra has probably gone the furthest in researching the complex dynamic between finance and the evolution of technical infrastructure. In his description of the automation of the London Stock Exchange (Pardo-Guerra, 2010; Pardo-Guerra, 2012), he provides a detailed account of the mutation of market devices from human dominated configurations to electronic automated systems. Moreover, in a recent paper he offers a detailed description of the evolution of stock markets through the history of a technical object, the electronic order book (Pardo-Guerra, 2013a). As we will see later, the electronic order book represents the most recent disruption, ushering a new era in financial markets, such as the advent of electronic computerized trading. While Pardo-Guerra tends to focus on the work of the financial engineers who helped bring this new infrastructure into being, he also proposes a novel avenue of research for SSF. As he puts it, the current sociological research on financial markets does not deal with:

[23] Their use of the language of assemblage theory occurs with minimal reference to Gilles Deleuze and Felix Guattari (1988) and none to the more recent assemblage theory of Manuel DeLanda.

> (…) how these infrastructures came to be, but rather with the imbrications between devices, social institutions and economic practice (…) Answering the question of how markets change needs engaging with an obviated fact: infrastructures matter (Pardo-Guerra, 2013a, p.5)

That is to say, most researchers look at how traders, bankers, economists, regulators, technological artefacts, economic theories assemble in networks in order to achieve certain objectives, such as creating a market for credit derivatives (Huault, 2009), profiting form arbitrage trades (Stark, 2009) or assembling a hedge fund (Hardie, 2007). Pardo-Guerra's infrastructural perspective represents an interesting shift in focus, looking at financial infrastructures as being already there in the background, but without which no transactional process would be possible. He also looks at how the recent evolution of stock markets has largely been a process of challenging the dominance of legacy technological infrastructures. In this sense, in order to understand the genesis of a certain financial markets he starts with their technical and infrastructural underpinnings.

This thesis is situated at this very junction, aiming to describe the past and present evolution of transaction machines as the infrastructural underpinnings of financial markets. The crucial difference is that the present thesis doesn't simply advocate a shift in focus, but argues for a different approach and understanding of financial markets. This move towards the technological and infrastructural underpinnings of financial markets also assumes a different understanding of the basic functions of financial markets. Within the SSF literature, there is a tendency to assign a certain calculative function to financial markets, namely as so-called ''calculative collective devices'' (Muniesa and Callon, 2003). Financial markets would thus be human/non-human hybrids with the ultimate aim of computing prices, (which in some cases is understood as a consensus regarding the value of goods). As Vincent Lepinay has argued, at the core of this literature is the assertion that: ''behind each price, a design'' (Lepinay, 2011, p.XVII). In a certain sense, our thesis will also focus on the question of design, but without reducing the diversity of market functions to the ultimate aim of price discovery. The point is not that one shouldn't pay attention to the issue of pricing[24]. While prices are an important aspect of financial markets, they are better understood as an output rather than the core operation underpinning financial markets. This thesis will argue that the core functionality of financial markets is the ability to maintain, organize and process the flow of financial transactions (Herrmann-Pillath, 2013), which is precisely why we look at transaction machines as the infrastructural underpinnings of financial markets. In this sense, we can argue that the efficient functioning of transaction machines is a prerequisite for the continuous and consistent output of prices. This is self-evident when we consider that efficient matching and clearing of order flow is a necessary even for something as simple as the ultimate dissemination of price data. As soon as there is continuous pricing, a lot of other operations are possible (e.g. investing, hedging, speculating, arbitrage, etc.). There is therefore s a risk in focusing too much on the question of pricing, namely that we obscure the rich diversity of processes and mechanisms that allow financial markets to work in the first place. Our aim is not to reduce the whole complexity of financial markets to its transactional infrastructure. It is simply to suggest that before we approach more complex market phenomena such as valuation, pricing, benchmarking or arbitrage, it might be useful to gain a better understanding of the basic transactional infrastructure of financial markets[25].

Consequently, the present thesis is less interested in mapping networks of humans and non-humans but posits the terminology of transaction machines understood as the infrastructure of financial markets. This requires a broader evolutionary account of socio-technological systems, beyond what is possible in the context of SSF and ANT. In leveraging the ontology of ANT, SSF are not longer restricted to the study of human interpersonal relationships and go beyond an understanding of agency as the sole monopoly of human beings. As Donald MacKenzie put it, equipment matters,

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[24] In fact, Caliskan (2010) has recently shown how something as simple as the price of cotton is underpinned by a complex web of technological platforms, specialized intermediaries, political and cultural constraints, etc.

[25] In this regard we followed on the footsteps of Juan Pablo Pardo-Guerra and his assertion that infrastructure matters. His history of the London Stock Exchange through the evolution of the electronic order book had a decisive influence on this thesis.

that is to say the object of sociological inquiry should comprise a wider diversity of hybrid associations. While this allows us to incorporate technical artefacts into the real of sociology, the mapping of networks of humans and non-humans is not sufficient for a detailed understanding of the functions performed by these markets. Unlike SSF, thesis will not focus on the question of who is connected to what in a specific market device (*agencement*), but think in terms of more complex transaction machines where both humans and technical artefacts as components parts. The difference between this thesis and SSF is not restricted to a shift of focus, but also revolves around a different ontological positioning on the question of technology. If the recent technologization of financial markets is part of a longer-term process, then perhaps these markets are best understood as complex machines from the very beginning. That is to say, drawing from an understanding of machines as information processing systems (i.e. cybernetics, computers science, etc.), one could look at the core operations of financial markets as specific transactional structures and mechanisms. That is to say, different to SSF, we posit the 'machinic' nature of financial markets as intrinsic to their functioning form the very beginning, in as much as we understand them as so-called transaction machines. The aim is to offer an account of these machines as exhibiting certain transactional regularities, which are independent of them being executed by human beings or electronic platforms. What matters here is their design, their operational schematic, or in other words, the way in which these systems perform specific transactional functions. Finally, the thesis will focus on how certain transactional capabilities are necessary in order to maintain functional financial markets and also how these so-called transaction machines evolve through time.

1.2 Assemblage Theory and Markets

As we have seen, the SSF literature is a compelling application of the ontology and methods of ANT to financial markets. The output has been a number of very detailed descriptions of financial markets comprising human beings, technical artefacts, economic and financial theories, assembled together in a functioning whole, an *agencement*. While the sociology of finance makes ample use of the language of assemblage theory, it does so without actually engaging with the broader philosophy of Gilles Deleuze and Felix Guattari (1980) or the more systematic assemblage theory of Manuel DeLanda (2006). DeLanda's work is interesting in that he offers both a refinement of Deleuze & Guattari's philosophy as well as addressing the topic of markets and capitalism. In one of his well-known books, *A Thousand Years of Nonlinear History* (1997) DeLanda tracks the evolution of geological, biological, linguistic and urban assemblages in an attempt to describe the morphogenesis of modern Western societies and Capitalism. This is an approach where the gradual stabilization of bureaucracies, markets and other institutions are part of a process leading to the emergence of large cities, nation states and multinational corporations, and all of these entities are analysed trough the lens of assemblage theory. One of Deleuze's favourite examples of an assemblage is the mounted archer of the Mongolian steps. The interaction between a horse, an archer and a bow leads to the emergence of an assemblage, a whole that is much more than the sum of its parts. One the one hand, this new assemblage exhibits emergent properties such as amplifying the power of the archer relative to a standing archer. On the other hand, it also forms the basis for larger assemblages, in that it drives the development of nomadic armies, which are more adaptable fighting formations (DeLanda, 2010). One initial observation would be that an assemblage is not just a hybrid collection of different elements, but a more complex whole exhibiting a series of emergent properties (new functions and capabilities). In any case, DeLanda's belief is that the two French philosophers never managed to fully develop a theory of assemblages and only left us with bits and pieces. He describes his own work as attempt to get rid of the rough edges of their theory and offer additional clarifications. In this context, what makes DeLanda particularly interesting is his commitment to a materialist and realist interpretation of Deleuze and Guattari's philosophy (Harman, 2008). DeLanda seems to be one of the few continental philosophers who can't really be classified as a correlationist[26]. For him, what is important is not so much how we relate to the world, but how the world itself changes over time and how we emerge and are part of this process of change. In fact, this it the fundamental difference between his theory and the more common notion of network, namely that assemblages are wholes that exhibit emergent properties. Drawing from Deleuze & Guattari, DeLanda relies more on concepts such as rhizome and multiplicity, rather than network.

Firstly, assemblages are composed of parts, which themselves are assemblages composed of other elements, and so on. Secondly, assemblages are aggregates but not totalities, as they can't be reduced to their parts. That is to say, an assemblage emerges as a more or less coherent whole from the relative disparity of the lower levels of complexity. Crucial here is that an assemblage is always a whole that is more than the sum of its parts. To put it differently, there is redundant potential in the interaction between different elements, which makes the emergence of assemblages a non-linear process. An additional important point is that an assemblage is characterizes by the external relations between its parts, which also means that some parts can be detached and inserted into other assemblages (DeLanda, 2006)[27]. It is interesting to see that his method avoids essentialism by acknowledging that an assemblage is never defined by a stable form but must be understood as a process of becoming. In this sense, DeLanda is reluctant to accept reified generalities like Nature, the Human, Society, Capitalism or the Market, but is interested in the morphogenetic process through which ecosystems, individuals and groups, markets and corporations come about. Moreover, in an evolutionary twist, there is always a population of different types of markets, societies, cities, that is to

[26] The term correlationism (Meillassoux, 2008) refers to a philosophy that focuses on the mutual hermeneutics between human being and the world, as ''a primordial correlation'' according to Graham Harman (2008).
[27] This actually means that assemblages are a shorthand for open systems, which can receive various inputs from their environment and but also dissipate various outputs.

say populations of different assemblages, rather than immutable essences. As DeLanda himself argues, there is no such thing as a zebra essence, but only real individual zebras, similarly, there is not one Market with a capital ''M'', but just real-life markets (irreducible to an eternal essence of markets). Third, DeLanda is clearly indebted to Deleuze and Guattari's notions of territorialisation and deterritorialisation, which means that his assemblage theory constantly tries to track specific processes of dissembling and reassembling (Harman, 2008).

According to DeLanda and following Deleuze, assemblages become particularly interesting above certain thresholds of complexity relative to ''the kinds of wholes that could be assembled on this planet'' (DeLanda, 2006, p.14). One can think of the emergence of genes or language as such examples of increasing complexity, but DeLanda argues that even atoms are capable of expression. As we already noted, most of the physical assemblages in nature are independent of humans being there. From atomic radiation to hurricanes and chemical clocks, most physical assemblages are independent of human presence. Living organisms represent more complex assemblages as they depend on basic physical/thermodynamic and chemical process, but they are also independent of human presence. While it is true that humans can act on these process and even trigger certain results that would have been very unlikely otherwise, these assemblages would still retain autonomy outside of human existence. The narrative becomes more difficult when he tries to give an account of social assemblages, As DeLanda himself describes it, while social institutions are independent of the content of our minds, they are vey much observer relative. That is to say, humans need to maintain a certain level of interaction in order to maintain social assemblages. This also applies to his understanding of technology. Within the context of social assemblages, technology represents a further increase in complexity. In fact, rather than thinking in terms of a hybrid mix of humans and artefacts, the ultimate aim of DeLanda's assemblage theory is to track the gradual evolution of these more complex assemblages.

In analysing more complex social and/or technological assemblages, DeLanda presents his readers with long encyclopaedic narratives (looking at everything from language, urban architecture and communication technologies). This is also the case in his treatment of markets and Capitalism. For him, markets are assemblages ''made out of people and the material and expressive goods people exchange'' (DeLanda, 2006, p.17). They are also historical processes of becoming dependant on the structure and the intensity of human interaction. He actually starts his account of markets by looking at the evolution of bazaars and medieval village markets, their integration into regional markets/fairs and ultimately their centralization into national markets such as England in the 19th century (DeLanda, 2010). In this, he very much follows the work of Fernand Braudel, whom he considers to be the greatest historian of capitalism. Braudel's legacy is part of the so-called *Annales School*, where the historical account is not centred around major historic figures or events but focuses on complex process where everything from geology to climate and from epidemics to technological innovations have a role to play. This is very important for DeLanda as it helps him reject the Marxist partitioning of history into slavery, feudalism and capitalism (DeLanda, 1999). All of these distinctions are generalizations that preclude the more complex processes of ecological, socio-economic and technological evolution. By largely ignoring the Marxist tradition, he is thus able to reject any notion of a ''monolithic and homogeneous 'capitalist system''' (DeLanda, 1999). In other words, he is not trying to give an account of Capitalism or the Market but a detailed description of how certain markets emerged in specific environmental, cultural and technological conditions. In his view not all markets are the same and he subscribes to Braudel's position that ''we must make an unequivocal distinction between markets and capitalism''. This goes against the ideological traditions of the Left and the Right, which tend to equate Capitalism with the Market. As Braudel famously put it:

> We should not be too quick to assume that capitalism embraces the whole of western society, that it accounts for every stitch in the social fabric…that our societies are organized from top to bottom in a 'capitalist system'. On the contrary, …there is a dialectic still very much alive between capitalism on one

hand, and its antithesis, the 'non-capitalism' of the lower level on the other (Braudel, 1984, p.630).

DeLanda also follows Braudel in his distinction between two types of economic institutions: markets (meshworks, decentralized interaction) and capitalism (monopolies, bureaucratic and hierarchical control). In short, the argument is that capitalism is a tendency toward oligopolistic price setting while markets involve a large number of anonymous interactions and exchanges. The capitalistic tendency refers to the establishment of ''large enterprises, large that is, relative to the size of the markets where they operate'' (DeLanda, 1996). Braudel highlights this tendency in the operations and behaviour of Italian medieval merchants (wholesalers), something that persists today in the dominant position of multinational corporations[28]. Markets, on the other hand, refer to more direct interaction without the need for large intermediary structures, which makes these markets truly ''self-organized decentralized structures'' that ''arise spontaneously without the need for central planning'' (DeLanda, 1996). So according to Braudel and DeLanda, we are faced with this duality between two socio-economic assemblages, one in which price setting is achieved through decentralized interaction and the other using network power to set prices in a non-competitive way. This ultimately leads to a very interesting position, namely that capitalism is by and large a non-competitive tendency, one that continuously attempts to control market dynamics. In returning to DeLanda's assemblage theory, we could say that markets are deterritorialised assemblages while anti-markets (capitalism or oligopolies) represent a more territorialized form of that assemblage. Moreover, in Braudel's opinion, ignoring the distinction between capitalism and markets has been one of the major mistakes of the Left. Because of this, the rich potential of markets as mechanisms for social change is lost. Therefore one ends up focusing solely on the duality between authoritarian state vs. unregulated free markets. In the last pages of his magnum opus *Capitalism and Civilization* (Braudel et al., 1981; Braudel, 1982; Braudel, 1984), Braudel seems to suggest that we should not contend ourselves with this false

[28] One can think here of the ample literature on the topic of vertical integration and monopolies.

opposition between the state and the so-called free market. On the contrary, he stresses the importance of more granular distinctions such as that between more transparent versus more opaque systems of exchange, markets vs. oligopolies (Wallerstein, 1991a). Braudel elaborates this view in the well-known second volume of *Capitalism and Civilization,* entitled *The Wheels of Commerce*. In that context, the market was a space of ʻʻliberation, openness, access to another worldʼʼ (Braudel, 1982, p.26) whereas the antimarket was the place "where the great predators roam and the law of the jungle operates" (Braudel, 1982, p.230; Wallerstein, 1991b, pp. 209-210).

Interesting as it may be, the distinction between markets and capitalism is ultimately based on a dialectical relationship. As DeLanda himself argues, even though we can distinguish between markets and oligopolies, they ultimately ʻʻcoexist and intermingleʼʼ and ʻʻconstantly give rise to one anotherʼʼ (DeLanda, 2006, p. 32). We would argue that his is precisely the problem with relying on dialectical dichotomies as sooner or later one is always forced to acknowledge their correlation and constitutive intermingling (Meillassoux, 2008). At this point, we can clearly identify the limits of DeLanda and Braudel's approach. The problem in thinking along the lines of a dialectical contamination is that one risks getting stuck in an ambiguous aporetic dynamic. If any given socio-economic assemblage is always some combination of markets and capitalism, what can we really say about the functioning of specific markets? Do markets ever really change or are they the endless repetition of this market/anti-market dialectic? Moreover, even when DeLanda addresses the question of decentralized transparent markets, he understands them as meeting places for open exchange. That is to say, there is little or no interest in the precise mechanisms of aggregating, matching and clearing transactions. This runs the risk of ignoring the greater diversity of firms and non-market forms of exchange. In other words, relying too much on the market/anti-market dichotomy, we miss some of the finer details about how certain exchange mechanisms are constructed and how they evolve in time.

Both DeLanda and Braudel's narratives offer great insight into the history of markets but they do not really address the transactional infrastructure and their diverse set of functionalities. On the other hand, this thesis will attempt to have amore granular approach and focus on certain transactional functions, such as matching and clearing. While the transaction machines performing these functions can all be seen as complex assemblages, it is difficult to construct a more detailed account of their functioning and evolution by relying solely on assemblage theory. As we will see later, Philip Mirowski's theory of markets as evolving computational systems, allows us to smooth out the rough edges of assemblage theory. We will address this topic in Chapter 3 of the thesis.

Conclusion

The aim of this chapter was to discuss two separate approaches within the social sciences and humanities, where markets in general and financial markets in particular as viewed as assemblages of different elements, including humans and technical artefacts. We draw valuable insights and also highlight some of the limitations and differences with the present thesis. We began by reviewing SSF in the context of Michel Callon's *The Laws of the Markets* (1998) and Donald MacKenzie's *An Engine, Not a Camera* (2006). These authors provide the basic building blocks of a new sociology looking at how different elements, including humans and non-humans, are assembled together in the construction of financial markets. In relation to this sociology of finance, the present thesis attempts a shift in both focus and approach, consistent with our understanding of transaction machines. Throughout this thesis, we will not focus on why market participants decide to trade this or that financial asset or why someone makes a certain investment. We are also not very interested in economic or financial models and their performativity. Lastly, we are not concerned with the effects of contemporary financial technology on the behavioural patterns of individual traders or how new products and markets are assembled. As stated above, this thesis doesn't approach socio-technical systems as networks made up of discrete elements, either human or non-human. Drawing from cybernetics and computer science, we look at socio-technical systems as types of information processing machines, with their own abstract schematic or algorithmic structure, that is to say, focusing on they way in which they perform certain functions. Within the framework of transaction machines, both humans and technical artefacts are components parts of complex machines exhibiting certain transactional regularities, such as the mechanism for matching and clearing financial transactions.

We then reviewed Manuel DeLanda's assemblage theory, which represents a more rigorous systematization of the philosophy of Deleuze & Guattari and their notion of assemblage or *agencement*. In his writings, drawing heavily form the work of historian Fernand Braudel, DeLanda spends a lot of time describing morphogenetic processes through which ecosystems, individuals and groups, markets and corporations come about. While he avoids thinking in terms of reified totalities such as the Market (with a capital M), he contends himself with dialectical dichotomies such as market/anti-market and doesn't approach market functions in any granularity. As we have argued, his account of markets does not allow him to look at the finer details of how these systems actually work and how their precise mechanisms evolve through time. Nevertheless, we retain from DeLanda his central focus on the issue of evolution and history in accounting for the present state of any assemblage, that is to say his commitment to the question of becoming. In fact, this is perhaps the most important aspect of his work, namely looking at the evolution of social and technological assemblages through time. Following in his footsteps, this thesis attempts to track and describe the evolutionary trajectory of transaction machines.

Both SSF and DeLanda's assemblage theory are hugely influential for the present thesis while also highlighting the need for a different approach. The subsequent theory chapters will attempt to address some of these points. For instance, Chapter 2 will focus on Gilbert Simondon's philosophy of technology as a complex system in its own right. Rather than relying on the ontology of networks and associations, Simondon draws from cybernetics and looks complex machines as systems exhibiting their own mode of functioning, operational schematics and designs, irrespective of their components parts. Chapter 3 then attempts to elaborate on the precise details of these machines. Drawing from Philip Mirowski's theory of markets as computational systems, we gain a better grasp of the formal functions performed by markets in general. Leveraging the work of those two thinkers, we will gain both a functional and an evolutionary understanding of socio-technical systems in general and provide a more solid basis for the understanding of transaction machines.

Chapter 2. Technology and Individuation

Summary:

The chapter addresses the philosophy of Gilbert Simondon and his account of technology, in as much as he draws from cybernetics, information theory and computer science. In this context, technology is the most recent phase of a broader process of individuation. He identifies several phases of individuations as the passing of thresholds towards more complex systems. The process of individuation takes us from the physical to the living, the psychic and the psychosocial and finally to the technological phase of individuation. While being the most recent phase of this process, technical individuation emerges and is constrained by the other phases. One the one hand, technical objects are independent of human beings in as much as they are physical and material objects. On the other hand, technical objects are invented and continue to develop under the constraints of a community of users. Moreover, he pursues an analysis of machines based on the functional differentiation between different modes of existence of technical objects (elements, individuals and ensembles). Until the modern age, human beings have been the dominant technical individuals, building and maintaining technical ensembles and perfecting technical elements. What is particularly interesting about Simondon's account of technical individuation is that he describes the way in which humans are gradually displaced as the dominant component parts of complex technical ensembles. In the industrial age this tendency is clearly at work in the march towards standardization, whereby tasks that were performed by human individuals are gradually integrated into the internal working of machines. Similarly, the 20th century has seen an equally impressive tendency towards higher levels of automation, whereby many cognitive processes performed by human beings can now be codified and performed by what he calls information machines.

2.1 Philosophy of Individuation

As we already noted, this thesis provides an understanding of machines as complex systems in themselves, rather then relying on a clear distinction between the humans and non-humans. Rather than thinking about technology as a tool to be mastered by humans, Simondon offers a more nuanced understanding of technology as a continuation of a much more general process of change, as the most recent phase of individuation. The philosophy of Gilbert Simondon has received increasing attention recently, both in French and English speaking academic circles. His work has come to the forefront because of his analysis of modern technology but also for his influence on philosophers such as Gilles Deleuze and Bernard Stiegler. The more recent literature on Simondon has emphasized his relevance for science and technology studies (Chabot, 2003; Barthélémy, 2005; Barthélémy, 2008; Bontems, 2009) or bioethics (Hottois, 1993). There is also a keen interest in Simondon as a potential renewal of political thought and critical theory (Combes, 1999; Toscano, 2006; Bardin, 2015). Several conferences and publications (Roux, 2002; Roffe et al., 2013; David Scott, 2014) have provided a renewed momentum for the study of this conceptually rich philosophy. Moreover, Brian Massumi (2009) has offered an interesting interpretation of Simondon's understanding of technical invention, which seems to be a fruitful line of inquiry given the recently published manuscripts such as *Imagination et Invention* (Simondon et al., 2008).

Our own interest for Simondon comes as a result of numerous conversations with the likes of Bernard Stiegler. In fact, he explicitly states that the core of his project is an attempt to formulate a conceptual synthesis of the two very different projects of Heidegger and Simondon (Stiegler, 2009). He extracts from Simondon's work the idea that our exosomatic organs (technical prosthetics) are just as important as our endosomatic organs. Moreover, all organs have a pharmacological nature entailing the ambiguous possibility of both negentropy and entropy (both gift and poison) (Stiegler, 2003). While for Simondon, the technical object fights against the death of the Universe (i.e. an increase in order) Stiegler understands technology as an ambiguous mix of entropy and negentropy, as both order and disorder. One can understand Stiegler's subsequent writings on attention, loss of knowledge, exhaustion of libido, etc., as a response to precisely these entropic tendencies at the heart of modern technology (Stiegler, 2010b; Stiegler, 2010a). While Stiegler's philosophy is very interesting, especially from the point of view of a critical political economy, it is less useful for the present thesis. As we will see, Simondon thus offer a very unique understanding of technical objects, their individuation and a detailed analysis of their modes of existence. A more detailed explanation would be needed here, but actually the basic tenants of Simondon's philosophy are largely incompatible with much of Stiegler's thought, particularly due to his reliance on Derrida's deconstruction and Heidegger's version of phenomenology. In many ways, Simondon is much closer to cybernetics and information theory and leaves little room for the mutual hermeneutics between man and machine or the deconstructive aporia of Dasein (Stiegler, 1998; Guchet, 2010).

It fact, it might be more useful to introduce Simondon's philosophy through the work of his doctoral supervisor, Georges Canguilhem, by focusing on a text entitled *Machine and Organism*. In that context, he proposes an understanding of technology as a ''universal biological phenomenon'' that allows ''man to live in continuity with life''(Canguilhem, 1992, p.63). He developed his thinking at the juncture of philosophy of science, epistemology and the so-called French biophilosophy, influenced by the likes of Claude Bernard, Raymond Ruyer, Gaston Bachelard and Kurt Goldstein. It has been argued that Canguilhem actually represented a repositioning of biology and the life sciences at the centre of social research (Wolfe, 2010). Simondon is directly influenced by Canguilhem's ideas and he understands biological systems as being constantly open to contingency and change. For both of them, no matter now complex and exceptional living organisms might seem, they are still part of a broader process of change and by no means an exception to the laws of physics or thermodynamics. In this sense, Simondon follows his professor to the very end, as it was Canguilhem argued that there is ''no kingdom within the kingdom'', meaning more complex systems evolve all the time but they are not exceptional in the sense of not being subject to the laws of nature (Canguilhem, 1965).

In any case, Simondon's own contribution (2009b) within the constellation of French philosophy has been to think of any system within a more general process of individuation, what he calls ontogenesis[29]. This is precisely why it is useful to draw from his philosophy, because of his commitment to the process of individuation as being that which always comes first with regard to the individuals it constitutes. That is to say, he emphasizes the process by which something comes about, not the already given effect or result. The question of stability and equilibrium offers a perfect example. For Simondon, the Western philosophical tradition has strictly differentiated between stability and instability, between order and chaos, being and becoming. Contrary to this tradition, he understand individuation as the process whereby a system gains coherence and identity, but remains at the same time at the edge of chaos (Prigogine and Stengers, 1984). His argument is that in order to understand the process of individuation, one must think in terms of an unstable equilibrium, a metastable state. Secondly, no individual is given as such, but has a preindividual reality from which it emerged, that is to say it has a history or a genesis. He does focuses on how various processes of individuation (physical, biological, psychosocial, technical) come about, stabilize and provide support for subsequent individuations or in other cases dis-individuate themselves (decay and disappear). Moreover, each phases of individuation is defined around certain critical thresholds. Because of his admiration of cybernetics, he sometimes describes these thresholds in informational terms (Simondon, 2010)[30]. In his view, it is meaningful to talk about individuation once a system reaches a certain scale, a certain order of magnitude. Below a certain topological and chronological limit, we have the preindividual, or the pre-physical. Beyond this initial threshold he identifies the phase of physical individuation and frequently references the formation of salt crystals as paradigmatic example. The oversaturated solution of sodium chloride undergoes crystallization (takes a new form) through the propagation of an initial signal, or a structuring germ. This gradual process of taking form, which in many

[29] Ontogenesis is understood here as the becoming of being, the gradual unfolding of reality (Simodon, 2009)
[30] By information, Simondon means any physical/energetic process or interaction (Simondon, 2010).

cases is almost instantaneous, sheds light on his understanding of physical individuation. That is to say, physical systems undergo individuation once and have only a small capacity to continue to individuate, or it in other words to continue to receive new information. This bears witness to his tremendous reliance on cybernetics and his informational understanding of the process of individuation. While the physical individuation can grow and amplify itself (just like in the case of crystallization), it is less open to receiving new information (Simondon, 1995). Contrary to this, the living individuation can receive continuous inputs of information, maintaining an on-going individuation. In this sense, Simondon understands information as a system's interaction with its environment. Therefore the transition towards the living individuation marks the passing of a threshold in the degree of openness to new information (Simondon, 1964; Simondon, 2013, p.152). To be precise, Simondon explains that the living individuation does not come after the physical individuation, but during this process of individuation. He suggests that we could think of the living as a physical individuation in suspension, maintaining the capacity to receive information for a longer period of time, as opposed to quasi instantaneity of the physical individuation. This point is particularly important, as each subsequent phase of individuation distinguishes itself because it maintains the capacity to receive information for a longer time, and from a wider variety of sources. This also accounts for the fragility of the more complex phases of individuation, which can only maintain themselves thanks to their reliance on the previous phases (Iliadis, 2013).

As with all accounts of ontogenesis, defining the thresholds that separate different domains is not always easy. In Simondon's case, the difference between the physical and the living individuation rest in the capacity to receive new information (Simondon, 2013, p.151). Subsequent phases of individuation such as the psychic individuation can be seen as the passing of a threshold towards even more complex systems. In short, the psychic is a continuation of the overall process of individuation as something that happens in the context of certain living beings. This process of psychic individuation takes us from living individuals to something more complex, namely psychic reality. That is to say, the psychic occurs when living beings can no longer resolve their problematic interaction with the environment. In his philosophical account, once the interaction between living individuals and the environment reaches a certain threshold of complexity, the living reaches a certain point of incompatibility with its milieu (Roffe et al., 2013, p.93). The passing of this threshold is described as the formation of the psychic, which is gradual process encompassing several stages including perception, affect, emotion and anxiety (Krtolica, 2009; Melanie Swan, 2014). While we cannot describe here the full richness of Simondon's account, it is essential to note that he takes great care to give an account of the gradual transition from living to psychic individuals as the resolution of incompatibilities or conflicts with the milieu. Moreover, it is equally crucial to note that for him the psychic individuation can only be fully accomplished at the level of the group (Combes, 1999; Toscano, 2007). As he puts it, the resolution of the psychic is accomplished by participating in the much broader individuation of the collective (Crary and Kwinter, 1992). Hence his interest for the next level of complexity, what he calls the psychosocial individuation (Simondon, 1989). In other words, the psychic reality is itself transitory and a relatively unstable resolution. Therefore, there is an immediate transition to the so-called psychosocial individuation (or the transindiviudal as he sometimes calls it) as a subsequent of stabilization of psychic reality:

> The entry into the psychic reality is the entry into a transitory path, because the resolution of the intra-individual psychic problematic (that of perception and affection) is achieved at the level of the trans-individual[31] (Simondon, 2013, p.166)

This paragraph is a testimony to Simondon's innovative thinking but also to the many unresolved questions surrounding his work. One recurrent issue is the inflation

[31] Original French text: ''L'entre dans la réalité psychique est une entrée dans une voie transitoire, car la résolution de la problématique psychique intra-individuelle (celle de la perception et celle de l'affectivité) amené au niveau du transindividuel''

of new concepts, which are not always well defined[32]. For instance, sometimes he seems to equate the psychosocial with the trans-individual, while and other times the trans-individual seems to be a transitory stage between the psychic and the psychosocial. Perhaps this is a symptom of his ambition to describe and give an account of processes of formation rather than stable entities (individual, group, etc.). The difficulty lies in the attempt to isolate and focus on specific details of a more complex process of becoming. He starts by asserting the importance of describing the process of individuation rather than focusing on already individuated entities. But once you being to describe the actual process you are forced to develop further conceptualizations. In other words, there is an intrinsic conflict in his philosophy between the dialectic tendency to think in terms of wider processes of formation and the analytical necessity to sometimes make more granular distinctions.

Nevertheless, Simondon's philosophy has been influential for contemporary philosophers, among them Bernard Stiegler. In Stiegler's account of anthropogenesis, this stabilization of the psychic through the social occurs thanks to external organs, or what he calls technical prosthetics. In fact, in Stiegler's philosophy, the human is at the same time fundamentally constrained and liberated by his technical prosthetics. The resolution of the psychic individual within the collective is only established through the intermediary of something other than the biological. That is to say, the psychosocial individuation is achieved because groups of psychic individuals are integrated through some sort of technical prosthetic. In this regard, both Simondon and Stiegler are influenced by the likes of Leroi-Gourhan (1971) in that they understand the acquisition of technology as encompassing everything from the most basic tools and techniques to the more advanced systems such as language and writing. For Stiegler, the invention of fire is a perfect example of a technical prosthetics, representing Prometheus's gift to the handicapped humans, after Epimetheus forgot to give them any evolutionary advantages in the fight for survival (Stiegler, 1998). In short, Stiegler's argument is that the human is the technical being par excellence. In this sense, anthropogenesis is a process

[32] For a more detailed account of Simondon's philosophy see (Scott, 2014, Roffe et al., 2013).

whereby the instability of the psychic individuation can only be resolved through a collective interaction, which itself can only be feasible in as much as it is technological. In other words, Stiegler makes no real distinction between the social and the technical, as it is impossible to move from the psychic to the social without the existence of a basic technical infrastructure. Somewhat different to this, Simondon thinks in terms of hierarchies of complexity and does not necessarily equate the social and the technical (Barthélémy, 2009, p.29). For Simondon, both the technical and the social are part of the process of individuation, while also acknowledging that the advent of technical individuation has a solidifying effect on the social, quite similar to Latour's assertion that technology is society made durable (Latour, 1991).

Both Stiegler and Latour draw from Simondon's philosophy, which in itself is a complex mix of Canguilhem's work and French biophilosophy while remaining grounded in cybernetics, information theory and thermodynamics. In his minor doctoral thesis, *On the Mode of Existence of Technical Objects* (1980, 1958), he attempts to synthesize all of these sources and construct a consistent ontological framework. The question of whether or not he succeeds in this endeavour is still very much open to debate. Nevertheless, in his account technology is understood as a complex system in itself, part of a more general process of change that includes physical and living, psychic and psychosocial systems. With every new phase of individuation we see the emergence of more organized or more individuated systems, which are also more efficient at reducing their degree of entropy:

> The machine is a result of organization and information; it resembles life and cooperates with life in its opposition to disorder and to the levelling out of all things that tend to deprive the world of its powers of change. The machine is something which fights against the death of the universe; it slows down, as life does, the degradation of energy, and becomes a stabilizer of the world (Simondon, 1980, p.9)

In this sense, we can see the huge influence of Norbert Weiner, in understanding the evolution of complex systems (including machines) as a constant fight against entropy understood as disorder. The problem with this conception is that both living organisms and technical objects are not opposed to entropy in a kind of dialectical standoff. The currently accepted view is somewhat more nuanced, stating that complex living organisms evolve not so much by opposing entropy, but by efficiently dissipating it (Prigogine and Stengers, 1984) at the highest rate possible (Salthe and Annilla, 2009). Following the current understanding of dissipative systems, one needs to make a distinction between the internal entropy the system and the external entropy of its environment (Herrmann-Pillath, 2013). We could thus correct Simondon's position, by saying that the machine is truly a mix of organization and information and that it resembles life in that it constantly minimizes its internal entropy. It fights against its own death, by dissipating at the highest rate possible, increasing the entropy of its environment.

In any case, Simondon's interdisciplinary framework allows him to think about technology as coherent systems in itself, rather than something that is added on top of an already existing social structure. As long as technical objects were relatively simple artefacts, they were effectively exosomatic organs of human beings, extensions of some of our bodily functions. Before the industrial period, technical systems were largely composed of humans and their prosthetics. Nevertheless, what is interesting about our modern age is that technical individuation moves towards technical objects with higher degrees of autonomy from humans (Chabot, 2003, p.132). We will devote the rest of this chapter to unpacking his account of technical individuation and follow his critique of our modern day understanding of technical objects. As we will see, he argues for the inadequacy of distinctions such as human/non-human or the understanding of technology as a tool and of the human as a tool-bearer. In this sense, he argues that modern technology is a process of individuation in its own right.

2.2 The Amplifying Relay and the Tendency of Concretization

As we have seen, Simondon's approach to the question of technology has a high degree of originality, while still being part of certain tradition of 20th century French philosophy. This is particularly true in the way in which he utilized the term 'mechanology' which was initially developed by figures such as Jacques Lafitte (Iliadis, 2013; Iliadis, 2015). For Lafitte, machines were understood as an extension of humans or as Lotka called them, exosomatic organs (Lotka, 1925; Lafitte, 1972). According to Bernard Stiegler, Simondon's philosophy of technology is very much indebted to Lafitte, but also to the Leroi-Gourhan's anthropology and Betrand Gilles' work on technical systems[33] (Gille, 1964; Leroi-Gourhan, 1971; Gille, 1978; Bontems, 2009). Simondon published his first book in 1958 and was clearly inspired by Norbert Weiner's cybernetics, leading to a negentropic interpretation of technology (drawing from cybernetics and information theory). Furthermore, he understands the process of individuation of technology as a continual development of systems that are more ordered in a thermodynamic sense. Building on this perspective, he can say that living, social and technical systems evolve by being more complex and efficient in terms of their internal functioning as well as their interaction (material, energetic and informational exchange) with their environment. This allows him to position technical objects on the same path and trajectory as the other phases of individuation.

In the context of the *On the Mode of Existence of Technical Objects* (1980), technical individuation is understood as a problem of science and engineering, while technical invention would be a question of solving intrinsic problems of design. More recently, Vincent Bontems (2009) and Simon Mills (2011) have attempted to criticize this tendency in Simondon, namely his attempt to insulate the evolution of technology from the interference of culture and the demands of social and economic forces. This critique is consistent with Paul Dumouchel's position, when he interprets

[33] Bernard Stigler has explored this topic in great depths in his first volume of *Technics and Time* (1998).

Simondon's philosophy as a failed attempt at a purist account of technology, which would somehow be unaltered by social and cultural constraints (Dumouchel, 1992). Our own position is that, through a close reading of the second part of the book and also some of the recently published text such as *Invention dans les Techniques* (Simondon, 2005) and *Communication and Information* (Simondon, 2010), it is possible to provide a more holistic understanding of Simondon's philosophy of technology.

On the one hand, technical objects are, from a certain point of view, independent of culture and social norms precisely because they are real physical/material objects, and thus subject to the laws of physics and thermodynamics. Moreover, when looking at the question of technical design it is apparent that specific design/engineering problems remain the same, in most societies. This technical autonomy is what Simondon tried to describe with his notion of concretization and technical lineages. On the other hand, technical objects can also be seen as evolving/developing under the constraints of living beings. This is true particularly when one understands technical objects as exosomatic organs, which is Alfred Lotka's position. In this sense, technical evolution is also conditioned by human physiology and metabolism, and represents an amplification of our capacity to access resources and increase our energy intakes. Moreover, technical objects can be said to evolve under the constraints of human culture and society (what he calls the psychosocial). In this sense they are observer relative, as their functioning depends on and is constrained by a community of users, both in terms of their biological/physiological and in their cultural specificity. A hand-axe can emerge as a technical solution for cutting wood in many different geographical location and cultural milieus. It evolves under the pressure of physical/material constraints, such as available metals, climate, vegetation etc. In that sense, it is independent from human observers. On the other hand, it could not exist outside of a society of users and inventors. The design of the axe evolves relative to the size and strength of its users and it's also relative to their social interaction. Thus an axe can have different functions as weapon or as a cutting tool, given different cultural settings and social scenarios)[34]. We can thus argue that Simondon has, in fact, a very complex understanding of machines as part of the most recent phase of the process of individuation developing under material, biological and social constraints.

Two of Simondon's most interesting essays *L'Amplification dans le processus d'information* and *Le Relais Amplificateur* (Simondon, 2010), focus on the technical lineage of the electric relay as a paradigmatic exampled of technical individuation in general. In this account he focuses on how subsequent designs are more complex and also more efficient and synergetic or, in his own words, more concretized. He begins the individuation of the electric relay by focusing on the vacuum tube, which functions because to the transduction of electrons from the cathode toward the anode. Additional electrodes can be interposed between the cathode and anode to act as modulators. This is true in the sense that they modulate the electric current, giving the tube the ability to switch. Although solid-state devices such as transistors have replaced vacuum tubes, they still represent the basic schematic for modern electronic devices. The next generation of the triode, was born by placing an additional electrode in between the filament (cathode) and plate (anode); resulting in the ability of the new device to amplify signals. The triode's functioning was hampered by the capacity between anode and grid, which could easily result in an undesired auto oscillation of the current in the tube. The pentode (five electrodes) was eventually invented as a resolution of this problem, another grid was added to the design, between anode and grid, and this functioned as an electrostatic insulation. Because of the potential between the anode and this extra grid (and between the extra grid and the original control grid) this new grid also functioned both as another control grid for the anode and as an anode for the original control grid, thus strongly enhancing the amplifying function of the tube (up to 200 times amplification instead of 30-50 times) (Simondon, 2010). In this sense, the extra grid functioned both as a solution for the original problem and as an enhancement of the overall function of the tube. This can also be understood as doing more with less, or

[34] There are famous examples in the evolution of warfare, when the development of certain weapons was stalled because they were considered as a dishonorable way of fighting (crossbows, firearms).

in Simondon's case the gradual increase in the efficiency, as a small change in the information grid, counts as a big change in the anode (Simondon, 2010).

The next stage in this phylogenetic line is the transistor, a device that can switch electronic signals even more efficiently than vacuum tubes. It is composed of semiconductor material with similar functional schematic as in the case of vacuum tube. Today, some transistors are packaged individually, but most are part of modern integrated circuits. These technical objects were made possible by the discovery of semiconductor materials, which could replicate the switching function of vacuum tubes. Simondon has never written about integrated circuits but we can easily introduce it into his overall description of electric relays. It is clear that integrated circuits represented a huge leap in terms of modulating electricity. The basic problem of these technical objects is the integration of large numbers of tiny transistors into a small chip, which represented an enormous improvement over the manual assembly of circuits. The integrated circuit allows for mass production, reliability and a building-block production method. Cost is much lower because the chips, with all their components, are printed as a unit by photolithography rather than being constructed one transistor at a time. According to Moore's law (1965), the number of transistors within integrated circuits more or less doubles every two years, recently reaching millions of transistors per square millimetre. Obviously there is a huge difference between having one transistor to having one million transistors that perform the same function in a more integrated way. In short, this process entails a gradual convergence of separate elements towards a more efficient overall functioning so that the concrete technical object is:

> (…) one which is no longer divided against itself, one in which no secondary effect either compromises the functioning of the whole or is omitted from that functioning (…) The essence of the concretization of a technical object is the organizing of functional sub-systems into the total functioning (Simondon, 1980, p.31)

This can help us understand Simondon's notion of concretization, in that the integrated circuit is more concrete than the basic transistor, which is also more concrete than the older vacuum tubes. If the triode comprised 3 metal plates, the integrated circuit is a more concretized design, effectively integrating millions of different transistors. Simondon calls this a move towards a more concretized design and it is the closest Simondon ever gets to a notion of technical evolution (Bontems, 2009). In this sense, concretization is a criterion that allows one to discern technical lineages, as the gradual development of functional synergies (Simondon, 1980, p. 14). Vincent Bontems (2009) has offered some of the most compelling analysis of Simondon's philosophy of technology. In his view, concretization is not just a way to think about technical evolution, but it can also help us map a progression of this technical individuality. While a simple tool becomes more concretized as it becomes more solid and reliable in it's handling, the combustion engine becomes more concretized as it attains a greater degree of autonomy and self-regulation. Bontems describes the technical lineage of diesel engines and identifies a gradual improvement as its functioning becomes more sustainable and concretized:

> (…) the first diesel engine could not last because its conception could not prevent it from bursting: oil and air were mixing before the compression. The second diesel engine, on the other hand, was sustainable because the mixing occurs after the compression (…) the different operations are thus well coordinated in order to ensure coherent functioning, in a synergistic way, while its "ancestor" was self-destructing (Vincent Bontems, 2009, p.5).

Bontems thus demonstrates that it is possible to use Simondon to understand the increased concretization of the diesel engine, which is consistent with Simondon's own example of the Guimbal turbine, where the oil and water serve multiple functions accounting for a more concretized design relative to earlier versions. These earlier designs are more abstract as they are composed of isolated objects, which is more like an aggregation of different components (Guchet, 2010). An evolutionary step occurs when a more concretized design is invented, broadly synergy and a higher efficiency in terms of performing certain crucial functions. In this sense, concretization is a gradual movement from one synergy to the next, as obstacles are incorporated into a new multifunctional whole. Thus Simondon envisages the evolution of technology as the passing of certain synergetic thresholds, moving from more abstract modes to more concrete ones (Simondon, 1980, p.21). This applies both to technical objects such as the electric relay but also to more complex machines, what the calls technical ensembles (workshops, factories, networks, etc.).

2.3 The Modes of Existence of Technical Objects

In line with his general account of individuation, Simondon looks at machines as having their own type genesis, understood as a ''unity of becoming'' (Schmidgen, 2004). One should not focus too much on particular technical objects but one must always look at the historical development of technical lineages. As we have seen in the previous section, his account of the electric relay hinges on describing the subsequent designs whereby the same schematic becomes more concretized. While the integrated circuit is evidently more complex than a vacuum tube, it is part of the same technical lineage (Combes, 1999, p.13). When talking about technical lineages, Simondon often refers to an operational schematic (''chaine operatoire'') as the formal algorithmic description of a function. The function of the electric relay is to modulate electricity (or to switch), and subsequent designs can be understood as performing this modulating function. What changes through time is the degree of concretization, which in the case of the electric relay translates to more efficient designs affording the switching and amplifying electric current.

In Simondon's account of technology technical objects are not natural objects in the sense that they do not simply emerge in the wild, but have their own modes of existence. Technical objects are invented within a certain social milieu, that is to say they evolve under the constraints of a certain community of users. This is what Simondon means by the associated milieu of technical objects, namely the environment that affords the invention and improvement of technical objects. For instance, an adequate understanding of the electric relay is not confined to the actual technical artefact but extends to the community of users, electric grids and power plants, that is to say, in as much as they are part of what he calls technical ensembles or what he have referred to when speaking of complex machines.

When addressing these complex machines, Simondon utilizes an interesting analytical framework, distinguishing between three modes of existence of technical objects, namely the element[35], the individual and the ensemble. There is no vertical hierarchy between these aspects, only a functional differentiation in terms of the role played in the evolution of a technical lineage. Whereas elements refer to basic technical artefacts, technical individuals refer to the integration of a number of different elements affording self-regulation in terms of the interaction with its environment. Technical individuals are those component parts that are open to outside information and, more importantly, are self-regulating. The cybernetic conceptualization of feedbacks and information was a huge influence on Simondon, in as much as he defines technical individuality based on the ''the criterion of recurrent causality'' (Simondon, 1980, p55). This reiterates the importance of Norbert Wiener's cybernetics (Bontems, 2009), particularly his understanding of negative and positive feedbacks for control and self-regulation in complex systems (Carver & Scheier, 1998). As Wiener himself put it, the:

> (…) physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feed back. Both of them have sensory receptors as one stage in their cycle of operation: that is, in both of them there exists a special apparatus for collecting information from the outer world at low energy levels, and for making it available in the operation of the individual or of the machine (Wiener, 1967, p.26)

Therefore the term of technical individual does not refer to human individuals but to that mode of existence of technical objects that is in constant interaction with the environment, regulating material, energetic and informational exchanges affording the stability to the more complex machine, what he calls technical ensembles. In a less known interview from 1968 entitled *Entretien sur la mecanologie* (Simondon, 2009a) Simondon states that in order for a machine to exist in must not be self-

[35] Simondon adopts a very general perspective when talking about the modes of existence of technical objects. Technical elements refer to technical objects as material artifacts, or prosthetics in the case of Stiegler. The term technical individual should not be reduced to human individuals, but it refers the capacity to self-regulate in relation to a milieu. Technical ensembles refer to the integration of technical individuals into a more complex whole.

destructive, or that it must maintain the stability in regards to the interaction with the milieu. One can think here of Simondon's favourite example, that of the Guimbal turbine. In this context, you have the complex ensemble of the hydroelectric power plant, which performs the main function of transforming the energy of flowing water to electricity. Within this ensemble, the water turbine is the central technical individual, maintaining the material and energetic exchanges with the environment (made up of flowing water on the one hand and electric grid on the other). The efficient and synergetic functioning of this technical individual affords coherence and reliability to the overall ensemble, and this is mainly due to its capacity to regulate the inputs (flowing water) and outputs (electricity).

If the technical individual can be said to be the site of self-regulation, the more complex technical ensemble is definitely the site of differentiation as it can accommodate several technical individuals. We could attempt to provide a more speculative example of a technical ensemble by look at hunter-gatherer groups. In this context, one can think of a primitive hunting party as a technical ensemble. Humans and their technical prosthetics (weapons) would be the essential component part of this ensemble. Integrating these elements leads to technical ensembles such as hunting strategies. In this sense, depending of the prey, the landscape, available weapons, number of hunters, etc., different ensembles can emerge. Simondon mostly describes technical ensembles of the industrial age, whose function is to produce technical elements that can be used and integrated in other ensembles. But one can look at other ensembles such as communication systems that have the function of processing information flows between groups of users. We can look at another speculative example in line with Lewis Mumford's work. For instance the technical ensemble of ancient writing as a technology composed of technical elements such as clay tablets, an alphabet, a grammar and technical individuals such as scribes. You can then think of temples and palaces as technical ensemble organizing information flows in ancient societies such as coordinating material economic flows or exerting political power. The inputs are requests/commands from political and religious elites and the outputs are instructions to be executed by the lower bureaucratic levels and the rest of society.

One of Simondon's favourite examples is the modern industrial factory as a technical ensemble because it houses a variety of different technical individuals and organizes their productive flows according to a predetermined plan. While technical elements stand the test of time and transmit any improvements into the future[36], both technical individuals and ensembles are more precarious structures.

In terms of the history of technical ensembles, Simondon often distinguishes between periods of dynamic acceleration of technical invention followed by periods of stagnation (Simondon, 1980). In his perspective, technical evolution does not follow a continuous path, as there are more dynamic periods are characterized by sudden breaks with previous designs, followed by periods of stagnation revolving around incremental improvements. The space of invention is truly a non-linear domain and an account of invention has to take the form of a history of technical case studies. He elaborates on this topic in a series of lecture notes published under the title *Invention dans les Techniques* (Simondon, 2005), where he looks at technical inventions in specific material, historic and social conditions. In the context of ancient societies and the abundance of slave labour, technical objects were fragmented and less sophisticated. Within this context, there was no pressure for developing more sophisticated technical objects. Ancient technical ensembles were thus more discontinuous, structured around harvest time, building sites of great monuments, war, etc. In a certain sense, the abundant supply of slave labour acted as a brake on technical invention as there was little pressure to develop new technical objects, beyond the existing tool-bearing slaves (Walbank, 1969). It was only in certain urban centres where more complex tools and instruments could emerge. In this context, tools and human individuals could form a relative unity; and the technical individual is in this case the figure of the artisan or the craftsman. Later

[36] Simondon seems to say that, for a long time, technical elements were the most important and efficient way to transmit information from one technical age to the other. The skills of the artisan and the craftsman and the technical tradition of guilds and workshops were contingent and dependent on the uncertainties of the social interaction (wars, famines, etc.). It was the technicality of the elements (tools, instruments) that was easier to maintain and transmit and also that which drove technical evolution forward.

on, medieval urban centres also fostered the development of technical individuals, which could organize themselves in more durable technical ensembles (guilds and workshops). Nevertheless, what Simondon seems to say is that for a long time technical individuals and ensembles were precarious and contingent structures. Until the industrial age humans were the dominant technical individuals. If for some reason the human element would disappear (famine, war, epidemic) technical ensembles would simply decay and collapse. Nevertheless, human beings performed this function for as long as there was not other alternative:

> (…) the machine as technical individual becomes for a time man's adversary or competitor, and the reason for this is that man centralized all technical individuality in himself, at a time when only tools existed. The machine takes the place of man, because man as tool-bearer used to do a machine's job (Simondon, 1980, p.16).

With the advent of industrial and information technology, humans are not the only self-regulating technical individuals. A more organized division of labour and higher levels of standardization emerged out of the ever-growing speed of the industrial production process. In Simondon's view, the advent of industrial technical ensembles entails the possibility of more autonomous technical individuals. Quite probably, the quest for a mechanized assembly line emerged by observing the workers perform the same tasks over and over again. Even before the pack-houses of Cincinnati, assembly lines were slowly being developed in grain-milling and in biscuit manufacturing by the British Navy, in which the grain or the baking trays passed through most of the process without ever touching human hands (Giedion, 1948, p. 125). This is why Simondon sees the emergence of an asymmetrical relationship between man and machine, which leads to the cultural understanding of machines as alienating and threatening man's authenticity (Massumi, 2009). Moreover, technical elements drastically increase their degree of standardization and while the early industrial machines still lacked in self-regulation, the general tendency was clear. One classic example is the Jacquard mechanical loom built in 1805 (DeLanda, 1989, p.155). In the case of the loom, instead of humans controlling every step of the process, a set of punch cards effectively regulated the operation of looming. So the industrial tool-bearing machine displaces humans and gradually replaces them in their function as technical individuals maintaining technical ensembles. In the industrial age:

> Man separated from his role as technical individual, from what is the essential work of the artisan, can become either the organizer of the ensemble of technical individuals or a helper for technical individuals (Simondon, 1980, p.68).

In any case, Simondon's account hinges on the fact that humans are gradually taken out of the loop. In the industrial age this tendency is clear in the constant movement towards standardization and automation, whereby tasks previously performed by human beings are gradually integrated into the functioning of self-regulating machines. According to Simondon, this is a consequence of what he calls a mentality of output, which acts as a constant pressure for technical ensembles. Simondon gives the example of transportation technologies, which once integrated into society, create a permanent demand for greater speed of movement. New and faster modes of transportation do not exhaust this need, to the contrary:

> (…) there is a continuous dynamic evident in that when a new mode of transport is introduced in a community it leads to the developed of a demand for speed, which promotes the development of a more efficient mode of transport: the first mode creates the functions and it inserts it into the overall dynamic of the community''[37] (Simondon, 2013, p.342).

That is to say, with every new technical capability, there is an immediate demand for increased throughputs and efficiency. In many ways, standardization and

[37] Original French text: il subsiste une continue dynamique qui consiste en ce que l'introduction dans la communauté du premier mode de transport a développe une exigence de rapidité qui sert a promouvoir avec force le second mode: le premier a crée la fonction et l'a insérée dans l'ensemble des dynamisme de la communauté''.

automation in technical ensembles is the equivalent of the tendency towards concretization in the case of technical artefacts. Nevertheless, Simondon belief is that technological progress can't be fully understood simply as an increase in standardization and automation. To the contrary, technical progress relates to the capacity to retain a ''margin of indetermination'' which is the ''machine's sensitivity to outside information'' (MOET, p.4). This is precisely the reason why Simondon is a great admirer of the modern information machines and the electronic networks, ICT, etc. For him, technical individuations allow for a new technical culture and a novel relationship between humans and machines, which would go beyond any kind of alienation suffered by the displacement of the industrial age:

> Far from being the supervisor of a squad of [technical] slaves, man is the permanent organizer of a society of technical objects which need him as much as musicians in an orchestra need a conductor. (…) This is how man functions as permanent inventor and coordinator of the machines around him. He is among the machines that work with him (Simondon, 1980, p.4).

This is a clear example of Simondon's optimism in terms of the benefits of modern information technology. Rather than being the alienated appendix of industrial technical ensembles, man becomes the one who modulates the margin of indetermination of the technical ensembles of the information age (ICT networks), making them more ''adaptable to the greatest possible exchange of information''. For Simondon, the information machines of the 20th century allow for a new type of technical ensemble characterized by distributed network architectures, quite different from the earlier forms of industrial concentration.

Conclusions

In this chapter we sketched a different understanding of complex machines, according to the philosophy of Gilbert Simondon. In his work, he offers a narrative that takes us from physical to biological and social and finally to the technological systems. Drawing heavily from cybernetics, technology is not something that is added on top of human social interaction, but it is part of a broader process of change. Simondon does not use dichotomies such humans versus non-humans, but looks at machines following the model of cybernetics, as some sort of information processing system. Therefore, both technical artifacts and humans are simply component parts complex machines. What is important for Simondon is the function performed by a given machine particularly when he focuses on complex structures such as technical ensemble[38] (de Vries, 2008). Most technical ensembles have the function to produce specific technical artifacts that can be used and integrated in other ensembles. Other technical ensembles such as communication systems have the function to process information between groups of users.

What is particularly interesting about Simondon's account of machines is his description of how humans are no longer the main components of technical ensembles. For most of technical history, humans have been the dominant component parts, but the advent of industrial and information machines means that human beings are no longer the main technical individuals. In the context of Simondon's philosophy of technology, the most striking development of the past two centuries is the advent of non-human self-regulation, that is to say the increased autonomy of machines relative to human beings. In this sense, he argues for a reversal of the standard account of alienation. In fact, for him, humans have been the dominant technical individuals for too long, a transitory solution until self-regulating machines could be built. Any task or process (either physical of cognitive) that lends itself to formalization and automation will likely be transferred to a

[38] The function of a forge is to refine and process metals, the function of a mining complex is to extract minerals; the function of a stock exchange data warehouse is to house the servers allowing the aggregation and matching of financial flows, etc.

machine (Brynjolfsson and McAfee, 2014). This is precisely why Simondon focuses on modern information technology, as he believes they represent an important turning point, the displacement of the dominant role of man within technical ensembles:

> The machine is superior to the human individual in terms of automation, because it is more precise in its teleological mechanism, and is more stable in its characteristics[39] (Simondon, 2013, p.347).

For most of human history, technical ensembles were based on human beings performing various functions, which led to our traditional understanding of technology as a tool and humans as tool bearers. But as technical objects move towards more and more complex ensembles, from workshops to factories and global electronic networks, this traditional point of view is put into question (Mills, 2011). In the industrial age, this tendency is clearly at work in the impressive march towards standardization, such as the case of modern assembly lines. Similarly, the 20th century has seen an equally impressive tendency towards higher levels of automation, whereby many cognitive processes performed by human beings can now be codified and performed by computing machines (Kurzweil, 1990; Kurzweil, 2005; Brynjolfsson and McAfee, 2014).

As we will see, one can look at long historical evolution of specific financial mechanisms utilized in the processing financial transactions. Ancient machines were composed of scribes and their clay tablets, writing and executing financial contacts for the future delivery of grain or slaves (Swan, 2000). Later on, different ensembles of humans and technical artefacts emerged in medieval Europe. Brokers and their accounting books intermediated the transfer of financial contracts such as bills of exchange. More recently, in most stock markets, financial transactions are intermediated by trading platforms. All of these were essentially systems developed for processing information flows taking certain inputs from a group of users that are

[39] Original French text: ''La machine est un automate supérieur a l'individu humain en tant qu'automate, parce qu'elle est plus précise dans ses mécanismes téléologiques, et plus stable sans ses caractéristiques'' (ILFI, p.347).

processed and lead to certain outputs, such as the exchange of financial assets for money and, among other things, the dissemination of price data. The actual way in which this is done evolves over time and depends on the nature of the contracts that are traded, the technical capabilities of the day, the demands of the community of users, various political and historical contingencies, etc. As we will see, it is certainly possible to describe a common technical lineage from the traders of medieval coffee houses, to the brokers on the floors of modern exchanges right up to contemporary electronic trading platforms. Whether they are paper-based or instantiated on electronic circuitry, the common tread for all of these transaction machines is that they essentially perform a precise set of operations relative to the processing of transactions. In the next chapter we will review Philip Mirowski's computational evolutionary economics, which offers a deeper understanding of the precise operations and algorithmic designs of markets, allowing us to fully develop our understanding of transaction machines.

Chapter 3. Markomata: Markets as Algorithms

<u>Summary:</u>

In the previous chapter we reviewed Simondon's Philosophy of technology and his account of complex machines, or technical ensembles. In this chapter we will turn to Philip Mirowski's evolutionary computational economics and his theory of markomata, where markets are understood as machines for the processing of transactions. In this context, Mirowski proposes the notion of markomata (markets + automata) understood as forms of computation. For him, markomata function according to algorithmic processes, by accepting a series of inputs (bids/asks) and producing a set of outputs (prices and quantities). He suggests a different research direction for economic theory, namely the exploration of the wide diversity of market structures, rather than remaining fixated on the agency of individual agents. In the context of his theory of markomata, this entails modelling the diversity of possible markets structures, by using the theory of automata and a particular account of evolution. Moreover, he looks as specific market designs as computational systems evolving in an environment made up of different human societies and cultures. The evolutionary units are the different market designs, while human societies would have a similar function to environmental pressures. In this sense, according to Mirowski, the theory of markomata opens up the possibility of a different type of evolutionary economics, in that it describes both processes of variation and selection as well as the mechanism for inheritance. In the case of markomata, reproduction is achieved when a new design is invented and developed that simulates the operations of more simple markomata. Variation is inherent as new designs of different computational power, with different aims and rules constantly emerge. All of this opens up economic theory to the study of the rich and evolving landscape of market designs and moves away from the century old tendency to focus on utility maximization by rational individuals.

3.1 Mirowski and Unorthodox Economics

We will dedicate this chapter to the work of Philip Mirowski, particularly his computational evolutionary economics and his theory of markomata. One way to approach his work is by positioning it in relation to certain heterodox economic theories, such as evolutionary and bio/ecological economics, as well as by highlighting the influence of cybernetics and the theory of computation. While he is usually referenced in relation to his work on neoliberalism and the history of economic thought, he dedicated his first major book *More Heat than Light* (Mirowski, 1989) to Thorstein Veblen and Nicholas Georgescu-Roegen, calling them ''the most profound economic philosophers of the 20th century''. While evolutionary economics has its roots in the likes of Thorstein Veblen and Joseph Schumpeter, bio/ecological economics is hugely indebted to the work of Nicholas Georgescu-Roegen and Keneth Boulding, Both strands of economic theory find there underpinnings in the assertion that the science of economics needs to open up to other disciplines, with particular interest for ecology, biology, thermodynamics and history, among others.

For instance, bio/ecological economics represents a particularly insightful critique of the economic orthodoxy, which has traditionally modelled the economic process as the allocation of given means in order to satisfy given needs (Lionel Robbins). As Georgescu-Roegen argues, at the core of this microeconomics is a principle of conservation (given means), a maximization rule (optimal satisfaction) and an economic agent that is essentially self-interested. In this static world, nothing can ever change because everything is already given, fully individuated. This mechanics of utility and self-interest and the postulate of a static state of equilibrium seem to leave no space for change and the emergence of novelty. The economy is thus a ''self-contained and ahistorical process'' (Georgescu-Roegen, 1971, p. 2). Thus bio/ecological economics makes substantial use of notions of qualitative change, understanding the economic process as an emergent phenomenon, or in other words as a whole that is more than the sum of its parts. Similar to chemical compounds, which have properties not exhibited by its elements in isolation, economic ‘compounds’ like markets or firms are constantly undergoing a process of qualitative change (Backhaus and Drechsler, 2006). This perspective is quite different from the standard account. As Herman Gossen argued in the 19th century, humans can act upon the environment only by causing motion, which reflected the influence of filed of physics for economic theory (Gossen, 1983, p. 40). In this sense, neoclassical economics cannot deal with irreversibility (Faber, 2008, p. 4) and relies on a notion of linear reversible transformation (locomotion), in which there are no emergent properties. In fact, the inability to deal with irreversibility is why mainstream economics has been less successful in accounting for real novelty and emergent properties (Dosi and Metcalfe, 1991).

While mainstream economics relies heavily on reversible principles, ecological economics is tied to thermodynamics, which was arguably the first serious scientific challenge to classical physics. Focusing on the importance of the 2nd law of thermodynamics, Georgescu-Roegen developed his economic theory around the concept of entropy. His famous statement that the ‘’entropy law is the basis of the economy of life at all levels’’ (Georgescu-Roegen, 1971, p. 4) won him both his notoriety and also led to his isolation within the academic community. Writing in the turbulent 1970’s, it became apparent to him that mainstream economic theory could not provide an adequate solution for addressing the huge task of Third World underdevelopment, depletion of natural resources, increasing pollution, etc. (Georgescu-Roegen et al., 1999). In his attempt to deal with these issues, he recognized that the main barrier was economic theory’s reliance on an out-dated model of physics. In this sense, he advocated for the usefulness of thermodynamics whose 2nd law would offer a much more fruitful theoretical foundation for economics. What was particularly appealing in this law was that it offered an understanding of change that was irreversible and, as he put it, irrevocable. Contrary to Newtonian mechanics, which understood change as locomotion, as a substance that stays the same trough time and space, entropy allows for qualitative change in which time and space are not independent variables. For if the entropy law operates at all levels, then one can understand the economic process as a continual exchange between low and high entropy. No matter how important these questions might be, energy exchange and entropic degradation cannot fully account for the complexity of economic and social phenomena. It was Georgescu-Roegen himself that warned of the futility of trying to describe the economic process by a system of thermodynamic equations (Georgescu-Roegen, 1975). In other words, there is no point in replacing a mechanistic dogma with an energetic one. Nevertheless, bio/ecological economics have had an important contribution in modeling the relationship between the economy and the wider ecology, issue of sustainable development, incorporating environmental aspects into a different understanding of welfare (Costanza and O'Neill, 1996). Moreover, Georgescu-Roegen's work has proved influential for many economists including the likes of Philip Mirowski, particularly in terms of highlighting the importance of having an interdisciplinary perspective. As we noted earlier, Mirowski's first major work, *More Heat Than Light* (1989), was dedicated to Georgescu-Roegen, and is a detailed analysis of how the framework of 19th century physics and was literally imported into neoclassical economics. While Georgescu-Roegen equated 19th century physics with Newtonian mechanics, Mirowski focuses on the impact of the 1st law of thermodynamics, the famous conservation principle. In this sense, he argues that neoclassical economics did not solely rely on mechanics but also leveraged the early version of thermodynamics, namely the so-called energy physics of conservation:

> The physics of the day [19th century], much admired by economists, assigned a central role to the conservation of energy. Potential energy could be represented as a vector field, indicating the direction in which particles would move unless constrained by other forces. The economic analogy treated individuals as particles moving in commodity space, where the spatial coordinates are quantities of different commodities (Ackerman, 2002, p.129).

Mirowski thus corrects Georgescu-Roegen and reworks his account of the relationship between physics and economics. The marginalist economists of the 19th century were very much attracted by notions of equilibrium, conservation of energy (Pilkington and Mirowski, 2013, p.341) motivated by the desire to attain the same scientific status as the natural sciences. It is not so much that economists ignored thermodynamics, but that they adopted what suited them most, namely the very important point about the conservation of energy. In a certain sense, they were very selective with what they took both from physics and mathematics. Moreover, he demonstrates how these theoretical imports were done without fully understanding the mathematics behind it, which has consequences for economic theory, even to this day.

It would also be interesting to address the importance of evolutionary economics for Mirowski's work. Evolution first entered the realm of economics in 1898 with Thorstein Veblen (Veblen, 1898; Geoffrey Hodgson, 1998) who was influenced by the biology and sociology of his time, and was critical of the assumptions of neoclassical economics. Moreover, he argued for the necessity of evolutionary explanations for economic behaviour. Alfred Marshall is also sometimes credited with being a proto-evolutionary economist, but mostly because of his famous statement that biology and not mechanics will turn out to be the Mecca of economists (Hodgson, 1993). More recently, it was Kenneth Boulding's book *Evolutionary Economics* (1981) that helped popularize the term (Hodgson 2010). Another crucial turning point towards and evolutionary theory of economics was Nelson and Winter's work *An Evolutionary Theory of Economic Change* (Nelson and Winter, 1982). Their work is still considered as the foremost reference for the field, as they relied heavily on biological analogies and saw themselves as neo-Schumpeterian. What is intriguing is that Schumpeter himself rejected biological analogies and only thought about evolution in the sense of a general process of change, what he calls ''development'' in the context of his theory of creative destruction (Schumpeter, 1983; Metcalfe, 1998; Shionoya and Nishizawa, 2008). Some of the more recent work in evolutionary economics has focused on a general understanding of evolution, going beyond biology towards a broader perspective (Hodgson 1993, 2003; Hodgson and Knudsen, 2006a). It goes beyond the compounds of biology towards the more general notion of Universal Darwinism, first introduced by Dawkins (1983). Universal Darwinism can be understood as an account of the way in which complex systems evolve, according to the process or variation-selection-retention[40]. But in each domain of applicability, the procedure or algorithm of variation-selection-retention is deployed is very different ways. In this sense, evolutionary economists such as Geoffrey Hodgson and Stanley Metcalfe (Hodgson, 2002) make an argument for a notion of evolutionary logic, which helps account for change in all complex systems (equally applicable in biology, sociology or economics):

> Nothing I have said is intrinsically a matter of biological analogy, it is a matter of evolutionary logic. Evolutionary theory is a manner of reasoning in its own right quite independently of the use made of it by biologists. They simply got there first (Metcalfe, 1998, p.36).

Ulrich Witt is an evolutionary economist who has taken more nuanced view with his ''continuity hypothesis'' (Witt, 2003). According to him, social and economic evolution is very much embedded and constrained by biological evolution. He makes clear that the processes by which evolution operates in nature and society are very different. Moreover, he is very sceptical about the merits of using biological analogies and trying to find the equivalent of genes in the world of business. He considers the direct translation of natural selection into the economic realm as metaphorical and with limited use (Witt, 1999; Geoffrey Hodgson, 2002; Geoffrey Hodgson and Knudsen, 2010)(Witt, 1999, p.24). John Foster (1997) has also proposed a critique of the use of Darwinian analogies, and suggests the adoption of the theory of self-organization as an alternative. Another approach that is intimately tied with Universal Darwinism is the research done in Complexity Economics. One if its best know proponents is Beinhocker, who rejects any accusation of analogical thinking and argues that evolution is the execution of an algorithm, as continuous unfolding of the process of variation-selection-retention. In Beinhocker's account, social and economic evolution is a:

[40] One can also think here of the philosophy of Charles Sanders Peirce (1898), who speculated that the laws of nature themselves were subject to evolution.

> (…) process of sifting from an enormous space of possibilities…There is no foresight, no planning, no rationality, and no conscious design. There is just the mindless grinding out of the algorithm (Beinhocker, 2007, p.198).

While it has provided numerous insights into the workings of the economy, evolutionary economics has often been criticized for the use of analogies and metaphors. For instance, Nelson and Winter's reliance on routines as possible units of selection has been the target of ample criticism (Geoffrey Hodgson, 2003). Other questions arise on the topic of reproduction and inheritance. Namely in what way can it be said that firms transmits genetic material to the next generation?

As we will see, while it is difficult to say that Mirowski is an evolutionary economist, he is however influenced by this body of literature. Rather than focusing on routines or business plans as the unit of selection, Mirowski looks at the institutional framework of markets as the units of evolution. In his account, markets evolve through time under the selective pressure of human societies and their material, historical and cultural specificities. We will elaborate on his perspective in the next section, different to most ecological economists his understanding of evolution is indebted to John von Neumann rather than Darwin.

3.2 John von Neumann's Theory of Automata

As will see, Mirowski's theory of markets as computational systems draws heavily from von Neumann's theory of automata (Mirowski and Somefun, 1998b), positioning information theory and computation at the centre of a different theory of evolution. John von Neumann was a well-known pioneer in many scientific fields, including applied mathematics, and is the founder of what today is called game theory, which of course had a profound effect on 20th century economics. Consequently, he is also one of the central figures of Mirowski's book *Machine Dreams* (2002), as the genius whose impact on economics, and other fields, has not yet been fully realized. For the purpose of our topic, he is interesting for this theory of cellular automata and the universal constructor. In a paper published as part of the Hixton Symposium held in Pasadena in 1948, he describes the basic blueprint of a machine capable of self-reproduction (von Neumann, 1951). In another paper from 1966 called the *Theory of Self-Reproducing Automata* (von Neumann and Burks, 1966) he spells out the details of self-replicating automata including:

> The functional part of the automaton; a decoding section which actually takes a tape, reads the instructions and builds the automaton; and a device that takes a copy of this tape and inserts it into the new automaton (Istrail and Marcus, 2012, p.7)

He also formulated an abstract model of this in the form of the cellular automaton, following a suggestion by his colleague Stanislaw Ulam. It consisted of a two dimensional structure made up of discrete cells. In the *Theory of Self-Reproducing Automata*, each cell has 29 possible states and a set of predefined rules for switching between states. The states could only change at specific time interval, depending on the cells own state and that of its neighbouring cells. After enough time intervals, even the simplest rules can lead to more and more complex patterns. Cellular Automata have been popularized in such applications such as The Game of Life, but they have proved particularly useful for research in the areas of urban growth, land use, soil erosion, etc. While Von Neumann's initial goal was to understand and study the possibility of self-replication in general, understood as the emergence of increasingly more complex patterns from the iteration of relatively simple rules. While gaining a complete understanding of replication in nature could be very difficult, he believed that we might have a better chance of understanding self-replication in the case of computational automata (von Neumann, 1951). In any case, without being able to do justice to von Neumann's ground breaking contribution, it can be said that his theory of automata, founded on Shannon's concept of information and Turing's notion of computation, was a way to understand any ''information-processing mechanism which exhibited self-regulation in interaction with the environment'' (Mirowski and Somefun, 1998b). Moreover, it represents a very interesting way to approach questions of complexity and evolution. Lower-level interactions lead to higher-level patterns, which are more complex than anything at the lower-levels.

> John von Neumann invented the theory of automata not to provide a pedagogical basis for 'computer science' (which is the position it occupies in contemporary textbooks), but rather to formalize a notion of evolution where abstract logical entities, in the process of replicating copies of themselves, might be able to produce offspring of greater computational capacity than they themselves possessed (Mirowski, 2007, p.230).

Nevertheless, von Neumann did not leave us with a fully developed theory of automata, as many important questions are still left unanswered such as: when can it be said that one automaton produced another more evolved version of greater computational complexity? (Mirowski, 2002, p.536). For example, the finite automata (also known as a finite state machine) can be seen as the basic layer of abstract machines. It consists of an alphabet or inputs, a set of states, a transition function, an initial state and a halting condition. This machine has no real memory capacity, as it only reads a tape containing a string of symbols. It reads each symbol and either accepts or rejects it, and is in this sense, a simple language recognition device (Mirowski 2007, p.25).

In trying to adapt this perspective to his theory of markets, Mirowski draws from Chomsky's work on the hierarchy of generative languages[41] (Chomsky, 1957). In this sense, one can understand complexity in computation along Chomsky's scale of language recognition: finite automata (regular grammar), pushdown automata (context-free grammar), linear bounded memory automata (context sensitive language), and, at the top of the hierarchy, the Turing machine (recursively enumerable) (Mirowski, 2002, p. 537, Mirowski, 2007).

Automaton type	Recognizes languages	Memory	Markets
Finite	Regular	None	Posted-price
Pushdown	Context-free	Pushdown stack	Sealed bid
Linear bounded	Context sensitive	Finite tape	Double auction
Turing Machine	Recursively enumerable	Infinite tape	None

Figure 2: Hierarchy of market complexity

(Mirowski, 2007, p25)

The table above illustrates Mirowski understating of the increasing complexity of different 'generations' of market designs. Firstly, a posted-price market would qualify as finite automata as it does not require memory, only the capacity to recognize symbols and accept or reject. As Mirowski explains it:

> A single unit of the commodity is offered at a single price, where the alphabet concerned is the rational numbers; order execution either matches that number as bid by the purchaser, or is rejected (Mirowski, 2007, p.25)

[41] In his 1955 thesis and later in Syntactic Structures (1957), Noam Chomsky studied the capacity for language acquisition in humans. His famous hierarchy of formal grammars is a classification based on their generative power.

The next layer of complexity would be sealed-bid auction, which need memory capacity in order to compare any new bid with previously recorded bids. In this type of market, the seller has a minimum ask, and the machine would halt only when the bids are higher than the minimum ask (Mirowski and Somefun, 1998a). This second design could be modelled as pushdown automata with two stacks, one for the submitted bids and one for the minimum ask. Going up on the ladder of complexity, a two-sided auction requires even more memory capacity, which is why Mirowski sees it as a good example of a linear bounded automata. Similar to a Turing Machine, the linear bounded automata can read the symbols on the tape and write on the cells, but it differs in that it the tape is not infinite (Mirowski, 2007). Elsewhere, Mirowski shows how it is possible to model a double-sided auction as pushdown automata with 3 or 4 stacks (Mirowski, 2002, 1998).

While this initial approach is very interesting, the auction algorithm by which transaction can be matched is only one of the many functions performed by markets. As Mirowski admits, even the most simple fixed-price posted-offer market performs a number of different functions, in addition to matching. This would include record keeping, price dissemination, etc. In other words, constructing a more complete model of such a market would entail a more detailed understanding of the way different market functions evolve. Consequently, the theory of markomata needs to also leverage a proper taxonomy of specific market forms.

3.3 Market Ecology

One of Mirowki's most interesting assertions is that markets are systems exhibiting a substantial diversity of possible designs. In this context, an auction refers to the way in which the matching function of the market is performed. Most accounts tend to reference the initial emergence of auctions in ancient Babylon, in relation to slave trade (Swan, 2000). Throughout history, different matching mechanisms emerged for the purpose of transacting slaves, tulips, physical commodities, art works, and are still an important part of contemporary commerce, such as the web-based platform eBay. In all of these cases, the auction mechanism is crucial because it provides the algorithmic blueprint for the matching of buyers or sellers. Because of the diversity of aims and goals on the part of the users of a markomata, but also the number of possible commodities for sale, the history of auction design comprises many possible technical solutions. Mirowski follows the work of Wurman and Wellman (Wurman *et al.*, 2001) in providing the initial distinction between two separate branches: the single-sided and the two-sided auction

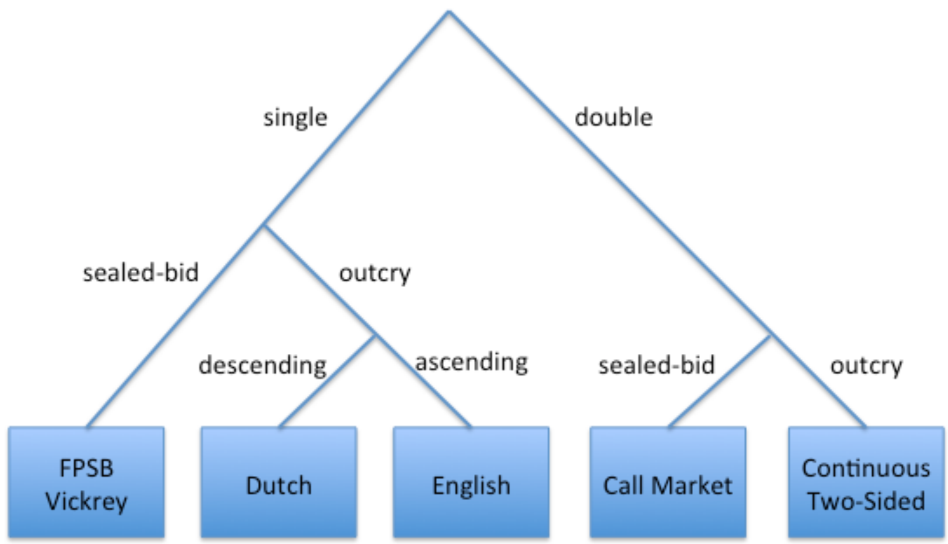

Figure 3: Classification of classic auction types

(Wurman et al., 2001

In the first branch, only sellers or buyers can submit quotes (bids or offers), while in the second version all parties can switch between buy and sell mode. Subsequent branches can be added by distinguishing between open-outcry or sealed-bid auctions. In the first version, all bids or offers are public from the start, while in the second they are revealed only at the end of the auction (Schneider, 2003). Further classifications are possible depending on the direction of the bids such as the ascending English auction or the descending Dutch auction. While the open outcry continuous double auction of the New York Stock Exchange have captured our imagination, we can also think about the single bid open-outcry auctions used in the case of tulips or works of art. The sealed-bid single-sided auction limits the identities of participants and the transparency of price setting. More recently, in modern stock markets, continuous double auctions provide pre and post-trade transparency and are more suited for liquid assets. A Dutch auction is best suited for quickly clearing the market while the modern continuous double auction allows buyers and sellers to submit bids at the same time, and seriously limits opportunities for arbitrage (Mirowski, 2007, p.228). Different auction designs have evolved for differ types of commodities. For instance, the English open-outcry auction is particularly useful for selling collectable items, while the Dutch version is better suited for perishable items, as it can quickly clear the market.

Thus Wurman and Wellman show us that by using just a few parameters one can construct a relatively complex taxonomy. Moreover, Friedman and Rust (1993, p.8) argue that beyond single/double sided and open-outcry/sealed bid, one can also think about direct/reverse, ascending/descending, unitary/multiple units, discriminatory/uniform payment, divisible/indivisible bids. This more complex taxonomy allows for a finer classification of auction models. The single-side auction can be split into direct or reverse, depending on who puts the goods for sale and how the offers are received. In a single-side direct auction, the seller presents information and receives bids from potential buyers. Depending on payment rules, one can distinguish between first-price sealed-bid auctions (FPSB) and second-price sealed-bid (SPSB or Vickrey). In both cases, the winner is the one who makes the highest offer, but in the SPSB (Vickrey) version, the winner only has to pay the second highest bid. Further parameterizations cam be developed depending on whether the good on offer is unique or composed on homogenous units, whether the bids are divisible or indivisible, etc. (Douglas D. Davis and Holt, 1993). Having a more detailed taxonomy of possible market auctions or matching mechanisms, leads to the possibility of more granular analysis of market structures. What makes the continuous double auction particularly efficient is the integration between bid/ask and buy/sell (market theory evolve and markets to). In this regards, substantial research has been done in analysing the market structure of the so-called synchronized double auction (Rust et al., 1993). In this format, the two steps are not integrated, so a bid or ask is not instantly converted into a buy or a sell. In other words, some market participants can develop parasitic strategies (Friedman, 2007). This highlights the fact that different market designs can favour specific participants. Moreover, it shows that apparently insignificant details regarding the matching or auction design can have significant impact in terms of the wider power dynamics of the market.

In any case, rather than reducing the homogeneity of market structures and auction design to one single Market, the role of economics should be to study this diverse ecology with particular interest for its historical evolution. Mirowski points out that the contemporary study of markets largely lacks such a taxonomy. Once such a natural history of markets is available, it will represent the final piece of the puzzle for what he calls a computational evolutionary economics.

3.4 Experiments, Market Microstructure and Zero Intelligence

A series of innovative research programs at the crossroads of economics and computer science have helped shape Mirowski's theory of markets. Among these, the most important are operations research, agent-based modelling, market microstructure as well as experimental economics and the research done on zero intelligence agents. In a recent lecture series at the Institute for New Economic Thinking (INET), Mirowski and Edward Nik-Khah offered a summary of these research agendas as well as detailed explanation of their impact on the core of orthodoxy[42]. For the purpose of this thesis, we will focus initially on the so-called market microstructure literature. This is a study of how different market rules influence the price formation process, looking at issues of information asymmetries, transparency, transactions costs, liquidity, efficiency, welfare, etc. (O'Hara, 1995; Madhavan, 2000). This body of research can be seen as a reaction to the introduction of ICT into financial markets led to a series of new developments such as electronic and algorithmic trading, but also to the large electronic platforms and novel forms of e-commerce auctions. Moreover, questions of transactions costs, information transparency and bid-ask spreads are cast in a new light when one has to build the infrastructure of a new electronic market from scratch (Mirowski, 2007, p.217). For instance, when designing the rules and details of a new trading platform, questions of efficient allocation and Pareto optimality become secondary at most. What is important is to satisfy the needs of different groups of participants, brokers, dealers, institutional investors, high-frequency traders, etc. In other words, a successful and efficient market design allows each participant to get what he came for at a reasonable cost (Lee, 1998; Lee, 2011).

The algorithmic nature of markets has also come to the fore because of the work done in fields such as Artificial Intelligence and Game Theory. In both cases, the goal was to model economic agents as computer programs, and only later did these

[42] Forthcoming Mirowski, P., Nik-Khah, E. (2016) *The Knowledge We Have Lost In Information*. Oxford University Press.

programs become sub-routines of a more complex algorithm, modelling entire markets. Outside of the real world of trading platforms, Experimental Economics essentially started as the study of how resources are allocated under different market formats. One early pioneer was Vernon Smith, who experimented with the market structure of the New York Stock Exchange (NYSE), the continuous double auction matching mechanism, in the 1950s. He intended to study the allocation characteristics of this format and through his experiments, revealed that the continuous double auction rules were superior to other market rules in terms of convergence to equilibrium. His landmark work *An Experimental Study of Competitive Market Behavior* (Smith, 1962) highlights the capacity of market algorithms, such as the NYSE matching mechanism, to rapidly lead to convergence even in the case of relatively uninformed agents. Smith was also curious to see if other market structures would produce rapid convergence, but his conclusion was that the double auction was the only format that provided theses ''superior outcomes'' (Mirowski, 2007, p.212). More importantly, his experiments led him to state his famous Hayek hypothesis:

> Strict privacy together with the trading rules of a market institution are sufficient to produce competitive market outcomes at or near 100% efficiency (Vernon Smith, 1991, p.223).

This famous hypothesis is particularly interesting as it suggests that markets work independently of the cognitive capacities of interacting agents. So the superiority of the double auction was not really dependent on the degree of rationality of market participants but on the very structure of the market, its institutional set-up, its formal algorithmic rules. This line of research was further developed in the work of Dan Gode and Shylam Sunder's work (Gode and Sunder, 1993). Their approach was to compare the two-sided market structure in two different situations, with human subjects and then with algorithmic agents called zero-intelligence agents, which were effectively random-number generators. These 'brainless' agents were bits of software that produced random bids or asks within the limits of their assigned price levels. They also modelled the same process with more 'evolved' agents, which had an additional budget constraint (Mirowski, 2002, p. 553). The first ‘brainless’ version of computerized traders did not lead to convergence but the second more evolved versions did reach so-called allocative efficiency. What was even more fascinating was the fact that these second algorithmic agents produced nearly identical results to experiments performed with human agents. This last point, ultimately led them to focus more on the algorithmic blueprint of markets and not on the psychological and cognitive state of the interacting agents (Mirowski, 2007, p.216). Nevertheless, they never really took the research to its ultimate conclusions:

> The terror before which G&S [Gode & Sunder] stood transfixed was not that economists would begin to confuse human beings with their bits of code (was it?), but rather that it was all too easy to draw some devastating morals from their exercise about the utter futility of more than a century of neoclassical economic theory (Mirowski, 2002, p. 553).

In any case, they continued to experiment with market structures, deconstructing the continuous double auction, ending up with a nested hierarchy of market rules. The basic layer was a Null market that matched zero-intelligence agents in a random way. The next level was a sealed-bid format, which was actually the more basic Null market with the additional of a second rule regarding price priority. This can be further enhanced by a call auction that periodically matched bids and asks, followed by a one round double auction (Mirowski and Somefun, 1998). What is essential is that they demonstrate an increase in Marshallian efficiency from one generation to the next (Mirowski, 2002, p.559). Building on Gode and Sunder’s work, Mirowski and Somefun’s 1998 paper describes the outlines of a hierarchy of markets, ranked along Chomsky’s computational hierarchy. They start with the so-called Null market and demonstrate how it can be modelled as finite automata. This would be a very simple machine that would answer yes or no if a bid or an ask was submitted and ‘’will arbitrarily halt or read the next available input’’ (Mirowski and Somefun, 1998). In order to move to the next generation, one needs a more advanced halting condition and more memory capacity. For example the sealed bid auction can be modelled as pushdown automata with two reading heads. In this case, the halting condition is accomplished when a bid is greater or equal to the value of the ask. While this second markomata is more computationally 'evolved' than the 'Null' market, it cannot sustain the complexity of a double auction. In this case, a four-head pushdown automata is needed. The machine must record both the highest bid and the highest asks and compared them to new bids and asks. This actually means that the double auction represents a further evolution from the point of view of computational capacity. So far, the history of markets has largely been dominated by fixed-price posted-offer markets of lower computational complexity but with high reliability in converging supply and demand. In certain environments, such as financial markets, a sealed-bid or continuous double auctions of higher computation complexity can emerge. There is also an element of irreversibility at play in all of this as the world of markomata is hierarchical. Also, as demonstrated by Mirowski and Somefun some markomata can simulate the functioning of others, but not vice-versa. For instance, the double auction can mimic the sealed bid auction because of increased memory capacity.

> DA [Double Auctions] is formally a "descendant" of the sealed bid market, and can therefore handle more complex information processing tasks. This formal result can then be brought to bear in the future on a "natural history" of markets, to research the possible ways in which these particular market forms have evolved relative to one another (Mirowski, 2007, p.23)

As we will see, what probably seemed secondary for Gode & Sunder, namely the evolutionary tendency of market forms, achieves centre stage in Mirowski's theory of markets. In his perspective, the double auction is more superior because it has greater computational capacity than the lower strata, and can cope with higher levels of complexity. In his view, this is the ultimate vindication to John von Neumann's theory of automata, namely that lower-level interaction between simple automata can lead to more complex structures. Secondly, this process partially undermines the neoclassical attempt to subsume all markets to one single Market. To the contrary, experimental economics open up the possibility o the study of different market forms of different complexity and very different set of goals.

3.5 Mirowski's Markomata

In *Machine Dreams* (2002), Mirowski attempts to rewrite the history of economic theory as a continuation of his earlier work *More Heat Than Light* (1989), which focused on the second part of the 19th century. Between these two books, he has become one of the most interesting historians of economic thought. One of the central ideas of this book is that economists have always dreamed of reaching a similar degree of scientific rigor to the natural sciences, but have always been selective in terms of what they adopted from these more precise sciences. In this sense, the marginalism of the 19th century can be seen as a more or less mathematically elaborate example of this machine dream, based on the adoption of classical thermodynamics and the field metaphor (Mirowski, 2002, p.517). As Mirowski points out (Pilkington and Mirowski, 2013), the second book was in some ways a reaction to the critiques generated by the first one. For instance, some (Walker, 1991; Cohen, 1992; Hands, 1992) have argued that although there might haven been appropriations from physics in the 19th century, economic theory has matured since then and energetic metaphors are not longer relevant. In responding to some of these critics, *Machine Dreams* represent an impressive tour de force in intellectual history, arguing that the same process happened in the 20th century, although with different metaphors. He thus identifies a turning point in economic theory as the transition from the reliance on energetic metaphors to the adoption of the language of computation and the framework of cybernetics and information theory.

> (…) whereas once upon a time market equilibrium had been thought to resemble a ball rolling to the bottom of a bowl, now it signifies something altogether different, something more like the economic agent as an information processor coming to 'halt' at the end of a computation'' (Mirowski, 1994)

That is to say, the advent of the computer in the 20th century engendered a gradual transformation of economic theory. From the early days of the Cowles Commission and game theory, to the theory of rational expectations, Nash equilibriums and the work of the Santa Fe Institute, cyborgs have been slowly, but surely, entering the world of economics. One of the most striking results of this progression is the switch in emphasis from the economy as the allocation of scarce resources, to an understanding of the economy as an information processor. Consequently, the computer metaphor has also influence broader political ideologies such as neoliberalism, as the market can now be seen as a far more superior information processor than any individual or any bureaucracy. But as argued by Mirowski, an informational understanding of markets also has the potential to undermine most of economic orthodoxy. This is because it renders the energetic metaphor of the field, the backbone of neoclassical economics, obsolete, as well as deemphasizing the importance of notions such as the utility function and the maximizing agent. (Mirowski and Nik-Khah, 2016).

In fact, the displacement of the dominance of physics in the economics profession could be seen as the very condition of possibility for a computational evolutionary economics. Mirowski thus argues that the future of economics will depend more on the sciences of computation and evolutionary biology (Mirowski and Somefun, 1998, p.6). The core of this displacement is not just about finding better functional analogies, but it represents a deeper shift in the very object of scientific research. Rather than remaining fixated on the agency of individual agents, economics will have to embark on a novel research program, the understanding of the wide diversity of market forms (Mirowski, 2007, p.211). But how does one reconfigure the focus of economic theory on markets, rather than economic agents? In Mirowski's case, this entails the modelling of diverse markets structures by using the theory of automata and subsequently organizing them according to a theory of evolution. He thus coins the term markomata (markets + automata), which allows him look at the 'diverse ecology of markets differentiated according to their formal computational structures'' (Mirowski, 2010, p.13). In a computational view of markets, markomata work just like any other algorithmic process, by accepting a series of inputs (bids/asks) and producing a set of outputs (prices and quantities). And just like most other things, there is not necessarily one perfect design for all possible market functions. One of the most interesting displacements of Mirowski's theory of markomata is relinquishing of any grand vision of the Market (with a capital M). Consistent with both our discussion of Social Studies of Finance and assemblage theory, Mirowski argues for the futility of thinking in terms of an eternal essence of the Market.

> '' (…) there are numerous diverse forms of rules and behavior which could be used to facilitate trade. Hence what we would call an 'economy' is really a patchwork of many market forms, imperfectly interlinked and integrated'' (Mirowski, 1994).

Mirowski thus argues for an account of markets as a diverse ecology of automata, as a far more appropriate perspective in the context of the present explosion of electronic trading platforms, e-commerce, algorithmic trading, etc. Consequently, he suggested a repositioning of economic research towards the 'laws' of market evolution rather than reduce the market to the microeconomics of the representative rational agent. In fact, a computational view of markets, based on the theory of automata, necessarily reduces the importance of the cognitive capacities of economic agents, while giving primacy to the way in which signals are transmitted and processed (Mirowski and Somefun, 1998a). As Mirowski himself says, it is more a question of syntax than semantics, the way in which agents interact is more important than the intention of the interacting agents. One can think of markets as networks, as institutions or as technical systems, but they can very well be seen as formal automata (a set or rules) performing a series of market functions.

He warns us against the danger of reifying the market and treating it like a Platonic form or as an unproblematic convergence of supply and demand curves. Thanks to various developments within economics, including computational economics, experimental economics, microstructure research, we now have a more detailed understanding of how markets actually work. As stated above, the wide variety of markets comes from the way in which they fulfil various functions including: order matching, routing, execution, clearing & settlement, computing prices, record keeping and information dissemination, etc. Depending on how these functions are performed, markets can be very different structures, with varying degrees of efficiencies and different sets of possible outcomes:

> There is no ur-model or uber-machine to which the blooming, buzzing profusion of markets can be reduced (Mirowski, 2007, p. 224)

In fact, the recent development of e-commerce supports Mirowski's theory of markomata as an ecology of computational forms. Market diversity is not simply a premise of the theory of markomata, but a historical given, as there have always been a variety of market forms going back to the dawn of human societies. Instead of following the neo-classical tradition and positing a single market throughout human history, Mirowski's approach is deeply rooted in the empirical plurality of markets, with their ''varying capacities and complexities'' (Mirowski, 2002, p.540). There is not one Market, objectively present in front of us at all times, and static throughout history. What actually exists is a plurality of markets performing various functions, matching buyers and sellers in different goods, commodities and assets. Different markets can have different auction mechanisms, different matching and clearing solutions, and different ways to settle transactions. Moreover, depending of market microstructure, markets can strategically favour certain participants over others; they can have different degrees of efficiency and can be more or less robust to external/internal shocks.

In any case, a computational understanding of markets fits well with a definition of a market as *a* ''set of rules which facilitate the conduct of exchange and the conveyance of information between buyers and sellers'' (Mirowski and Somefun, 1998, p.13). This functional perspective is far removed from the standard goals of efficient allocation or Pareto optimality. On the one hand, the computational view of markets suggests that thinking in terms of different degrees of efficiency, pertaining to different markomata, is a more accurate picture of real markets than simply presuming that the Market is efficient. On the other hand, the study of markomata could very well indicate other market goals beyond allocation, such as the efficient matching of trade requests, or the immediate dissemination of price information. All of these are very important questions for the future of economics and the functioning of real markets. In a certain sense, inviting economists to study the ''machines that facilitate our attempts to trade'' rather than building reductionist models of the complex behaviour of human individuals:

> Let's model these irreducibly social phenomena as software machines, and proudly confess that we (in our capacity as economists) are not yet equipped to model real human beings in all their fascinating ontological and epistemological diversity and perversity (Mirowski, 1994)

As we will see in the next section, he also proposes an evolutionary trajectory for markomata, emerging in an environment made up of different human societies and cultures. In this context, the evolutionary units are the different market designs, while human societies would be the environmental pressures responsible for the processes of variation, selection of retention. Moreover, according to Mirowski, the theory of markomata can be seen as a different type of evolutionary economics, in that it describes both processes of variation and selection as well as the mechanism for inheritance. In the case of markomata, reproduction is achieved when one markomata manages to simulate the working of another markomata within its own functioning. Variation is inherent as new markomata of different computational power, with different goals and rules are constantly being designed. Human societies/cultures ultimately select specific markomata, due to their capacity to process transactions and produce prices and more importantly, their capacity *to* ″successfully emulate other relevant market calculations emanating from other market automata'' (Mirowski, 2002, p. 544).

3.6 Markets as Evolving Computations

As we have seen, Mirowski's approach is to understand markets as computational systems performing a series of functions relative to a group of users. In this sense, markets are highly complex technical systems and deserve the same kind of attention form social scientists as nuclear reactors, particle colliders or the Internet. To a certain extent, this adds to the already on-going deconstruction of the black-box of finance, aligning itself with the work done by the social studies of finance, in terms of the sociology, anthropology or history of financial markets (Knorr-Cetina and Bruegger, 2002; Knorr-Cetina and Preda, 2006; MacKenzie, 2006; Morrison and Wilhelm, 2007; Matthew Watson, 2007; MacKenzie *et al.*, 2008; Ho, 2009; MacKenzie, 2009b; Esposito, 2011). Mirowski's computational evolutionary economics arguably goes much further in acknowledging the crucial role of technology and computation in understanding market dynamics. Rather than remaining fixated on the agency of individual agents, Mirowski argues for a novel research program, the understanding of the wide diversity of markets founded on the theory of automata. In Mirowski's project for a computational evolutionary economics, the multitude of functions performed by markomata would be subject to specific formalizations. Depending on design complexity, a number of different algorithms are required in order to fully account for the workings of a particular market. Simple market structures would be easier to model, such as the order execution function of a posted (fixed price) market, the framework of modern retail supermarkets. Simple as this markomata may be (requires no memory), all of the other functions require their own tailored formalizations. Thus, any real life market is complex system encompassing many automata of ''various degrees of computational capacity''. Even the most common posted price markomata could reach very high levels of computational complexity, not to mention a sealed-bid market or a continuous double auction[43]. As we have seen, beyond the basic design of fixed-price posted offer, one can formalize a sealed-bid auction, which require

[43] More elaborate definitions of each class of automaton can be found in Mirowski (2002, pp. 88–92)(Mirowski, 2002, p. 571)

memory capacity as each submitted bid has to be compared to previous ones. A double auction requires even more capacity, as various sequences of both bids and asks need to be compared and matched, the equivalent of a linear bounded automaton (Mirowski, 2007, p.226). Moreover, Mirowski uses the cost of computation as an explanation for the traditional success of posted-offer fixed price markets (lower computational costs) and the relative rare occurrence of continuous double auction matching mechanisms (higher computational costs), despite the higher efficiencies exhibited by the latter. As we have seen, he uses Chomsky's hierarchy of complexity in order to explain this evolution from lower level to higher-level markomata, as well as the reason why all of them still persist in our modern day economies.

> It would appear that markomata capable of advanced simulation arise chronologically later than their simpler relatively self-contained predecessors (Mirowski, 2007, p.227).

The population of possible markomata are thus organized according to a hierarchical system of computation complexity, with each new markomata being able to simulate the functioning of lower level markomata. Reproduction occurs when one markomata succeeds in reproducing the operations of other markomata ''incorporating a simulation of the operation of the specific market format into their own, different market format'' (Mirowski and Somefun, 1998, p.21). Whether or not there is a time arrow in this trajectory, history shows us the subsequent development of more and more computationally complex markomata. The fact that markets don't emerge in a vacuum is a question of common sense, but it requires some intellectual effort to understand that markomata actually evolve within an ecology of human beings, technological artefacts and the wider environment. It is this wider environment that acts as selective pressures on the diverse population of markomata and leads to the selection of specific localized designs.

> Some markomata become established in certain limited areas (such as double auctions in finance) because they are perceived to bundle an array of functions

> deemed particularly suited to the community constituted to promote certain objectives (futures and options, arbitrage, rapid market clearing) whereas others become more evenly distributed across the landscape (such as posted price) due to their relative robustness to a wide array of situations (Mirowski, 2007, p.237).

One interesting selection pressure is the increase of transaction volumes, which poses new demands and challenges to market structure. As we will see in a subsequent chapter, the history of most stock exchanges from the 19th century to the present would reinforce such a statement (Friedman, 2007). The history of exchanges shows us that given certain conditions, buyers will tend to favour markets with a lot of sellers and vice-versa. More recently, the rise of automation and electronic trading has ushered in a new era in the research and design of markets. This means that question regarding markets become and engineering questions rather than an issue of philosophy or ontology. When one has to design new trading platforms for scratch, the whole inventory of neoclassical economics will be of little help.

> For as programmers are hired to automate markets, they will be brought up abruptly against the fact that small differences in market algorithms make big differences in market outcomes; and, furthermore, that one cannot load all the computational capacity onto the artificial agents and none onto the environment within which they are presumed to operate''(Mirowski, 2002, p.567)

In any case, the advent of electronic automated markets opens up the question of invention and production of novelty. The design of the market matching algorithms, i.e the auction process, is crucial. Thus, moving away from dogma of efficient allocation, markets must be analysed by looking at how the perform specific market functions. As there is not necessarily one perfect design for all possible market functions, the wide variety of markets comes from the way in which they fulfil various functions: order matching, routing, execution, clearing and settlement, computing prices, record keeping and information dissemination, etc. Success in efficiently implementing these functions is no trivial thing. The continuous production of prices and their dissemination is a sign that a particular markomata is working, i.e. maintaining the continuous flow of transactions.

Conclusions

In the previous chapter we explored Simondon's general understanding of technology, inspired of cybernetics, information theory and computer science. Drawing from the same lineage, Mirowski looks at markets in particular as technological systems that ''facilitate the conduct of exchange and the conveyance of information between buyers and sellers'' (Mirowski and Somefun, 1998, p.13). To this aim, we reviewed his computational and evolutionary economics and his theory of markomata, where he argues for the possibility of formalizing markets in general as particular types of algorithms (Mirowski, 2010). In this account, markomata work just like any other algorithmic process, by accepting a series of inputs (bids/asks) and producing a set of outputs (prices and quantities). Rather than fixating on the rational optimization of individual agents, Mirowski's unorthodox approach highlights novel possibilities for economic research, such as the study of the great diversity of market forms. The evolutionary units are the different market designs, while human societies would be more like environmental pressures. But Mirowski insists that this evolutionary perspective is not Darwinian but comes from von Neumann's theory of automata and Chomsky's understanding of computational hierarchy. For a long time, fixed-price posted-offer markets, of lower computational complexity but with high reliability and resilience, have dominated economic exchange. In certain environments, sealed-bid auctions (government infrastructure projects), Dutch auctions (selling tulip bulbs) or continuous double auctions (stock exchanges) emerge above this basic level of markets. It might seem strange to understand markets as a diverse ecology of automata. But it is a far more appropriate perspective in the context of the present explosion of electronic trading platforms, e-commerce, algorithmic trading, etc. In any case, it is obvious that Mirowski's theory of markomata offers a solid foundation for our understanding of **transaction machines**. His work is a brilliant attempt at combining computational, evolutionary and institutional economics, which allows one to think about markets as machines evolving under the selective pressures of human society.

We have offered a definition of transaction machines in the introduction, namely as those socio-technical systems performing certain functions that maintain the flow of financial transactions, i.e. the infrastructure of financial markets. In terms of their most basic formal understanding, these machines receive a certain number of inputs (trade requests/orders), process them according to a set of rules and procedures (algorithms) and provide certain outputs. Both Simondon's philosophy of technology and Mirowski's computational evolutionary economics allow us further elaborate our initial definition and clarify our overall approach:

- Transaction machines are socio-technical systems. They emerge in the context of human social interaction and exchange. For the purpose of this thesis, we focus on transaction machines that perform certain functions (matching and clearing) relative to the exchange of financial securities.
- They comprise a specific set of rules and procedures (algorithms) and a physical hardware on which to execute them. Whether they are paper based or instantiated on electronic circuitry, executed by human individuals or computers, the common tread for all of these transaction machines is that they essentially perform a precise set of tasks relative to the processing of financial flows.
- The thesis focuses on those transaction machines that act as the crucial infrastructure of financial markets, that is to say, the basic operations that make financial markets function in the first place.
- Change occurs when new transaction machines are developed, with more efficient and complex designs. In this sense, more evolved versions incorporate the operations of previous ones while also adding novel functionalities. Moreover, there is an evolutionary trajectory that leads to more complex transaction machines, which are also more computationally expensive.
- Transaction machines continue to evolve under the demands and needs of its users, new technological innovations, regulatory changes, as well as the introduction of more complex financial securities.
- In time, these constraints and pressures lead to higher levels of automation and standardization. The 'hardware' of transaction machine moves from

human-based manual processes to ICT-based platforms. Human beings are no longer the dominant technical individuals process the transactional flows

- The control of transaction machines is a crucial aspect of the power dynamics in financial markets, understood in terms of the ability to maintain, organize and process the flow of financial transactions.

In the subsequent chapters we will apply the theoretical framework to several historical examples in order to track the evolution of specific transaction machines. The ultimate aim is to show how this perspective can be used to offer a different understanding of the history of financial markets and shed a different light on their contemporary transformations.

PART II: HISTORY

Chapter 4. Medieval Transaction Machines

Summary:

This chapter describes the gradual development of transaction machines in medieval Europe. We start by looking at the rebirth of the European economy, with the growth of agricultural, trade and urban life allowing the emergence of a group of specialized commercial and financial intermediaries. We focus particularly on the case of Florentine merchant-banking partnerships, involved both in banking and commercial enterprises. These were international companies managed by a managing partner through his holding company using techniques such as current accounts and double-entry bookkeeping. In time, a need arose for more efficient transactional mechanisms developed specifically for the needs of the growing world of finance and commerce. We describe the development of two different types of transaction machines, a ***matching machine*** *and a* ***clearing machine****. Both of them developed in order to service the needs of international merchant-bankers and their complex web of transactions. The first* ***matching machines*** *developed around the activity of brokers and their specific matching algorithms. The city of Bruges and then Antwerp were the first to establish a Bourse, affording the aggregation of a larger number of brokers, performing matching in a more centralized way. Later, the Amsterdam Exchange was a more concretized machine composed of some 300 licensed brokers. In this context, brokers developed a number of different matching algorithms, such as single-sided auctions in both a sealed-bid and open outcry format. With the increase in transaction volumes, merchant-bankers also needed to reduce and compress the complex web of exposures accrued amongst themselves. At this point we focus on the* ***clearing machine*** *as it developed in the case of the clearing fairs of Champagne and Piacenza. We describe the overall mechanism, using bilateral and multilateral clearing, comprising both cycles and chains. While they represented a substantial increase in transactional efficiency, these machines were essentially based on human beings and required extensive amounts of manual labor. Finally, we show how these medieval transition machines can be seen as the basic building blocks for the more 'evolved' modern versions such as the London Stock Exchange and the London Clearinghouse.*

4.1 Towns and Markets

This chapter begins our historical narrative with the beginning of the last millennium, a period of great turmoil and opportunity for the western societies. It was a time of general delirium, of a very special kind of dis-individuation, the gradual break-up of the once mighty Carolingian empire. As Éric Aliez puts it, the year 1033 was the year of general disarray, the so-called ''Parousia of the Last Day'' (Alliez, 1996, p. 141). The social institutions based on agriculture, religion and warfare that had dominated for centuries, were now undergoing tremendous change. If we follow Aliez's hypothesis to the end, a contamination occurs when the military-religious colossus of Charlemagne enters into contact with the highly developed urban centres of Islamic world. Sometimes between the 9th and 10th centuries, change was underway, and its main effect was the shakedown of the established social and economic order:

> (…) Catholic Europe moved from stagnation at the lowest level to a social and economic mobility full of dangers but open to hope (Lopez, 1971, p. 31)

Perhaps the one who has provided us with the most detailed account of this gradual transformation is Fernand Braudel in his *Capitalism and Material Life 1400-1800 (Braudel, 1975)* and *Capitalism and Civilization 15th-18th Century* (Braudel *et al.*, 1981; Braudel, 1982; Braudel, 1984). His account of the development of capitalism, is very interesting, particularly in terms of his interest for the early commercial city-states, Venice, Genoa, Antwerp and Amsterdam, etc. What is sticking in these cases is that all of these proto-capitalist powerhouses gradually developed as a result of the connection, conjugation and resolution of several flows of technological objects, goods, and people.

> Then in the late eleventh century there was an outburst of energy and confidence seen before only in Periclean Athens (…) Change was everywhere (…) by 1100, cities, merchants, and cloth manufacturing were suddenly in rapid growth (Franklin, 2001, p. 14).

Andrew Watson's 1974 article on the Arab agricultural revolution and its impact on the European economy is particularly useful in understanding this gradual rebirth of socio-economic life. In that text, Watson argues for the decisive influence of Arab agricultural innovations*,* as something that impacted heavily on the entire Mediterranean. Watson's interest goes towards the introduction of new crops, new techniques, farming manuals and the modes of organization that come with it (Andrew M. Watson, 1974; Decker, 2009). While the actual magnitude of this revolution is still debated by economic historians, it is clear that the gradual development of tools and techniques had a direct impact on the European continent. This makes sense in as much as the Mediterranean must be seen as a porous space between Christian Europe and the Muslim Levant, a space of mutual contamination, which certainly had some impact on the so-called European Medieval Agricultural Revolution of the 11^{th} century. The innovation of open field agriculture based on the heavy plough and crop rotation, and the way in which new tools and techniques came together in a different way (McCloskey, 1991; Gies and Gies, 1995; Alliez, 1996, p. 152; Richardson, 2005). In Braudel's account, the expansion of material life is linked to the great agricultural boom at the eve of the last millennium. Urban centres, which had been in degradation since the fall of the Roman Empire, began to regain their functionality, their former glory. This process was related to an increase in population, which in turn meant a concentration of labour that resulted in the improvement of the land, the multiplication of tools, ameliorations of techniques and the stimulation of agricultural and non-agricultural activities (Lopez, 1971, p. 30). Thus, medieval Europe became a puzzle of small markets and fairs, which gradually developed into regional markets, reaching its peak in in the golden age of the fairs of Champagne (Braudel, 1982). As trade routes began to converge on a geographic location, a new commercial hub would emerge, such as Venice, Genoa, Antwerp or Amsterdam in later periods. Manuel DeLanda understands these commercial cities as attractors for regional and continental commercial flows (DeLanda, 1997).

As we will see, this impressive rebirth of material life and commerce would sustain not just the emergence of a commercial capitalism but also that of financial markets, with more sophisticated transactional capabilities. We will dedicate the next chapters to the emergence of specialist financial intermediaries such as the Italian merchant-bankers and their advanced transaction technologies (double-entry bookkeeping and bills of exchange). It will also be interesting to see how financial flows will gradually converge towards the commercial cities of Northern Europe, which developed specialized institutions such as the Bourse in Bruges or the Amsterdam Exchange.

4.2 Merchants and Double-Entry Bookkeeping

In his 1889 doctoral dissertation, published as *The History of Commercial Partnerships in the Middle Ages* (Weber and Kaelber, 2002), Max Weber studied the development of medieval contractual law and of various types of commercial partnerships. He saw these forms of organization as the seeds of a new social order, as possible building blocks for modernity and capitalism. Small ventures were manageable by single merchants but large-scale trade needed specific financial arrangements that could raise necessary capital and also evaluate the potential loss and profits. As we have seen, the medieval Agricultural Revolution was strongly influenced by contacts with the Levant. Similarly, the medieval Commercial Revolution was also a process that borrowed practices and techniques from the Byzantine Empire and Islam in particular. According to Lopez and Raymond (1955) one of the most important commercial innovations, the Italian commenda had its origins in contracts such as the Roman ''societas'', the Byzantine ''chreokoinonia'', and the Muslim ''qirad'' (Udovitch, 1962; Pryor, 1977). The commenda was a legal contract by which a group of merchants would pool capital to one venture organized by an agent-manager, who upon completion would return the initial investment plus a share of the profits. In the case of a loss, the agent-manager would lose only his effort and labour while the investors lost their whole investment (their principal). In fact, no other form of liability was possible under the commenda (Udovitch, 1962, p.198). The way in which it was set up was for a sedentary investor ''commendator'' to entrust his capital to the hands of a travelling merchant ''tractator''. The ''tractator'' might also add capital of his own but his main contribution was his effort. Upon completion of the venture, he would return in order to divide the profits, but he could also send the sum without returning to the homeport of the investor. Usually, the ''commendator'' would receive ¾ of the profits and bear all liability for the loss, while the ''tractator'' would gain ¼ of the profits but bear no liability (Pryor, 1977, p.6).

An even more interesting innovation was the Florentine merchant-banking partnership comprising many different business ventures spread across geographies. As we already noted, Max Weber recognized the importance of medieval partnerships and saw them as one of the driving forces behind modern capitalism. One of the crucial novelties introduced by the partnership system was double-entry bookkeeping technique, which allowed for more efficient ways of organizing a business. It was a new way of organizing incomes and expenditures and gain a clear picture of the profitability of an enterprise[44].

> Formerly noncomparable objects are made commensurable: apples and oranges find a common denominator in monetary price. Commensurability makes it feasible to compare and evaluate alternatives (…) In an account, outcomes can be reduced to a single numeraire, money, and their relative profitability assessed (Carruthers and Espeland, 1991, p.58).

Once this technique is in place, the pursuit of profit and accumulation of capital becomes feasible and it can be seen as a triumph of rationality consistent with Weber's account of modernity (1930). Werner Sombart (1902) also saw medieval accounting techniques as the very foundations of modern capitalism, understanding double-entry bookkeeping as absolutely essential in valuing something like capital in the first place. In addition to Weber and Sombart, Schumpeter (1976) also saw a close connection between, accounting, rationality and capitalism. Profit could for the first time take a precise quantitative form, calculated in monetary terms. The argument is based on the fact that double-entry bookkeeping ''makes it possible for capitalists to evaluate rationally the consequences of their past decisions'' (Carruthers and Espeland, 1991, p.32).

Many historians have downplayed the actual impact of the technique (Yamey, 1964) or demonstrated that it was not fully developed and used until the late Middle Ages (Ryan, 2014). More recently, questions were raised about the origin of the

[44] The system is particularly useful in terms of error correction as credit and debits need to match for every account.

technique, whether it emerged in the world of trade or in the domain of banking and finance. In our current understanding, double-entry bookkeeping is a system of accounting whereby every transaction has two entries in two separate accounts. Part of Yamey's position was that unless the balancing of accounts occurred regulatory, then the systems would not offer any major improvement relative to single-entry bookkeeping. Because he could not find any evidence of regular balancing, Yamey concluded that the system was mostly used to keep records of business activity and not really used to calculate profits and capital. This last perspective is consistent with one of the first written explanations of double-entry bookkeeping dating back to the medieval mathematician Luca Pacioli, when in 1494 he was praising the merits of the technique:

> This is very useful, because it would be impossible to conduct business without due order of recording, for without rest, merchants would always be in great mental trouble (Quoted in Carruthers and Espeland, 1991, 26).

While double-entry bookkeeping was certainly used before his time, Pacioli's treatise offers the first detailed algorithmic description of how to maintain the order in ones business affairs. While this might seem like a simple operation, the method of recording every transaction twice in a tabular manner, both as a debit and as a credit, was a significant innovation for that time. All business counterparties had their own current account in the book. Balancing the accounts would allow one to gain a lot more clarity on what is owed and/or what is due with respect to its business partners, the State, suppliers, customers, etc. In this sense, the balance between debits and credits represents profits or losses. But this accounting method is also crucial in the case of auditing the operations of an enterprise, which was particularly important in the Middle Ages when merchants were under the supervision of the Church, the State and guilds.

Alan Sangster (2015) has recently argued that one should look for the origins of double-entry bookkeeping with the bankers of medieval Italy, rather than the likes of (Zerbi, 1952) (Littleton, 1933) who see its origins within the world of trade. He argues that it was a lot more important for bankers to know precisely what the balance was between debtors and creditors, as it was a ''fundamental for survival'' (the Genesis of Double Entry Bookkeeping Alan Sangster). Moreover, double-entry bookkeeping was more likely to be initially used by bankers because certain political and religious authorities demanded a clear audit trail. One can think here of the prohibition of usury, enforced by the Catholic Church, but more importantly the requirements of guilds responsible for resolving business disputes and accounting mismatches. By analyzing the ''libri de cassa'' of Florentine bankers, Sangster concludes that it was in this context that double-entry bookkeeping first emerged:

> The process of double entry was born when the decision was taken by a banker to allow transferences between the accounts of his customers without involving movement of cash, a process facilitated by including the accounts for all debtors and all creditors in one book (Sangster, 2015, p.14).

He also argues that the terminology (''die dare'' and ''die avere'') used in the 12th and 13th centuries bookkeeping was specific to the activities of bankers. One of the reason why historians have focused more on the accounting practices of merchants was that, for a long time, bankers used a mixed form of single-entry and double-entry bookkeeping in order to hide the charging of interest and evade the interdiction of usury.

In any case, rather than focusing too much either on bankers or merchants, it is possible to understand the emergence of double-entry bookkeeping precisely at the confluence of these two groups. In a series of recent articles, John Padgett and Paul McLean (2006; 2009; 2011) have constructed a detailed picture of the emergence of merchant-banking partnership in medieval Florence. They begin by arguing for the importance and impact of the Ciompi Revolt (1378-1382), which was a considerable upheaval of Florentine society. But what matters for them is the way in which power relations were restructured after the revolt, such as the change in status and rights of bankers. Before the revolt, the guild system effectively limited the expansion of banking beyond Florence. On the other hand, merchant families were heavily involved in international trade. The other difference consisted in the fact that banking was organized along master-apprentice contractual relationships while merchant companies were built on family ties. The aftermath of the revolt saw the blending of these two groups both by the bankers taking public office and through marriages:

> The result was a modularized hybrid—short-term contracts with both family and nonfamily branch managers—in other words, the partnership system. (…) this new organizational form led Florentine businessmen to new ways for companies to relate to each other in the market, through current accounts, credit, and double-entry bookkeeping (Padgett and McLean 2006, p. 1472).

These new Florentine merchant-banking partnerships were involved both in banking and commercial enterprises, establishing branches with both family members and external partners across Europe. They were in effect European-wide transactional networks managed by the managing partner through his holding company and supervised using techniques such as current accounts and double-entry bookkeeping. An analysis of the Datini[45] holding company reveals the impressive complexity of merchant-banking partnerships (Padgett and McLean, 2006, p. 1476). But the stability of theses networks could only be achieved if supervision was possible from the centre. In this sense, double-entry bookkeeping was essential in giving the managing partner a clear picture of the transactional flows between with his many partners.

> Formally, ongoing relations of business credit were recorded primarily in the bookkeeping device of current accounts, tabulated in bilateral format. Extensive and deep credit relations among Florentine merchant-bankers were the primary reason for the century-long dominance of international finance in Europe by Florence (Padgett and McLean, 2006, p.1467).

[45] Francesco Datini was at the centre of a merchant-banking partnership, which in the 14th century comprised many branches from London to Barcelona, Genoa and Florence (Padgett and McLean, 2006).

The importance of these partnerships should not be ignored. In fact, Fernand Braudel emphasized the difference between merchant-bankers and the other of groups comprising medieval urban life. While shopkeepers, craftsmen, moneychangers, etc. where all locked in their profession, merchant-bankers had a very unique position. Through their management of capital flows, they had partial exposure to all of these fields. They would invest in different domains, pertaining to the economic climate (grain, spices, wool, cloth, iron, etc.) (Braudel, 1982). While the system of double-entry bookkeeping allowed merchant-bankers to better organize their internal partnership dealings, it also provided the basic technique for the expansion of inter-partnership credit provision (Padgett and McLean, 2011). Local markets and regional fairs had their own intermediaries that facilitated transactions but international trade and finance was largely the monopoly of these specialized merchants (de Roover, 1948). The function performed by the merchant was a very important one, connecting flows of production to various opportunities of consumption. Local markets could only produce, consume and distribute goods in a certain area but medieval merchants at the centre of an international transactional network. As international merchant-bankers converge towards certain urban centres, these in turn became financial and commercial hubs (such as Venice, Genoa, Bruges, Antwerp, Amsterdam). Moreover, as transaction volumes grew, they also began to utilize more sophisticated mechanisms in order to transact more efficiently. We are of course talking about the bourses or exchanges and the medieval clearing fairs, which can be seen as transaction machines specifically adapted for the needs of this sophisticate set of users.

4.3 Matching: Brokers and Bourses

As we have seen, merchant-bankers gradually developed complex trading networks. Consequently, this group required equally sophisticated mechanisms allowing them to transact more efficiently. The rest of the chapter will focus on two types of transaction machines (matching and clearing) that emerged on order to meet the needs of this commercial and financial community of users.

A soon as the centre of gravity of trade moved from regional markets to large commercial cities, the function of intermediation was taken over by brokers (Bairoch, 1988). In fact, of the reasons that commercial flows converged towards a certain town was the presence of brokers who could perform matching (Boerner and Quint, 2010). In a certain sense, merchants could only take the risk of leaving their hometown and travel to other cities if they were pretty sure they could always find someone willing to take the other side of the trade (Verlinden, 1971). Without a specialized function that could maintain markets in different goods, merchants would be less likely to bear the risk of transporting goods from one city to another (costs of searching, bargaining, etc.). In other words, as trade volumes grew, bilateral search and bargaining gives way to organized brokerage institutions. Therefore, Boerner and Quint have shown, medieval ''towns implemented brokerage as an efficient matchmaking institution in a two-sided market problem'' (Boerner and Quint, 2010, p.3). Brokers mostly matched foreign sellers and local buyers; because foreign sellers had little knowledge of the local demand side so they would they were more inclined to use the services of brokers. On the other hand, foreign buyers would not necessarily need brokers because they could easily find the local sell side, as in most medieval cities local sellers would tend to converge around certain districts (e.g. Saville Row in London). In as much as brokers allowed all parties to avoid the costs of searching for counterparties and agreeing on a price, they would effectively step between the buyer and the seller. At the same time, as trade was essential for the growth of towns, brokers were subject to very strict regulation:

> (…) the broker could not tell a buyer the price the same seller had charged in an earlier deal. The broker was also not allowed to inform the buyer if the

seller was in a hurry to sell his goods, nor tell the seller if the potential buyer was rich or poor (Boerner and Quint, 2010 p2).

Depending on local regulations and the way in which they were compensated, brokers could be more accommodating towards sellers or buyers. By far the most dominant matching mechanism was one which certified a limited number of brokers who could act only as matchmakers (Boerner and Quint, 2010). That is to say, they could only match buyers and sellers and were not allowed to perform market making (buying and selling goods on their own behalf)[46]. In some cases, foreign merchants were forced to use local brokers while in others they were not required to do so. In any case, as shown by Boerner and Quint, the urban landscape of Medieval Europe generated a wide diversity of different matching mechanisms. While merchants were channelling commercial flows towards certain towns, brokers were implementing and executing what we have called a matching machine, bringing buyers and sellers together. While the famous historian Raymond de Roover (1948) considered the exchange of medieval financial products as the quasi of Italian merchant-bankers, recent research by Kathryn Reyerson (2002) has argued that brokers were also very much involved in matching financial products such as bills of exchange. In this sense, we can understand broking as a matching mechanism that developed for wholesale commercial trade but which was also adopted for financial instruments such as bills of exchange and, as we will see, bonds and ultimately stocks.

Components		**Algorithms**
Bills of Exchange	Brokers Merchants-Bankers	Bilateral matching (direct matchmaking)

Figure 4: Composition of bilateral matching machines

The table above tries to unpack the most basic medieval matching machine, constructed around the activity of individual brokers. The function of this machine

[46] There were a small number of regulations that did allow brokers to deal on their own behalf but it did create conflicts such as those between the Hanseatic League and the city of Bruges (Boerner Quint, 2010, p.9).

was, for instance, to connect a foreign seller to a local buyer. As we already said, most regulation did not allow for brokers to deal on their own behalf. That is to say, the mechanism could only execute a transaction if there was a direct match between the offer of the seller and the bid of the buyer. We could call this mechanism a bilateral matching machine; a simple algorithm whereby a bid and an offer coincided and could be matched or it would not (therefore perhaps requiring several iterations). While this might seem like a relatively primitive transaction machine, it was perfectly adapted to the needs of foreign sellers traveling through medieval cities. As long as the transactional needs were limited there was not need for developing a more complex matching machine.

Nevertheless, with the growth of medieval commerce and finance, it was only a matter of time before a new and more evolved matching machine would be constructed. In his *Bruges, Cradle of Capitalism 1280-1390* (2005) James Murray offers a detailed description of the sophisticated transactional networks of medieval Bruges and its money market. This was a consequence of a critical mass of brokers and also the presence of Italian merchant-bankers and moneychangers who settled in Bruges in the 14th and 15th century. As the center of gravity of European trade migrated to Northern Europe, more and more Italian merchant-bankers set up offices (factories) in Bruges where they traded in the 'Place de la Bourse'. Around 1516, most of them eventually left Bruges and moved to Antwerp, which had experienced a series of floods expanding its harbor and allowing it to become a major commercial city (Swan, 2000, p.141). As the Italian merchant-bankers moved to Antwerp, a new bourse was established din 1531 bringing together a larger number of brokers. Interestingly enough, Antwerp saw for the first time a differentiation between those that traded in commodities and those that traded in financial contracts such public bonds and bills of exchange (Michie, 2006).

As explained by Fernand Braudel, after the sack of Antwerp in 1576, Amsterdam became the new dominant commercial hub as well as also the dominant financial center of the continent. One of the reasons for its attractiveness was the establishment of the public Exchange Bank of Amsterdam in 1609, allowing merchants to easily engage in pan-European monetary transactions. In addition to this, Amsterdam saw another crucial innovation, namely the establishment of Dutch East India Company in 1602, one of the first joint stock companies. While short distance trade could be managed by individual merchants or by a small partnership, the long distance trade with Asia was a much more complex challenge. Participating in the spice trade could be very profitable but also very risky. In order to manage the complexity of global trade, the Dutch East India Company issued a substantial number of stocks from the public, raising a staggering 6.45 million guilders (Ferguson, 2008, p.127). In a certain sense, the guarantee for the loan was a share in the ownership of the company and the promise of payback. The company was initially supposed to last only 21 years, and investors were only entitled to withdraw their money after 10 years. As the first journeys were not particularly successful, the option to withdraw the initial investment after 10 years was postponed in 1612. This uncertainty about the future value of the shares triggered the beginning of trading (Michie, 2006, p.28). This led to many investors wanting to exit their investment, i.e. to sell their shares. Therefore, a new matching machine for shares was constructed around brokers called ''rescounters'', who would match the transfer of these shares. Someone who had too much risk on his or her hands could offload it to a speculator who was willing to take it, at a discount. Trading in theses shares expanded and as early as 1607, as much as a third of the shares was no longer in the hands of the original owners. Up until 1608, financial transactions were executed in the streets (Fergusson, 2008, p.131). Then a new Bourse was built and was in fact the first modern exchange, housing some 300 officially certified brokers (Marsilio, Forthcoming 2015, p.12). In addition to that, there was a second-tier community who unofficially performed similar financial transactions, but located in the city's coffee houses (Fergusson, 2008).

While the Amsterdam Exchange provided a more consolidated transaction environment, matching machines was still based on the simple bilateral algorithm, managed by individual brokers (Bochove, 2013). Trades were arranged separately between seller and the broker or between buyers and the broker on the other side. This mechanism could pose serious problems of information asymmetry, as it was hard to attract buyers or seller while it was clear that brokers had a considerable informational advantage (Bochove *et al.*, 2012, p.3). This simple bilateral matching machine was not adequate for more illiquid assets such as financial securities. In order to solve some of these problems, a new and more evolved transaction machines was developed. One such machine was developed using the so-called Anglo-Dutch[47] auction algorithm, particularly for the sale or resale of public bonds and shares. This was a single-sided open outcry model, whereby every participant could see what other people are bidding in a transparent manner. This of course had the advantage of attracting more interest and thereby sustaining a more liquid market. This mechanism was initially developed for real-estate assets or certain commodities and it was essentially a combination between the ascending English auction and the descending Dutch auction. The issue with the English auction is that it poses a disadvantage to weak bidders while the Dutch auction is not able to aggregate a large number of bidders. As it was performed, the Anglo-Dutch auction entailed a first ascending round, which would start with a minimum value and the highest bidder would win. But he would not be granted the asset straight away, but would get a premium for wining the first round. The second round was a descending auction. It would start with a higher bid than the first round wining bid, and would descend form there. If someone posted a higher bid than the one recorded in the first round then they would win the asset and the winner of the first round would only keep the premium. If nobody made any bids in the second round, the first round winner would take both the asset and the premium. We can call this a multilateral matching machine, whose great advantage was that it could consolidate the liquidity of a number of different bidders and find a match with an individual seller. The transparency of the algorithm means that bidders had no issues in engaging with the process. This more complex and evolved machine was also more computationally expensive in Mirowski's sense of the word, and thus harder to maintain. That is to say, this type of machine became feasible only for the purpose of selling more illiquid assets such as certain financial securities. As argued by Christiaan van Bochove, Lard Boerner and Daniel Quint (Bochove et al., 2012), the

[47] Within Mirowski's taxonomy, this is an open outcry single-sided auction, both descending and ascending.

Anglo-Dutch mechanism was very successful in maintaining a liquid market for financial securities and was still used in the late in the 19th century.

Components		Algorithms
Bills of Exchange Shares Bonds	Brokers Merchants-Bankers	Bilateral matching (direct matchmaking)
	Bourses Exchanges	Multilateral matching (Anglo-Dutch auctions)

Figure 5: Composition of medieval multilateral matching machine

Amsterdam thus saw the development of the first modern financial market and, as explained in the table above, the first evolution of a transaction machine from the more simple bilateral mechanism to the more complex Anglo-Dutch auction. This could be seen as a consequence of the social and economic environment of the Dutch Republic in the 17th and 18th centuries. As Christiaan van Bochove (2013) has shown, while the Amsterdam financial market was very innovative it was a particularly illiquid market, specifically for public bonds and stocks. In this sense, the matching machine of the Amsterdam Exchange was very much a product of this less liquid market, as an adaptation to environmental conditions (liquidity, trading volumes and overall size of the market).

Innovative as it was, we will not focus too much on Amsterdam but dedicate the next chapter to the development of an even more complex matching machine, namely the double-sided auctions on the floors of the London and New York stock exchanges. These exchanges can be seen as descendants of the Amsterdam Exchange, but they also provided the framework for a further evolution of matching machines. As long as trading volumes were relatively low, there was no real need or pressure to build continuous double-sided auctions, as participants did not require continuous access to liquidity. It was only later, in the modern exchanges of London and New York, that financial markets were liquid enough in order to sustain and warrant more computationally expensive transaction machines. Moreover, we will also look at the gradual displacement of human brokers as the sole holders of the monopoly of matching buyers and sellers. The introduction of the telegraph, the stock ticker, the telephone and eventually the computer, will see the migration of the matching function from human hands to electronic platforms. These topics will be covered in Chapter 6.

4.4 Clearing Fairs and Bills of Exchange

We have already described the impressive growth of commerce in medieval Europe and the establishment of broking as a matching machine in order to facilitate the trading of financial instruments. Their increasing use of financial instruments also led to the accumulation of substantial levels of mutual exposures between market participants. This led to the need for another type of transaction machine performing the function of clearing. This afforded the reduction of offsetting debts (Boerner and Ritschl, 2009). As Italian merchant-bankers were the main participants in medieval financial markets, we will firstly review their use of bills of exchange and then we will look at the transaction machines developed to clear their overlapping web of debts.

The bill of exchange was one of the great innovations of medieval commercial capitalism. It was a financial instrument that effectively guaranteed the transfer of an amount of money from the drawer to the drawee. In a sense, the bill of exchange was a solution for overcoming the basic obstacles of 12th Century Mediterranean commerce. It had the potential to eliminate payments in metal coins, while allowing for the transfer of debts and reduced the need for face-to-face settlement.

It was an accepted means of payment, it reduced the risk of robbery associate with handling large quantities of coins, and it provided an easy system for contract enforcement. One can think about medieval trade as consisting of a basic form arbitrage, in which a merchant would sell some goods in a certain market and then use the money to buy other goods and sell them again in another market. In this sense, the merchant was always conditioned by his next port of entry, by the goods put up for sale there and by his subsequent trading opportunities. The bill of exchange was developed precisely In order to reduce the risk and the inefficiencies of such a model (Kindleberger, 1984, p.65). This financial instrument involved four participants, a debtor and a creditor in one town, and a subsequent payer and payee in another town (Abulafia, 2011, p.65).

> To illustrate the bilateral case, if A in Florence bought goods from B in Bruges, he would often pay for them by buying a bill of exchange drawn by C in Florence, or perhaps another Tuscan town, who had sold goods to D in Flanders. C draws a bill on D and collects his money by selling it for local currency to A, usually indirectly through an exchange dealer. A sends the bill to B in payment for his goods, and B collects from D when the bill matures (Kindleberger, 1984, p.40).

To put it differently, the bill of exchange moves around from D to C, then from A to B, and finally returns back to D when it matures. Goods are exchanged between B and A and between C and D. Money moves from A to C, then to D and B. The essential element that boosted trade was that D was allowed to acquire goods from C without having to pay for them on the spot. C would enter into such a transaction because he could easily redeem the bill for money from someone like A, who could in turn exchange the bill for certain goods from B who could ultimately be paid by D when the bill matured.

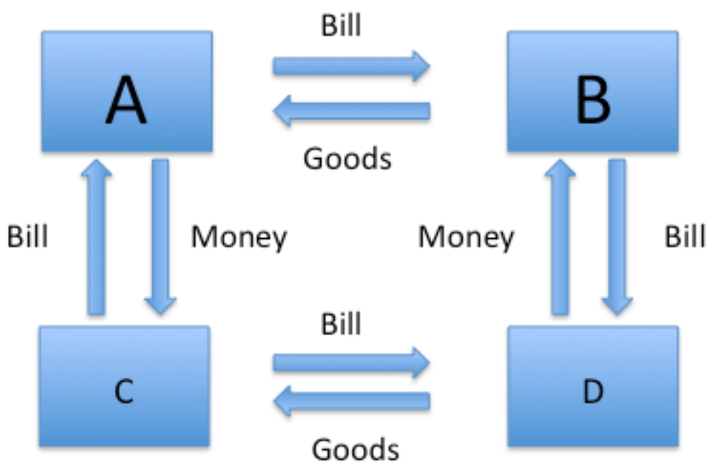

Figure 6: Example of medieval bill of exchange

The bill allowed for long distance trade without having to physically move large quantities of coins and was thus a substitute for money (Greif, 2002; Greif, 2006) (Greif 2002, 2006)(Boerner and Hatfield, 2014). Before the use of bills of exchange, a merchant could only trade if he was liquid on the spot, but now he could negotiate future payment dates depending on his future expected liquidity (Usher, 1943)

(Boerner and Ritschl, 2006). In the end, bills of exchange were an advance of money to the seller that would be repaid at a latter date in a different place (Roover, 1948).

As they developed in medieval times, wholesale commercial and financial transactions were primarily the monopoly of merchant-bankers. As trade volumes increased, merchant-bankers began to focus more on dealing in bills of exchange rather than commodities (Abulafia, 2011, p.65). The very nature of bills of exchange meant that there was a substantial time difference between the moment when of negotiation and the ultimate settlement. In other words, merchant-bankers would accumulate large exposures between them[48]. That is to say, the more one would engage in trading bills of exchange, the higher the risk of counterparty default. What the merchant-bankers needed was a mechanism for reducing the complex web of counterparty exposure and the cumbersome task of settlement. The regional fairs of Champagne represented one such solution. At the end of each fair there was a pressing need to settle liabilities, so merchant-bankers would meet in designated places to settle bills of exchange and rebalance their positions (Boerner and Hatfield, 2014). Clearing bills of exchange quickly became an established practiced of the fairs in Champagne, but was also practices in the fairs in Besancon, Piacenza and Novi, which effectively became clearinghouses for European financial markets.

According to David Abulafia, medieval fairs can be traced back to the Merovingian fairs in the seventh-century (Abulafia, 2011, p.67). In the 12th and 13th centuries, the famous fairs of Champagne were in effect the major commercial hubs of the continent, particularly due to the protection offered the Duke of Burgundy. The fairs were organized all year long in the towns of Troyes, Provins, Lagny and Bar-sur-Aube, which were principal crossroads of European trade routes. For each fair, there were a number of days for trading cloth and then leather and goods sold by weight; finally there were fixed number of six to eight 8 days for clearing and final settlement of transactions (Usher, 1943, pp. 118-19) (Kindleberger, 1984, p.36). The fairs of Champagne were in fact an annual cycle starting on the 2nd of January in

[48] Counterparty credit risk refers to the uncertainty of a transaction counterparty defaulting on their obligations.

Lagny, then in Bar-sur-Aube in March, followed by the May fair in Provins, a summer fair in Troyes, followed again by a fair in Provins; the clearing year ended just before Christmas with the 'cold' fair, again in Troyes. Each fair lasted about 50 days and was perhaps the first centralized venue for commercial and financial transactions (Abulafia, 2011, p.68). In fact, the fairs had a golden age from 1260 to 1350 when they were in effect the dominant commercial and financial hubs of Europe. While the early Champagne fairs were largely commercial markets, after 1260 they also became the dominant centres for trading and clearing bills of exchange (Marsilio, 2014, p.6).

The annual cycle of the fairs allowed for the easy movement of large sums of money and goods between the various towns and regions of Europe. As counterparty exposures became more complex, there was an increasing need to clear offsetting transactions. We will focus on the clearing mechanism as it was performed in the Genovese fairs of Piacenza where the decentralized clearing mechanism for bills of exchange (''rescontre'', ''skontrieren'' or ''virement des parties'') was particularly sophisticated (Boerner and Hatfield, 2010). In fact, Boerner and Hatfield have provided a detailed description of the clearing algorithms of the fairs where each participant kept an accounting book called ''scartafaccio'', recording of both debits and credits, the ''vostro'' and the ''nostro''. Any unbalanced positions could be carried along to the next fair and reintroduced into the next clearing cycle. In as much as a fair could last for many weeks, the actual clearing was performed in the last few days of the fair. Each cycle lasted up to 8 days, but could be extended if needed. The participant merchant-bankers were called ''trattanti'' and they would gather each day in the residence of the ''consul''. The would have to follow a very strict calendar from drawing up a first provisional balance to the final swap of bills of exchange representing the netting of their positions.

The usual clearing process was quite complex comprising large number of merchant-bankers, some 50-60 in Besancon and up to 110 in Piacenza **(**Boerner and Hatfield, 2010, p.7). The first step was the confirmation and registration of debts. Then participants would start the clearing process often mediated by a broker, but usually in a decentralized way. The clearing algorithm started with the canceling of bilateral obligations. If merchant A owed an amount to merchant B who also had and opposite exposure to merchant A, then they could mutually offset their positions. When all such possibilities were exhausted, whoever still had unbalanced positions would need to engage in multilateral clearing, through chains and clearing cycles. In a clearing chain, if A owed B and B owed C, then B would reduce his exposure by creating a new debt relationship between C and A. Clearing cycles could be performed when A owed B and B owed C who again owed something to A. The minimum amount owed between all of them could be offset and cleared from their books. These clearing algorithms could be repeated several times, using both bilateral and multilateral clearing, until everyone had reached a net position. Whatever was left at the end of this procedure, would either be paid in cash or new bills would be put forward to the next fair (Boerner and Hatfield, 2010, p.9).

The medieval fairs can thus be seen as the environment for the development of a complex transaction machine. The clearing machine comprised two separate stages, namely the simple bilateral version and the more complex multilateral designs. Similar to the evolution of matching machines, the simple bilateral clearing procedure was used first as it was easier to execute. Once all the bilateral clearing was exhausted, they would switch to the more difficult multilateral clearing. Using two different algorithms (chains or cycles), this more complex clearing machine allowed for the compression of offsetting balances between at least three different merchant-bankers.

<table>
<tr><th colspan="2">Components</th><th>Algorithms</th></tr>
<tr><td rowspan="2">Bills of Exchange</td><td rowspan="2">Merchants-Bankers
Clearing Fairs</td><td>Bilateral clearing
(direct clearing)</td></tr>
<tr><td>Multilateral clearing
(clearing chains and cycles)</td></tr>
</table>

Figure 7: Composition of medieval multilateral clearing machine

As explained by Boerner and Hatfield, evidence form the 1632 Frankfurt fair shows that this clearing machine was particularly successful, as 99.3% of transaction volumes were cleared by the reduction of offsetting exposures. Looking at the ledger of Frankfurt merchant-banker Johan Bodek, it is surprising to see that he transacted in the value of 135000 florins with only 4000 florins actually paid in cash (Boerner and Hatfield, 2010 p.15). This impressive performance was clearly due to the capacity of the multilateral clearing machine to bring together several offsetting balances and net them out. While more difficult to execute and more computationally expensive in Mirowski's parlance, the benefits of this machine were substantially in reducing the need for actual cash settlements between participants.

According to Fernand Braudel, the early fairs of Champagne declined in the 14th century, this triggered gradual move towards Southern Europe. By this time, Italian merchant-bankers were mainly focusing on financial transactions (Marsilio, Forthcoming 2014, p.3). The dominance of the Geneva fairs was short lived mainly due to the intervention of the king of France, who prohibited French merchants to participate in the Geneva fairs. There were subsequent political interventions that lead to the exclusion of Genovese merchants from the Lyon fairs and in 1535, the Genovese senate voted to establish a rival fair in Besancon under the protection of emperor Charles V. The Italian merchant-bankers eventually moved south towards Piacenza in 1579, where the fair were still called Besancon and it soon re-established itself as the main financial hub (Kindleberger, 1984, p.36). The flourishing of the Piacenza fairs lasted until 1621 when there was a split between Italian merchant-bankers. The Genovese moved to Novi while the Tuscans and the Lombards kept meeting in Piacenza. The disturbances caused by the 100 years war, coupled with the later move of European trade towards the Atlantic, triggered the decline of the Italian fairs in the late 15th century. Nevertheless, even in these circumstances, the overall volumes were still impressive (Kindleberger, 1984, p.37).

The complex clearing machine of the fairs dominated medieval financial markets, and there is strong evidence that it was still in use well into the 18th century (Boerner and Hatfield, 2010). As long as participants were dealing with well-known counterparties, they would prefer the clearing machine of the fairs (Boerner and Hatfield, 2010, p.24). As we will see, the multilateral clearing mechanism of the fairs will experience a further evolution in the case of the modern clearinghouses. As trading volumes increased, financial intermediaries were forced to develop a more centralized clearing machine in order to reduce counterparty risk. In Chapter 6, we will track the evolution of clearing machines, for payments in the case of the London Clearing Club, for stocks in the case of the London and New York Clearinghouses and for derivatives in the case of the Chicago Board of Trade.

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Conclusions

In this chapter we followed Fernand Braudel's description of medieval Europe as a puzzle of small markets and fairs, regional markets, the great fairs of Champagne and the large commercial cities such as Venice, Genova, Antwerp and Bruges. The expansion of material life and markets provided opportunities for specialized commercial and financial intermediaries. Florentine merchant-banking partnerships were involved both in banking and commercial enterprises and became the nodes of European-wide transactional networks. As medieval finance became more complex, new ways to organize transactional flows emerged. In this sense, we described the development of two different transactional infrastructures, a matching machine and a clearing machine. Both of them developed in order to service the needs of merchant-bankers, facilitating the exchange of certain financial instruments (such as bills of exchange, shares, bonds).

The functioning of the more simple bilateral matching machines relied on individual brokers and their ability to match offers with bids. What started as mechanism for matching commercial flows, also expanded to the transaction of financial instruments The city of Bruges and then Antwerp were the first to establish a bourse, housing a larger number of brokers, performing matching in a more concerted way. The Amsterdam Exchange was a collective matching machine composed of some 300 certified brokers. In response to the relative lack of liquidity and transparency, the Amsterdam brokers developed a more efficient matching mechanism. This entailed the execution of more complex single-sided auctions in an open outcry format, the so-called Anglo-Dutch auction. The mechanism entailed two rounds of bidding, an English auction followed by a Dutch auction, allowing for the aggregation of large number of bids while also affording more transparency.

We have also described the first attempts to build a clearing machine in the context of trading positions accrued in bills of exchange. The very nature of bills of exchange meant that there was a substantial time difference between the moment when of negotiation and the ultimate settlement. In other words, merchant-bankers would accumulate large exposures resulting in considerable credit counterparty risk. Merchant-bankers needed a mechanism for clearing this counterparty exposure and reduce the complex web of debts. The inputs of the machine were already executed transactions and the output was the netting of offsetting debts. The benefits of using such a machine were considerable, particularly as volumes increased. We focused on clearing as it was performed in the Genovese fairs of Piacenza, starting by using bilateral clearing followed by a multilateral clearing mechanism, using clearing chains and cycles. The process could last up to eight days using both bilateral and multilateral clearing, until everyone was close to or reached a net position**.**

For both matching and clearing we thus observe a certain evolutionary trajectory from bilateral to multilateral designs, from simple to more complex and computationally expensive mechanisms. While the building blocks of these machines developed in different locations throughout medieval Europe there was a clear tendency for the convergence of the both the **matching** and **clearing** functions towards the larger commercial cities, which thus acted as transactional hubs. In time, London provided the suitable environment for the development of matching with double-sided auctions within the context of London Stock Exchange, but also for daily multilateral clearing such as in the case of the London Clearinghouse.

Chapter 5. Modern Exchanges

Summary:

This chapter describes the evolution of matching machines as they developed in the case of modern stock exchanges. We first look at the London Stock Exchange (LSE), where the maintenance of a continuous double auction was the responsibility of jobbers. We then review the founding of the New York Stock Exchange (NYSE) and its development in the 19th century. After several institutional and technological mutations, such as the incorporation of the telegraph, the stock ticker and the merger with the Open Board, NYSE became the dominant transaction machine for US stock markets. The double auction was a centralized matching design as liquidity was aggregated around the specialists on the floor of the exchange tasked with matching order flow and maintaining a fair and orderly market. We then look at the major transformations brought about by the adoption of modern information technology and the regulatory requirements for more transparency. In this context, we address the development of new trading platforms at the end of the 20th century. ECNs such as Instinet, AZX, Globex or Tradepoint and their electronic order book technology represented a leap forward in terms of the efficient aggregation and matching order flow. We also review the gradual development of the NYSE Hybrid Market, where investors have a choice between immediate automated matching or routing the order for manual execution on the floor. Deployed in 2006, this new design replicates both the matching done on the traditional trading floor or on the more sophisticated electronic platforms, while the reverse is not possible. The NYSE Hybrid Market represents a new more concrete design, as it integrates a number of different elements, such as the specialist trading floor, the SuperDOT, Direct+ and the Archipelago ECN, while affording novel functionalities in terms of providing more tailored execution to a wide set of investors. Thus we highlight the continuous evolution of matching machines under the pressures and constraints of various constituencies of users.

5.1 The London Stock Exchange

The matching machine constructed in Amsterdam in the 16th-17th centuries would eventually be adopted and further developed in London. While the Amsterdam Exchange was a central marketplace, it was still very much dominated by individual brokers running what we have called a multilateral matching machine (most brokers could accept busy and sell order form a multitude of investors). In London, the development of the stock market was gradual, with a relatively small number of active stockbrokers, about 50 people in 1712 (Michie, 2006, p.30). As long as people did not require continuous access to liquidity, there was no real need or pressure to construct a more complex machine. Moreover, the 18th century saw a number of speculative bubbles, particularly between 1717 and 1720, which affected the growth of the market[49]. Nevertheless, London gradually became the most important financial centre in Europe. This was partially due to the expansion of British public debt, which tripled from 1790 to 1815, and an influx of bankers and merchants from the continent (Michie, 2006, p.51). Before the opening of the London Stock Exchange, the early stockbroking community assembled in the Royal Exchange intermediating transactions for shares in the small number of joint stock companies. In 1762, the London Stock Exchange was founded as a club comprising 150 stockbrokers, based at Jonathan's coffee house (King, 1947). As more members and investors were attracted to the opportunities afforded by the stock market, there was a need for a more efficient mechanism for processing transactions. From an institutional perspective, the brokers organized themselves as a club, with a subscription fee and common rules of governance, as the question of trust and market discipline was essential, as well as the need to exclude participants with low credit-worthiness. The establishment of an ordered administrative framework allowed for the stabilization of the London Stock Exchange, whose membership grew from 363 in 1802 to 5,567 by 1905 (Michie, 2006, p.53).

The London Stock Exchange experienced tremendous growth in its first two centuries, aggregating capital from a diverse pool of investors, both British and

[49] The famous South The Sea Bubble.

international. In as much as investors were committing their money towards shares, there was an immediate need to also be able to exist investments quickly and efficiently. That is to say, contrary to consumers of posted offer markets such as those for retail goods, investors in shares required more flexibility in terms of executing transactions. The problem then was to provide investors with a transactional infrastructure affording the possibility to both buy and sell stocks at any given time during the trading day, that is to say a continuous double-sided auction. It was precisely this requirement that differentiates any stock exchange from other single-sided auctions or posted offer fixed-price markets. While we have referred to the members of the exchange as stockbrokers, the system of the London Stock Exchange developed quite a complex organizational structure. In order to satisfy the requirement for a transparent and continuous double auction design the exchange implemented a division of labour between those who aggregate order flow and those who manage the matching mechanism. The first category was represented by brokers who acted as agents for the investing public. The second group is that of the jobbers, specializing in matching orders for particular types of stocks. While brokers would continually interact with outside investors, the jobbers could only receive orders from the brokers on the floor of the exchange. Another difference with the situation in Amsterdam lies in the fact that the London brokers were generalists, acting as a conduit between investors and the market, while jobbers had to specialise in a limited number of shares. While brokers were tasked with aggregating order flow, jobbers were primarily tasked with matching incoming buy or sell orders. Jobbers were in effect a:

> (…) body of men trained to judge supply and demand, who are willing to buy stock to hold until the next buyer comes in or to sell short of stock until the next seller comes in (King, 1947, p.6).

Jobbers would have to come in before the opening of the market and position themselves at their 'pitches', usually around the pillars of the floor. Once there, they would set up their boards, quoting bids and offers in the shares they were responsible for (Morgan and Thomas, 1969, p.261). Jobbers where thus required to provide a continuous double-sided market for all of the brokers on the floor (Maguire et al., 1954, p.5). But precisely because of this, they also needed to be able to change their quotes, being able to adapt to market trends. In a certain sense, jobbers were not interested in the actual prices, as their quotes depended only on the relative predominance of buyers or sellers in their respective stocks. If sellers dominated, jobbers would have to lower quotes until buyers would be attracted. Similarly, when buyers were predominant, the same jobbers would increase their quotes so as to encourage sellers. In other words, the jobbing community was responsible for maintain a certain level of liquidity, that is to say to keep the market 'alive':

> Stock Exchange is in reality comparable to a delicate scientific instrument faithfully and automatically recording every impulse from the slightest tremor to the most violent upheaval (Maguire et al., 1954, p.9).

These tremors and upheavals were transmitted trough the intermediary of brokers serving their clients, that is to say the public outside of the walls of the exchange. While brokers would earn commissions on every executed trade, jobbers could only earn the spread between the bid and the offer, if they were lucky and skilled. This type of compensation was called the 'turn' referencing the ability of jobbers to adapt to changing market conditions (King, 1947, p.39). The problem was that jobbers would not no in advance whether a broker was a buyer of a seller. Depending on market conditions he would quote a more or less tight spread. For example, in a deep liquid market, the spread would be tighter referencing the abundance of both buyers and sellers. Conversely, a less liquid market would necessarily entail much wider spreads, referencing the risk jobbers faced in holding on to inventories of stocks. The functioning of the market was dependent on jobbers being able to constantly rebalance their position; keeping an account of incoming buy and sell orders, adapting to changing trends. This is precisely why it was common to refer to activity of jobbers as 'keeping the book'. In some ways, just like medieval merchants needed to organize their debits and credits, so too did jobbers need to keep track of buy and sell orders.

We could say that the London jobbers were in fact part of a new transaction machine by performing matching and facilitating the execution of incoming request from brokers. The 'hardware' of the machine comprised the jobbers and brokers themselves, their books and paper trails. The functioning of the machine followed a set of simple rules. The core of the mechanism was the maintenance of two separate set of quotations, the buy and sell. Differently to a posted offer or a single-sided market, where you either star with a fixed price or you can modify it afterwards, the two-sided market provides a sell price ('offer' or 'ask'), which is always higher than the buy price ('bid'). Any buy order that matches the sell quote and any sell order that matches the jobber's buy quote will be executed. The spread changes according to the liquidity of the respective stock and the balance between bids and offers. In other words, the actual price is not relevant for the workings of the machine, only the volatility, that is to say the rate and direction in which quotes move. Taking all of this into consideration, the most important function of this double-sided matching machine was to provide a continuously liquid market for listed stocks:

> (…) the primary task of the Stock Exchange is to maintain a market. (…) it is essential to maintain a market in which it is at all times possible to buy and sell freely and without delay (Maguire et al., 1954, p.9).

We will develop this further in our discussion of the New York Stock Exchange, but it is clear that providing a continuous double auction was the most important function of the jobbing community of the London Stock Exchange. Consequently, with the increase in trading volumes and the number of participants, this more computationally expensive matching machine became both necessary and feasible.

5.2 The New York Stock Exchange

As Braudel demonstrates, throughout the Middle Ages, seafaring was fastest way of moving goods, people, money and information. While initially scattered across the continent, commercial and financial flows began to converge around a small number of commercial hubs (Venice, Genoa, Amsterdam). Those same locations provided the perfect environment for the development of more sophisticated transaction machines. The industrial revolution had a crucial impact on this process, the steam engine, the railroad and especially the telegraph all made their mark on 19th century financial markets (Preda, 2009). In as much as a primary function of matching machines is to aggregate and match a multitude of trade request, the development of more efficient communication technologies can surely be seen as an important catalyst for financial innovation.

In this sense, it might be useful to understand the way in which communication technology conditioned the development of these complex machines. For instance, the first telegraph network was optical, which it had a lot of limitations, due to weather conditions in the British Isles and it was also not particularly efficient at night (Standage, 1999, p.21). The subsequent generation was the electric telegraph, which was in fact the product of an exaptation in as much as electricity was initially developed as cheaper energy source and not so much as a tool for communicating (Mokyr, 1990). A whole series of inventors from S.T. van Soemmering to William Cooke gradually perfected the telegraph. In 1844 Samuel Morse transmitted the first telegraph message from Washington to Baltimore. This very simple principle, of sending electric pulses through a medium, is still the basic blueprint of modern ICT technology. One of the early pioneers of financial infrastructure is Baron Paul Julius von Reuter. He first started a news agency in 1840s using carrier pigeons to transmit business-relevant information between Brussels and Aix-la-Chapelle. Reuters grew his network of correspondents through which he could collect the latest prices for stocks and bonds and redistributed them to his subscribers. When electric telegraph networks began to link cities in Europe, he integrated this new medium into his business and eventually moved to London in 1851 (Standage, 1999, p. 151). Before the advent of the telegraph, relationship building and reputation were crucial in establishing commercial and financial networks (from the Medici to the Rothschild family). Up until the middle of the 19th century it was very hard to extend theses networks outside of certain circles of trust, but this was changing with the advent of the telegraph. The cotton trade between the US and Europe is a prime example of this overhaul. Merchants, such as the Liverpool cotton traders, were at the centre of a long intermediation chain dominating trade across the Atlantic. Their main activity was market making, matching buyers and sellers, but also certifying goods, and extracting rents from information asymmetries. They had huge operations, maintaining warehouses and credit lines, effectively underwriting the whole cotton trade (Morrison and Wilhelm, 2007, p.158). But everything began to change in 1866 with the deployment of the transatlantic telegraph cable, an event that transformed trade relations on both sides of the Atlantic. Manufacturers in Europe could now buy cotton on cable as it where, reducing the previous level of intermediation. It is safe to say that commercial relationships were being seriously altered by the advent of this new technology that integrated previously unconnected realities.

The same forces that led to dramatic changes in the world of commerce, also affected financial markets. We will now look at evolution of the New York Stock Exchange (NYSE), a highly complex machine performing the function of market matching. One can trace the roots of this institution to the 1792 Buttonwood Agreement, whereby 24 brokers agreed to trade securities only with each other and at fixed commission of 0.25%:

> We the Subscribers, Brokers for the Purchase and Sale of the Public Stock, do hereby solemnly promise and pledge ourselves to each other, that we will not buy or sell from this day for any person whatsoever, any kind of Public Stock, at a less rate than one quarter percent Commission on the Specie value of and that we will give preference to each other in our Negotiations (Teweles *et al.*, 1992, p.97).

This oath was formally institutionalized in 1817 when the group took up the name of the New York Stock & Exchange Board. The institutional framework went beyond the fixed commission charged to outsiders. For example, NYSE members would be fined 10$ for ''assaulting'' each other with paper darts and 5$ for smoking a cigar on the floor of the exchange (Markham, p. 288). But what is essential was the tiered hierarchical structure, which meant that the insiders had a huge advantage to any outsiders, namely they had direct access to liquidity. Up until this point in time, a call market mechanism was used, whereby the so-called Regular Board of the NYSE performed two trading session one in the morning and one later in the day. The President would begin by reading out loud the list of stocks and the brokers would then trade each security one by one. For as long as trading volumes were relatively low, this procedure was more than able to match incoming orders. An alternative system was set up in 1864 by a group of competitors, the so-called Open Board, which had lower membership requirements (membership of the NYSE was as high as $8,000). Whereas the more traditional NYSE Regular Board traded two separate sessions a day, the Open Board operated continuous trading during the day. Moreover, while the sessions of the NYSE Regular Board were not public, the Open Board was constantly permeable to outsiders. This two-tiered framework posed considerable challenges:

> The existence of two markets in the same building—one continuous, the other discontinuous—contributed to multiple prices and to parallel, heterogeneous time structures. The technology obscured any direct relationship between the published price data and the interaction side of financial transactions (Preda, 2009, p.125)

Consequently, the 1869 merger between NYSE and the Open Board Exchange brought together the two separate pools of liquidity. Moreover, this merger also led to what we could call a contamination as the new exchange adopted the Open Board's model for continuous trading. Instead of having two auctions every day, a new algorithm was put in place in 1871, with matching performed continuously between 10am and 2 pm by designated intermediaries (Lhabitant and Gregoriou, 2008, p.288). Because of time discrepancies between ever-larger trading orders, continuous trading required a solution similar to the London jobbers, an intermediary who could act as the seller for every buyer and the buyer for every seller. This led to the establishment of the specialist and his post, centralizing the matching his designated shares. Effectively, those brokers who tended to trade in a certain security became specialists in that stock and were expected to maintain a fair and orderly market.

Components		Algorithms
Bills of Exchange	Brokers Merchants-Bankers	Bilateral matching (direct matchmaking)
Shares	Bourses Exchanges	Multilateral matching (Anglo-Dutch auctions)
Shares	Exchanges (LSE, NYSE)	Centralized matching (continuous double auction)

Figure 8: Evolution of centralized matching machines

The table above explains how the LSE and NYSE, and their continuous double-sided algorithm, represent another evolutionary step in the trajectory of matching machines. The simple bilateral matching machine would work only if the bid and the offer coincided while the multilateral machine, based on the single-sided Anglo-Dutch auction, could match a number of bidders with a single seller. Under the pressure of higher volumes and requirement for superior execution, modern exchanges developed more sophisticated matching machines. Different to these earlier designs, the continuous double auction aggregated all bids and offers in a central matching machine, organized around individual specialists and their trading books. In this sense, the human specialist was the essential component part of the machine tasked with matching of buys to sells, insuring a fair and orderly market in the shares they were responsible for. On the one hand, specialists would execute orders entrusted to him by floor brokers, for whom he acted as an agent. On the other hand, he also acted as a principal, dealing on his own account:

> Whenever there are public buyers but no public sellers, or public sellers but no public buyers, he is expected, within reasonable limits, to buy or sell for his own account in order to decrease price differences between transactions and to add depth to the market (Wolfson and Russo, 1970, p.707).

This second aspect is linked to the specialists' obligation to provide both buy and sell quotes throughout the trading day. In this sense, he would inevitably end up holding on to stock inventories and dealing on his own account in certain situations. But this also means that the specialist was a monopolistic ''price administrator'' and thus his trading activity had to be closely supervised by the exchange. Specialists were allowed to deal on their own account only if "reasonably necessary to permit such specialists to maintain a fair and orderly market'' (Wolfson and Russo, 1970, p.718). What we are describing here is the overlap between matching orders and maintaining a market, also called market making, which was absolutely necessary in order to have a continuous double-sided matching machine.

In addition to the evolution of matching algorithms, what we call the 'hardware' of matching machines also transformed dramatically under the pressures and constrains of technological innovation. In the 19th century, brokers and clients still used letters on a large scale, leading to huge latencies in the transmission of data, sometimes up to twelve days (Preda, 2009, p.121). On the whole, the actual process of trading was quite disorganized. Brokers employed messenger boys who were the backbone of a pen and pencil network for communicating price data. A growing market brought with it growing levels of noise and confusion, such that in 1867 a telegraph operator by the name of Edward Calahan was struck by inefficiency of the system

> [He] thought that much of this noise and confusion might be dispensed with (…) and that the prices might be furnished through some system of telegraphy which would not require the employment of skilled operators (Standage, 1999, p. 176).

As Alex Preda (2009) describes it, Calahan went on to develop a stock ticker that could produce a printed record of prices in a continuous manner. The advent of the stock ticker was about to change financial markets, as it connected the broker's offices directly to the trading floor by offering ''the beating of the financial pulse''. The stock ticker was based on the printing telegraph and price data was printed on the ticker tape. Instead of a whole group of people using pencils, paper and running around Manhattan, the stock ticker integrated all of that in a machine and its operator. Similar to the way in which contemporary Bloomberg subscribers get real-time access to global financial markets, stock tickers could be rented from information intermediaries such as Western Union. Interestingly enough, Calahan had worked as a messenger boy himself and thus understanding the necessity of quelling the noise and the confusion of the stock exchange. In a certain sense, the main impact was not simply about disseminating information outside of the walls of the exchange, but in restructuring information flows and channeling them while offering continuous and reliable price data. The advent of the stock ticker, the telegraph and the telephone streamlined the flow of information from investors and brokerage houses to the floor of the exchange. What was previously the responsibility of runners and clerks would gradually be transferred to these machines.

This overlap of functions and the increased economic importance of NYSE also led to more intense regulatory scrutiny, in particular from the Securities and Exchange Commission (SEC). As early as 1938, questions were raised about the complex overlap of functions embodied by the floor specialists and the consequences for pricing. But throughout the early 20th century, reforms largely amounted to more regulatory scrutiny and supervision, particular in terms of the minimum capital requirements for being an approved specialist (in 1939 this stood as $10,000) (Wolfson and Russo, 1970, p.707). In fact, the framework of US stock markets will remain largely unchanged until the second part of the 20th century, when a confluence of regulation and the advent of ICT technology led to a new wave of innovation. We will address this in the next section on electronic trading and further on in the chapter on High-Frequency Trading (HFT).

5.3 Development of ECNs

As we have seen, the NYSE inherited a well-defined institutional framework from its evolution in the 19th century. As it stood in the second half of the 20th century, the human specialists still dominated the order matching process on the floor of the exchange. Change had only been allowed in as much as long as it did not threaten the existence of the specialists on the floor. But interestingly enough, innovation was already at hand outside of the walls of the NYSE, and it came form the most unexpected sources. The period 1968-69 has many important connotations in recent political history, but it was also a crucial period in the development of contemporary financial markets. The end of the 1960s witnessed a surge in trading volumes, both from retail individual investors and more importantly due to the increased activity of institutional investors (pension funds, insurance companies, mutual funds, etc.). While institutional volumes stood at $49bn in 1967, they had reached $80bn in 1969, just two years later (see the Specialist System).

> The tremendous growth of institutional participation in the markets places an increasing burden on the specialist's capacity as dealer to meet the demands created by such large transactions (Wolfson and Russo, 1970, p. 741).

While the specialist system had proved resilient for more than a century, the growing volumes of trading and increased pressure from regulators would change everything. In fact, the so-called 1968 paperwork crisis proved to be a defining moment in the adoption of modern technology by the world of finance. The problem was that the surge in volumes at the end of the 1960s had lead to a never-ending trail of paperwork. The NYSE exchange began closing one day a week to allow firms to catch up on their paper work. Another issue was a growing mistrust by the regulators with the long chain of intermediation that was prone to supernatural rent extraction ((Pardo-Guerra et al., 2012, p.7). The need for institutional investors to trade larger blocks of shares and the possibility of matching these trades without the intermediary of a human specialist was at the hart of financial innovation.

The first sign of change came in 1968 with NASDAQ, an initiative of the National Association of Securities Dealers (NASD) to establish an electronic quotation system, in which trades were made over the phone through designated market makers but prices were displayed using computers. Another step forward in this direction came in 1969 with the deployment of Instinet, the first Electronic Communication Network (ECN). Jerome Pustilnik and Herbert Behrens founded the company with the aim of competing with traditional venues by sidestepping their monopoly on aggregating and processing financial information. Institutional investors could trade blocks of shares between them without the need for intermediary specialists. Instinet's subscribers were connected through terminals to a time-shared computer in Watertown, Massachusetts using limit order book technology. Subscribers would submit bids and offers that would be matched according to the closing price of the NYSE market. Although the adoption was slow in the 1970s, the firm grew rapidly in the 1980s followed by other ECNs such as Delta, AZX, Archipelago, Island, etc. Much later, in 1983, NASDAQ introduced the Computer Assisted Execution System (CAES), and the Small Order Execution System (SOES) in 1984 (Leinweber, 2009, p. 66).

Within the sociology of finance, the work of Fabien Muniesa on the Arizona Stock Exchange (AZX) is paradigmatic in understanding the automation and the adoption of Information and Communication Technology (ICT) within financial markets (Muniesa, 2011; Muniesa, 2014). Similar to other ECNs, the AZX was seen as an attempt to override traditional exchange venues and techniques and posed serious legal questions, in terms of the difficulty to decide of these new platforms where distinction brokers, dealers or exchanges. In terms of defining what is an exchange, the AZX was pivotal in forcing the move from a traditional club-like understanding to a algorithmic definition of a matching mechanism for financial transactions (Muniesa, 2007, p.6). The company started in 1990, when Steven Wunsch founded Wunsch Auction Systems in New York and it latter changed name to AZX and moved its operations to Phoenix, Arizona. This new platform offered an alternative and cheaper way to trade stocks listed on NYSE and NASDAQ. Among its many innovations, AZX was a an electronic call market, that is to say, where all orders are aggregated at the same time as opposed to a continuous auction market where orders are matched as soon as possible (Muniesa, 2007, p.15). Wunsch had already experimented with the matching design called ''sunshine trading'' while working at Kidder Peabody in the 1980s. As we have said, the aim was to concentrate all available liquidity at one point in time, that is to say calling the market to meet up and transact at midday. Although Wunsch's intention was to design a mechanism which would bring stability to the process of matching, ''sunshine trading'' was seen by many brokers and exchanges as an irregular attempt to fragmenting liquidity, as well as enriching on their privileges. In any case, what was unique about the AZX was the existence of two order books. The first one called the ''open book'' used time priority as matching criteria with all orders being publicly displayed. The second one called the ''reserve book'' had hidden orders that were executed according to price priority. Time priority was given to those who would display their orders publicly, in that way limiting more aggressive pricing practices (Muniesa, 2007, p.18). As innovative as AZX was, it was forced to close down in 2002 due to a lack of adoption and decreasing market volumes. But what is important is that AZX legitimized the possibility of an exchange embodied in a matching algorithm running on a computer, effectively replacing the system of floor brokers and specialists of the NYSE floor.

Another turning point in the evolution towards fully automated financial markets was the Island Exchange (1995-2002). Island was synonymous with a decisive new development that changed the world of stock trading, as it was the first to provide fully automated trading, very low fees, liquidity rebates and most importantly, the now standard service of colocation (MacKenzie and Pablo Pardo-Guerra, 2014). Similar to other ECNs, Island developed as an innovative 'appendix' to the established venues such as NYSE and NASDAQ. As we have seen, NASDAQ was dominated by voice broking until 1984 when the Small order Execution System (SOES) was introduced which allowed for the electronic processing of smaller orders. Initially designed for NASDAQ brokers, SOES started to be used by a new group of intra-day traders called ''SOES bandits'' (MacKenzie and Pardo-Guerra, 2014, p.13). Because the SEC required the broker-dealers to accept any electronic order coming from SOES, the new ''bandits'' were making profits by arbitraging inefficiencies between the different NASDAQ participants. Island evolved out of several innovations of an entrepreneurial software architect, Josh Levine. His first attempts, FREDY and MonsterKey, allowed traders to enter orders into SOES with as few keystrokes as possible. Later on, he developed Watcher, a particularly efficient trading system allowing for market monitoring and facilitating trader response to market changes. Initially, Watcher could be used to trade with NASDAQ broker-dealers via SOES. But quite quickly, Levine noticed that there were ample opportunity for Watcher users to trade with each other (Mackenzie and Pardo-Guerra, 2014, p.17). Consequently, Island effectively emerged as a new matching machine when Watcher users were allowed to trade with each other avoiding the intermediation of NASDAQ broker-dealers. Higher execution speeds and automation facilitated the birth of this new machine, reducing the level of intermediation of the NASDAQ broker-dealers and providing a cheaper and more efficient pool of liquidity. As we have already said, Island was a particularly advanced piece of technology, which coupled with colocation allowed for automated market making. Island's distinctive architecture allowed market makers to move quickly and not be caught by the market. This low risk environment was absolutely necessary for Island's success and led to a kind of symbiotic relationship with electronic/automated market makers who could thrive in such an environment. All of this coupled with the introduction of liquidity rebates and colocation led to and incredible growth story. By 2002, Island had a 9.6% share of NASDAQ volumes rivaling another ECN, Instinet (Biais et al., 2003, p.6).

One must understand the development of alternative trading platforms not simply in terms of technological innovations but also through the lens of regulation, which fostered competition and transparency (Lee, 1998). The first regulatory response to ECNs was a 1969 Concept Release from the Securities and Exchange Commission (SEC) proposing regulation of automated electronic markets. Rule 15c2-10 was a direct consequence of ECNs this new hybrid species, a strange crossover between and exchange and a broker-dealer (Domowitz and Lee, 2001). While Instinet, Delta and the AZX shared many similarities; they also exhibited different operational structures and can thus be seen as different types of matching machines:

> Instinet was an automated continuous double auction based on a limit order book for equities. The Delta system is oriented towards continuous trading in government options. In stark contrast, the AZX is based on a computerized periodic Walrasian auction model, with varying levels of pre-trade information depending on user choices (Domowitz and Lee, 2001, p.13).

The SEC had traditionally defined a dealer as anyone engaged in buying and selling securities for his own account, through a broker. Consequently, a broker was defined as any person engaged in the business of effecting transactions in securities for the account of others. The crucial difference between these two types of financial actors and an exchange was the centralization of trading and the capacity to list new stocks. While AZX used a centralized system for aggregating and execute orders, which qualified it as an exchange, Delta and Instinet where deemed not to have the same characteristics and were not required to register as an exchange (Domowitz and Lee, 2001, p14). Subsequently, the SEC passed the Regulation of the National Market System (Reg NMS) in 1974, which required increased transparency and connection between markets (Pardo-Guerra et al., 2012, p.9). Finally, the Inter-market Trading System (ITS) allowed participants on one market to route the order to another market when a better price was displayed. In 1999, a new regulatory framework for Automated Trading Systems (ATS) allowed alternative trading systems to register as a broker, or register as an exchange, or operate as unregulated ATS (Gyurko, 2011). This finally solved the new problem posed by ECNs in as much as they looked like an exchange but were in fact a dealer (Freedman, 2006). Another important step was the repeal of Rule 390 on May 8, 2000. The rule was supposed to disallow the trading of stock listed prior to 1979 outside of the NYSE exchange. Although NYSE argued that this was designed in order to safeguard liquidity in those stocks, the rule applied to 30% of listings, accounting for 50% of volume (Kim, 2007, p.43). Abandoning this restrictive measure allowed ECNs to match orders in all US listed stocks. In addition, in 2001 the SEC imposed the switch from traditional sixteenths ($.0625) to penny spreads ($.01), reducing transaction costs for smaller investors and, in a sense, force the adoption of more efficient electronic systems. This was further reinforced by the 2005 introduction of rule 610, granting equal access to all markets by all players and rule 611, demanding that orders should trade at the best possible price (Pardo-Guerra et al., 2012, p.12). Therefore, the regulatory push for more transparence and the adoption of information technology ultimately led to a more level playing field in the business of aggregating and matching order flow. Eventually, some of the ECNs developed large market shares overtaking NYSE and NASDAQ as the main aggregators of order flow in the US stock markets. This increase in competition from alternative trading venues triggered a wave of acquisitions with NASDAQ acquiring Instinet in 2005 and NYSE merging with the Archipelago Exchange in 2006.

5.5 London, Paris and Chicago

From New York to London and from Paris to Frankfurt, the function of matching the trading of stocks was a sacred monopoly of humans specialists located in a clearly demarcated space, the only legitimate venue of ''collective calculation'' (Muniesa, 2003; Muniesa and Callon, 2003). For the purpose of this chapter we have focused only on the centralized forms of matching, that is to say, the publicly regulated forms of exchange[50]. It is in this context that we have followed the impressive evolution of matching machines in the context of US stock markets, moving towards higher levels of efficiency and technological sophistication form the early introduction of the stock ticker to contemporary electronic trading platforms such as ECNs. The post World War II period was particularly important in this regard, due to the introduction of computer technology into economic and social spheres (Mirowski, 2002). The new possibilities afforded by information and communication technologies were already apparent in the 1960s, namely that

> (…) in a fully automated system the specialists function must also be automated. This means the system must be programmed to maintain orderly markets without the intercession of the human element (Youngblood, 1969)

Moreover, as early as 1971 Fischer Black argued for the full automation of stock exchanges arguing that the pricing mechanism could be reduced to the logical process of a network of computers (Black, 1971). What up until then was executed by human-based 'hardware' could now be translated into almost fully automated computer operations. Radical as it was, the technological innovation of the last three decades took some time to some time to overcome the resistance of the floor-based human specialists. We have seen this process unfold in the case of the NYSE and US stock markets, but it is also useful to quickly summaries this process in the case of

[50] We will address the issue of Over-The-Counter (OTC) markets in the last chapter of the thesis, but only for the case of complex derivatives such as swaps. This is mainly because for both stocks and simple derivatives such as futures and options, their modern evolution has revolved around the public exchange model.

European stock markets. For instance, the London Stock Exchange has earned its name as one of the oldest venues for aggregating the trading in shares. Historically, it has been the site where liquidity providers and liquidity removers would meet to match their positions. Moreover, by the 20th century it had become a highly exclusivist ‘’natural monopoly’’ (Lee, 1998), as matching order flow was the exclusive privilege of jobbers and stockbrokers. While the telegraph, the stock ticker and the telephone had put up serious challenges to this design, the human components of these machines still dominated well into the second part of the 20th century (Pardo-Guerra, 2010; Pardo-Guerra, 2012). Nevertheless, the same conditions and pressures that led to the electronic revolution in US stock markets were eventually replicated in the case of the LSE. According to Pardo-Guerra, the British stock exchange gradually exhibited the same trend towards automation and adoption of ICT technologies, initially through the development of the systems such as the Market Price Display Service. While technology provided the means, they main bone of contention was the opaque fixed commission model of the London brokerage industry. In an attempt to sidestep the traditional brokerage houses, a group of merchant banks (Issuing Houses Association) developed an electronic platform in 1973, the so-called Automated Real-Time Investments Exchange Limited (ARIEL), based on the American Instinet model. While this posed an early challenge to the old structure of the exchange, it was not until 1986 when regulatory reforms, commonly known as the Big Bang, led to a radical change of market structure (Attard, 1994; Attard, 2000). This entailed the end of fixed commissions for brokers, the elimination of the distinction between jobbers and brokers, and opening the possibility of electronic trading platforms (Pardo-Guerra, 2010). Following on from this, one of the first attempts for an alternative venue was Tradepoint, which launched in 1995 and was later acquired by SWX Swiss Exchange in 2000 and renamed virt-x. Just as the US-based ECN platforms, Tradepoint used an electronic order book system. More importantly, it allowed the opening up of the process of matching outside of the walls of the LSE. In fact, Tradepoint forced the LSE to develop SEAQ, an automated quotation system based on the NASDAQ model. Later innovation such as Baikal Global or Turquoise can represent the final transition towards automated electronic trading in London.

Across the channel, the evolution of the Paris Bourse would also follow a similar path to the LSE. The importance of the French stock exchange goes back to the 19th century, when according to an urban myth it influenced the thinking of one of founders of neoclassical economics, Leon Walras (Muniesa, 2003). But the origins of the exchange date to the 18th century when in 1724 a room called the ''Parquet'' in a building on the Rue Vivienne was designated as the legitimate venue for the exchange of securities (Michie, 2006, p.39). In this context, the aim of government intervention was not to encourage trading such as in Amsterdam but to control and restrict it. As Michie (2006) describes it, unlike the continuous double auction machine developed in New York and London, the Paris Bourse functioning according to call market algorithm. This is known as ''tâtonnement'', a mechanism allowing the discovery of a market-clearing price in several stages. An employee of the exchange would quote and opening price, and then brokers would signal their buy or sell intentions. If the case of a mismatch, new call auctions could be repeated until matching was achieved. As we already noted, the market was not continuous, but there were separate trading session throughout the day (Kregel, 2007, p.149). Brokers (''agents de change'') were regulated similarly to the UK, in the sense that they were not trading on their own behalf, but only transmitting market orders from their clients. Up until the 20th century, the Paris Bourse handled mostly government bonds and railway shares, whereas a parallel market was trading in foreign shares as well as buying and selling for future delivery. Gradually, banking houses based their operations around the building of the Paris Bourse and connected their provincial networks, effectively creating a centralized financial system (Michie, 2006, p.94). While the Anglo-Saxon model was revolved around brokerage houses and broker-dealer banks, the French market relied on the absolute monopoly of exchange agents (''agents de change'') who were the licensed deal in securities. This model effectively meant that the matching mechanism of the exchange was the privilege of a number of personal interests (Muniesa, 2003). Despite having a different market structure from the NYSE and LSE, Hautcoeur and Riva has shown that the Paris Bourse was nevertheless a very efficient transaction machine (Hautcoeur, 2012). In fact, despite all their differences, the history of the automation of the Paris Bourse bears similarities to what happened in New York and London. Fabian Muniesa has offered a detailed account of the complex process by which the stock exchange moved to an electronic automated system, how it changed but also how it preserved certain aspects of the original structure. This was a difficult journey as the established brokers were for a long time reluctant to adopt any technical innovation that would infringe on their special privileges. Just like in London, the investment banks were particularly interested in the disintermediation of the monopoly of the brokers. While the brokers wanted to keep a tight grip on the matching process, and in particular to their fixed commissions. The deadlock between the French banks and brokers was finally broken when the Paris Bourse began to lose market share to London. As the more advanced systems in London were drawing volumes away from Paris, an urgent process of automation began that finally ended in 1989 with the CAC (''Cotation assistée en continu'') system, modeled after the Toronto Exchange (Muniesa, 2003).

This tendency towards automation and the adoption of electronic technology, was not restricted to stock markets but also within derivatives markets. Following from the previous analysis of the automation of share trading in the US, it is useful to review a similar process involving the US futures and options markets based in Chicago. Ever since the 1970s, Chicago was a hotbed of innovation, particularly in the area of financial derivatives (Kummer and Pauletto, 2012). On May 16, 1972 the Chicago Mercantile Exchange (CME) launched of the IMM (International Monetary Market), a currency futures market (Melamed, 1988) (Hasbrouck et al., 1993). This can be thought of as the passing the threshold towards new financial capacities and the opening up of a wide space for financial innovation. In this sense, ever since the 1970s, Chicago built a preeminent position in the international futures market. In this context, trading solely in the human-based open-outcry pits proved to severely limiting for future growth. When the Chicago pits were open it was night in Asia, so there was a real need for 24 hour trading system (MacKenzie, 2015). The problem with introducing an electronic platform was the fierce resistance from the pit traders. The membership of the CME would only accept it if it wasn't directly competing with their own business. The first electronic derivatives trading platform, Globex, entered into development in 1987 as a joint venture with Reuters, and was officially launched in 1992. It was effectively the first electronic platform specifically designed for trading futures contracts. It initially traded only CME futures contracts, in German marks and Japanese yen but was then extended to Swiss francs, British pounds, etc. After one year, systematic trading was possible for equity futures leading to in impressive growth of volumes, 1.2 million/day contacts in 2002 (Aldridge, 2010, p.12). Initially, it only traded at night, but then it was permitted to trade during the day but only in contacts that were not traded in the pits. This in turn led to further contractual innovation such as the E-Mini, a security developed as a complement to the pit traded S&P 500 future. In fact, the E-Mini was quickly adopted as it allowed traders to profit from arbitrage opportunities between Globex and the pits (MacKenzie, 2015, p.22). The use of Globex terminals, which had a first in first out matching algorithm, and very fast arbitrage opportunities, meant that execution speed was essential. Europe soon followed Chicago's example with Deutsche Terminbörse in Frankfurt, LIFFE Connect, and MATIF in Paris. In any case, it was the huge success of Globex that allowed the CME to merge with its long time rival the Chicago Board of Trade (CBOT) to form the CME Group in 2007, becoming the largest matching machines for futures contracts. In conclusion, Globex was a crucial moment in the history of financial markets, fostering the transition towards electronic trading of derivative contracts but it was only in 2015 that CME decided to close most of its open outcry trading floors (the pits) leaving open only those for S&P 500 futures and options. This final decision came as the volumes traded in open outcry by human market makers reached an all time low if 1% of daily futures transactions.

Finally, the development of electronic trading in the case of the Chicago derivatives markets is similar the transition of stock exchanges both in Europe and the US (Scott and Barrett, 2000). Under the pressures of information technology, the demand for lower trading costs, the regulatory push for transparency and automation, we have seen the gradual evolution towards more complex matching machines, based on automated electronic platforms. We also elaborated on the gradual displacement of humans within the workings of matching machines. Initially through the stock ticker, the telegraph and the telephone and ultimately through the computer, we saw a continuous expansion of automation and standardization whereby function such as the matching of orders, the dissemination of trade data, etc. are all performed by computer technology. As Pardo-Guerra (2013a) has argued, this process does not entail the disappearance of humans form the functioning of markets, but leads to the rise of financial engineers understood broadly (software developers, risk analysts, quants etc.). Similar to the way in which Simondon thought about modern technology, humans are no longer the dominant component of complex machines but become maintainers and managers of machines. As long as it was impossible to build data warehouses, servers, matching engines and electronic order books, a function such as the matching of order flows was the monopoly of human individuals. The technological innovations of the late 20th and early 21st century have changed all of this and set the stage for our contemporary financial markets.

5.4 NYSE and the Hybrid Market

As we have seen, the development of alternative matching machines such as ECNs had a significant impact on the incumbent exchanges. For instance, NYSE introduced the first electronic order routing system Designated Order Turnaround (DOT) in 1976, which was designed to assist human specialist on the floor of the exchange (Leinweber, 2009, p. 68). DOT and subsequently SuperDOT, were effectively order routing systems connecting members of the exchange directly with the specialist post on the floor without having to go through brokers. While at first glance it might seem that NYSE was willing adopter of new technology, it was only doing so in as much as it did not radically disrupt the institutional arrangements inherited from the 19th century. As we have seen, the transformation of NYSE was a long and arduous process, involving technological and regulatory pressure as well as increased competition form electronic trading platforms (Zimmermann, 2008; Zimmermann, 2011). The push for automation and efficiency (Pardo-Guerra et al., 2012) produced a level playing field allowing more nimble electronic platforms to gain market share at the expense of the established exchanges. This is already a secular tendency that was apparent when the 19th century bucket shops attempted to take business away from the bigger brokers by gaining access to stock ticker technology. In the late 20th and early 21st centuries, the technological novelty of alternative trading platforms such as ECNs disrupted the exchange/broker/dealer distinctions and revolutionized the specialist system of the NYSE. It is useful at this point to review the normal day-today operation of the NYSE as it stood in the early 1990s and its subsequent transition towards a hybrid system. Despite the innovation brought about ECNs like Instinet, Delta and AZX, the aggregation of order flow on NYSE was still performed through the coordination of specialists and floor brokers. Order matching in a given stock was processed at the assigned specialist posts (Hasbrouck, 1993, p.4). The specialist and his clerks were always at the post, managing order flow and the display panels (a trading post would have some 18-22 panels) ensuring a continuous market in a certain number of stocks. Floor brokers are in constant contact with their firms through telephone booths positioned near the walls. They were conduits for order flow, receiving information from the firm's trading desk and channeling it to the specialist's post. Despite the level of technical automation the majority of trades were still not executed automatically but were entered into the system or approved by the specialist. In this sense, the NYSE specialist was still integrating a whole series of functions including ''auctioneer, catalyst, agent and principal'' (Wolfson and Russo, 1970).

Nevertheless, the adoption of DOT and SuperDOT would severely limit the use of floor brokers, as it allowed the submission of orders directly to the specialist's Display Book at his post. Consequently, human floor brokers would only handle the more sensitive orders, usually in less liquid shares or for bigger block trades. This trend towards automation was further reinforced by the development of Direct+, which provided an automated execution options that circumvented the specialists. First rolled out in October 2000, the Direct+ system provided automated execution for market orders below 1,099 shares. The scope of this system was expanded in 2004 with the elimination of any limits on the size and type of orders that could be submitted for automated execution. Whereas in the case of DOT or SuperDOT, the final execution was still done by the specialist on the floor, with Direct+ it was possible for smaller orders to be matched automatically. Finally, the acquisition of an ECN, the Archipelago Exchange, in March 2006 cemented the radical transformation of NYSE from a floor-based system to the hybrid market it operates to this day (Fabozzi, 2008, p.140). Building on the technology and automated matching or the Archipelago Exchange and its SuperDot and Dirtect+ systems, the NYSE launched its Hybrid Market in 2006. In this new design, clients could send orders directly to the floor or simply opt for electronic execution.

> The NYSE Hybrid Market offers customers the choice between the auction system with the opportunity for price improvement provided by the specialist system and very fast automated trade execution provided by the electronic system (Fabozzi, 2008, p.141).

As the previous system, the Hybrid Market operates a continuous double auction during the trading day and a call action for the opening and the close of the market. The optionality of having both fast electronic execution (for all orders below 1 million shares) and the possibility of better pricing means that the Hybrid System is able to service the needs to a diverse set of market participants (some investors value immediate execution while others require optimal pricing of their orders) (Fabozzi, 2008). As stated at the time by the NYSE Chief Technology Officer Steve Rubinow[51], the adoption of the Hybrid System will lead to execution times going down from 9 to 0.3 seconds, aligning NYSE with the rest of the industry[52].

In any case, all of this had a major impact on the human specialists and brokers on the floor of the exchange. As Hendershott and Moulton (2007), have shown, the percentage of NYSE order flow processed by the specialists and the brokers on the floor steadily declined from 70% in 1991, 50% in 1999 to about 10% in 2006 (Harris and Hasbrouck, 1996; Sofianos and Werner, 2000; Fabozzi, 2008). With the decline in order flow, the number of specialist firms also followed suit. The possibility of having most orders matched automatically, means that specialists and floor brokers lost the so-called last-mover advantage and there is less scope and need for manual execution (Hendershott et al., 2010). With the adoption of SuperDOT, Direct+ and finally the Hybrid Market, the human specialists and brokers on the floor were gradually relegated to a more marginal role in the process of matching order floor. From some 40-specialist firms operating in the 1990s there has been a continual decline to 18 firms in 2001 and to as little as five firms as of 2007. While the adoption of the Hybrid System has been beneficial for the NYSE market, by reducing the cost of trading and achieving superior execution speeds (Storkenmaier and Riordan, 2009), it also consecrated the decline of the human specialists and brokers. This does mean that humans are no longer involved in the matching of order flow but simply means that they do not have a monopoly over the function. Drawing from Simondon, we could say that human specialists dominated the matching of order

[51] http://www.computerworld.com/article/2554166/app-development/nyse-launches-new-hybrid-trading-system.html

[52] This would also allow the NYSE to register as a fast market under the new Reg NMS regulatory framework, essential criteria in terms of being able to compete with the other electronic trading platforms (Hendershott, 2010).

flow for as long as there were no machines capable of performing the same function:

> Man has played the role of technical individual to the extent that he looks on the machine-as-technical-individual as if it were a man and occupying the position of a man, whereas in actual fact it was man who provisionally took the place of the machine before real technical individuals could be made (Simondon, 1980, p.97).

One could look at matching algorithms and electronic order books as simply replacing human specialists and their actual paper books. But one mustn't see this as a fight or a contest between man and machine. In terms of the matching of order flow, we have tried to think about modern exchanges as complex machines centered on human specialists as the dominant technical component. In the case of NYSE, human specialists would receive inputs from investors, process and match order flow and transmit certain outputs, such as executed prices and quantities. The function itself can be performed humans and their paper books, by matching algorithms such as in the case of ECNs, or by humans and machines such as in the case of the NYSE Hybrid Market. Viewed from the outside, the matching machine is the same, in the sense that it performs the function of matching order flow. The mix between human or electronic is an important aspect, as well as the actual matching algorithm employed (continuous double auction), as they lead to qualitatively different outputs. While some investors want immediate execution others want their trades to be executed at the best possible price. In this sense, some investors will opt for their order to be executed on an alternative electronic platform, while others would chose to send their order to the floor of NYSE. In any case, at the end of the day all of the different matching designs perform the same basic function of matching order flow. There is no alienation of loss of authenticity involved in any of this. To the contrary, the hybrid system deployed by NYSE since 2006 could be seen as a further evolutionary step in terms of matching machines. We have defined evolution (both in reference to Simondon and Mirowski) as the development of a new design that can simulate the functioning of previous designs. In this sense, the Hybrid Market can easily simulate the matching done either on the traditional trading floor or on more sophisticated electronic platforms, while the reverse is not possible. Moreover, this new matching machines integrated a number of different elements, such as the specialist trading floor, the SuperDOT, Direct+ and the Archipelago ECN and afforded novel functionalities in terms of providing more tailored execution to a wide set of investors. This evolutionary step does not fully eliminate the role of humans. In fact, it has been recently argued that even in the NYSE Hybrid Market, the role of specialist is essential in providing liquidity in less liquid stocks and in times of greater volatility (Fabozzi, 2008, p.127). As we will see in the next chapter, the NYSE Hybrid Market is perhaps superior to the other existing designs in terms being a more stable liquidity pool in times of market stress (Beunza and Millo, 2015).

Conclusions

This chapter followed the evolutionary trajectory of matching machines in modern times. We first looked at the founding of the LSE in the 18th century, where the maintenance of a continuous double auction machine was the responsibility of jobbers. We also focused on the NYSE and its development in the 19th century where specialists were tasked with maintaining a similar double call auction for shares. The advent of the telegraph and the stock ticker led to the growth of trading volumes (Friedman and Rust, 1993) leading to the emergence of alternative machting machines such as the Open Board, which provided a continous rather than a call auction. The competition, conflict and ultimate merger of the NYSE Regular Board and the new Open Board shows us that the evolution of transaction machines is not just a technical question of developing more efficient designs but is also a political question, that of maintaining control of the order flow. Thus after several political/institutional and technological mutations, the matching machine of the NYSE, based on continuous double auctions, became the dominant hub for US share trading. To recapitulate, we also provided an outline of the evolutionary steps of the matching machine from the medieval bilateral matching, to the multilateral design in Amsterdam, leading to the centralized matching performed by the specialist on the floor of the NYSE.

Components		**Algorithms**
Bills of Exchange	Brokers Merchants-Bankers	Bilateral matching (direct matchmaking)
Shares	Bourses Exchanges	Multilateral matching (Anglo-Dutch auctions)
Shares	Exchanges (LSE, NYSE)	Centralized matching (continuous double auction)

Figure 9: Evolution of matching machines

Following both our overall theoretical framework and the historical narrative, it is clear that each new generation of matching machines is more complex and more computationally expensive. At the same time, each design is more efficient in terms of processing higher volumes of transactions from an increased number of participants. In addition to addressing the evolution of matching algorithms we also looked at the gradual transformation of what we called the 'hardware' of these machines. The matching machine developed on the floors of modern stock exchanges was radically transformed at the end of the 20th century. Together, the regulatory pressures for more transparency and the new ICT technology favored the development of new electronic platforms exhibiting higher levels of automation and efficiency. Therefore, electronic order books gradually replaced the specialists on the floor, and rather than relying on the labor of human specialists, ECNs such as Instinet, AZX, Island and Globex enabled electronic automated trading.

We also reviewed the more recent mutations of matching machines, namely the NYSE Hybrid Market, where investors have a choice between immediate automated matching of routing the order for execution on the floor. Deployed in 2006, this new design can easily replicate the matching done either on the traditional trading floor or on the newer electronic platforms. The NYSE Hybrid Market can thus be seen as a further evolution towards a more concretized machine as it integrates a number of different elements, such as the specialist trading floor, the SuperDOT, Direct+ and the Archipelago ECN and affords novel functionalities in terms of providing more tailored execution to a wide set of investors.

In conclusion, electronic order books and matching engines have allowed for matching to be done without much human intervention, anonymously and with considerably lower costs. But the automation of matching directly impacted the way in which market making is performed, i.e. the provision of liquidity in the order book. We will address this topic in Chapter 7, where we will focus on the topic of High-Frequency Trading (HFT) within the context of contemporary electronic market making.

Chapter 6. Clearinghouses & CCPs

Summary:

This chapter builds on the previous account of medieval clearing machines and elaborates on their modern evolution. We start by looking at the banking clearinghouses developed in London and New York as a continuation of the clearing practices of medieval merchant-bankers. Similarly to the medieval clearing fairs, the London Clearinghouse performed multilateral clearing allowing banks to compute their mutual debts and compress the settlement of bank checks. We also show how the clearing of bank payments eventually developed into a mutual safety mechanism against bank panics. Furthermore, we follow the migration of multilateral clearing to the stock markets, such as in the case of the London Stock Exchange Clearinghouse. We also review the adoption of multilateral clearing by the New York Stock Exchange with the establishment of its own clearinghouse in the 19th century. The introduction of multilateral clearing had a huge impact in terms of reducing counterparty risk through the netting of offsetting exposure. We also discuss the clearing of derivatives such as forwards and futures, by focusing on the less known example of the Dojima Rice Exchange. The crucial breakthrough is achieved in the context of the futures market of Chicago where we focus on the evolution towards central clearing. Established in 1883, the Board of Trade Clearing Corporation (BOTCC) initially served as a multilateral clearing facility. A few decades later, the Board established the BOTCC as the only counterparty taking responsibility for the portfolio of any defaulting member, thus becoming a Central Counterparty (CCP), the buyer to every seller and the seller to every buyer. In this context, we also propose an evolutionary trajectory from bilateral to multilateral and finally central clearing. Each new generation of clearing machines is more complex and responds to the growing demands and needs of its users. Similar to the matching function, the history of clearing exhibits a tendency towards automation and the gradual transition from a human-based pen and pencil infrastructure to modern electronic platforms. We conclude by providing an overview of the functioning of central clearing through CCPs, the benefits afforded by the clearing of derivatives and also the contemporary adoption of ICT and development of automated real-time clearing systems.

6.1 Bank Clearing in London and New York

With the increase in complexity of financial markets, both the clearing of stocks and monetary payments began to be more and more concentrated and consolidated around ''natural monopoly'' type structures[53] (Pirrong, 2009; Lee, 2011; Pirrong, 2011). In the early modern period (17-18th century), just as the order matching function eventually migrated from Amsterdam to London, so did the clearing function find its new center of gravity in London. Although a proto-clearinghouse can be found in Lyon around 1630, it was the growing financial centre of London who will see the development of an efficient banking clearinghouse (Norman, 2011). In 1773, the London banks, instead of clearing their accounts bilaterally, decided to consolidate the clearing activity into a ''clearing club'' situated in a room in Five Bells tavern on Lombard Street (Kindleberger, 1984, p.78). The club was a way for London bankers to start devising a system in which they could exchange all of their checks at one place and at one time. This temporal compression reduced the sums on money necessary to cover all of their reciprocal settlements (Camp, 1892).

> The clearing procedure was very similar to the procedure known from the clearing fairs. Each morning during the week the representatives of the banks met and presented the financial obligations. During the day the representatives had time to verify the debts. In case the obligations were approved, the representatives offset their credits and debts. The remaining open positions had to be paid in cash (Boerner and Hatfield, 2010, p.14).

The first record of this type of financial institution dates back to 1773 when a charge for using the clearing room appears on the books of Martin & Co. The nascent clearing club turned into a clearinghouse in 1775, when the representatives of the member banks moved into a new building on Lombard Street (Norman, 2011). As in the case of the clearing mechanism of the medieval fairs, the output was the reduction of the actual amount of money used for settling transaction (Cannon,

[53] A natural monopoly situation is one where certain service is more efficiently provided by a single entity rather than through open competition.

1910). In the case of the London Clearinghouse, the clearing mechanism was based on two sets of books that contained columns with the name of all the other clearing members. Each bank had one book that consolidated the amounts to be received, handled by an outclearer, while another book with the some to be paid was at the clearinghouse handled by an inclearer (Cannon, 1900). The clearinghouse room itself housed about 30 clerks (inclearers), positioned in alphabetical order with an open box besides them and the name of the firm above their heads (Babbage, 1856). As James Cannon described it, the role of the outclearer would start early in the morning, when he would gather all of the various bank cheques drawn on the other clearing member banks. Then he would make his way to the clearinghouse where between 10 and 11 am, he would go around the desks of the various banks and deposit his charges to the inclearers. At 16 pm the boxes are removed and each clerk calculates his debits towards the other banks. The task of the inclearers is to compute all of the charges and to make sure that the totals match, that is to say, the ''in'' of any bank must be consistent with the ''out'' of the other clearing member:

> Should the totals not agree, the clerks sings out in a loud voice the name of the bank with whose total he differs, and the representative of that bank is obliged to go to the desk of the complainant and take with him his 'outbooks'. The items are then run over and the mistake detected and rectified (Cannon, 1900, p.325).

Following the vocabulary of Callon and Muniesa, the whole process was a complex collective calculation of the exact exposures between all the other banks. This is of course similar to the clearing practices of medieval merchants, as the use of double-entry bookkeeping allowed them to balance debits and credits with their respective counterparties. The most efficient way to balance the books was for a critical mass of merchants to meet in special locations, such as the Clearing Fairs of Champagne, and offset their counterparty exposure. Similar to that, the London Clearinghouse allowed banks to compare their books, that is to say their mutual debts and credits, in other words an advanced transaction machine for the clearing of offsetting balances between member banks. The inputs were the charges of all the banks, which would then be processed according to the algorithm describes above. The final output was the compression of offsetting exposures, which would drastically limit the actual cash settlements between banks. This was the highpoint of the clearing mechanism was at the end of the day when, between 16 pm and 17 pm, final settlement was performed. At 17 pm each clerk pays their due amounts to the clearinghouse inspector and receives a ticket in exchange.

> The noise, which seems to betoken cessation of work, is really a cloak, as it where, to the busiest time of the whole day, for a settlement must be made of all the transactions, and the clerks are agreeing their different totals and casts, checking amounts (Cannon, 1900, p.329).

What might seem like a ''noisy'' chaos for outsiders was in fact a very efficient of mechanism for the compression of debts. All clerks where in a race to agree the netting and quickly correct any errors, thereby preventing the eruption of a much louder disturbance, the breakdown of the payment system as such (Noyes, 1893).

The transaction machine first developed for bank clearing in London would eventually finds its way to the new world. From the War of Independence up until the early 19th century, US banks were chartered either by the individual States or Congress. This situation changed dramatically with the free-banking law of New York enacted on the 18th of April 1838. This new regulatory framework led to the multiplication of banking licenses, with every institution being independent and having to rely only on itself and its customers for functioning (Cannon, 1900). As the number of New York banks increased from 24 to 60 at the end of the 1840s, the settlement of balances between banks was put under sever stress. The whole system was running with considerable inefficiencies and risk. Each bank was keeping a different ledger for every other bank, and was settling balances bilaterally. All off this, coupled with the physical distance between the banks, proved to be unsustainable as the number of banks grew. Before the establishment of a clearing mechanism, each bank would send their porters on the ''bank circuit'', wasting considerable time and causing delays as porters from several different banks would end up in queues delaying the overall settlement process (Cannon, 1900, p.128). For this very reason a daily settlement was not possible, and eventually Friday morning was set as a fixed settlement date. The problem with this weekly settlement was that it would allow for debtor banks to abuse the system, while creditor banks could often be operating close to their limit. Because of that, daily clearing was gradually introduced with the establishment of the New York Clearing Association on the 11th of October 1853, a separate institutions to house and maintain daily clearing and settlement. The association comprised all 52 New York banks at that time. Non-member banks could also clear through the member banks, but the later were fully liable for the transaction (Cannon, 1900, p.151).

Information about the New York Clearinghouse is relatively abundant due to the fact that the New York Clearing Association maintained a complete record of its daily transactions since inception, as well as a weekly report on the solvency of each member bank (Camp, 1892). The clearing mechanism itself was similar to the one in London. Each bank had to types of operators the delivery clerk or porter and the settling clerk. The first type of clerk delivered packages while the second would receive orders from the curriers of the other banks. The whole process would start at 10 am, with both the settling and the delivery clerks taking up their positions at the desk. At 10 am on the dot, the clearinghouse manager would start of clearing process, and each delivery clerk moves to his right, depositing his charges and receiving receipts from the other banks settling clerk. Gradually, each delivery clerk deposits his banks packages to all the other bank desks, completing the operation in about 10 minutes. At that point, the settling clerks have to sum up all of the amounts and make out tickets containing the credit and debit situation to the proof clerks. In a few hours, each respective bank is aware of the amounts they have to pay or are due to be paid to them by the clearinghouse. The collective computation performed by the delivery, settling and proof clerks end at 10.30 am, without any money exchanging hands. After the clearing process, the next step is the completion of the settlement of payments. A crucial point here is that debtor banks have to make the payments first. Before 13.30 pm, each debtor bank makes the required payments to the clearinghouse and only after that can the creditor banks receive their balances

(Cannon, 1900, p.188). Payments were made through a Bank of America backed certificate, which was the official deposit bank of the Clearinghouse Association (Statistics clearing houses 1839 p.31). The success of this clearing mechanism was evident and by 1893 there were clearinghouses in 57 cities in the United States clearing a total of: ''$61,017,839,067 and yet the transaction of this enormous volume of business was accomplished with the use of $4,881,777,289 in money'' (Hepburn, 1893, p.376).

The whole clearing process was an incredibly precise and highly regulated activity. The clearing community was by definition very conservative and risk adverse, evidenced by the very strict membership requirements of the early New York Clearinghouse. In the first few years of operation, no more than eight banks were forced out because of their inability to meet the stringent requirements of the clearinghouse. Unsound business practices could have been concealed in the past, but with the advent of multilateral clearing, more transparency and better business practices were introduced (Camp, 1892, p.687). Other events proved hazardous for the business of the clearinghouse such as the presidential election of 1860, or subsequent bank failures in 1884 and in 1890. Whenever a member bank's solvency was in question, the clearinghouse committee would swiftly call for an investigation to ascertain the stability and viability of the institution. Thus the clearinghouse mechanism had allowed for an increase in transactional efficiency but also regulated the behaviour of member banks. In the context of the frequent banking panics of the 19th century, the mechanism proved to be a ''tower of strength in times of financial distress'' (Camp, 1892, p.686). What started as a solution to the problem of clearing bank transactions developed into a mutual safety mechanism that would prove its effectiveness particularly in times of panic. For instance, the panic of 1907 revealed that institutions such as the New York City trusts, which were not members of a clearinghouse, had been subject to larger levels of withdrawals than banks that were members of a clearinghouse. In as much as banking became a more tightly coupled system, every individual failure affected the whole system as the ''the banking community is an organic whole, no member of which can suffer without detriment to the body'' (Young, 1910, p.134). In this sense, the clearing mechanism acted as a stabilizer for the banking community, maintaining a robust payments system.

6.2 Clearing the Stock Market

As we have already said, clearing of reciprocal stock positions was a normal activity for trading participants in early-modern financial centers. The Amsterdam Stock Exchange already had special clearing days in the 1650s and London in the 1740s (Boerner and Hatfield, 2010, p.13). In the previous sections we focused on how bank clearing managed to successfully reduce cash payments, to as little as 4-5% of actual transactions (Noyes, 1893, p.254), the adoption of the clearing mechanism had a similar effect in the case of clearing stock exchange transactions. The first modern clearinghouses for stocks was set up in Frankfurt in 1867, Berlin in I869, Hamburg in I870, Vienna in 1873 and London in 1876 (Norman, 2011).

London, as the major financial centre of the 19th century, also saw the establishment and development of a stock exchange clearinghouse. In the 1870s, three different institutions dominated London's financial centre: the Bank of England and the other banks, the Lloyds of London insurance market (primarily focused on maritime insurance and trade finance) and the London Stock Exchange (Wheeler, 1913; Wincott, 1947; Morgan and Thomas, 1969). Over the course of a trading day brokers were likely to accumulate substantial volumes of transactions on their books. As volumes increased, it became harder and harder to settle these on a bilateral basis. The Stock Exchange Clearinghouse emerged as a solution for reducing the number of settlements by moving from separate bilateral settlements to having one single settlement with all counterparties (Noyes, 1893, p.247). Similar to the bank clearinghouse, the Stock Exchange Clearinghouse could organize and direct all participants towards a more efficient compression of transactions. Without the existence of a clearing mechanism, they would have to settle their balances with each other on a bilateral basis. So instead of having a large number of single settlements, the clearing mechanism would direct each member in such a way as to net out, as much as possible, their offsetting balances. The clearing machine for stocks was similar to the design of the London Clearinghouse used for bank checks. Moreover, while the stock exchange clearinghouse started to attract more members, this reduced the number of actual monetary transactions even more. Each member provides a statement of what he has to receive and what he has to deliver to the other members. The managers of the clearinghouse then compare and verify these statements

> Those who have to receive on balance are put on one side, and those who have to deliver on the other, and a direction is given as to the distribution of the deliveries, the aim of course being to make them from as few to as few members as possible (Noyes, 1893, p.247)

As the LSE Clearinghouse settled every fortnight, this coincided with the busiest days for the banking clearinghouse as well. Interestingly, the two clearinghouses became connected and their efficient functioning was mutually beneficial. While the Stock Exchange Clearinghouse would compress the trading of stocks and sustain larger volumes of intraday trading, the London Clearinghouse allowed the compression of monetary settlements. The functional synergies between the two clearing mechanisms meant that a significantly larger number of stock transactions and monetary payments could be accomplished, with only small amounts of stocks and cash actually changing hands. We could understand this as taking drag out of the system, as any offsetting balances (i.e. unnecessary or redundant) would simply be compressed on the books between clearinghouse members without any need for actual settlement. We could thus say that both the banking and the stock clearing house two clearinghouses were becoming more concretized, as previously isolated bilateral transaction could now be integrated through multilateral clearing and compressed. Both the early London Clearinghouse and the London Stock Exchange Clearinghouse were associations of clearing members whose role was to ''direct the delivery and payment for balances of stock'' (Noyes, 1893, p.248), but who had no responsibility for the ultimate settlement of transactions. The clearing algorithm would separate those who had to receive from those who had to deliver and net their offsetting exposures. Efficient as it was, it was ultimately up to the clearing members to participate in the clearing process. As this was a relatively costly operation, clearing members would only participate if the benefits were considerable. For instance, not all of the brokers of the London Stock Exchange participated in the clearinghouse association and even those that participate did not do so for all traded stocks. In fact, as we already noted, financial markets need to reach a certain level of complexity of trading volumes in order to warrant the adoption of more complex and expensive transactional machines.

Across the Atlantic, the Philadelphia Stock Exchange and the Consolidated Exchange pioneered multilateral clearing as early as 1886 and was soon also adopted by the New York Stock Exchange (NYSE). Recent research on the history of the NYSE Clearinghouse has highlighted the positive impact of multilateral clearing in terms of reducing counterparty risk, narrowing bid-ask spreads, netting offsetting exposures and leading to more efficient settlement processes (Reed, 2011). Prior to the introduction of a multilateral clearing mechanism, the NYSE operated bilateral clearing and settlement arrangements. That is to say, for each transaction brokers were obliged to directly exchange (send and receive) checks and shares. In addition to this, NYSE employed a so-called T+1 settlement cycle, which meant that brokers had to settle (deliver the checks and/or shares) by the next day at 2:15 pm (Bernstein et al., 2014). With the increase in the number of transactions, it became difficult to settle all trades by the next day. Therefore it became common practice for banks to extend overnight loans to brokers, in order to allow them to keep up with the pace of transactions. In the context of a financial panic, the overall reduction in credit resulted in substantial brokerage failures. For instance, the panic of 1873 led to the failure of 54 brokers (Bernstein et al., 2014; Eames, 1894). The subsequent financial panics of the late 19th century and the pressure from the New York banks led to the introduction of a multilateral clearing mechanism (McSherry and Berry, 2013; McSherry et al., 2013).

The NYSE clearinghouse started operating on May 16th 1892 and its membership comprised some 340 brokers, clearing just four stocks (Noyes, 1893, p.261). Nevertheless, because of the benefits of compression, it soon became more popular and at the end of the year, membership had reached 427 brokers. According to early accounts, the introduction of multilateral clearing substantially reduced the need for bank loans for up to 65% and also saw substantial reduction in the number of stocks that needed to effectively change hands (Bernstein et al., 2014) (Pratt, 1909). While beneficial for the overall workings of the NYSE, many clerks working in the brokerage houses opposed the new system. This was mainly because the mechanism meant they had nothing to do earlier in the day, but would have to work longer hours to facilitate clearing and settlement, sometimes all night. Despite these difficulties, the advantages of the new system were soon apparent in reducing the actual physical exchange between brokers. Just as monetary payments could not be brought back to a time when transactions were executed with bags of silver and cold coins, the bilateral clearing and settlement of stocks now seemed out-dated and overly cumbersome. Another important aspect of multilateral, was that the identity of the trading parties was not important, as the clearing mechanism was almost an automated computation reducing everybody's exposure (debits or credits) to the clearinghouse:

> (…) the brokers between whom given amounts of stock are to be actually exchanged are named arbitrarily by the clearing-house manager. Any broker having 500 shares of St. Paul to deliver may be directed to deliver it to the broker presenting the above sheet. He may have had no personal transaction with the broker assigned to him; that is a matter of no concern. The clearing-house deals with exchanges, not with bargains - with balances, not with persons (Noyes, 1893, p.264).

In this sense, the NYSE clearinghouse was a complex transaction machine, producing a clear picture of balances and managing the efficient compression of offsetting exposures. As trading volumes increased those brokerage firms, that had offices near the NYSE building and a large contingent of clerks, dominated both the matching and clearing of shares. Moreover, the clearinghouse imposed relatively strict requirements on membership and ''members had to pay 2 1⁄2 cents per each 100 shares cleared'' (Reed, 2011, p.5). Gradually a limited number of clearing members emerged; which would could clear in their own name or for some exchange members who did not want or could not afford to be participate in clearing directly.

Nevertheless, even at the end of the 19th century it was apparent that the next step in the evolution of clearing would be for the clearinghouse to transition from an association directing the clearing of its members to a standalone third party performing centralized clearing on a daily basis. Such a transaction machine could in theory receive trading information from the Stock Exchange and perform clearing, effectively becoming the buyer to every seller and the seller to every buyer. This would effectively act as:

> (…) an imperium in imperio in the Stock Exchange, to which the privilege of admission would be jealously guarded, and the members of which would virtually insure one another (Noyes, 1893, p. 264).

As long as clearing was performed between a limited number of participants who knew and trusted each other, there was no immediate need to establish a utility type institution. Moreover, the thorny issue of centralized clearing of transaction required the development of a new design that could also manage the credit risk of the various clearing members. This is perfectly compatible with our understanding of the evolution of transaction machines. Once a new and more efficient clearing mechanism was developed for bank check payments, it was only a matter of time until it was adopted for other transactions (e.g. stocks and later for derivatives). As we will see, the evolution towards central clearing was painfully slow in the case of stocks but it was much faster in the case of derivatives, where the efficient management of counterparty risk was a much more important issue. The crucial difference was that in the case of derivatives such as futures and options, the risk of a counterparty defaulting was much more acute. Thus, as we will see, derivatives markets will be the first to adopt a more complex centralized clearing mechanisms.

6.3 Clearing Derivatives

Derivatives are a very special type of financial instrument, a contract whose value depends on the future evolution of an underlying asset (commodities, shares, bonds, currencies, interest rates, etc). By using a derivative, one can participate in a certain market without actually owing the underlying asset. A derivative thus offers a superior degree of freedom (optionality), affording exposure to the fluctuations in value of the underlying assets. This optionality relates to the dual function of derivatives, on the one hand hedging against future price fluctuations but also being able to speculate of these future states of the world (Ayache, 2010; Esposito, 2011). While we tend to focus on modern financial derivatives, some of the basic blueprints of these instruments can be traced back to ancient times. Following Edward Swan[54], one could speculate that they are some of the oldest forms of written contracts. Drawing from his account, one could outline the basic building blocks of a derivative contract: ''A usually dated written agreement; a descriptions of the parties; a description of the asset to be transferred; the price of the transaction; the date of performance; a list and description of witnesses'' (Edward Swan, 2000, p.297). To see how old these 'technologies' actually are, it is interesting to mention the 48th law of the Code of Hammurabi from 1750 BC describing a certain type of derivative written on grain as the underlying asset:

> If any one owe a debt for a loan, and a storm prostrates the grain, or the harvest fail, or the grain does not grow for lack of water; in that year he need not give his creditor any grain, he washes his debt-tablet in water and pays no rent for the year (Kumer, 2012, p2).

As some have argued this can be translated as a modern put option, as a way of hedging/insuring against a future event. If the harvest is successful, the option can expire, but if it fails, the owner of the contract can refuse to make any payments. In Mesopotamia, similar contracts could be made for the future delivery of slaves or

[54] Edward Swan has recently produced a comprehensive history of derivatives from Ancient Mesopotamia to the pits of Chicago

sesame seeds from the Indus Valley (Kumer, 2012, p.6). A regular supply of agricultural products was essential for the growing population of ancient Mesopotamian cities, thus the need of forward and option contracts on grain and slaves. Later on, medieval contracts such as the Italian commenda could also be seen as a financial derivative. Antwerp was also a hotbed for financial innovations, were contracts for differences could be written between the spot price and the future delivery price (Kumer, 2012, p.5). Perhaps on the most famous derivatives markets was the Amsterdam futures market for tulips, which lead to the now famous Tulipmania 1636-37 (Fergusson, 2008). For all of Amsterdam and London's sophistication in the realm of finance, it was France that produced one of the first modern treaties on derivatives. Trading in futures and forwards based on government bonds flourished in Paris in the 1820s, a phenomenon that attracted the attention of Proudhon (1857) (Weber, 2008).

Futures and forwards[55] are contracts guaranteeing the delivery of a certain asset at a certain price within a specific time period. Options on the other hand give the buyer the right but not the obligation to deliver the asset at expiration. Derivatives emerged primarily by tracking or offering exposure to price changes in certain commodities (grain, rice, steel, gold, etc.) and for most of history were transacted Over-The-Counter (OTC), that is to say not within a public forum. In this, sense, the development of public exchanges organizing the trading of such financial instruments can be seen as a major event in the history of financial markets. One early example of this was the Dojima Rice Exchange (Moss and Kintgen, 2009). Established in 1730 it was possibly the first public forum for the transaction and clearing of commodity futures. While for most of financial history, derivative contracts were negotiated and handled bilaterally, the Dojima Rice exchange was the first public exchange performing the matching of derivative contracts, particularly forwards and futures on rice warehouse certificates. Interestingly enough, this exchange had all of the characteristics exhibited by modern futures exchange, but emerged a century before any western equivalent (Schaede, 1989).

[55] Futures are simply forward contracts that are traded on an open exchange.

As Ulricke Schaede (1989; 1998) describes it, the Dojima Rice Exchange was the most complex financial institutions of the Togugawa-period Japan and probably in the whole world at that time. The exchange was situated in the commercial district of Osaka, at the centre of rice trade, which the main resource dominating the Japanese economy. Osaka was located at the crossroads of the main roads connecting the West and East of the country, but because transporting rice over land was expensive, the feudal lords built warehouses in Osaka and would transport rice over water (there were 124 such warehouses in 1730). Each feudal warehouse had a manager and a money raiser (accountant) who kept the books and organize rice auctions issuing rice bills. As the feudal lords had expenditures over the whole course of the year, they needed to phase out the income from rice harvests. Consequently, the feudal warehouses would obtain money (silver) from moneychangers in Osaka by giving them rice bills in exchange. Whereas most of Japan was trading rice in small spot markets, Dojima slowly developed a derivatives market through the secondary trading of rice bills. The crucial innovation came when rice bills were written not just on the rice in storage at the warehouse, but on the rice that was yet to be harvested (futures contracts). As volumes of futures contracts increased, there were 110,000 bales of rice outstanding for only 30,000 actual bales of rice in existence (Kumer, 2012, p.9). The Dojima Rice Exchange was thus a matching machine organized around two groups of participants, rice traders and rice brokers (Schaede, 1998). The first group comprising 500 individuals had the privilege of taking part in the rice bill auctions at the warehouse. The second group comprising some 800 individuals could trade bills on the secondary market. The questions of default or credit counterparty risks were solved through a very simple and efficient clearinghouse system. Clearers developed out of the moneychangers who were keeping deposits from rice merchants and exchanging rice bills for money. All participants in the market would entrust the actual settlement of their transactions to the moneychangers. Consequently, the Dojima Rice Exchange had a very complex institutional structure, with specific fixed trading periods between the various traders who were licensed members. Rice was standardized in terms of quality and quantity and all trades had to go through a decentralized clearing system that offered credit lines and protection against default (Norman, 2011). Whereas the Dojima Rice Exchange developed both a trading and clearing machines for rice futures, it was the French port city of Le Havre, which marked the decisive breakthrough in the western world. In 1882, merchants in Le Havre were trading futures contracts on coffee and cotton and the Caisse de Liquidation des Affaires en Marchandises was acting as a clearinghouse for those contracts. Setting an example for all modern clearinghouses, the Caisse would register the counterparties and collect deposit margins as a guarantee for the contracts (Norman, 2011). Le Havre's example was adopted in Paris with its Caisse de Liquidation in 1887 and London's Produce Clearing House in 1888.

While the commodities exchange and clearinghouse of Le Havre received less attention, the grain exchange of Chicago is still credited by many as the birthplace of modern derivatives trading and clearing. As most farmers would try to sell their grain at harvest time, this would lead to large oversupplies in the autumn and major shortages in the spring. Consequently, prices would fall dramatically in the autumn and rise in the spring (CME, 2001). The Chicago Board of Trade (CBOT) emerged in that context as an association of 82 merchants founded in 1848 in order to regulate the grain trade and ensure a smoother supply of grain. In addition to trading the actual commodity, the exchange quickly developed a market for financial instruments deriving their value from the price of grain, namely forwards and futures[56]. The matching mechanism of this market was organized in trading pits in an open-outcry fashion, not that dissimilar from the architecture of NYSE. The CBOT also established a special department in 1858 in order to classify grain into different grades, a necessary step in order to have fungible futures contracts and a standardized futures market (Swan, 2000, p.218). This becomes evident once we imagine the most basic situation involving a future contract comprising, lets say, a producer and a manufacturer. The producer enters a futures contract by agreeing to sell 1 tone of grain in 6 months at $1000. If in 3 months time the price increases to

[56] The ''Board'' as its called, is to this day the oldest futures exchange still in operation, and has merged with the Chicago Mercantile Exchange (the ''Merc'') in 2007 to form the CME Group (Kumer, 2012).

$2000, the producer might want to get out of the contract, because he would stand to make more money if he could sell his grain at the superior price (if the trend continues to go up). The manufacturer might think that this price increase is not going to last, so could agree to enter into another contract. In this second contract the manufacturer agrees to sell the producer 1 tone of grain in 3 months at $1500. Now, if we imagine that the two parties are not really interested in the delivery of grain but are two futures traders, it would be possible to offset the two contracts. This is possible because the contracts are standardized and fungible. The clearing and settlement of these two positions results in a net cash payment of $500 form the producer to the manufacturer or between futures trader A and futures trader B[57].

While the example above is relatively simple, it would not be uncommon for the futures traders to enter into such positions several times over the course of the trading day. If we now extend this example to the market comprising the initial 82 merchants of CBOT, it is easy to expect the sudden development of a complex web of mutual exposures, which would take a long time to clear and settle one by one. It thus becomes essential to develop a mechanism for clearing offsetting positions and reduce the complexity of trading. A step in this direction was taken when on September 23, 1883 when the clearing of transactions became possible through the establishment of a clearinghouse, the Board of Trade Clearing Corporation (BOTCC). The BOTCC would net the obligations of different members and collect margin payments before settling contracts. The initial design performed multilateral clearing by organizing clearing rings, with the exchange and the clearinghouse acting as intermediaries and mediators. In fact, ringing, as a clearing mechanism, was particularly popular in Chicago. Similar to the clearing cycles and chains of medieval fairs, buyers and sellers would form clearing rings, for the purpose of compressing their offsetting positions. Efficiency gains were immediate in the first 9 months, with the actual transfer of just ''76500 cheques compared to 740000 under the old system'' (Norman, 2011, p.64). The only problem with the system was that it was

[57] Approximately 97% of futures contracts are offset and result in a net cash payment, with only 3% resulting in actual physical delivery (CME, 2001).

''only as strong as its weakest link'' and the initial clearinghouse took no responsibility for contract performance. That is to say, even if multilateral clearing reduced the complexity of exposures, there is nothing the guarantee the performance of derivative contracts. In fact, bankruptcies were not unusual and they usually affected large parts of total membership (Norman, 2011).

The ultimate breakthrough in terms of managing this counterparty credit risk came with the adoption of central clearing, when the clearinghouse becomes a Central Counterparty (CCP), effectively a buyer to every seller and the seller to every buyer (Moser, 1998). This threshold was passed when the BOTCC decided to take full responsibility for all contracts, transitioning from multilateral clearing via rings to complete central clearing. On September 3, 1925, the Board established the BOTCC as a CCP, that is to say the only counterparty to all transactions. In the case of any defaults, the BOTCC would take responsibility for the portfolio of the defaulting member. In order to achieve mutualisation, members of the exchange had to purchase shares in the clearinghouse. In the case of a default, if loses exceeded the posted margin and the clearinghouse's own capital, then the rest of the members were obliged to purchase more shares and effectively bail out the clearinghouse (Kroszner, 2006). Coupled with these financial buffers, the BOTCC had an independent governance structure, which allowed it to make decisions in terms of safeguarding the safety of all clearing members. In just a few decades, the BOTCC evolved from multilateral clearing to what was in fact a mutual insurance mechanism, being the sole counterparty and guarantor for every trade. As Moser (1998) has argued, the whole evolution of clearing mechanisms revolves around the need of members to manage the risk of nonperformance of contracts, that is to say to mitigate to counterparty credit risk entailed by the sudden default of one or more clearing members. This last aspect is probably what really distinguishes derivatives from other securities such as shares, namely the higher risk entailed in the management of the lifecycle. It's one thing to agree to a transaction (to get a match) but it's a totally different thing to actually make good on it, to ensure that the trade performs right up to the expiration date of the derivative. One could thus understand derivatives trading as first and foremost an exchange of promises.

Consequently, the clearing of derivatives is essentially the management of the intrinsic contingency of these promises. As Edward Swan understands them, derivatives offer everyone something to trade on, namely their ability to keep a promise:

> Such promises are not manufactured in a factory, grown in a field or mined from the earth. They are created by the human imagination. They are a true and virtually unlimited ''intellectual capital'' (Swan, 2000, p.298).

Perhaps the common understanding of derivatives as contracts that derive their value from an underlying asset is only partially correct. Also partially correct is the understanding of derivatives as instruments of speculation. In the end, any kind of theory or understanding of the value of a derivative contract depends on the ability of the two counterparties to respect and keep their promise. In other words, ''the value of a derivative instrument depends on the ability of the promisor to perform on his promise'' (Swan, 2000, p.298). Another way to understand this is by referring to Elie Ayache's definition of derivatives as contingent claims (Ayache, 2010). While all financial instruments can be understood as promissory agreements, it is the longer horizon and higher leverage entailed by derivative contracts that makes them particularly fragile and contingent in regards to the risk of default. In terms of the research done in the social sciences and humanities on the topic of derivatives, there has been a tendency to look either at the performativity of derivatives pricing models (Mackenzie, 2015b) or the way in which the social structure of the trading pits resisted and responded to technological innovations (Caitlin Zaloom, 2006). What we are suggesting here is that in order for a derivative market to work in the first place, a whole infrastructure needs to be in place that can maintain continuous trading and clearing of transactions. In the previous chapter on exchanges, we have already looked at the importance of matching in maintaining the continuity of financial flows. In the current chapter we have focused on the importance of clearing mechanisms in streamlining this process in the case of bank check payments, shares and futures markets. Different from stocks, derivatives such as futures are more complex financial contracts operating over longer time horizons and the management of their lifecycle requires an equally complex financial infrastructure. It is for this very reason that derivatives markets developed clearing mechanisms almost from the very beginning. Both the Dojima Rice Exchange and the Chicago Board of Trade developed complex risk management arrangements in order to ensure the performance of transactions. In the next section we will take more detailed look at the evolution from bilateral to multilateral and finally to central clearing as well as the gradual transition of clearing from a human-based paper and pencil ‘hardware’ to our present day real time clearing electronic platforms.

6.4 The Evolution of Clearing Machines

Up until this point, we have described the long and complex evolution of clearing machines, from its early beginnings in the medieval fairs to the more complex designs developed in modern financial markets. As long as transactions could be settled on the spot, directly between buyers and sellers, there was no need for a clearing mechanism. But as soon as settlement is not possible immediately, such as in the settlement of bank check payments, or when you have financial products with long-dated maturities, such as futures or options, there is an inevitable accumulation of unsettled balances. There is then an urgent need for a mechanism to untangle the complex web of offsetting exposures and streamline the flow of transactions. With the growth in trading volumes, and particularly in the 20th century with the rise of institutional investors, clearing arrangements were put under increased strain in terms of being able to efficiently process financial flows. In this sense, one can look that evolution of clearing machines as a gradual process of change under the constraints and pressures of the financial community, who required a streamlined and efficient financial infrastructure (Matthews, 1921).

As we have seen, the gradual evolution of clearing includes a multitude of multilateral and central clearing arrangements. In fact, there is an extensive literature dedicated to the diverse landscape of clearing designs (Moser, 1998, Kroszner, 1999). Without being able to rely on substantial historical data, bilateral clearing arrangement has been probably the most simple and widespread clearing solution throughout history. It has survived to this day particularly in the markets for complex Over-the-Counter (OTC) derivatives (Jackson and Manning, 2007, p.3). In fact, Moser references (Emery, 1896) when discussing one of the earliest examples of bilateral (direct) clearing as early as the 1730s, in the context of East India Company forward contracts for certain metals. Other early examples include the settlement of grain contracts at the Buffalo Board of Trade in the 1840s (Moser, 1998, p.12). In the case of bilateral clearing, market participants must compare their positions and agree to net offsetting positions. In the case of derivatives contracts, they also have to request and make collateral/margin payments in order to maintain open positions. As the value of the contract fluctuates between the day of the trade and its expiration date, margin requirements can change on a daily basis. For instance, a long futures contract in a market where the price is going down would lead to higher margin requirements. As long as the market was largely made up of traders who knew each other, bilateral clearing was sufficient but limited to the original counterparties of the trade. As the number of market participants grew, a need arose for more complex clearing arrangements such as multilateral designs, partially driven by the costs of maintaining derivate positions for longer periods of time. As we have seen in the case of medieval clearing fairs, the first operation entailed merchants finding possible bilateral offsets before engaging in more the complex clearing mechanisms, such as clearing cycles and chains. According to Mirowski, it's not really surprising that simpler and less computationally expensive clearing designs would be used more common, as they are easier to implement and maintain. Similar to the situation of the matching function, where posted offer of single-sided designs were more prevalent then the more complex continuous double auctions, clearing arrangements are also subject to a hierarchy based on computational complexity. Bilateral clearing was perfectly adequate to a certain degree of trading complexity, namely when medieval merchant-bankers or modern jobbers/specialists could come together and quickly offset their reciprocal balances. One could argue that for as long as this was the case, there was no real need for more computationally expensive or time consuming arrangements. But with the growth of trading volumes and the subsequent increase in counterparty exposure, more complex clearing machines were possible, affordable and necessary. Thus the adoption of clearing chains/cycles in clearing fairs, the later adoption of clearing arrangements in the case of bank payments (London Clearinghouse), and the transition to ring clearing in the futures markets of Chicago.

Moser (1998) suggest that the migration of multilateral clearing mechanisms started with the banking clearinghouses of London and New York, and was gradually adopted by stock and futures markets. In the context of the Chicago derivatives markets, traders would enter into ring clearing arrangements in order to reduce ''the cost of maintaining open positions'' (Moser, 1998, p.14). Different to bilateral clearing, multilateral clearing mechanisms make individual exposures substitutable, so what it becomes crucial to finding the most efficient compression method. For instance, ringing allowed the traders of Chicago to compress their exposures, thereby reducing the volumes of transaction that actually needed to be settled and reducing the margin required for maintaining non-cleared exposures. As both Moser (1998) and Kroszner (1999) note, ringing affords the ''netting of exposures, but without novation to a common central counterparty'' (Jackson and Manning, 2007, p.3). Moser's research offers an example highlighting both the benefits of multilateral clearing as well as the added complexity of central clearing. He looks at the Chicago ring clearing with four counterparties where ''A sold to B at $1.00; B sold to A at $0.95; C sold to B at $0.97; and D sold to C at $0.93'' (Moser, 1998, p.14). The ring clearing mechanism works by computing one single clearing price, which allows for the compression of all of these exposures. As Moser demonstrates, the correct clearing prices for the ring comprising traders A, B, C and D is $0.93. So while not all trades have been matched at $0.93, the structure of their reciprocal exposures means that they can compress their positions at this price, without modifying their profits or losses. Moreover, instead of keeping multiple positions open, most of which require the posting of margin, each trader arrives at one single net position and reduces its overall costs.

Counterparty	Buy Price	Sell Price	Profit/Loss	Net
A	0.93	**1.00**	0.07	**0.05**
	0.95	0.93	(0.02)	
B	**1.00**	0.93	(0.07)	**(0.09)**
	0.93	**0.95**	0.02	
	0.97	0.93	(0.04)	
C	0.93	**0.97**	0.04	**0.04**
	0.93	0.93	0.00	
D	0.93	**0.93**	0.00	**0.00**

Figure 10: Example of multilateral clearing with rings

Table reconstructed after (Moser, 1998, p.18).

While at the beginning all parties had both long and/or short positions, after the clearing process, A and C have a net profit, B has a net loss, while D is neutral. Perhaps what is most important is that the number of open positions is drastically reduced (in this case to three positions) leading to lower margin requirements for all participants. The benefits of netting offsetting exposures are valid only as long as all counterparties keep their promise so to speak, as any failure within the clearing ring could endanger the solvency of all participants (Moser, 1998, p.28). Efficient as it was in term of netting, multilateral clearing through rings would not allow for a clear picture of the total exposure of participants the risk inherent in their portfolios. While the early modern clearinghouses simply reduced the volumes of actual payments between members by crediting and debiting their accounts, derivatives clearinghouses would eventually need to develop a more complete clearing machine.

As clearinghouses became more and more involved in the market, they also gradually became the effective guarantors of the performance of derivatives contracts (Millo et al., 2005). With the advent of complete central clearing in the context of CCPs, all contracts are extracted from their initial bilateral situation and become part of a complex matrix of substitutable exposures. In addition to being a more efficient mechanism, the central clearing algorithm also represents an increase in complexity. The registration process entails identifying counterparties and their liabilities. The CCP then performs novation, the legal detachment of trade counterparties and the establishment of new contractual relations to the CCP. Next, the CCP performs multilateral netting leading to substantial savings for all participants. This function allows the CCP to net all offsetting positions and replace them with a ‘’single debit/credit between itself and each counterparty’’ (Hasenpusch, 2009, p.24). The figure below reproduces the exposures between traders A,B,C and D but also interposes the clearinghouse/CCP as an additional counterparty. For all counterparties, the clearinghouse takes to opposite side of the trade. So for instance, A sold at $1.00 and bought at $0.95 so the CCP buys from A at $1.00 and sells at $0.95. While A’s initial trades were with different counterparties, now both trades are with the CCP. While in the case of ring clearing, the clearinghouse would perform the netting of exposures but all payments would be done bilaterally between the counterparties, in the case of central clearing all payments are process by the CCP. Consequently, A has to receive 0.05 from the CCP, B has to pay 0.09 to the CCP, and again C has to receive 0.04 from the CCP. In this example, the CCP simply receives payment from B and transmits it further to A and C, with counterparty D being neutral.

	Buy Price	Sell Price	Profit /Loss	Net	Buy Price	Sell Price	Profit /Loss	Net
A	0.93	**1.00**	0.07	**0.05**	**1.00**	0.93	(0.07)	
	0.95	0.93	(0.02)		0.93	**0.95**	0.02	**(0.05)**
B	**1.00**	0.93	(0.07)	**(0.09)**	0.93	**1.00**	0.07	
	0.93	**0.95**	0.02		**0.95**	0.93	(0.02)	
	0.97	0.93	(0.04)		0.93	**0.97**	0.04	**0.09**
C	0.93	**0.97**	0.04	**0.04**	**0.97**	0.93	(0.04)	
	0.93	0.93	0.00		0.93	**0.93**	0.00	**(0.04)**
D	0.93	**0.93**	0.00	**0.00**	**0.93**	0.93	0.00	

Figure 11: Example of central clearing with CCP

Table reconstructed after (Moser, 1998, p.32).

This complete integration allows the netting of offsetting exposures leading to substantial capital efficiencies and lower margin requirements, crucial in the context of clearing large volumes of more and more complex exposures. In addition to that, the CCP is also the legal guarantor of all contracts, and takes responsibility for contract performance (Jackson and Manning, 2007, p.3)**.** While the first modern clearinghouses only performed a ''contingent integration'', CCPs allowed for permanent integration and full mutualisation of counterparty risk (Kroszner, 1999). So while bank check clearing simply facilitated and increased the efficiency of payments, CCPs become legal parties to all trades, the buyer to every seller and the seller to every buyer. Moreover, CCPs developed various methods and safeguards in order to mitigate credit risk such as: strict membership requirements, default funds, mutualisation of losses and margin payments in order to collateralize transactions (Moskow, 2006, p.47).

Margin payments (initial and variation) were perhaps the most important safety mechanism of central clearing, a complex process of measurement, calculation and risk management. Initial margins were designed as a basic firewall, which protects the CCP against normal market movements and risk of non-performance

(Hasenpush, 2009, p.29). Variation margin was a further layer of protection that is called upon when the market value of derivatives position change (Valiante, 2010). Because of this, the CCP bears no market risk itself, only credit risk and as the value or open positions changes over time, this market risk is transmitted to the counterparties of the contract through periodic adjustments in the level of variation margin. So while the CCP is market neutral, it takes full responsibility for credit risk, thus transferring the monitoring responsibility from market participants to a centralized institution (Bliss and Steigerwald, 2006, p.24). In this sense, the CCP has a crucial role to play in promoting market liquidity by ensuring that trades as performed as quickly and as cheaply as possible (Bernanke, 1990, p.140).

Therefore, the complete clearing performed by CCPs can be seen as the most recent evolution of clearing machines. The table below outlines a sketch for an evolutionary trajectory beginning with bilateral clearing (or direct clearing), multilateral clearing (medieval clearing chains and cycles or modern clearing rings) and central clearing (or complete clearing as it is called in the context of CCPs):

<table>
<tr><th colspan="2">Components</th><th>Algorithms</th></tr>
<tr><td rowspan="2">Bills of Exchange</td><td rowspan="2">Merchants-Bankers
Clearing fairs</td><td>Bilateral clearing
(direct clearing)</td></tr>
<tr><td>Multilateral clearing
(clearing chains and cycles)</td></tr>
<tr><td rowspan="2">Payments
Shares
Futures</td><td rowspan="2">Clearinghouses
CCPs</td><td>Multilateral clearing
(clearing rings)</td></tr>
<tr><td>Centralized clearing
(complete clearing)</td></tr>
</table>

Figure 12: Evolution of centralized clearing machines

We have already seen a similar trajectory for matching machines (from bilateral to multilateral and centralized designs), were there was a clear evolutionary trajectory from posted-offer to single-sided and then continuous double auctions. Similar to that, each new generation of clearing machines represent an increase in complexity as well as being more difficult to implement and maintain:

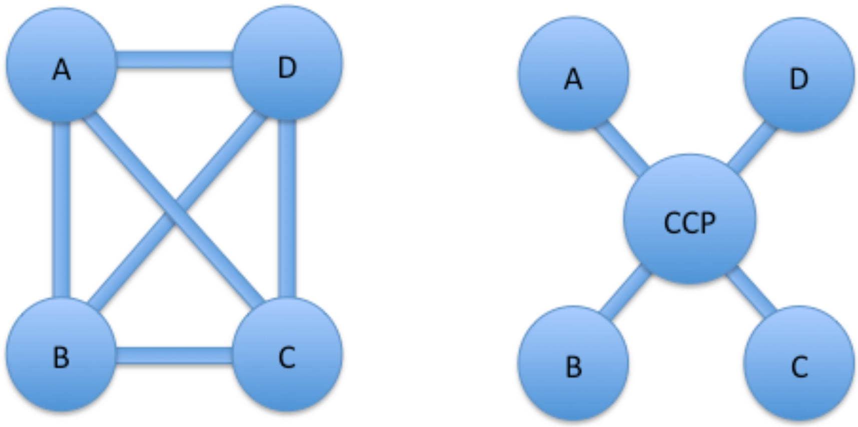

Figure 13: Difference between bilateral and central clearing with CCP

For instance, in the case of simple bilateral clearing, the operation consists basically of comparing two sets of books, a relatively simple machine from a computational point of view. Going back to the example of the London Clearing House, one bank clerk would go one by one to the other clerks and submit his charges. Going up the ladder of complexity, a derivatives clearing machine would have to incorporate the fact that positions are not settled on the spot. As we have seen with multilateral clearing through rings, extra memory capacity would be needed in order to keep track of current, future and settlement prices, as well as accounting for the larger number of ring participants. Things get even more complicated with central clearing, which would have to be modelled as formal automata with a larger number of memory stacks, as it would have to incorporate margin payments, price volatility, credit ratings, offsets between correlated assets, etc.

Each new machine is composed of more elements than the previous one, having to process larger volumes of increasingly more complex financial products. Following Mirowski, each new generation can simulate the functioning of the previous ones, but the opposite is not true. That is to say, the clearing machine of CCPs can easily perform bilateral and multilateral clearing, but it also introduces additional capacities, namely novation, guaranteeing the performance of all contracts and managing the credit counterparty risk of market participants. Evolution occurs under the constraints of the financial community, such as the need of market participants for more efficient netting, lower margin requirements and the increase in risks entailed by clearing more complex and less liquid products. So far, we have described the evolution of clearing in terms of the process and procedures, i.e. the overall clearing mechanism and algorithms. But the same constraints have also led to the gradual reduction of the human element within the clearing process and the move towards more automated systems. In the next section, we will focus on this gradual transition from human dominated pen and pencil ‘hardware’ to modern day real time electronic clearing platforms.

6.5 Clearing with Computers

We have so far looked the evolution of clearing in terms of their specific algorithmic design and their gradual adoption across different financial markets. At this point, it would be useful to understand the evolution of clearing machines more broadly. That is to say, we will look at how they became more automated, similar to a certain extent to the parallel evolution of matching machines. Ben Bernanke has addressed the technological aspects of clearing in his analysis of the performance of US clearinghouses during the 1987 crash. In that context, there were several technological issues with the clearing infrastructure as the volume of trades ''clogged the system'' and affected trade completion and payments (Bernanke, 1990, p.143). These problems had the potential to further aggravate the overall crash, as financial institutions were not certain of their own financial health or that of their counterparties. His work highlights the importance of the clearing infrastructure for the smooth functioning of markets as well as its systemic importance. In fact, as we have seen, clearing machines have always performed a crucial function in terms of managing financial flows. With the growth of financial markets and the need to clear more complex products, there has also been a continuous pressure towards higher levels of automation and efficiency in terms of managing the transaction lifecycle.

Charles Babbage was intrigued by the complexity and efficiency of the operations of London Clearing House, characterizing it as a well-designed machine. His fascination with clearing is described in a little known text dating back to the 1830s, *On the Economy of Machinery and Manufactures* (Babbage, 1833), where he dedicates a whole chapter to the clearinghouse, called *Of Money as a Medium of Exchange*. In fact, as Yuval Millo has recently argued, Babbage's description of the London Clearing House is surprisingly similar to the architecture of modern computers:

> It is striking how the structure of the Bankers Clearing House, as described by Babbage, resonates with modern computer architecture: input and output, some kind of memory (the clerks, books), and a proto-CPU organised around the inspector (Millo et al., 2005, p.235)

His account has influenced historical research, such as some of the work done on the history of information processing. For instance, in Campbell-Kelly's account, computation in the Victorian period is seen as being performed by a pen and paper infrastructure (Campbell-Kelly, 2010). Drawing from Babbage, he applies this perspective to a different clearing mechanism, namely the 19th century Railway Clearinghouse, a human-based computing machine processing the distribution of railway receipts (some 3423 clerks by 1921). Looking at clearinghouses as complex technical systems is thus nothing new. For instance, in 1921 Robert Holland-Martin, then Chairman of the Committee of London Clearing Bankers, describes the functioning of the London Clearinghouse as a complex ''machinery''. He went even further and imagined a system that could connect the clearing banks to the clearinghouse by:

> long pneumatic tubes that will bring the cheques straight from the banks to the Clearing House, without the perils of the road and the interruptions of the Lord Mayor's Show (Matthews, 1921)

The subsequent evolution of clearing would not lead to any designs based on pneumatic tubes but as with all other market functions, it revolved around the adoption of electronic and information technology. In his 2011 book, *The Risk Controllers: Central Counterparty Clearing in Globalised Financial Markets* (2011), Peter Norman has offered a detailed account of the technological and institutional evolution of clearinghouses. As he describes it, the first technological displacement did not originate from electronics but from mechanical technology, the so-called Burroughs adding machines. The clerk-dominated pen and pencil 'hardware' of the London Clearing House incorporated Burroughs adding machines in 1902, substantially improving its processing capacity (Matthews, 1921). Even if in some cases the clerks reached impressive levels of performance (apparently up to 1200 cheques in an hour), the clearing machine could not keep up with the increase in volumes of cheques that had to be cleared. While simple calculation machines increased the efficiency of human clerks, it was the introduction of the computer that would change the operational architecture of clearing. One of the first instances of this was the London Produce Clearing House (LPCH), which became the International Commodities Clearing House (ICCH) in 1973 (Norman, 2011, p.114). LPCH was a very innovative institution as it took the path of computerization as early as 1963. The first automated system was based on a punch card computer used for clerical and accounting operations assisting with the registration and processing of contracts. A further innovation came in 1965 when the punch card system was upgraded to one using a magnetic tape. The efficiency gains were substantial at a time when clearing volumes increased 20 times during the 1960s (Rees et al., 1972).

The 20th century saw a similar trajectory for the derivatives markets of Chicago. From the 1920s on, the BOTCC showed great resilience surviving the volatile period of the Great Depression and WW2 when volumes fell from 9 million in 1929 to 1.9 million in 1943 (Norman, 2011). After WW2, the increase in volumes led to a growing strain on the operations of the BOTCC, which resulted in the purchase of a computer in 1963. According to Peter Norman, the impact of computers was significant as the cost per trade fell from 25¢ in 1941 to only 5¢ in 1963. Automation was thus extended across the CBOT from trade entry and matching to the clearing and settlement of contracts. The introduction of the Transaction Accounting and Bookkeeping Service (TABS) further increased the efficiency of calculating member position. Another decisive step was taken with the development of a paperless clearing operation, the Online Transaction Information System (OTIS), which went live in 1981. OTIS constituted a streamlined and continuous trade processing and information management system. According to Norman (2011), the BOTCC saw other important technical innovation in the 1980s, such as the Trade Entry and Matching Service (TEAM) and the Shared Market Information Systems (SHAMIS). Together they allowed for a single point of entry for multiple exchanges and for the monitoring of clearing members across different trading venues.

As clearinghouses embarked on the path towards automation it became increasingly important to be able to evaluate the impact of market events on the portfolios of clearing members. This becomes evident when one considers that the core function of modern CCPs is one of risk management, calculating initial and variation margins and managing the credit risk of its clearing members. The most recent innovation in terms of developing an automated risk managing systems for clearing was the development of the Standard Portfolio Analysis of Risk (SPAN) system by the Chicago Mercantile Exchange in 1988. It represented a breakthrough in terms of calculating margin requirements based on the likely impact of market prices on the portfolio of clearing members. Rather than just focusing on a sole trade, SPAN looks at the overall picture, the total exposure of certain portfolio and number of possible market scenarios (Millo et al., 2005, p240). SPAN's input is the actual portfolio of the clearing member as well as the latest prices for the relevant derivatives contracts. The output is the most likely daily loss of a clearing member's portfolio (Value at Risk methodology), which is used to calculate margin requirements for their portfolios. At the centre of all of this is the so-called risk array, which is a model of how a certain contract can change in value under certain scenarios. The SPAN algorithm requires a certain number of parameters, historic price ranges, historic volatility, the delivery period, etc. Because of this, Yuval Millo has argued that in fact, central clearing in the case of derivatives becomes a more and more computationally complex process, as the CCP ends up monitoring the whole market in order to manage the counterparty risk of its members (Millo et al., 2006, p.241).

To this day, SPAN is very much an industry standard particularly in terms of the clearing of futures and options, which has led to the development of a variety of software solutions. But what is even more interesting is the recent integration of SPAN type algorithms into more complex real time clearing systems, such as the ones developed by Cinnober, a Swedish financial technology company. The TRADExpress platform was specifically developed by Cinnober in order to clear and manage the risk of contemporary financial transactions in real time with very small latencies (Christensen and McPartland, 2011). The architecture of the TRADExpress platform is highly adaptable and has been implemented in a variety of market places, such as the London Metal Exchange (LME) Clearinghouse, the Brazilian Stock Exchange, the Dubai Gold & Commodities Exchange and the Johannesburg Stock Exchange (JSE). This is a highly complex clearing system allowing for real time risk management across the trade lifecycle. More specifically the systems takes inputs at pre-order stage (validating orders before the enter the order book), pre-trade (validating an order before it is executed) and post-trade margining and portfolio validations (using a variety of risk algorithms such as the CME SPAN method outlined above). The system is also highly scalable, allowing for cross-asset clearing and can ''handle millions of trades per day with thousands of trades per second for a single instrument, and still be able to disseminate position updates and risk calculations within microseconds''. In many ways, Babbage's early idea that the clearinghouse itself can be seen as a giant computation machine has taken shape with the recent development of automated real-time clearing systems, providing the market with efficient margining, real-time netting and complex risk management, while processing ever-larger volumes of transactions. Consequently the whole clearing ecosystem is gradually moving away from the more ''inefficient and error-prone workflows that require a tremendous amount of manual intervention'' (Christensen and McPartland, 2011) to fully automated clearing. What would have taken hundreds of thousands of human clerks to compute can now be done by these highly advanced real time clearing machines. As with our earlier discussion of the matching function, the question is not one of choosing between humans and machines. Humans (quants, risk analysts, IT engineers etc.) are still very much involved in clearing but they are largely maintainers and designers of these electronic systems. In many ways, this can be seen as the alignment of the clearing function with the technological revolution already at hand in the case of the matching function where electronic /algorithmic trading is very much an established norm.

Conclusions

In this chapter we described the modern evolution of multilateral and centralized clearing. First, we focused on the banking clearinghouses as they developed in London and New York. As with the clearing mechanism of the medieval fairs, the main benefit of multilateral clearing consisted in the reduction of the actual amount of money used for settling transaction. In this sense, the London Clearinghouse can be seen as more complex clearing machine affording the netting of offsetting balances between member banks. Due to its success in the bank check payment systems, the clearing mechanism slowly migrated to stock markets. In London, the Stock Exchange Clearinghouse emerged as a solution for reducing the number of settlements by moving from separate bilateral arrangements to having one single settlement with all counterparties. Later on, the New York Stock Exchange Clearinghouse organized and directed all participants towards an efficient compression of transaction volumes. As long as clearing was only performed between a limited number of participants who knew and trusted each other, there was no pressure to transition from multilateral designs to centralized clearing.

The evolution towards central clearing first occurred in the world of financial derivatives such as futures and options on commodities. This is because credit counterparty risk is more important in the case of derivatives, where both leverage and default risk are issues of major concern. The Chicago Board of Trade (CBOT) founded in 1848 was one of the first modern derivatives exchanges. The expansion of trading in futures and options meant that managing credit counterparty risk became a crucial aspect of ensuring market stability. In 1883, the Board established the Board of Trade Clearing Corporation (BOTCC) performing multilateral clearing. The initial clearinghouse mechanism comprised multilateral clearing through rings, with the clearinghouse acting as intermediary and mediator. The BOTCC becomes a CCP in 1925 when the Board established the BOTCC as the only counterparty to all transactions, that is to say the buyer to every seller and the seller to every buyer.

Components		**Algorithms**
Bills of Exchange	Merchants-Bankers Clearing fairs	Bilateral clearing (direct clearing)
		Multilateral clearing (clearing chains and cycles)
Payments Shares Futures	Clearinghouses CCPs	Multilateral clearing (clearing rings)
		Centralized clearing (complete clearing)

Figure 14: Evolution of clearing machines

The table above provides a sketch for an evolutionary trajectory from bilateral clearing (or direct clearing) to multilateral clearing (medieval clearing chains/cycles or modern clearing rings) and central clearing (or complete clearing with CCPs). Each new generation of clearing machines represents an increase in complexity as well as being more difficult to maintain and more computationally expensive. For instance, the growing complexity of clearing machines was highlighted in our analysis of CCPs, who perform novation, multilateral netting and risk management.

In as much as clearing is subject to economies of scale, we have also looked at the increase in automation across the clearing workflow, from trade management to margining and risk management. This is particularly relevant in the context of more complex risk management algorithms such as SPAN, or more recently with the development of electronic real-time clearing systems. Processes that in the 19^{th} century necessitated small armies of clerks (Campbell-Kelly, 1998) taking days and weeks to accomplish, can now be done in real time by automated clearing systems. That is to say, clearing exhibits the same tendency as matching, namely the relentless move towards automation and the transition from human-based pen and pencil 'hardware' to electronic systems.

PART III: CONTEMPORARY TRANSACTION MACHINES

Chapter 7. Matching in the Age of High Frequency Trading

Summary:

This chapter continues to track the evolution of matching machines. In the previous chapter on modern stock exchanges, we focused on the transition of the order matching function from the control of human specialists/jobbers to electronic orders books and matching engines. The current chapter focuses on the other function performed by the human specialists, namely liquidity provision or market making. To this aim, we analyze the current state of electronic market making and the emergence of High Frequency Trading (HFT). We begin by describing the contemporary structure of the US stock markets, comprising both the established exchanges (NYSE, NASDAQ) and also alternative trading platforms such as ECNs and darkpools. Within this complex network of trading venues, HFT trading firms are at the forefront of an arms race for higher speeds, lower latency and more advanced algorithms. We review some of the more interesting controversies surrounding HFTs, particularly in terms of how they exploit the complexity of the current market structure. In the context of contemporary electronic markets, the privilege of making markets and facilitating matching becomes a question of who has better algorithms and faster execution. Therefore, being at the centre of liquidity and controlling the matching of order flow affords a crucial advantage in any market as well as substantial profits. We also offer an understanding the 2010 Flash Crash. We leverage Doyne Farmer's ecological perspective, the work of Andy Haldane on financial stability and Mirowski's theory of markomata, in arguing that while HFT firms are not directly to blame for the Flash Crash, such events might be a normal output of HFT-dominated financial markets. While contemporary matching machines have reached high levels of efficiency and immediacy of execution, there are important concerns regarding market stability. We also review some of the current reform initiatives and new market designs and interpret them as a shift from a focus on immediacy of execution to other issues, such as the quality of liquidity and overall market resilience.

7.1 Algorithmic Ecosystem and Electronic Matching

As we have seen, computer assisted trading was just the beginning of a gradual transition towards higher levels of automation. The second part of the 20th century saw a series of technological and regulatory innovations that led to the emergence of new trading platforms, new electronic liquidity suppliers but also new types of matching machines. Within this context, human individuals are less involved in the actual process of matching trades and begin to perform other functions, such as designing market structures, building data centres, programing matching algorithms, etc. The skills of a specialist on the floor of the NYSE were much more about the ability to handle information exchange in the intense environment of the trading floor (Zaloom, 2006). For this reason, market makers were quite vocal, well built and relatively adversarial. But with the advent of electronic trading it became clear that one doesn't necessarily need the noisy interaction and the jostling of the trading floor, just to be able to match incoming order flow. In many ways, the first attempts at building electronic trading platforms put into question our basic understanding of what is an exchange. That is to say, is the exchange a community of human individuals performing some sort of exoteric computation or is in fact a well-defined formal algorithm for matching buys and sells. To say that buy and sell orders meet in the market is one thing, but the devil is in the details because what is at stake is where exactly do they met, at what time, in what order of arrival and according to which set of rules (algorithm). As we have seen with AZX, Instinet, Island and Globex, the noisy interaction on the floor of the exchange was ultimately formalized and translated into a set procedures performed by computers. For more clarity, is worth giving a brief example of such an order book and its matching algorithm:

Quote	TIME	QUANTITY	BID/OFFER	QUANTITY	TIME	Quote
			100.30	300	12:05	SELL
			100.30	100	12:02	SELL
			100.25	100	12:04	SELL
BUY	12:08	200	100.20			
BUY	12:07	100	100.15			
BUY	12:10	200	100.15			

Figure 15: Example of electronic order book I

The figure above represents a limit order book, running a continuous double auction matching algorithm, where the various orders are organized according to Price/Time priority (first according to price and then according to the time at which they were submitted). Also know as FIFO[58], this particular algorithm gives priority to the lowest sell order and the highest buy order. Now, if someone where to submit a new buy order or 300 shares at 100.40, then the order book would look like this:

Quote	TIME	QUANTITY	BID/OFFER	QUANTITY	TIME	Quote
			100.30	200	12:05	SELL
BUY	12:08	200	100.20			
BUY	12:07	100	100.15			
BUY	12:10	200	100.15			

Figure 16: Example of electronic order book II

The first order to be filled will be the 100 shares at 100.25 (time 12:04), then the next 100 shares at 100.30 (time 12:02) and finally another 100 shares at 100.30 from the third sell order (time 12:05). This leaves the remaining 200 shares at 100.30 in the order book still to be filled. If on the contrary someone were to submit a sell order of say 400 shares at 100.10, the order book would change to this:

Quote	TIME	QUANTITY	BID/OFFER	QUANTITY	TIME	Quote
			100.30	300	12:05	SELL
			100.30	100	12:02	SELL
			100.25	100	12:04	SELL
BUY	12:10	100	100.15			

Figure 17: Example of electronic order book III

Again, because of price priority the first order to be filled is 200 shares at 100.20 (time: 12:08) followed by 100 shares at 100.15 (time 12:07) and finally the third order with 100 shares at 100.15 (time 12:10); leaving another 100 shares of that order still in the order book. This has been a simple example of what happens in an electronic order book in the context of a continuous two-sided market. Once the

[58] FIFO is one of the many matching algorithms employed by the Chicago Mercantile Exchange (CME), other being Allocation, Pro-Rata, threshold Pro-Rata, etc. http://web.archive.org/web/20120626161034/http://www.cmegroup.com/confluence/display/EPICSANDBOX/Match+Algorithms

basic operations and process performed by the floor specialist where formalized as specific set of rules and procedures, it opened up the possibility of experimenting with many different market structures. As we have seen, the early ECNs all had different approaches and designs and different ideas about a market should do.

In many ways, the diversity of matching algorithms is dwarfed by the even greater diversity of trading algorithms that support the wider financial markets. Recent work (Gyurko, 2011) offers a broad description of different algorithmic classes including matching, systematic, high frequency, low-latency, market making, etc. Electronic trading is more of an umbrella term, designating all forms of trading in which the transmission of orders is done electronically as opposed to phone, mail or face to face. Algorithmic trading is a subset of electronic trading and in entails a higher degree of automation both of execution and decision-making (Aldridge, 2010). Low-latency refers to the fastest possible execution and routing of orders, irrespective of trading volume or frequency of trading. This usually entails colocation in an exchange data center. High frequency refers to capability to make and cancel large numbers of orders in short time intervals. There are also systematic algorithms that perform market making functions or exchange algorithms that handle order routing and matching (as the FIFO algorithm described above).

Contemporary markets are organized around a certain number of trading venues and their matching algorithms. But the great majority of trading algorithms are execution algorithms handling the order flow of market participants. If it was possible to automate the matching of order flows, it became apparent that submission of orders was even easier to automate. In his now famous book *Nerds on Wall Street* (2009), David Leinweber goes to great lengths to describe the history of what he calls the ''robot phase transition''. He begins with his own experience in the 1980s, when trading desks were still dominated by humans operating computer screens (Leinweber, 2009, p.188). The basic function of those computer screens was not that different from the old stock tickers, namely the dissemination of price data. Moreover, the PC revolution allowed for the adoption of systems capable of higher-level computation, like displaying a graph, etc. In 1987, Leinweber and Dale Prouty founded Integrated Analytics and developed an expert system tool for trading called

MarketMind. The crucial aspect of the system was that it could keep up with high-speed incoming market data in real time and make trading recommendations based on the data (Leinweber, 2009, p.161). In many ways, this could be as seen as one of the starting points of electronic trading, namely traders could make and execute trading decisions with the assistance of computers.

The great benefit of execution algorithms is that they can efficiently partition orders so as to reduce market impact, which has always been a major concern for market participants. Transparency is at the core of this problem, as too much of it can attract front running and not enough can scare possible counterparties away (i.e. fading liquidity). Large block trades would be particularly vulnerable to front-running, as well informed traders would buy or sell in front of them, thus raising the cost of trading. Fading liquidity also relates to this point, as limit orders need to be constantly updated as a large trade comes in, or face getting hit on the way down. As soon as the market becomes aware of a large order it becomes very difficult to fill it at a low cost. Traditionally, institutional investors who wanted to execute large block trades would try and establish close relationships with the brokers and specialists on the floor, whose skill was essential in minimizing market impact, and achieve a good average price. The pressure to reduce market impact has driven the development of more advanced execution algorithms. For example, volume-weighted average price (VWAP) algorithms employ complex randomization functions optimizing the size and execution times. There are other execution algorithms based on measuring the success of the trade: time-weighted average price (TWAP), implementation shortfall or arrival price, volume participation, smart routing methods, etc. (Kim, 2007, p.10). In any case, the degree of their success depends on their capacity to stay under the radar so to speak, that is to say to create as little noise as possible. Advanced versions are able to cover their tracks, by introducing certain levels of randomness, even temporarily buying back the stock that they are actually trying to sell (Kim, 2007, p.13). Dark pools are another adaptation, as they are trading platforms offering a 'safe heaven' for large institutional orders. Dark pools don't have pre-trade transparency, thus reducing the advantages of well-informed traders, which allows the large institutional orders to get a better average price than on a fully transparent exchange (Angel et al., 2010, p.35). The dark pool's capacity to reduce price impact is done through uncertainty/anonymity about the actual execution of trades. As they do not provide any open price discovery process, they have to use certain reference prices from primary lit exchanges, similar to early ECN crossing networks (Gyurko, 2011). As we will see later, we can understand the advent of dark pools as an adaptation to new so-called 'predatory' strategies, often attributed to High-Frequency Trading (HFT) practices (Mittal, 2008; Kratz and Schöneborn, 2014).

In any case, it is clear that contemporary financial markets, particularly US stock markets, are best understood as a complex web of interacting algorithms dispersed across large number of trading venues housing electronic order books (either dark or lit)[59]. Within this complex ecosystem, trading algorithms and strategies continually evolve responding to technological innovation and regulatory change (Leinweber, 2009, p.70). In this context, the algorithmic/electronic ecosystem is in some ways an arms race in which human traders have transferred the ''heavy lifting'' to computers. But more precisely, it is the transition to a situation where both the transactional infrastructure of the market and market participants themselves are based on increasingly sophisticated algorithms.

[59] Exchanges such as NYSE, NASDAQ, BATS afford trading and listing of new stocks. In addition to that, there are as many as 50 dark pools in the US, operated either by exchanges, agency brokers (Instinet, Liquidnet), broker dealers (Goldman Sachs, Credit Suisse, Morgan Stanley, Barclays, etc.) or market makers (KGC).

7.2 High Frequency Trading

The general accepted view is that the move towards electronic trading has revolutionized the stock market. The advent of electronic order books has reduced bid-ask spreads, decreased volatility and added to market depth (Brogaard, 2010; Hendershott et al., 2010; Brogaard, 2011; Benos and Sagade, 2012; Hasbrouck and Saar, 2012). With the advent of ECNs and electronic trading, the order matching functions was transferred from the hands of human specialists to electronic order books and their matching algorithms. Trading venues and exchanges can offer electronic order books and matching engines that can cross incoming orders, but how do these orders reach the trading venue. It is important to understand that the exchanges' electronic order books do not post bids and offers, as their role is only to facilitate trading. This begs the question about the other functions performed by the human specialists on the floor, namely market making. That is to say, who provides continuous access to liquidity in the context of electronic trading? Who can post bids and offers in all stocks so as to maintain a fair and orderly market? While matching different incoming orders is an important functionality, how does one attract and aggregate orders in the first place. How does a certain trading venue become appealing to all sorts of market participants, and becomes a conduit of order flow? It is worth going back to our previous example of an electronic order book. In that case the lowest sell quote was 100.25 and the highest buy quote was 100.20. In such as situation, nothing happens, matching is not possible and the market is effectively not functioning.

Quote	TIME	QUANTITY	BID/OFFER	QUANTITY	TIME	Quote
			100.30	300	12:05	SELL
			100.30	100	12:02	SELL
			100.25	100	12:04	SELL
BUY	12:08	200	100.20			
BUY	12:07	100	100.15			
BUY	12:10	200	100.15			

Figure 18: Example of electronic order book IV

If the market is liquid enough, it is likely that a superior buy or an inferior sell order will be submitted and a match will be eventually executed, as we showed in our previous examples. But if the market is not liquid enough, then it can take some time for an order to arrive that match either BUY 100.20 or SELL 100.25. The central question here is who provides continuous liquidity and effectively makes the market. While many investors may trade several times per day or per hour, depending on their overall strategies, any liquid venue requires a number of participants who perform market making, that is to say posting buy and sell quotes throughout the day. In order to have a liquid market, it is particularly useful to have a market participant that can step in and take both sides of the trade. This is precisely what the specialists did on the floor of the NYSE or the jobbers in the case of the LSE. That is to say, in addition to matching, they provided liquidity and effectively made markets.

In this sense, an important aspect of the new market structure of electronic trading is that competing venues need to attract a critical mass of trading firms in order to maintain deep and liquid markets. One way to achieve this is to have designated market makers, such as the case of the NYSE. Another way is to offer rebates to anyone who posts liquidity and charge anyone who removed liquidity. This led to the development of electronic market making strategies performed by particular trading firms who would post bids and offers and get rewarded by the trading platform for providing continuous liquidity. Moreover, trading platforms mostly compete terms of providing tighter spreads between bids and offers. As these spreads are largely the result of the activity of market making firms, it was useful to create an almost frictionless environment for them to operate in. This meant that trading venues had to offer certain advantages to market makers, effectively becoming a privileged group not unlike the old specialists on the exchange floor. Some of the advantages offered to market making firms include colocation and ultra low latency connectivity[60]. Moreover, in todays' market structure any market maker requires

[60] Market making firms need to have their servers as close as possible to the matching engines of the exchange. This has led to question of fairness and equal

near real-time access to the actual raw data feed of the exchange. The ability to quickly aggregate and process trading data from multiple venues is absolutely necessary in order to quickly adapt to changing market conditions. Market participants performing electronic market making include the traditional designated market makers such as brokers and broker dealers (investment banks) as well as new entrants such as Getco or Knight Capital. These designated market makers, particularly the broker dealers built large trade execution businesses facilitating market access to a diverse set of clients (institutional and retail investors, high-net worth individuals, etc.). Competition between large investment banks consequently led to the development of services such as Ultra-Low Latency Direct Market Access (ULLDMA) allowing almost frictionless access to a variety trading venues to anyone willing to pay for it (Dacorogna, 2001). Technical innovations such as electronic order books, algorithmic trading and ULLDMA, as well as the fragmentation of liquidity across many competing venues means that designated market makers are not the only market participants who can perform electronic market makers. In fact, the conditions described above have led emergence of new market participants who could also thrive in this new electronic trading ecology.

It might be worth going back to our earlier example of the electronic order book with BUY 100.20 and SELL 100.25. We previously suggested that these might be separate orders pertaining to different investors. But in contemporary markets it is more plausible to think that both of these quotes are posted by an electronic market maker, hoping to gain the spread (0.05) between buying and 100.20 and selling at 100.25. In this situation any incoming buy or sell order at those levels will get immediate execution. But even more important is that any executed trade will impact the subsequent evolution of the market makers quotes. If for instance someone other investor sends a buy order for 100.25 it will execute against the market maker’s 100.25 sell quote. Immediately after that, the market making algorithm would have to cancel his 100.20 and post a new set of quotes such as 100.26 /100.27. If on the contrary someone sends a sell order for 100.20, then this

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access, which in turn led the exchanges to provide the same cable length to all members.

will execute and the market making algorithm would again cancel his older quotes and could post new ones at 100.19/100.24. If there are more buyers, the market making algorithm will increase its quotes and if there are more sellers it will decrease them. That is to say, these algorithms adapt to incoming orders and adjust their quotes similarly to the human specialist on the floor of the exchange. This however means that for each executed quote the algorithm has to cancel the opposite quote, which has become outdated. The situation becomes more complicated when you have a fragmented market operating a number of exchanges and alternative trading platforms. Let say an algorithm performs market making in specific stock across 10 different venues. This means that, lets say, for every executed buy quote it will have to cancel 10 sells and the remaining 9 buys, which amounts to 94.74% order to trade ratio (you only execute 5.26% or your quotes). This high turnover of posted and canceled quotes is generally refers to as High Frequency Trading (HFT).

HFT is thus a subset of electronic/algorithmic trading broadly referring to trading strategies with super-fast optimized execution and high turnover of trades in short periods of time. As of 2011, the Commodity Futures Trading Commission (CFTC) has provided a provisional definition of HFT algorithmic strategies based on certain criteria including: very high speed of submission and cancelation of orders, high degree of automation in terms of decision making, use of co-location and low-latency access to exchanges, high order to trade ratio[61], no overnight positions and short time horizon (CFTC, 2011). What is important is to understand that HFT algorithms combine both very sophisticated methods for generating trading signals and highly optimized execution in order to profit from the fragmented architecture of US stock markets. Moreover, different from the larger and well-capitalized market makers such as the investment banking broker dealers, HFT relies on very small returns per trade and requires high volumes of trading and usually no overnight positions. Because such firms have a small capital base, they cannot carry overnight market risk so they have to be able to enter and exit the market very easily. As long

[61] Refers to the fact that a high percentage of trades are actually cancelled before they are executed.

as there is fragmentation in the market, HFT firms can access a variety of liquidity pools and alter their position at lightning speeds, which also leads to the very large number of trade volumes attributed to HFT. As of 2010, HFT makes up 70% of consolidated volume in the US, 40% in Europe and up to 77% in the UK, according to research by TABB Group (Zhang and Baden Powell, 2011)(Angel et al., 2010).

The transition from human-based matching machines to the low-latency electronic ecology of today has attracted a lot of public attention. One of the reasons has to do with the differences between the humans and contemporary trading systems. A chess grandmaster who needs 650 milliseconds just to realize he is in trouble (Johnson et al., 2012), which can be considered an eternity in the low-latency world of HFT. Thus speed becomes an essential element of this new financial ecosystem. Low-latency connections and sophisticated algorithms are 'evolutionary traits' that are crucial for survival in this highly competitive environment. The difference between informed and uninformed traders depends more and more on their relative speed and geographic location (Haldane, 2011). A recent study has shown how the dramatic decrease in latency has increased the importance of geographical location, especially for statistical arbitrage strategies (Wissner-Gross and Freer, 2010). In a certain sense, even satellite links might be too slow in some instances, as 250 milliseconds is not much in today's markets (Leinweber, 2009, p.72). A frequently quoted example is a company called Spread Networks, who invested $300 million in a fiber cable connecting Chicago and New York and reducing latency by a few milliseconds (MacKenzie et al., 2012, p.14). Although this is small improvement in absolute terms, it allows the owners of the cable to charge substantial amounts for those willing to use it. A company called McKay Brothers who, together with Aviat Networks, developed a low latency wireless transmission system and has taken things much further. Modern microwave technology can achieve lower latency than fiber optic alternatives because the speed of light in air is approximately 50 % faster than the speed of light in fiber optic cables (Rudisuli and Schifter, 2014).

In as much as fiber-optic links between various data centers have gained strategic importance, there is a second tactical issue regarding colocation. In the particular case of HFTs, it is of crucial importance for these firms to position their servers as close as possible to the matching engines of the venues they trade on. As the race to zero constantly accelerates, small incremental differences become more and more important. When a few milliseconds can decide the future of a group of firms or trading strategies, investment in colocation and low-latency seems like a small price to pay for ones survival. Sal Arnuk and Joseph Saluzzi (2009) argue that, in today's market, trading is not done by people who analyze fundamentals about companies but by proprietary trading firms who pay for colocation, giving them an unfair advantage. The issue is somewhat more complicated as Manoj Narang (2010) has demonstrated, in as much as any attempt to ban colocation would still not resolve the race for proximity (e.g. trading firms renting office space next to the data centre). Moreover, colocation has already been made fairer through equal cable length to all servers. Finally, colocation is available to anyone who can bear the costs, but it's mostly useful for specific HFTs engaging in above mentioned electronic market making.

The success of HFT strategies is not simply a product of their technological sophistication but is also due to their deep understanding of the new regulatory environment. Certain rules and regulations like the SEC's Flicker Quote Exception to the Order Protection Rule can lead to situation in which very fast traders such as HFTs can gain strategic advances over much slower time-delayed players (McInish and Upson, 2012; Biais and Foucault, 2014; Hoffmann, 2014). Moreover, because of fragmentation in US stock markets, there are latencies in updating quotes that again provides opportunities for ultra-fast HFTs, which are not accessible to slower participants (Angel et al., 2010, p.38). Another important advantage of HFTs comes from the complexity of the electronic order books itself. HFT strategies are highly optimized and take into account the overall dynamic of the order book, i.e. if orders are displayed or hidden, rate of cancellation of orders, the size and sequence of orders, depth of the order book, etc. (Brogaard, 2011). In a similar fashion, order to trade ratios, trade frequency and time of day can be equally important in providing leads for future price movements. What might seem as white noise to most market participants, actually represents tradable signals to professional HFTs. Many investors may simply have no incentives in overly optimizing their strategy, but their behavior represents a valuable resource for HFTs, who can systematically exploit it.

More to the point, the current situation is quite similar to old floor-based exchanges where specialists would always have certain spatial and temporal advantages. The difference is that in that context, specialists were required to match orders but they were also required to provide continuous liquidity. But in today's markets, engaging in market making and providing continuous bids and offers, can prove very risky unless one can move very quickly to constantly adjust the bid-ask spread. That is to say, anyone who wants to be in the business of market making needs to be able to quickly post and cancel orders (Leinweber, 2009, p.70). While designated market makers are obliged to post two-sided quotations, HFTs engaging in electronic market making can exist the market entirely in a matter of milliseconds. This aspect as particularly problematic as many participants have complained about the difference between available liquidity and actual executed volume; something called 'disappearing liquidity' (Zhang and Baden Powell, 2011). This may be a valid point in the sense that available liquidity appears just as quickly as it disappears and is mainly due to the fact that HFT related liquidity is not a given as it used to be with the human specialist on the floor of the old NYSE. That is to say, contemporary HFTs are more than willing to provide double sided bids and offers but they will only do it as long as they can adapt their spreads very quickly and take advantage of low-latency and colocation.

By many measures, HFTs can be considered to be part of electronic market making (Hendershott et al., 2013), supplying liquidity and providing very tight bid-offer spreads. Nevertheless, there are many counter arguments to this position, as it is clear that the liquidity provide by HFTs is not as reliable as one might assume (Jarrow and Protter, 2012; McInish and Upson, 2012; Kirilenko *et al.*, 2014). The crucial point here is that the human specialist was obliged to step in and take the other side of the trade, maintaining a fair and orderly market. No such regulatory requirements exist for HFTs who can exit the market at lighting speeds. Whether or not HFT is a positive or negative aspect of contemporary markets is still hard to ascertain. What is certain is that HFT is a controversial issue and we will try to unpack its multifaceted nature in the next sections of this chapter.

7.3 HFT Controversies

Over the course of its development, HFT has become a negative buzzword reflecting a number of misunderstandings of the function of market making but also genuine concern with HFT practices more broadly. In a well-known series of papers, Sal Arnuk and Joseph Saluzzi have described certain HFTs practices as ''predatory'' and even illegal (2009). In a nutshell, predatory HFTs would be those trading strategies that go beyond simply performing electronic market making. It entails using their technical and informational advantages to force institutional investors (pension funds, insurance companies, mutual funds, etc.) to buy or sell at ''prices higher or lower than where the stock had been trading, creating a situation where the predatory algorithms can lock in a profit from the artificial increase or decrease in the price'' (Arnuk and Saluzzi, 2009). If the institutional order has a limit price, the whole trick is to ascertain what that limit is. The predatory HFT algorithm then has to ''run up the institutional algo to its limit'', and make it pay the maximum of what it is programed to pay. Manoj Narang has offered a counter critique to this position by arguing that it is perfectly fair for someone with superior computational capacities and more advanced low-latency technology to use available information to make a profit, as long as it is legal. What is not fair, in his opinion, is to abuse the regulatory framework and for instance to ''jump ahead of an order that was placed earlier at the same price by another trader'' (Manoj Narang, 2010).

Another contentious topic relating to HFT is the previously mentioned aspect of to liquidity rebates, which could be seen a way for trading venues to offer unfair profits to HFTs. This refers to instances in which HFTs perform electronic market making and cash in a rebate when they provide liquidity. As we have said, the use of rebates is common because the ultimate aim of an exchange is to attract order flow. On certain venues, when an order is filled, the liquidity provider receives a rebate while the remover is charged a fee. What Arnuk and Saluzzi argue is that these HFTs can make a profit without actually adding much to overall liquidity. Again the work of Narang helps us put this into perspective, as not all stocks are equally liquid. In the case of very liquid stocks, the market tends to move in favor of the taker of liquidity and against the provider of liquidity, i.e. the market maker. In the case of less liquid stocks, it might not be that unreasonable for the market maker to have an advantage, such as a rebate, as market making in those stocks is much more risky. On the other hand, what is certainly questionable is a tiered rebate system, in which trading firms with higher volumes (e.g. HFTs) get larger rebates as opposed to participants with smaller rebates.

The third and probably most important recent controversy revolves around the ability of HFTs to arbitrage the regulatory framework. We have already mentioned this in the previous sections but we will briefly elaborate on this, particularly in the case of rule 611 of Regulation National Market System (Reg NMS). This regulatory framework was promulgated in 2007 in the context of enhancing completion and investor protection in US stock markets[62]. It entailed twelve rules but it has been rule 611 that has drawn a lot of attention in the context of problems associated with HFT strategies.

This rule is particularly important as it prohibits the execution of quotes that would lock or cross the protected quotations of other trading centers. More to the point, the rule refers to the way in which broker dealers and exchanges are obliged to enforce the National Best Bid Offer (NBBO) and prevent orders to be executed at inferior prices. For instance, exchanges are forced to route incoming orders to the venue that displays the most competitive price. This framework is immediately put to the test when a broker dealer attempts to access all markets at the same time on behalf of its client. In such an instance, he might be prevented from accessing all venues and will have to ''chase liquidity with orders that are denied by exchanges in an effort to comply with Rule 611'' (Bodek, 2013). In respoding to this proble, Reg NMS provided an exemption from rule 611, called the Intermarket Sweep Order (ISO), which allowed the execution of sweep ordes immediately, before quotes on different venues get a chance to update. As the figure below shows us, an ISO trade is amuch more efficeint way to aces liquidity whereas using non-ISO orders opens

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[62] https://www.sec.gov/spotlight/emsac/memo-rule-611-regulation-nms.pdf

up the possibility of being rerouted thus wasting time and probably not getting optimal execution:

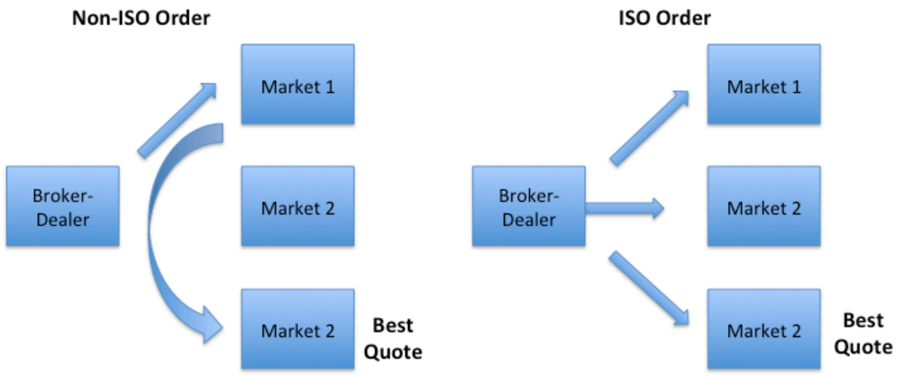

Figure 19: Example of trading with Intermarket Sweep Orders

(Chakravarty et al., 2012 p,26)

This exemption was meant for the specific case of executing large institutional orders, also called block-trades. Instead of executing the large block sequentially, the use of ISO orders allows for simultaneous access to all venues and thus leads to more efficient execution (Chakravarty et al., 2012). By definition, ISO ordes are available to exchanges and broker-dealers, but they can make them available to other participants, such as experienced HFTs (MacKenzie, 2014). Haim Bodek has argued that this rule has in fact represented a major turning point for HFTs and draws attention to the way in which it helps them exploit the current regulatory framework (Bodek, 2013). The asymetric acces to ISOs can thus be seen as another advantage given to certain market participants to the detriment of others.

In any case, all of this allows us to highlight one crucial point, namley the continous power struggle within our contemporary electronic trading ecosystem. First of all, it shows us that being a liquidity provider and performing market making grants one substantial advantages relative to other market participants. Second, it shows that certain participants, who operate at millisecond time horizons, have disproportionate impact and control over the ultimate execution of bids and offers. Finaly, it shows that dependig on computational and technological capabilities, spatial and temporal proximity, different participants can have access to substantially different types of liquidity. This is also an acurate description of the privileged status afforded to human specialists or jobbers on the old trading floors. Similar to our present day situation, the specialists in New York, the jobber in London or the market makers of Chicago were better informed than other market participants. But what seems stricking in the case of contemporary electronic trading is that the present asymetries are of much higher order of magnitude. While traditional market makers were able to earn the spread between the bid and the offer, contemporary electronic trading has vastly expanded the range of profitable trading strategies.

In the past, the matching machine was directly controlled and managed by groups of human specialists and brokers, such as in the case of NYSE in the 19^{th} century. That is no longer the case today, where trading in US stocks is fragmentated across a large number of exchanges, alternative trading venues such as ECNs and dark pools. Moreover, to a large extent both the mathing and the market making functions have been incorporated into the working of machines. The introduction of electronic order books affords direct market acces to a diverse set of market participants, deploying a variety of different strategies. This in turn leads to a arms race driven by lower latencies of execution, constant optimization and large investments in advanced technological capabilites, just to be one millisecond ahead of everyone else. In the end, HFT trading firms enjoy an advantage, which is ''the result of a 'technicality' of trading that is opaque to outsiders'' 20. This has recently razed many concerns as to the fairness of equity markets (Bodek, 2013) and financial markets more broadly:

> Nanex: 'On ... Aug 5, 2011, we processed 1 trillion bytes of data ... This is insane. ... It is noise, subterfuge, manipulation. ... HFT is sucking the life blood out of the markets: liquidity ... [A]t the core, [HFT] is pure manipulation' (MacKenzie at al., 2012, p18)

Such reactions might be overly dramatic, but they testify to the intense struggle going on in the electronic ecology of high frequency trading every day. In this sense, the question of HTF could also be framed in terms of this intense power struggle, where complex trading algorithms constantly jostle for position in order to be at the centre of liquidity, as close as possible to the core of the mathing machine. This is because, as we have tried to show before, desigining and maintainign transaction machines is eually a question of power struggle, not simply one of deciding on technical details. That is to say, the way in which market making is performed influences the extent to which HFTs are allowed to control and manage the dynamics of the order book. Consequently, one could attempt a critique of HFTs not in terms of some arbitrary moral distinctions but by focusing the impact on market stability and resilience in the context of HFT-dominated electronic market making. This is exactly what we will attempt to do by looking at a very specific event, the 2010 Flash Crash.

7.4 Flashes and Crashes

The aftermath of the 2008 financial crisis has seen an increased attention for the workings and complexities of international finance. As a result, a large number of catch phrases have entered into the public discourse, mostly as a reaction to the opacity that characterises the world of finance. From 'shadow banking', 'short-selling', 'flash crashes', 'weapons of mass-destruction' to 'vampire squids', 'dark pools' and 'greedy bankers'. All of them have had quite a successful career in the public media, but perhaps none have attracted as much attention as HFT. As we have seen, HFT has emerged as the contemporary version of market making operating across a ''distributed patchwork of exchange and multilateral trading platforms'' (Haldane, 2011, p.4). This has been the case particularly in the US equity markets where share trading has at the same time become more efficient and more fragmented, and where a series trading venues, from the established exchanges to new alternative platforms such as ECNs and dark pools, compete for the privilege of organizing and managing the provision of liquidity. Within this environment high-speed traders such as HFTs have evolved primarily by performing market making strategies. Due to HFTs capacity to provide liquidity and channel order flow, trading venues have a direct interest in attracting market participants to their platforms. Co-location, low-latency, liquidity rebates, privileged access to certain order types such as ISO are all examples of the ways in which trading venues attempt to gain the support of HFTs. Speed and adaptability are essential for today's electronic market makers, particularly the ability to post and cancel large numbers of quotes as the market moves. This aspect of HFT activity relates to the fact that being informed actually means being faster and able to quickly respond to market movements. This begs the question of whether or not contemporary matching machines can still be characterized by the phrase ''a fair and orderly market'', or whether they are intrinsically more fragile than earlier designs.

For instance, one example of the fragility of contemporary ecology is the now famous 2010 Flash Crash, when the ''Dow Jones Industrial Average (DJIA) index dropped almost 9% from the beginning of the day (…) and the biggest one-day point decline, 998.5 points, on an intra-day basis in the history of the DJIA index'' (Golub et al., 2012). For a brief moment, US stock trading halted as certain stocks, such as Accenture, fell dramatically and others received incredibly high valuations. According to Kirilenko, Kyle Samadi and Tuzun (2014), the Flash Crash was a complex and sudden market crash triggered by the unexpected sale of a large block of E-mini S&P 500 futures contracts (75,000 contracts worth some $4.1bn) by a trading algorithm. The rapid and continuous sale of such a large block of futures overwhelmed the E-mini S&P 500 market as market making algorithms were not able to handle the massive order imbalance. Although these algorithms did manage to buy for about 10 minutes, once they reached they maximum inventory limits, the market effectively began a downward spiral. This initial effect immediately triggered a reaction from other algorithms trading both the futures contracts and the underlying index, namely the S&P 500, further exacerbating the sell off. In short, a breakdown in the futures market eventually found is way and was amplified within the broader stock market. To put things into perspective, it represented the wipe out of about $1 trillion in the scope of minutes (Haldane, 2011). Both the SEC-CFTC (2010) report and the more recent UK Foresight Review have not been able to find an individual blame and have explained the phenomenon in terms of the coming together of several unrelated events that led to a ''perfect financial storm'' (Kirilenko and Lo, 2013, p.62).

One initial conclusion would be that such events could just be a normal occurrence in the complex ecology that has emerged out of the technological and regulatory innovation of the past decades. In fact, the topic of electronic market making, as it is performed by HFTs, renders a lot of credence to an ecological/evolutionary view of financial markets. Doyne Farmer (2011) has recently developed precisely such an approach applying it to both HFT and algorithmic trading in general. In this context, he identifies functional similarities between financial systems and other complex biological and ecological systems, and thus understands algorithmic strategies as having a 'natural' life cycle. As a new inefficiency is detected, i.e. a new niche, a strategy can be successful as long as it does not become to common. As more and more financial actors adopt it, the performance tends to decrease, but as it provides steady returns, it might drive out other types of strategies:

> Strategies, markets and regulations co-evolve in competitive, symbiotic or predator-prey relationships as technology and the economy change in the background (Farmer and Skouras, 2011, p.6).

An interesting aspect of this perspective revolves around the question of algorithmic crowding. As soon as a particular algorithmic strategy becomes very successful other participants will jump on it, resulting in a lot of similar algorithms all acting at the same time, possibly creating market wide trends. Perhaps the most valuable aspect of the ecological approach lies in understanding that the new interdependencies between various trading algorithms and the fragmented landscape of trading platforms may lead to a fragile financial ecology. Because of the novel capabilities offered by algorithmic trading and the nature of HFT activity, different trading platforms become more closely connected, leading to potential contagion ''between stock prices and derivatives written on these stocks'' (Haldane, 2011, p.14). Overall, the electronic trading landscape resembles a tightly coupled ecosystem where changes are transmitted across different trading venues and markets in almost real-time:

> Taken together, these contagion channels suggest that fat-tailed persistence in individual stocks could quickly be magnified to wider classes of asset, exchange and market. The micro would transmute to the macro. This is very much in the spirit of Mandelbrot's fractal story. Structures exhibiting self-similarity magnify micro behaviour to the macro level. Micro-level abnormalities manifest as system-wide instabilities (Haldane, 2011, p.10).

Although this type of approach has yet to become the mainstream of financial regulation and supervision, recent events suggest that the new ecology of electronic market making is not as stable as one might think. One can build on the ecological perspective by adding insights from the theory of computation. Philip Mirowski has recently provided an interesting account of the Flash Crash along these lines, in the context of his theory of markomata. What is common to both the ecological interpretation and Mirowski's computational perspective is the question of complexity and interconnectivity. For instance, one can think of the electronic trading landscape as a network of tightly interconnected markomata, which gradually lead to an increase in systemic complexity:

> As individual markomata become increasingly networked, their computational powers become increasingly augmented in complexity (in the Chomsky definition), and transcendental guarantees that a particular market format will continue to operate as it has done in the past are repeatedly falsified (Mirowski, 2012, p.383)

From the perspective of mainstream economics, the Flash Crash could simply be seen as a market failure in the traditional sense, which could be fixed by increasing the scope of the market (more competition, lower transaction costs, less regulation). From this point of view, it would be easy to identify certain obstacles and transaction costs that hinder free competition and obstruct the price discovery process. Creating a smoother trading environment would thus allow market forces to operate unhindered and reduce the likelihood of failures such as the Flash Crash. But from the point of view of the theory of markomata, market failure has a totally different meaning. Rather than being some sort of mispricing, the failure of markomata is in fact the break down of the market matching machine. Given erratic inputs coming from a number of HFT automated trading algorithms, the matching engines broke down and ''prices appear to have no floor or ceiling'' (Mirowski, 2012). Using the vocabulary of computation, Mirowski explains this as matching algorithms not being able to halt. As there were either no bids or asks, the matching engines were not able to match orders and produce prices. In his sense, the near real-time cross-market arbitrage performed by HFTs lead to a tightly coupled network of markomata that exhibit unexpected emergent properties, such as sudden breakdowns like the Flash Crash.

In conclusion, having surveyed the various accounts of the Flash Crash it is difficult to argue that HFTs market making firms are to blame for it. It would be fair to say that HFTs are the present culmination of a tendency towards fragmentation and immediacy of trade execution that ultimately leads to a very fragile financial ecology. As the recent evolution of financial markets have led to faster and more interconnected financial ecology (Johnson et al., 2012, p.2), the question is not so much on the good or bad intentions of HFT, but more on its impact on the resilience of the overall system (Haldane, 2011, p.10). Moreover, as Kirilenko has shown, this points to a much more deeper problem of the inadequacy of financial regulation in a context where ''the growing interconnectedness of financial markets and institutions has created a new form of accident: a systemic event, where the ''system'' now extends beyond any single organization or market and affects a great number of innocent bystanders'' (Kirilenko, 2013, p.68). Consequently, the Flash Crash has triggered several debates as possible ways to reform the current matching and market matching infrastructure.

In two recent papers, Daniel Beunza (2013; 2015) has argued in favour of the hybrid market structures such as that of NYSE, where one can combine the benefits of both a closely knit social structure (specialists on the floor) and automated electronic systems. He argues that, during the Flash Crash, fully automated exchanges such as BATS or Direct Edge had many erroneous traders that had to be cancelled while the NYSE did not have this issue. According to Beunza, this suggests that contemporary electronic markets should be designed by taking ''into account the functions performed by the original intermediaries'' (Beunza, 2015, p.42). Ultimately, he argues that there were many informal rules on the open outcry exchange floor, which have been lost in the translation to automated electronic trading. This of course presupposes that there are certain aspects of the behaviour of human market makers that are not formalizable, but were essential for maintaining stability. Given the overall perspective of this thesis, we would argue that there is little benefit in framing the issue in terms of the dichotomy between social structure and technology. Once we understand the infrastructure of financial markets as transaction machines it is clear that, human or non-human components, what matters is the design of the matching algorithm. If something has been lost in the transition from human dominated trading floors to automated electronic platforms it is because we do not understand the full complexity of what was enacted on the floors by the human market makers. In some ways, rather than bringing back human individuals as conduits for order flow, we should perhaps focus more on improving the algorithmic structure of contemporary electronic markets. Just as computers have improved the aggregation and matching of order flow, they should be equally well suited to supervising and regulating markets, fostering the development of an equally complex algorithmic infrastructure with the sole purpose of assuring market stability (Kirilenko, 2013).

In this regard, particularly since the Flash Crash, both regulators and market participants have made the argument for the soundness of circuit breakers operating as stabilizers of market dynamics. Something that might seem as unnecessary obstacles by orthodox economists, have been of crucial importance for the engineers and designers of trading platforms. In fact, on the occasion of the Flash Crash circuit breakers did kick in as the ''Chicago Mercantile Exchange imposed an automatic 5-second pause on trading in its S&P 500 E-mini futures contracts'' (Haldane, 2011, p.16). As it has been argued by Andy Haldane, circuit breakers allowed the market to calm down, as it where, and are thus an essential element insuring financial stability[63]. Other solutions to the unintended consequences of electronic market making could be the implementation of minimum resting times, effectively imposing a limit on the speed of trade execution. That would force market making HFTs to hold on to positions for longer periods of time and thus widen their spreads, but which might also lead to a more resilient stock market.

Recent research has actually shown that the continuous double auction matching mechanism, run on limit order book technology, is perhaps not an optimal design (Budish et al., 2015). In fact, Budish, Cramton and Shim argue for complementing the continuous double auction market design with an additional sealed-bid double

[63] During an interview with an employee of the Deutchse Borse (the German stock exchange), faulty circuit breakers on US trading platforms were singled out as the cause of the Flash Crash. The same person assured us that something like the Flash Crash would be very unlikely on the Deutsche Borse, as their systems have well calibrated circuit breakers.

auction executed every 1-second, which would eliminate the ''socially wasteful'' race to zero as exhibited by HFTs. This idea has recently drawn a lot of attention as the NYSE announced a plan to introduce a midday auction at some point. This would be a 5 minute long auction similar to the open and close auction performed and the beginning and end of the trading day (Bullock and Stafford, 2015). The great advantage of such an auction is that large investors can execute trades without the danger of prices moving against them, as they would happen in normal continuous trading. This is very much similar to what happens in trading platforms known as dark-pools, and is in some ways a replica of the sunshine auction mechanism of the now defunct AZX exchange. Another interesting new development is IEX, which is a trading platform owned by market participants such as mutual funds, hedge funds, and family offices, who are particularly sensitive to issues of market fairness and the quality of liquidity. IEX has recently received a lot of attention in the context of Michael Lewis's book of *Flash Boys* (2014). The platform has recently applied to be a public stock exchange and markets itself as a venue providing a level playing field for all participants. The many innovations of IEX include simpler order types, equal access to trade data, no collocation and more importantly, a 38-mile fiber-optic cable creating a delay that deters the more predatory aspects of HFT (Bullock and Stafford, 2016).

All of these developments are a shift from the ultimate focus of the matching machine from immediacy of execution to the reliability and quality of liquidity and overall market resilience. In the context of increasing automation and standardization, markets have obtained high levels of efficiency affording cheap and almost instant execution. But if history and the evolution of financial markets can teach us anything is that immediacy is perhaps not the only aim and function of matching machines (Kirilenko and Lo, 2013, p.68). It would be useful to remind ourselves of the central task of the specialists and jobbers of modern exchanges, namely to maintain a 'fair and orderly market''. Perhaps the next evolutionary step of matching machine will occur but by unpacking and formalizing the full complexity of this phrase and the rules, practices and algorithms that supported it[64]. The future of evolution of matching machines will hopefully entail more complex designs taking all of this into account.

[64] Marc Lenglet (2011) has recently highlighted the complex relationship between rules and regulations on the one hand and computer code o the other.

Conclusions

This chapter has addressed one of the most important issues for contemporary matching machines, namely the new face of electronic market making. As we have seen, the evolution of matching designs has led to the late 20^{th} century transition towards centralized matching machines, based on automated electronic platforms. On the floor of the stock exchange, human specialists would match order flow and perform market making, that is to say provide liquidity and ensure a fair and orderly market. This is no longer the case today, where trading in US shares is fragmentated across a large number of exchanges, alternative trading venues such as ECNs and dark pools. In the context of contemporary trading platforms matching is performed on electronic order books executed by sophisticated matching engines. This state of afairs affords direct market acces to a diverse set of market participants such as HFTs, who now tend to dominate electronic market making.

As we have seen from previous chapters, power in financial markets is best understood as the ability to control order flow. Therefore, human specialists on the floors of the exchange have always defended this privilege, because matching order flow affords crucial advantages as well as substantial profits. In today's situation, the power struggle for the privilege of being at the centre of liquidity is a question of having better algorithms and smarted trading strategies. This in turn leads to a arms race driven by lower latencies of execution, constant optimization and large investments in advanced IT capabilites, just to be one millisecond ahead of everyone else. As highlighted by Andy Haldane, this new algorithmic/electronic ecology is best understood as a downward spiral or a race to zero, with HFTs at the centre of a daily struggle for controlling and channelling order flow.

While all of this means that contemporary matching machines are more efficient than the earlier designs of open outcry floor trading, there are also many concerns about fairness, equal access to liquidity and market resilience. Leveraging Doyne Farmer's ecological perspective, the work of Andy Haldane on financial stability and Mirowski's theory of markomata, we argued for a critique of HFT in terms of its impact on overall market stability and resilience. Namely, while HFT firms are not directly to blame for events such as the Flash Crash, these liquidity meltdowns are perhaps the normal output of HFT-dominated market making**.** In as much as stock markets have reached high levels of efficiency and immediacy of execution, these are perhaps not the only aims and functions of matching machines. We suggest that contemporary matching machines should attempt to incorporate the more complex set of rules, practices and techniques performed by the traditional human market makers in their pursuit of a fair and orderly market. In fact, some of the current reform initiatives and new matching designs can be interpreted as a shift in focus from immediacy of execution to the quality of liquidity and overall market resilience. This includes the integration of the continuous double auction with frequent call auctions in the case of the LSE or NYSE or the innovative market structure provided by IEX. This new design affords a level playing filed to all participants, restricting the activity and profits of HFTs (Lewis, 2014). Finally, this highlights the fact that the design of matching machines is not simply a question of technical details but is a crucial aspect of the power dynamics in financial markets, understood in terms of the ability to maintain, organize and process the flow of financial transactions.

Chapter 8. Clearing OTC derivatives

Summary:

This chapter looks at the contemporary development of clearing machines such as CCPs in the context a more complex type financial asset, Over-the-Counter (OTC) derivatives. Following the 2008 crisis, the failures of Lehman Brothers and AIG have raised many concerns about the robustness of the OTC transaction infrastructure. During the 2009 G20 summit in Pittsburgh, central clearing through CCPs emerged as the ultimate and most effective solution for a safer and more sustainable OTC derivatives market. Upon completing a review of the relevant literature on OTC derivatives, we pursued a qualitative research through semi-structured interviews and secondary desk research. We described the development of the market and its bilateral clearing mechanism. While this early system was a consequence of the dealer-dominated structure of the OTC market, we describe the transition towards a new transaction machine based on centralized clearing (CCPs). The rest of the chapter summarizes a number of 30 face-to-face and telephone interviews with senior professionals of the OTC derivatives market. The background of the research was the regulatory overhaul in the OTC derivatives markets, in the context of legislation such as Dodd-Frank, EMIR and MiFID II. Interviews were conducted between October 2012 and June 2013 with employees of CCPs, exchanges, global banks, trade associations, UK and EU regulators and independent consultants. We identified a number of themes including regulation, standardization, risk, collateral scarcity, transparency, social function, and shifting market dynamics. While all participants saw the new regulations as a burden, there was a strong perception that reforms would have asymmetric effects on different constituencies. We also highlight the fact that the design of clearing machines is not just a technical issue but directly impacts the power distribution within the market. The new regulatory framework has a strong impact on dealer banks, reducing their control of the clearing function and forcing them to direct trades through CCPs. More to the point, OTC products move to a centrally cleared model, they also more standardized and liquid enough to be traded and matched on electronic platforms, which further affects the OTC business of banks.

8.1 OTC Derivatives

In terms of the different types of financial securities we have mostly focused on the less complex exchange-traded derivatives such as futures and options. In this context we have seen the gradual emergence of exchanges and CCPs as transacting machines allowing for centralized matching and clearing, guaranteeing the execution and performance of contracts (Singh and Segoviano, 2008; Gregory, 2010). In addition to those executed on public exchanges, financial transactions have also been traded off-exchange, directly between counterparties. We are referring here to the Over-The-Counter (OTC) markets, which until recently were based on less developed matching and clearing mechanism, mostly voice broking and manual processing and confirmation. The existence of these markets is partially explained because counterparties have an interest in not disclosing their intention to the rest of the market and because their needs could not be fulfilled by the standardized contracts traded on exchanges, as well as the fact that some securities were not liquid enough for a continuous double auction design. Financial markets have seen a recent expansion of these more tailor-made OTC derivatives, which as of 2007 was five times large than the one for exchange-traded securities. The size of the OTC derivatives market has recently reached a total notional of above $600 trillion worth of contracts[65], a number that also gives us some understanding of the risk entailed by these markets (Singh and Segoviano, 2008, p.6). To this day, a number of different financial instruments are transacted this way, namely sovereign bonds, asset-backed securities, derivatives such as swaps, larger blocks of stocks, etc. (Duffie, 2012, p.2). In terms of matching, OTC derivatives markets have traditionally been quote-driven not order-driven. That is to say, investors need to contact an OTC dealer bank, which provides two-sided quotes for a certain products (this can be over the phone or via an electronic interface). While in order-driven markets (such as contemporary stock and futures exchanges) any participant can submit orders into the central order

[65] According to the Bank of International Settlements, the total notional amounts of OTC derivatives stands stood at $630 trillion as of December 2014. This is a very large number but the more relevant one is the gross market value of these contracts, which stood at $21 trillion (http://www.bis.org/publ/otc_hy1504.htm).

book, in quote-driven markets only market makers can quote prices and everyone else is a price taker (Fabozzi, 2008).

One of the most well known OTC derivatives is the swap, which can include interest rate swaps, currency swaps, equity risk swaps, total return swaps or credit default swaps, inflation swaps, etc. All of these financial products are more or less created for a very specific need of corporates or institutional investors (asset management firms, hedge funds, sovereign wealth funds, pension funds and insurance companies). That being said, a lot of effort has been put in standardizing OTC contracts, particularly under the guidance of the International Swaps Dealers Associations (ISDA), which was founded in 1985. The higher complexity of OTC derivatives is evident from the basic outline of the Interest Rate Swap (IRS), which is nevertheless one of the simpler OTC products. This particular type of product allows market participants to change the way in which they pay their debts or to hedge expected changes in the overall interest rate. Lets say that counterparty A borrows money at a fixed rate of 8% from its commercial bank while counterparty B boroughs at a floating rate of LIBOR +1% from another bank. For the sake of simplicity we assume that both counterparties borough the same amount of money, the notional amount of the swap.

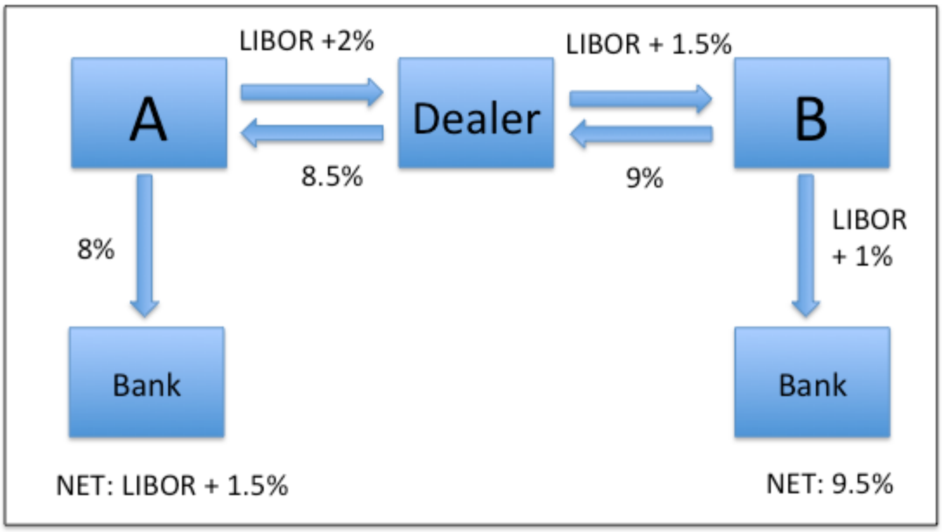

Figure 20: Example of Interest Rate Swap derivative contract

The next step is to assume that due to some unexpected event, counterparty A would like to change its payments from fixed to variable and counterparty B would also like to swap its rate from variable to fixed. At this point, we need to introduce a swap dealer (usually an investment bank) who can resolve this disparity. It does this by performing matching, that is to say entering into two separate interest rate swap contracts. It negotiates the first contract with counterparty B, whereby the dealer agrees to pay LIBOR + 1.5% on the notional amount and counterparty B pays 9%. The next step is to negotiate an opposite contract with counterparty A, whereby A pays LIBOR + 2% to the dealer and the dealer pays 8.5% fixed on the same notional amount.

The dealer bank is thus an intermediary matching the needs of the two counterparties and earns the spread between the two swaps (profits 0.5% from B and another 0.5% form A). We have to keep in mind that the bigger the notional amount of the swap, the bigger the profit for the swap dealer. What changes is that counterparty A now pays a net variable rate of LIBOR + 1.5% and counterparty B pays a fixed rate of 9.5%. The costs of achieving this transformation are effectively the profits accrued by the dealer. What is even more interesting is that the two counterparties could be multinational companies looking to hedge exposures to potential interest rate changes, pension funds looking to hedge their long term liabilities or hedge funds looking to speculate on the future movement of the LIBOR rate. In fact, the speculative potential of the swap is immediately apparent from the structure of the cash flows. Let say that every two months the dealer pays counterparty B the difference between 9% and LIBOR + 1.5% and it pays counterparty A the difference between LIBOR +2 % and 8.5%. What if after six months LIBOR is 10%. Counterparty A now effectively pays a net 11.5% which is higher than its initial fixed rate of 8%. At the same time, counterparty B continues to pay 9.5% fixed which is lower than the 11% (LIBOR at 10% +1%) it would have paid without the swap. In conclusion if LIBOR goes up A stands to gain while if it goes down B is more likely to gain. Either way the swap dealer earns the same profit because it matched two offsetting contracts and earns the spread.

As we can see from the figure above, even a simple OTC derivative is already more complicated than other securities such as stocks or futures. While a stock transaction is the result of an immediate intention and can be settled very quickly, OTC derivatives contract operate at different time horizons, and the counterparties are tied together for the whole life of the contract. Unlike stock or futures markets where central clearing is performed by CCPs, in bilateral OTC markets he counterparties have to monitor and manage market and credit risk throughout the life cycle of the contract and agree margin payments in order to manage the risk of non-payment. For this very reason, credit risk considerations are absolutely essential in the case of OTC derivatives (Pirrong, 2006). Nowhere has this been more acutely evident than in the case of another type of OTC swap, the credit default swap (CDS). Similar to the IRS, the CDS allows two counterparties to exchange an exposure that they did not want to bear. One party buys protection against the default of a corporate bond, sovereign debt, etc. and pays a premium upfront, while the other offers insurance against such dramatic events. Gillian Tett's *Fool's Gold* (2009) is a detailed description of the development of credit derivatives in the 'laboratories' of JP Morgan in the early 1990s (as well as their role in the 2008 financial crisis). In 1994, JP Morgan had extended several billion dollars to Exxon who was also facing the possibility of very high damage payments due to the Valdez oil spill. This was thus a very risky exposure for JP Morgan and they were obliged to hold substantial capital against the possibility of an Exxon default. In order to reduce the capital they had to hold, JP Morgan structured a derivative that would allow them to transfer the credit default risk of this trade to a different counterparty, the European Bank of Reconstruction and Development (EBRD). Having eliminated the credit risk of the Exxon trade, JP Morgan could free up more capital and deploy it elsewhere.

It is clear from these examples that OTC contracts are not as standard as more simple securities and are thus more inherently illiquid. That is to say, the more customized a contract is, the more difficult it is to transact it with other investors other than the original counterparties. The lack of liquidity and increased complexity means that most OTC contracts are not natural candidates for exchange trading (Duffie, 2012, p.6). Moreover due to the infrequency of publicly available prices, users of such contracts need to develop the knowhow and technical sophistication in order to value them, which is not easy to do. In addition, the need to manage complicated cash flows and monitor credit counterparty risk means that the OTC markets are used by large financial institutions, governments, multinational corporations and sophisticated investors (Millo et al., 2005), as they are the only market participants who could bear the costs of handling such financial products. To this day OTC markets are still dominated by major dealer banks assisted by inter-dealers brokers. Nevertheless, because of the efforts of the International Swaps and Derivatives Association (ISDA) most OTC products have become much more standardized, which in turn means that they can be more easily traded on electronic platforms. In any case, before the financial crisis, the OTC market was still miles away from the more transparent matching machines, based on centralized electronic order books, used for the trading of stocks or futures.

This lack of transparency around OTC derivatives was not limited to the way in which they were traded, i.e. the way in which different positions were matched, but also in terms of the dominant clearing model, which was bilateral. A famous example of the limits of such arrangements is the failure of American International Group (AIG), which had huge exposures through their CDS portfolio. As long as everything was fine and its credit rating was secure, AIG would receive premium payments for the CDS protection they were offering (Huault and Rainelli-Le Montagner, 2009; Huault and Richard, 2012). Because of its high credit rating, AIG was not even required to post margin by some of its counterparties (Singh and Segoviano, 2008, p.9). As losses mounted in the securitized mortgage markets, AIG was asked to post margin and compensate their CDS counterparties. Unfortunately, AIG failed in 2008, when CDS related losses compounded the firm wide risk failings in most of its other business, such as securities lending. It has been argued that because of bilateral clearing arrangements, the full extent of AIG's exposures where not apparent. As long as everything was fine and AIG's credit rating was outstanding, its counterparties would not require collateral to keep the positions open. As the value of that protection skyrocketed, AIG could not post the additional collateral and the US Government were forced to bailout AIG. If those trades had been cleared through a CCP then the:

> collateral calls still would have been problematic for AIG, but they would have come sooner and more frequently. Hence, uncollateralized exposures would not have been given the chance to build to levels that became systemically critical (IMF, 2010, p.9).

The general accepted view is that if the CDS market had been centrally cleared, these risky exposures would have been discovered earlier and could have been collateralized and managed by a CCP (Lewandowska, 2010b; Lewandowska, 2015). Following the 2008 crisis, both the failures of Lehman Brothers and AIG have raised many concerns about the robustness of the OTC transaction infrastructure, particularly in terms of clearing. In fact, during the 2009 G20 summit in Pittsburgh, central clearing through CCPs was singled out as the solution for a safer OTC derivatives market. In the next section we will explore this post-2009 regulatory mandate for the central clearing of OTC derivatives and its impact on various market participants.

8.2 OTC Dealers and Central Clearing

As we have seen, the OTC markets evolved around the market making activities of large dealer banks, the so-called G14 dealers (Markose, 2012). As clients may have very specific hedging requirements, matching and market making is not as simple as in other asset classes. In addition to this, the relative illiquid nature of OTC products has traditionally limited the degree of standardization and thus the feasibility of matching mechanisms as those for stocks and futures (Smyth and Wetherilt, 2011, p.332). Moreover, because of attractive spreads and higher potential profits in OTC derivatives, the large dealer banks always had an interest in maintaining a low level of transparency and standardization:

> Dealers have a vested interest in maintaining trade in OTC markets, where the profitability of intermediation is enhanced by market opaqueness. Once liquidity is established in OTC markets, it may be difficult for exchanges to compete for a critical mass of order flow, as investors are naturally drawn to the most liquid available market (Duffie, 2012, p.7).

Smyth and Wetherilt (2011) have provided a detailed account of the OTC derivatives landscape and its transactional architecture. For instance, single-dealer platforms (SDPs) are electronic systems offered by large dealers using either click-to-trade or request-for-quote types of execution. In the first instance, clients can choose the maturity and the size and then decide whether to trade or not. In the second instance, particularly for bespoke products, clients ask for quotes and then receive a response from the dealer. There are a few alternatives to SDPs, namely the multi-dealer platforms provided by Bloomberg, Tradeweb (owned by Thomson Reuters) and MarketAxess. These platforms have basically the same structure as with SDPs, but prices are based on submissions from a variety of dealers. The advantage of such arrangements is that clients can send requests to more than one dealer and chose the best price (Smyth and Wetherilt, 2011).

The quote-driven bilateral matching design allows OTC dealer banks to dominate the market and extract substantial profits. Being a market maker in an opaque market is certainly a useful advantage for large dealer banks, but it is further enhanced by the prevailing use of the bilateral clearing model. That is to say, the level of margin required for certain OTC positions are decide between the client and the dealer bank. As we have seen, the lack of transparency and the risk entailed in such clearing arrangements has led to spectacular failures in the context of the recent financial crisis (Singh and Segoviano, 2008). By the end of the 20th century, most asset classes had adopted one form or the other of central clearing through a CCP (Kroszner, 1999). Monitoring, transparency, margining and default fund contributions are normal risk management practices performed by CCPs in the case of stock and futures markets (Bliss and Steigerwald, 2006). In the case of OTC derivatives, there was not incentive for dealer[66] banks to mutualize their credit risk through a clearinghouse or a CCP. In fact, it has been argued that the substantial difference between order-driven public exchange markets and quote-driven OTC markets is that the latter do not mutualize default risk (Pirrong, 2006, p.24).

Consequently, even at the beginning at the 21st century, most of the OTC derivatives markets were using the more primitive bilateral clearing arrangements, relying more on the capacity of large dealer banks to monitor and evaluate the counterparty risk of their clients. The figure below is an illustration of the traditional bilateral clearing model servicing this market pre-2009. Large financial institutions dominate the transaction life cycle but are supported by a complex ecosystem of information and technology providers, payment and settlement platforms, inter-dealer brokers, trade information warehouses and trade organizations such as ISDA promoting standardized contractual terms.

[66] This includes likes of JP Morgan, Bank of America, Citi, Deutsche Bank, Goldman Sachs, Morgan Stanley, etc.

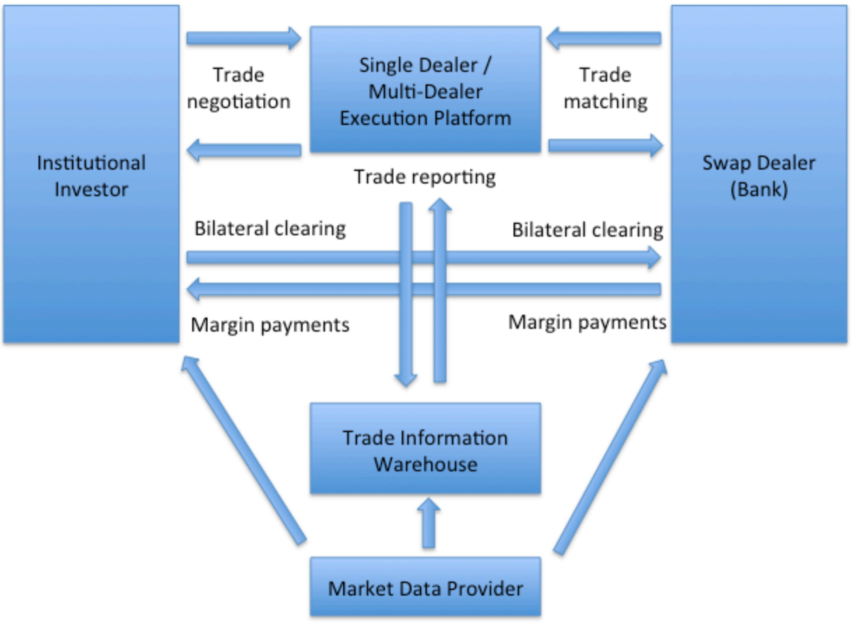

Figure 21: Bilateral clearing model for OTC derivatives

The downside of this model is that dealer banks are managing counterparty risk on a bilateral basis, which means that they are also susceptible to runs (Pirrong, 2006, p.43). The situation is not so different from depositors who can collectively bring down a bank, as seen in the situation faced by Bear Sterns[67] and Lehman Brothers[68] in 2008. In the case of market stress, rating downgrades, etc., any of the bank's counterparties can 'pull' on it to post more collateral. There is thus an incentive to be the first to exit a position with counterparties that are perceived to be weak or whose creditworthiness is deteriorating, which ultimately leads to a run on the bank (Pirrong, 2006, p.39). Moreover, in times of market stress, participants also have a tendency to reduce trading which leads to reduced liquidity, compounding any initial fears (Smyth and Wetherilt, 2011, p.331). In this sense, confidence is crucial for OTC, as the market could not sustain itself if participants can't adequately manage counterparty risk (Lee, 2011, p.62). The 2008 financial crisis brought to light the risk

[67] On the 14th of March 2008, a number of money market funds decided to exit their positions with Bear Sterns, refusing to engage in repo contracts even though Bear Sterns could provide adequate collateral. The investment bank thus went from having several billions dollars to negative in a few days, which led to its collapse.

[68] In September of 2008, Lehman Brothers received a $5 billion collateral call from JP Morgan, one of its largest counterparties. A few months earlier, JP Morgan required no collateral. Moreover, based on JP Morgan's decision, Citigroup also decided to take similar action. This compounded Lehman's liquidity problems leading to its failure on the 15th of September 2008.

and limitations of bilateral clearing mechanisms in the OTC derivatives markets. In the aftermath of the crisis, the 2009 G20 summit in Pittsburgh decided on a radical overhaul of the OTC market infrastructure, namely that:

> All standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms, where appropriate, and cleared through central counterparties by end-2012 at the latest. OTC derivative contracts should be reported to trade repositories. Non-centrally cleared contracts should be subject to higher capital requirements (FSB, 2010).

The introduction of centralized clearing corrects some the fundamental design flaws allowing for monitoring and risk mitigation based on much more precise information as every dealer bank has to clear through a CCP. As we can see from the figure below, the CCP interposes itself at the center of the clearing ecosystem, becoming the central counterparty to everyone.

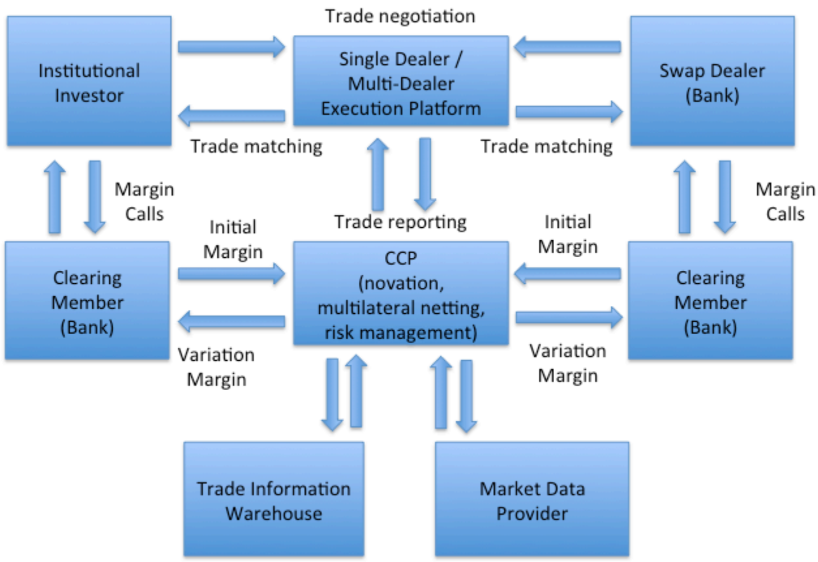

Figure 22: Central clearing model for OTC derivatives

The CCP is thus at the centre of a complex informational ecology, performing central clearing and managing the collective counterparty risk of the market. In the case of a transaction between an institutional investors and a dealer bank, the trade can still be matched either directly over the phone or through a dealer owned platform, or through an inter-dealer broker owned platform. After the transaction is confirmed and registered in a Trade Information Warehouse, the CCPs can start the first stage of clearing, namely the novation process. This replaces the initial transaction with two separate contracts between the CCP and the two counterparties. As we have seen, this is essential in order for the CCP to guarantee the initial trade and manage the risk of default. Moreover, CCPs receive price information from providers such as Markit (aggregated from data submitted from the large dealer banks), which in turn allows the CCP to set initial and variation margins (Lewandowska, 2010a).

We have thus far attempted to provide a sketch for the transition of OTC markets from bilateral to centralized clearing. As we have seen, this process of redesign entails numerous intricate details as to the basic architecture of these markets. Nevertheless, as we have shown on several occasions, the question of design and evolution of transaction machine cannot be reduced to specific technical details but is also a question of politics. That is to say, the imposition of a centralized clearing machine leads to a substantial redistribution of power within these markets. We will dedicate the rest of the chapter to gaining a better grasp of this reorganization of the OTC derivatives markets in the context of centralized clearing.

8.3 Interviews on OTC Central Clearing Reforms

8.3.1 Methods and themes

As we began to explore the topic of OTC derivatives clearing reforms it became clear that a review of the literature, publicly available information and news would not be sufficient in understanding the full extent of these changes. There was also a lack of clarity as details of these reforms were still being negotiated and debated in 2012-2013. In trying to get a better understanding of a situation in flux, we set out to reach out and interview individuals directly involved in the ongoing transformations. What began as a focused inquiry led to a number of encounters and the idea of pursuing several interviews. Therefore the next section summarizes a number of 30 face-to-face and telephone interviews with professionals of the financial services industry, exploring the overhaul of the OTC derivatives market. The research was predominantly conducted in London and Brussels, and over the phone with professionals in Paris and Frankfurt. The background of the research was the regulatory changes in the context of legislation such as Dodd-Frank, EMIR and MiFID II. First, we will discuss the methodology adopted for the purpose of this empirical research. Upon completing a comprehensive review of the relevant literature on OTC derivatives, we pursued a qualitative research through semi-structured interviews and secondary desk research (mostly online/media publications, more recent academic papers, conference papers, webinars, etc.). Secondly, the results of the research are presented through a review of the main themes of the interviews.

It is important to highlight one of the limitations of the interviews, as the results represent only a limited snapshot at a particular point in time. They were conducted between October 2012 and June 2013 with employees of Clearinghouses/CCPs, Exchanges, Banks, Financial Trade Associations, UK and EU Regulators and independent consultants. Each semi-structured interview lasted between 60-90 minutes and a research outline and interview questions were emailed in advance. While we set out with a semi-structured approach, discussions were ultimately dominated by open-ended questions, through which interviewees were encouraged to expand were appropriate. This was inevitable in as much as we were dealing with topics and issues that were still very much in flux. During the interviews, extensive notes were taken and some meetings were recorded and transcribed, but a most conversations were no recorded due to confidentiality issues. In fact, all interviewees requested to remain anonymous and their views confidential as most were directly involved in ongoing negotiations/dialogue with regulators or policy makers. This research coincided with a crucial period for the OTC markets, namely with some of the final decisions on essential details of the new regulatory regime. Consequently, people in the industry, specifically banks and clearinghouses, were understandably very cautious about opinions and views they shared with outsiders.

The first step entailed identifying the relevant parties involved in the overhaul of the OTC derivatives markets (regulators such as FSA and EU Commission, banks such as Citi, Deutsche Bank and JP Morgan, clearinghouses such as LCH.Clearnet, Eurex, DTCC, CME Clearing, trade associations such as ISDA, FOA, FESE, AFME, etc.). Through secondary desk research, we identified relevant individuals and approached them either over email or cold calling. Potential interviewees were selected on the basis of their experience and knowledge of the OTC derivatives markets. All interviewees had a good understanding of current regulatory reforms and most were frequent speakers on the conference circuit. Given the sample used and short time interval it is hard to make any ambitious claims about the representativeness of this research. Nevertheless, the diversity of the pool of interviewees was a deliberate choice in order to capture a comprehensive perspective and to collect as much relevant data as possible. This is precisely the reason why we have also interviewed a number of consultants who were advising industry participants on how to respond to the new regulatory regime. Their input was particularly useful as they allowed us to cross check the main themes emerging out of the discussions. As they stood both outside and were also involved in the topics discussed, they acted as a crucial benchmark for the rest of the interviews.

We finally constructed a narrative elaborating on the following main issues and themes: regulation, standardization, risk, transparency, social function and shifting market dynamics. In each case, the discussion starts from a general point of view (market stability, systemic risk, investor protection, etc.) and identifies certain crucial details of the ongoing regulatory overhaul. While there was a broad consensus on most issues, participants from different constituencies (banks, clearinghouses, regulators) had different positions on the more granular details of the new regulatory regime. Apparently technical questions such as which OTC derivatives can be standardized, the level of transparency for certain products, the margin requirement for becoming a clearing member, what qualifies as eligible collateral or should CCPs be connected or standalone structures, also turn out to be political issues. That is to say, as a new clearing machine was being constructed, all these small details were not just technocratic in nature, but were leading to radically different power dynamics. The overall direction of the redesign of the clearing machine was indicative of the superior power position of regulators and CCPs in relation to the previously dominating dealer banks. With the move from bilateral to central clearing, CCPs become the central hubs for processing and clearing OTC derivatives. As we will see, this has major consequences for dealer banks but all for the rest of the OTC markets. This reiterates our assertion that transaction machines are crucial for understanding power in financial markets

8.3.2 Regulation

Signed into law on 21 July 2010, the Dodd-Frank act represents a major overhaul of US financial markets. The ultimate aim was to introduce transparency to the OTC derivatives markets through mandatory central clearing and electronic trading where possible. Across the Atlantic, the European Commission proposed a similar piece of legislation, the so-called European Markets Infrastructure Regulation (EMIR). While central clearing under EMIR is scheduled to come into effect from April 2016, the new rules have already been implemented in the US. In any case, both pieces of legislation are a response to the 2009 G20 agenda and represent an important transformation of the OTC market structure. In fact, the radically different nature of incoming regulation has been a recurring theme throughout all the interviews. Pre-crisis, OTC derivatives were under relatively light regulatory oversight. While there were a series of industry initiatives to clear swaps, central clearing did not become an industry wide trend. In that context, the ruling paradigm was that the market can self-regulate and that unilateral state regulation would do more harm than good. This state of affairs ended in 2008, as the financial crisis has spurred an inflation of proactive regulatory initiatives.

Post 2008, the political and social pressure to do something led to the decision that substantial reform was urgently needed. As one interviewee put it: ‘’everything technical is political, regulation is not a technical activity of cost and benefits’’ (Consultant, OTC derivatives). In the US, it was the Commodity Futures Trading Commission (CFTC) that took centre stage as the clearing of derivatives automatically meant an expansion of its remit and powers. In Europe, it was the EU Commission and other European regulators that supported central clearing seen as a way to bolster their influence. The entities that had the most to lose from this overhaul are the ones benefiting from the already existing transaction machines, the so-called major swap participants, i.e. the large dealer banks operating in the OTC arena.

> Within financial services, players respond when their interest are affected. Large banks trading in derivatives certainly don't like the regulation as it takes away a very profitable line of business (Senior Economist, UK Regulator).

Echoing this view, interviewees from banks and certain trade associations were particularly concerned about the shifts in regulatory regimes and possible regulatory overshooting. In some instances they argued that problems occurring in certain markets and with certain participants led to unnecessary wholesale changes across the board. More to the point, their position was that financial markets are complex systems that should be handled with great care. One way to argue for this was through the use technological metaphors and analogies between the financial system and other complex systems. One participant suggested regulators and industry professionals could learn a lot from the past experience with other complex technical systems such as nuclear power plants and air transport. All those areas abound with breakdowns, accidents and major catastrophes. The major difference is that in all of those cases it is possible to perform crash tests and rigorous forensic procedures are in place once something goes wrong. In the case of financial markets, we are not even close to ideal experimental conditions, as it would ''be very hard and dangerous to crash test the capital markets'' (Consultant, OTC Derivatives). While that is true, the recent adoption of stress tests for systemically important financial institutions is certainly a step in the right direction.

Professionals from CCPs were less concerned about incoming regulation, as it represents a new set of opportunities for their respective businesses with more products being diverted to their platforms for central clearing. Nevertheless, the new regulatory frameworks were generally seen as too complex and therefore difficult to understand and implement. In as much as regulation can help restore confidence, there was genuine concern around regulatory overshooting. Repeatedly, interviewees stated that current regulation is to a certain extent suffocating and that there will be some rolling-back of regulation, eventually. In fact, the complicated nature of regulation was a recurring theme as most participants characterized regulation as too detailed and demanding. This has been evident from several interviews, were people argued that ''level 1 regulation is too inflated'' (Regulatory Affairs Executive, Bank), referencing the move from an environment based on self-regulation towards more proactive regulatory mandate. This was compounded by a shift in the EU Commission's approach from an emphasis on directives, where there is some flexibility in interpretation, to straightforward regulation. This shift was seen as a direct consequence of the lessons learned during 2008, ''as it had become clear that Armageddon is possible'' (Policy Officer, European regulator). While regulators conceded that the OTC derivatives reform is a difficult process that affects all market participants, the goal was to restore the reputation of financial services industry as a whole. Echoing the concerns of industry professionals, regulators were also concerned about potential regulatory overshooting, but stressed the necessity and inevitability of reforms. Even more interesting, regulators were particularly concerned about the degree of harmonization across national boundaries. The convergence of regulatory regimes was seen as essential in order to prevent any regulatory arbitrage, so it was important that crucial details shouldn't be left to national interpretation.

The stated aims of reforms revolved around systemic stability, market integrity and efficiency and last but not least, investor protection. Relative to theses desired outcomes, the regulators themselves face a set of contradictory constraints. In periods of sustained growth and normal markets, regulators were told not to do anything, as the ''market takes care of itself''. On the other hand, in times of crisis the regulatory bodies got most of the blame for ''sleeping on the job'' **(**Regulatory Officer, EU Commission**)**. This frustration was often voiced, namely that regulators get no credit or praise when things go well but get most of the blame when things go wrong. This state of affairs was also seen as being the cause of discontinuous and asymmetric interventions. This has been evidenced during one interview in which a senior officer of an EU institution suggested that the current reforms are also a question of momentum: ''some regulators did not want to miss the chance to regulate, as it became legitimate to do so after 2008'' (Regulatory Officer, EU Commission). In other words, there are strong incentives for regulatory overshooting built into the system due to the difficult position that regulators find themselves in.

A majority of interviewees acknowledged that, in the post 2008 era, regulation has changed both its scope and its scale. Before the 2008 crisis light touch regulation was the established norm. Within the context of Dodd-Frank and EMIR, macro-prudential regulation and focus on systemic risk are the two defining features of the new regulatory regimes. As the clearing machine of OTC derivatives markets is being reconfigured it becomes clear that the pressures and constraints of regulatory authorities are the main driver of this new design. From the regulators point of view, the reforms are in the interest of the whole market, including the dealer banks, CCPs and wider participants (IMF, 2010), but they also affect the distribution of power within this market. Most regulators saw the 2009 G20 decision as a signal for them to enter the OTC market and transform the regulatory approach from incentives-based to detailed intervention, that is to say: ''there was a need to do something politically, which was welcomed by some interested parties in the market'' (Consultant, OTC derivatives). Thus the regulatory reforms represented a convergence between a political commitment at the G20 level, an opportunity window exploited by regulators and vested interests of the CCPs that were already clearing OTC derivatives and wanted to increase their market share.

8.3.3 Standardization

As we have seen, OTC derivatives are not as liquid or as standardized as more simple financial securities such as stock and futures. For example, a CDS depends on binary events (whether a company defaults or not), which can be very difficult to manage. While there are a lot of economic benefits in using these instruments, they have also proved to be problematic mainly because of their capacity to spread risk through the financial system (Moskow, 2006, p.47)(Singh and Segoviano, 2008). Credit derivatives such as CDS have historically not been cleared through a CCP but the 2008 crisis has forced the need to move them to a centrally cleared environment. Overall, the people interviewed acknowledged that a change had occurred in the way in which regulators understand the costs and benefits of OTC derivatives. The crisis has made it clear that most OTC products need to be centrally cleared, but this begs the question of whether or not all OTC products are eligible for central clearing.

The difference between the more standard products (shares, futures and options) and OTC products (swaps) is not simply a question of complexity but also one of more complex and longer life cycles. For instance, contracts such as CDS can be traded frequently at first but become very illiquid as they approach maturity (Pirrong, 2011, p.18). In trying to remedy some of these issues, the International Swaps and Dealers Association (ISDA) has been at the forefront of standardization and transparency of CDS contractual terms. Without earlier industry-led initiatives as the ISDA Master Agreement, the present transition towards central clearing would have been even more difficult. While some products are simply not standard or liquid enough, most OTC derivatives can be move to a centrally cleared environment:

> (…) the vast majority of bilateral interest rate swap and index-based CDS contracts are expected to move to CCPs, as are most single-name CDS contracts. However, commodity-based, equity-based, and foreign-exchange-based derivatives will be harder to move (IMF, 2010, p.10)

Any concern about the eligibility of OTC products for central clearing ultimately relates to their degree of standardization. Standardization is the process by which a product becomes mature, liquid, and simple enough to be transacted frequently and in large volumes. All of this is a prerequisite for CCPs to be able demand margin for these products, and for their lifecycle to be processed automatically. In case a clearing member defaults on its obligations, the CCP needs to be able to quickly liquidate the member's positions. This means that it is essential for CCPs to be able to choose the products they clear and are not simply forced to clear whatever type of contract. While the ''world of products is infinite'', it is important that regulators don't end up ''forcing CCP to clear what they can't clear'' (Consultant, OTC Clearing). In order for central clearing to work, contracts need to be standardized, traded frequently at publicly available prices (Pirrong, 2011). The less traded an instrument is, the harder it is to mark it to market, that is to say, to value it. While CCPs reduce the impact of a default on the rest of the market, they can also amplify risk by overcollateralization (i.e. increasing margin requirements) in times of market stress. This is particularly true regarding less liquid and/or less standardized products.

Unsurprisingly, professionals from banks had a heightened concern about the standardization of these less liquid products. In most cases, a reference was made to the fact that these more customized, tailor-made products allow for more precise hedging and fit more closely to the needs of certain clients, such as multinational corporations. Any kind of increase in standardization will obviously affect that side of the bank's business and reduce profits. There is another reason why bankers would be concerned about the increased standardization of OTC products. That is to say, even something as technical as the question of product standardization is ultimately a political issue in terms of who controls the processing of order flows. It is important to note that standardization facilitates not just clearing but the whole trade life cycle from trading to the settlement process. This is because more standardized products are more streamlined from a legal and operational point of view and are thus easier to process. Consequently, as contracts become easier to process, they will also become more amendable to be traded on order-driven electronic automated platforms (similar to the continuous double auction matching machines for shares and futures). In this sense, the standardization required by central clearing would have the added effect of also shifting the trading and matching of OTC derivatives from the control of dealer banks.

8.3.4 Transparency and liquidity

As we have seen, the eligibility of OTC contracts for clearing is an essential aspect for the future success of the new regulatory regime. Standardization is one element of this process, as well as questions of adequate liquidity and transparency (Lee, 2011). The OTC derivatives markets have historically been opaque relative to the exchange-traded products. This was mostly due to product specificity but also because major participants, such as dealer banks, had an interest in maintaining a low degree of transparency. Consequently, the majority of contracts were matched and cleared on a bilateral basis. The Lehman Brothers and AIG failures disclosed the considerable hidden risks of that opaque market structure. Before 2008, it was not possible to detect the build-up of risk in certain institutions and the systemic risk of interconnectedness. Once the creditworthiness of some systemically important players was put into question, the underling opacity led to a severe lack of liquidity (Gorton and Metrick, 2012).

As we have seen, the advent of electronic order books for shares and futures as well as the central clearing of these products led to more transparency for those markets. Different to those simpler financial products, it has be argued that OTC derivatives are what we could call episodic products, that is to say they trade more infrequently. From this point of view, some parts of the bond market are similar to OTC markets and for that very reason is less susceptible to exchange trading and central clearing. Some OTC instruments and some bonds trade in the first few weeks after they are issued and less frequently after that. For entities that are not directly involved in markets, there is a certain misconception that liquidity is always readily available, that is to say that you can always transact easily. For instance, in bond markets the market making dealer banks are engaged in the constant ‘’maintenance’’ of liquidity. A product that does not trade continuously entails a higher risk in terms of trading, matching and clearing. Consequently, for certain financial instruments too much transparency could have the paradoxical effect of limiting liquidity, in other words ‘’too much transparency kills liquidity’’ (Senior Regulatory Affairs Officer, Global

Inter-dealer Broker). Whether or not this is also true for OTC derivatives remains to be seen. What is certain is that increased transparency impacts the business models of dealer banks. As we know, the OTC derivatives landscape has largely been dominated by single-dealer or multi-dealer platforms, where over the phone voice broking was a dominant practice for matching trades (Smyth and Wetherilt, 2011, p.336). This state of affairs suited the major dealer banks, as they profited from the lack of transparency in the market. Consequently, the 2009 G20 mandate for higher levels of transparency through central clearing and electronic trading is likely to have a major impact on the profitability of the OTC business of banks.

> Resistance from the banks, as why should dominant players want to be on a level playing field with smaller competitors? The introduction of CCPs levels the playing field (Senior Executive, European Clearinghouse).

In conclusion, the effects of increased transparency are intimately linked with more standardization. As OTC markets become more transparent, the bank's dominance of both matching and clearing is likely diminished. Nevertheless, while the combination of central clearing and matching are expected to improve the resilience of OTC markets, a question remains on whether transparency is good in itself? In some of the more exotic OTC products, even if trading infrastructure improved, it is still hard to find the other side of the trade. In this sense, both pre and post-trade transparency become equally problematic and can lead to a deterioration of liquidity provision (Smyth and Wetherilt, 2011).

8.3.5 Risk

As we have seen from our description of the simplest IRS product, OTC derivatives can best be understood as risk transmission mechanisms. In the case of CDS, one party is looking to buy protection from certain credit events (defaults), while others are willing to bear that risk (Valiante, 2010). One of the issues with these kind of products is that while each party has an understanding of their own exposure and risk, they have no way of grasping the overall levels of systemic risk (Haldane and May, 2011). In fact, a recurring theme in our interviews was that of systemic risk and its multifaceted nature.

> The way CCP will be regulated should make them super robust. Multiple CCP default will be unthinkable (Policy Officer, European Regulator)

In order to better understand the issue surrounding CCPs and systemic risk, it is important to stress the difference between idiosyncratic risk on the one hand and systemic risk on the other. In the case of idiosyncratic risk, the problem lies in the particular situation of a single individual clearing member with no reference to the rest of the network. If risk was only idiosyncratic, then defaults would be random and basic risk management techniques could reduce the role of CCP to simple insurance practice (Bernanke, 1990, p.141). The financial crisis of 2008 has highlighted the importance of systemic risk, which is not isolated to any one single entity. In the context of regulatory reforms, the concern was that this type of risk was not going away, but merely being transferred to CCPs:

> The risks have not dematerialized. They have been concentrated in CCPs, (…) It is vitally important that CCPs are sufficiently robust that they don't fall over (Senior Director, Derivatives Trade Association).

In any case, it was obvious from the interviews that there was another important question regarding the optimal architecture for the central clearing of OTC. Namely, was it better to have a number of isolated CCPs consolidating OTC volumes or should these CCPs be interoperable and connected[69]? In other words, was the interoperability of CCPs likely to bring huge benefits or was it more likely to lead to more risks, such as that of contagion. If a large clearing member, connected to multiple CCPs, would go bankrupt, this would raise margin requirements across the board, affecting the whole market at once. Conversely, within a network of interoperable CCPs any default would immediately be transmitted to the rest of the network. As a default event propagates itself through the network, all CCPs would ask clearing members for more margin, requiring extra collateral for their portfolios. Problems could arise in times of market stress when participants engage in fire sales in order get hold of good quality collateral requested by CCPs, which would further amplify the problems. While a lot of things need to go wrong before a CCP fails, most interviews were very concerned about the issue of contagion risk. This leads to perhaps the most important risk-related issue, namely whether or not the central clearing of OTC derivatives replaces one type of ''too-big-to-fail'' financial institutions (banks) with new ones (CCPs)? In as much as CCPs need to be robust and resilient, only a few of them will be able to take on the challenge of clearing OTC products. Consequently, the concentration of OTC clearing around a small number of CCPs means that they could become the next systemically important institutions. In this sense, major CCP defaults would be another catastrophe for the global financial systems:

> CCP clearing of derivatives does not make the system safer, it simply transfers risk from the banks to the CCPs (Head of Collateral Management, Global Investment Bank).

While it is generally accepted that CCPs have very robust risk management practices, most professionals interviewed voiced serious concerns that central clearing could actually increase systemic risk and concentrate it an a small number of CCPs.

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[69] The contemporary landscape of OTC clearing is relatively fragmented between LCH.Clearnet, Intercontinental Exchange, CME Group and the Depository Trust and Clearing Corporation.

8.3.6 Social function

Throughout the interviews, we were also interested to understand the way in which OTC professionals relate to society. In fact, most of them highlighted the social impact of OTC market as something they were concerned about, acknowledging that one way or the other, there was no going back to the pre-crisis situation. Since then, it has become apparent that whatever goes on in complex derivatives markets can have a direct impact on society. Therefore, the regulatory response has been to publicize what used to be opaque private transactions and to standardize what used to be more customized contracts. Moreover, as the taxpayer ended up bailing out the systems, it now has a say in the way these markets operate. Because of this, the industry needs to explain itself and urgently regain some level public confidence.

> There is a lot of populism and public pressure, but introducing clearing through legislation is a good thing, as it will lead to important behavioral changes (Regulatory Affairs Officer, Global Investment Bank).

Most interviewees voiced their frustration with the negative perception of the financial services industry, as a result of the recent financial crisis, the excess of the industry as well as public's misunderstanding of financial markets. Consequently, there was a strong recognition of the need to educate the public, particularly as the taxpayer ended up supporting the system in the end. As one participant to the research told us: ''the collapse of AIG and Lehman Brothers proved that there were a lot of problems with OTC derivatives'' (CEO, Derivatives Trade Association). Nevertheless, the group of people we interviewed were convinced that financial services in general and most OTC derivatives have a beneficial effect on society:

> Financial services are ''the oil of the economy''. The more open the economy, the more important the financial sector. There is something real in the financial sector (Senior Executive, European Clearinghouse).

One recurrent position was that although certain OTC contracts were deemed not ''socially useful'' and should be made more expensive to use by market participants, they should not be banned altogether. In their view, the function of finance is to provide specific transactional services to society as a whole. Unlike academics, the professionals we interviewed were not thinking about issues of efficient allocation of welfare maximization. They actually meant the transactional functions that ultimately provide deep and liquid markets for institutional investors such as ''pension funds who bring assets to the market and play an important role in society'' (Senior Executive, European Clearinghouse). Therefore, the general accepted view was that, to a large extent, OTC markets service the long term hedging needs and ensuring the long-terms stability of such financial institutions.

On the other hand, even if one accepts the point about the social function of OTC derivatives, this should still beg the question as to the multifaceted nature of hedging and/or speculation in financial markets. Namely that in many cases the difference between hedging and speculation is a question of interpretation. While the distinction between good banking and 'casino' banking is certainty too simplistic, focusing solely on the hedging use of OTC derivatives precludes the wide spread systemic risk entailed in their use. Earning their livelihoods in these markets, it is easy to understand why most interviewees would not be inclined to make these more granular distinctions and would focus predominantly on the positive effects of these financial instruments.

8.3.7 Shifting market dynamics

All participants were concerned that a major market structure shift is underway, putting huge burdens on all participants on the OTC markets. The incoming changes entail considerable cost for all parties such as investments in IT infrastructure, additional legal and compliance requirements. As most interviewees noted, a lot of investment is required in order to make sure that you can confirm, clear and report trades. Moreover, the new central clearing regulations will require most market participants to post collateral in order to trade and keep derivatives positions open. Collateral efficiency is a central question for both investors and dealer banks, and in this context it will require considerable investment in collateral management systems. As one professional told us: ''CCP clearing of derivatives forces investors to worry about intraday cash positions and margin/collateral calls'' (Head of Collateral Management, Global Investment Bank). In fact, regulators are conscious of the burden put on the industry and have accepted exemptions or deferrals for certain categories of participants.

Because of the higher costs of participating in OTC markets, most people expressed concern about the inevitable concentration and consolidation resulting from the reforms. The complex process and workflows entailed by the central clearing model means that clearing really becomes a question of economies of scale and scope (Hasenpusch, 2009). That is to say the burden of operating in the new environment will likely drive small and medium sized players out of the market, leading to consolidation around a small number of CCPs and dealer banks acting as direct clearing members. Consequently, it should not come as a surprise that the clearing of OTC products becomes dominated by a number of global clearinghouses such as CME Clearing (owned by the CME Group), LCH.Clearnet (owned by the LSE), ICE Clear (owned by the Intercontinental Exchange) and Eurex Clearing (owned by Deutsche Borse).

As OTC derivatives transition to central clearing, the large dealer banks are no longer in control of the clearing function but nevertheless remain a dominant group within this new ecology. This is due to the fact that CCP are very risk adverse and prefer to interact with highly capitalized counterparties, which leads to a tiered membership structure (Galbiati and Soramaki, 2013). This first tier is made up by the so-called direct clearing members or Future Commission Merchants (FCMs)[70], which are highly collateralized financial institutions who contribute to the default fund and have very strong credit rating. These are usually the large dealer banks that have both the balance sheet and the technical base to bear the costs of central clearing. The next tier is that of non-clearing members who can only clear through the first tier members. This second group is composed of participants who do not meet the high standards of the CCPs in terms of creditworthiness or do not want to bear the full costs of clearing. As Pirrong (1997) argues, tiered clearing architectures emerge because members with better credit rating would not be inclined to subsidize weaker members. This goes both ways, as the CCPs are also not inclined to deal with counterparties who have lower credit rating. Moreover, a highly tiered clearing ecology is also indicative of the power of clearing members with a more robust financial position (Pirrong, 2011), namely the dealer banks.

On the other hand, some interview participants argued that the mandatory central clearing of OTC derivatives is likely to affect the dominance of dealer banks and have a decisive effect on how trading and matching is done. As we have already discussed, when a market adopts central clearing, products need to have a certain degree of standardization, which also means that they could become liquid enough to be traded on an order-driven platform, such as the electronic order books. In this sense, clearing ultimately shifts market share from dealer banks to other types of platforms. As more than one interviewee has highlighted: ''with clearing comes trading'' (Senior Executive, European Clearinghouse) which refers to the possibility that changes in one market function impacts other functions. In fact, this was already implied in the 2009 G20 declaration, as "all standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms, where appropriate'' (FSB, 2010). During the last few decades, electronic trading has already

[70] http://www.swapclear.com/service/our-members.html

revolutionized both stock and futures markets, but it had a more limited impact on OTC derivatives and as of ''June 2010 around 12% of interest rate swaps and just below 17% of all credit default swaps were traded electronically'' (Smyth and Wetherilt, 2011, p.334). Nevertheless, the present introduction of central clearing is likely to also accelerate the transition of matching towards electronic platforms. One such example would be the so-called Swap Execution Facilities (SEFs). Traditional inter-dealer brokers (ICAP, Tullett Prebon, Tradition) as well as Bloomberg and Tradeweb have set up such facilities. In addition to this, exchanges who own CCPs such as CME and ICE have also established SEFs and are competing for market share in trading and matching of OTC products such as interest rate swaps and credit default swaps, according to recent research by McKinsey (Rudisuli and Schifter, 2014).

In conclusion, a considerable number of interviewees suggested that one long-term consequence of the reforms is the gradual transfer of both clearing and matching of OTC derivatives from the dealer banks to CCPs and order-driven exchange-type platforms such as SEFs. In fact, according to Rudisuli and Schifter (2014), the large dealer banks stand to lose as much as $4.5 billion per year from the regulatory changes, which in some cases could pose an existential treat to entire business lines. This tendency seems to be very similar to what happened over the course of the 20th century to other markets such those for shares and futures. In fact, most interviewees interpreted current reforms as a regulatory-induced transition towards the matching and clearing designs already established in these markets. From the perspective of the evolution of transaction machines, we could see this as the transposition or exaptation of the matching and clearing designs from one financial market to another, an example of 'machinic' contamination.

Conclusion

Following the 2008 financial crash and the failure of major financial institutions, regulators and governments decided to radically overhaul the OTC derivatives market. The 2009 G20 decision promoted transparency and mandated the transfer of more standardized products such as IRS and CDS from bilateral to central clearing via CCPs. As we have seen, CCPs act as the buyer to every seller and the seller to every buyer, requiring initial margins, monitoring portfolios and imposing robust risk management methodologies (Pirrong, 2011, p.16). That is to say, in the aftermath of the 2008 financial crisis, regulators decided there was an urgent need to reconfigure and redesign the clearing machine of OTC derivatives markets.

In trying to gain a better understanding of this new clearing machine and its new dynamics, we pursued a number of interviews with senior professionals from the OTC derivatives market. The results of these interviews were summarized along a series of general themes: regulation, standardization, transparency, risk, social function and shifting market dynamics. To a large extent, all of these themes reflected specific concerns regarding the new regulatory regime. The aim of this research was to highlight the current state of the OTC market and the impact of this transition from bank-dominated bilateral clearing towards a new design based on centralized clearing dominated by CCPs.

While all participants saw the new regulations as a burden, there was a strong perception that reforms would have asymmetric effects on different constituencies. For instance, banking professionals were mostly worried about the levels of transparency and standardization brought about by the reforms, which have a direct impact on their business. Regulators were mostly concerned with questions of systemic risk and market resilience. Another important point regarded the impact on market liquidity of pushing less standardized products into central clearing. The issue of transparency frequently came up particularly as well as the question of contagion risk, particularly in the context of CCPs becoming the new too-big-to-fail institutions. In the face of intense public critique, most interviewees tended to focus on the use of OTC products for hedging rather than the systemic risk entailed in them.

During the course of the interviews it became clear that the major themes emerging could be brought back and reinterpreted in light of our transaction machines framework. Namely, that the intricate details surrounding the current regulatory reforms could actually be understood as a process of redesigning a complex clearing machine. Moreover, as the OTC market transitions towards central clearing, CCPs are now becoming its dominant transactional hubs. For instance, all participants now have to adopt specific clearing practices of CCPs, such as netting, novation, margining, etc., in order to keep trading OTC contracts.

The large dealer banks that used to control the OTC clearing business now find themselves in a secondary position, as clearing members of CCPs. They must contribute to CCPs default funds, post margins and ensure that their clients comply with the rules and procedures set forth by CCPs. These changes are not simply technical issues but are very much political in the sense that the granular details of the new clearing model are impacted by certain power dynamics in the market, such as the much stronger position of regularity authorities and CCPs relative to the dealer banks. Moreover, as OTC derivatives move to a centrally cleared model, they are also more standardized and liquid enough to be traded and matched on electronic platforms, such as SEFs. This will likely have an additional impact on the revenues of dealer banks (Rudisuli and Schifter, 2014). While banks are still the major participants in the OTC markets as market makers, functions such as matching and clearing are gradually moving to a CCP utility type model, quite similar to the decade-long process of change that transformed the markets for shares and futures.

Conclusions

Transactions in the Age of Intelligent Machines

Manuel DeLanda's *War in the Age of Intelligent Machines* (1991) was a source of inspiration for this thesis. In this early book, he offers an account of the evolution of weapon technology ''under the selective pressures of human warfare'' (Erik Davis, 1992). In a certain way, the aim of this thesis was to explore a similar approach by describing the evolution of transaction machines under the selective pressures of human society and economy. In his history of weapon technology, DeLanda proposes a map of the critical thresholds of the development of warfare, with a particular interest for modern mechanized armies (DeLanda, 1991, p.23). In that context, the use of written orders ultimately led to a substantial increase in paperwork. Under these constraints, he sees the advent of the Prussian general staff as the first ''organization for gathering, process and transmitting information over vast distances'' (DeLanda, 1991, p.70). Later in the 20th century, a further increase in the information flows means that centralized command centres become a great vulnerability; leading to the development of decentralized communication networks in order to increase overall ''survivability''. One example of this trend was the ARPANET network of the US military (which was effectively a blueprint for the Internet), allowing for distributed information processing. A crucial point here is that the advent of electronic networks allows for development of ''localized intelligence''. He calls this tendency of electronic networks to develop decentralized intelligence as ''demons'' or ''independent software objects'' as they are not under a continuous centralized control. This also leads to higher levels of automation and a reduction of the role played by humans. Interestingly enough, writing in 1991, he also identifies broader socio-economic consequences such as the advent of automated electronic markets:

> Independent software objects will soon begin to constitute even more complex computational societies in which demons trade with one another, bid and

compete for resources, seed and spawn processes spontaneously (DeLanda, 1991, p.121)

We could say that DeLanda's intuition was incredibly accurate and it still resonates today in the context of contemporary e-commerce, as well as being relevant to the recent transformations in financial markets. As we have argued, giving an account of this technological evolution is an absolutely necessary step for any kind of account of contemporary financial markets. Moreover, as we have also seen, this is by no means an easy task as it requires an adequate understanding of the relationship between the social and the technological as well as the way in which markets can be understood as complex machines in their own right.

In fact, Donald Mackenzie (2014) himself has recently argued the present state of automated electronic markets is still ''largely opaque to economic sociology'' (MacKenzie, 2014, p.3). He organizes the Social Studies of Finance (SSF) literature into three types of perspectives. First, you have approaches describing situations where market participants are human beings and the market structure is fundamentally a form of human interaction. Secondly, there are accounts where most participants are still human beings but the market is understood as an algorithm. The third type of approach is where both the users and market structure itself is driven by algorithms (MacKenzie, 2014). Within this taxonomy, he positions most of the SSF literature within the second category and it could be argued that the present thesis tries to position itself somewhere in the third category, while also taking the position that financial markets have an algorithmic or 'machinic' nature from the very beginning. That it is possible to model and understand even the oldest forms of financial markets as comprising precise rules and procedures that can be formalized as a series of algorithms. Moreover, the way in which society uses these markets can also be seen in an algorithmic gaze. As we have already explained, this thesis assumed the 'machinic' nature of financial markets from the start, rather than as a recent epochal shift disrupting a pre-established social structure. The important difference is that this thesis has not engaged with financial markets in as much as they are social structures, but has focused on their transactional infrastructure, on those mechanisms specifically designed to perform certain market functions[71].

We used the term transaction machines, guided by the general framework provided by cybernetics, informational theory and computer science. As we have shown, the notion of transaction machines allowed us to grasp both Simondon's multifaceted understanding of machines while at the same time remain focused on specific transactional capabilities as described by Mirowski's theory of markomata. The aim of the thesis wad not to dehumanize financial markets or to argue that human beings are no longer involved in them. To the contrary, it seemed more interesting to look at how financial markets function at their most basic level, to a large extent independent of the composition of their 'hardware'. In practice, this meant focusing on the complex machines that process and manage the flow of financial transactions. This was certainly different from studying how hybrid networks of humans and non-humans assemble in order to create a new financial product, how financial models can have a performativity effect or the way in which financial technology impacts on the behavioural patterns of human traders. Departing from this literature, the thesis offered an understanding of past and current financial markets by looking at the unfolding of a 'machinic' trajectory, the evolution of specific transaction machines performing a number of functions relative to the processing and maintenance of financial flows.

[71] While this infrastructure entails a diverse set of functions, the thesis has focuses on two of them, namely the matching and clearing of order flow, in as much as they represent essential mechanisms for the very existence of financial markets.

The Evolution of Transaction Machines

The structure of the thesis was divided into three parts. Part I was composed of three theoretical chapters followed by Part II organized around three historical chapters. These provided a gradual unfolding of what we mean by transaction machines and then reinterpreting the history of financial markets in light of this theoretical framework. Our approach was directly inspired by Philip Mirowski's assertion that any kind of critique of the present political economy requires a natural history of markets. In his theory of markomata he provides the initial building blocks for such a history, by looking at the evolution of matching/auction designs. We leveraged his work in our description of the matching function and also provided an initial sketch for the evolutionary trajectory of clearing. In fact, the importance of history cuts across the whole thesis as we endeavored to shed light on the complex evolutionary process that led the current state of financial markets.

We first tracked matching machines as they developed in the context of medieval brokers performing bilateral direct matching. Later, the brokers of the Amsterdam Exchange developed more complex multilateral matching machines. In the 18th and 19th centuries the LSE and NYSE represented another evolutionary step, establishing a matching based on continuous double auctions.

Components		Algorithms
Bills of Exchange	Brokers Merchants-Bankers	Bilateral matching (direct matchmaking)
Shares	Bourses Exchanges	Multilateral matching (Anglo-Dutch auctions)
Shares	Exchanges (LSE, NYSE)	Centralized matching (continuous double auction)

Figure 23: Evolution of matching machines

We also developed a different narrative focused on the clearing function as it first emerged in the context of medieval fairs. As modern financial markets became more complex, they also required more elaborate clearing machines, such as the multilateral designs of the London and New York Clearinghouse. Moreover, we looked at how multilateral clearing migrated to the stock market, such as in the case of the NYSE Clearinghouse. The crucial step occurred in the Chicago with the transition towards the central clearing of derivatives. The BOTCC initially served as a multilateral clearing facility, but ultimately became a Central Counterparty (CCP), the buyer to every seller and the seller to every buyer.

<table>
<tr><th colspan="2">Components</th><th>Algorithms</th></tr>
<tr><td rowspan="2">Bills of Exchange</td><td rowspan="2">Merchants-Bankers
Clearing fairs</td><td>Bilateral clearing
(direct clearing)</td></tr>
<tr><td>Multilateral clearing
(clearing chains and cycles)</td></tr>
<tr><td rowspan="2">Payments
Shares
Futures</td><td rowspan="2">Clearinghouses
CCPs</td><td>Multilateral clearing
(clearing rings)</td></tr>
<tr><td>Centralized clearing
(complete clearing)</td></tr>
</table>

Figure 24: Evolution of clearing machines

The table above provides a sketch for the evolution of clearing similar to our analysis of matching, from bilateral clearing (or direct clearing) to multilateral clearing (clearing chains and cycles or modern clearing rings) and finally to central clearing (or complete clearing with CCPs). In fact, the two tables above summarize our attempt to organize the evolutionary trajectory of transaction machines by distinguishing between bilateral, multilateral and centralized designs. This trajectory takes us from the simple to the complex, from more common to more complex designs. Under certain conditions, a certain community of users adopts a specific transaction machine, deemed sufficient and adequate in terms of servicing their transactional needs. Then something happens such as increased volumes, more sophisticated users, new financial instruments, more advanced technical capabilities or regulatory/political interventions that trigger the evolution towards new transaction designs. Consequently, each generation of transaction machines tends to be more computationally expensive and more difficult to construct and maintain. As we have seen, more elaborate matching machines, such as continuous double auctions, and clearing machines performing central clearing only emerge in financial markets which a more sophisticated investor base, higher levels of liquidity and more intricate risk exposures. As we have seen, this evolutionary process is not simply the result of the need to reduce costs and streamline the process. It is also a consequence of a long series of financial panics and crashes over the course of the last 200 years, a process of learning and experimenting. As a response to these selection pressures, we have seen the gradual systematization of transaction machines towards centralized matching and clearing organized in more integrated structures such as exchanges and clearinghouses. For instance, this tendency is clearly at work in the integrated silo structures of the largest global stock and derivatives exchanges.

	London	**Frankfurt**	**Chicago**	**New York**
Exchanges (matching)	LSE	Deutsche Börse	CME/CBOT	NYSE/NASDAQ
CCPs (clearing)	LCH.Clearnet	Eurex Clearing	CME Clearing	DTCC

Figure 25: Current financial infrastructure providers

As the table above highlights, there is indeed a trend towards consolidation around a small number of financial infrastructure providers, integrating matching and clearing across different financial instruments[72]. The most obvious examples are the vertical silo structures of the Chicago Mercantile Exchange Group and the Deutsche Börse, incorporating and aligning the matching and clearing functions in one single flow

[72] As explained by Pirrong (2009), Lee (2011) and Hasenpush (2009), there are considerable economies of scale and scope in integrating both the matching and the clearing function across all financial instruments such as shares, bonds, futures, options, swaps, etc.

architecture. With the adoption of electronic trading and central clearing in conjunction with the increased standardization of financial products, these integrated exchange and clearinghouse become the dominant transactional hubs of global financial markets. In other words, as financial markets mature they require an increasingly efficient transactional infrastructure. In fact, over the course of the thesis we tried to describe the gradual systematization and organization of more elaborate transactional capabilities.

Present and Future of Transaction Machines

Part III of the thesis comprised two chapters focusing on the contemporary state of matching and clearing machines. Part I and II of the thesis were dedicated to fully elaborating the theoretical framework and then following the evolutionary trajectory of transaction machines through history. In this regard, we focused on how different transactional designs move from bilateral to multilateral and centralized algorithms, as well as the way in which the 'hardware' of these machines gradually transitioned from human-based pen and pencil infrastructure to electronic automated platforms. Part III, comprising chapter 7 and 8, was a continuation of this narrative but also an attempt to focus on the question of politics and power in framing and designing contemporary transaction machines. In as much as these machines change under the constraints and pressures of its users, it would be wrong to look at their evolution as simply a narrative of increased technological efficiency and complexity[73]. In fact, as we have already noted, the control of transaction machines is a crucial aspect in grasping the power dynamics in financial markets, understood in terms of the ability to maintain, organize and process the flow of financial transactions. That is to say, it is also important to look at how the actual design of transaction machines is both influenced and impacts the intricate power distribution of financial markets. Therefore, the last two chapters of the thesis have focused on the importance of power in the context of contemporary transaction machines.

In Chapter 7, we reviewed the current state of matching machines, the development of electronic order books as well as the new forms of market making in the context of HFTs. As the processing of order flow shifts from human hands to electronic order books, matching becomes more efficient, automated and anonymous. At the same time, the advent of electronic market making entails a shift in the power dynamics of markets, as the matching functions is no longer the monopoly of human specialists

[73] In fact, as we have seen both in Simondon and Mirowski's case, the structure of machines is heavily influenced by the wider human society.

on the floor of the exchange but becomes open to competition. As we know, the privilege of making markets and being at the centre of liquidity affords a crucial advantage in any market as well as substantial profits. This in turn leads to an arms race driven by lower latencies of execution, constant optimization and large investments in IT capabilites, just to be one millisecond ahead of everyone else. According to Andy Haldane, this algorithmic/electronic ecology is best understood as a downward spiral or a race to zero, with HFTs at the centre of a daily struggle for controlling and channelling order flow. We also offered an understanding of the 2010 Flash Crash as an inevitable output of HFT-dominated markets, and some of the recent design innovations aimed at addressing this problem.

In Chapter 8 we addressed the current state of clearing, focusing on the adoption of central clearing for OTC derivatives. Following the 2008 crisis, the failure of several large financial institutions raised serious concerns regarding the resilience of the OTC clearing infrastructure. Consequently, the 2009 G20 summit mandated the central clearing of standardized OTC derivatives, resulting in a radical overhaul of OTC markets. We also pursued a number of qualitative interviews to highlight the current state of the OTC market and the impact of the transition from dealer-dominated bilateral clearing towards a new design based on centralized clearing. As we saw over the course of the interviews, issues and concerns that seem to be related to specific technical details could also be understood as political, in the broadest sense of the term. That is to say, the new centralized clearing design obviously led to different power distributions, as dealer banks would lose the substantial benefits of the bilateral clearing model. While these banks are the main market makers of OTC derivatives markets, functions such as matching and clearing are gradually moving to the CCP utility type model, similar to the century-long process of change that unfolded in stock and futures markets.

We thus argued that certain processes and mechanisms that at first glance seem to be primarily technical aspects of transaction machines are actually a core part of the functioning of global financial markets. This is clearly evident in the integration of matching and clearing machines around a small number of financial infrastructure providers that dominate the processing and maintenance of financial flows. The design of this complex architecture has a decisive impact on the structure and power dynamics of financial markets. Details pertaining to issues such as minimum resting times before a an order is matched, limitations on the number of canceled orders or the access to colocation and low-latency, are all crucial in determining who can control the matching of order flow. Similarly in the context of clearing, technical details such as what constitutes a standardized products, how much margin and collateral is needed in order to clear, are CCPs interoperable or not, what are the requirements for clearing membership are all crucial in determining the landscape of clearing participants. Moreover, as we have seen in the case of the 2010 Flash Crash and more broadly in the context of the 2008 financial crisis, apparently insignificant technical details of transaction machines can have a huge importance and have significantly impact market resilience and stability.

As we have said in the beginning, the aim of the thesis was not simply to satisfy an intellectual curiosity about the 'machinic' nature of financial markets. While the initial goal was to offer an account of the past and present of these markets through the interdisciplinary lens of transaction machines, the thesis also opens up the possibility of a broader critical engagement with finance. Different to critical approaches looking at the relationship between money and debt (Graeber, 2011, Lazzarato, 2011), this thesis aims at a constructivist way of looking at financial markets. First, it unpacks the various functional layers of financial markets, highlighting the fact that categories such as 'global capital' or the 'Market' are perhaps too general and preclude a more granular understanding of how financial markets actually work.

While financial markets can be seen as just another means for global capital domination or as an optimal allocation mechanism, they can also be seen as complex machines for the processing and maintenance of financial flows. In fact, as we have seen, perhaps the primary function of financial markets is to provide a stable and reliable platform for the processing of financial transactions. To this aim, the thesis developed a taxonomy of transactional designs making a contribution to what

Mirowski called a natural history of markets. In a certain sense, even talking about financial markets in general can be problematic as the integration of different transaction machines can lead to significantly different market structures, different outputs and significantly different power distributions in terms of controlling financial flows. It was therefore essential to deconstruct the various functional layers of financial markets and offer an account of the evolutionary process that led to the complex flow architecture underpinning contemporary financial markets.

As we have seen, this approach can be used to shed new light on what is at stake in the current transformations of transaction machines, which is particularly important for the political economy of contemporary finance. As noted by Michael Moskow, referring to exchanges and clearinghouses as the 'plumbing' of markets is perhaps not the most adequate metaphor. In as much as they integrate the matching and clearing functions, managing the flows of financial transactions, it might be more accurate to refer to them as the ''central nervous system'' of financial markets (Moskow, 2006, p.46). This is a particularly important point in the context of clearing and the migration of more complex derivative products towards CCPs. As larger volumes of flows are channelled through them, CCPs effectively become the new too-big-to-fail financial institutions. This concern has been recently been acknowledged by former Deputy Governor of the Bank of England Paul Tucker, when he characterized CCPs as being super-systemic institutions that perhaps should to be regulated like public utilities. In his own words, their importance for contemporary financial markets shouldn't be ignored:

> Although the distance from households to clearing houses is large, the public now depends on the safety, soundness and efficiency of CCPs. If this part of the plumbing were neglected, it would be a disaster (Tucker, 2014, p.12)

While the post-crisis period has been dominated by the critique of the major banking institutions, it is clear that the center of gravity of global financial markets is now shifting towards the integrated financial infrastructure providers, comprising both exchanges and clearinghouses/CCPs, controlling and maintaining the matching and clearing of financial flows.

It this sense, a detailed account of the evolution of transaction machines is needed more than ever. Understanding what design was developed, for what purpose, under what constraints, benefiting which constituency and exhibiting various degrees of stability and resilience to external shocks. In fact, any critical engagement with financial markets should perhaps start with an analysis of the fragility of these transaction machines, acknowledging the level of risk and complexity that is perhaps intrinsic to these systems. In this context, one does not need to choose between either rejecting these machines outright or accepting the dominant designs of the day. To the contrary, it allows us to act more like engineers, effectively taking these machines apart and perhaps designing new ones, which could be more resilient in their functioning and more equitable in their outcomes.

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