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Machines that make and keep promises - Lessons for contract automation from algorithmic trading on financial markets

Maria José Schmidt-Kessen[a,*], *Helen Eenmaa*[b], *Maya Mitre*[c]

[a] *Assistant Professor, Legal Studies Department, Central European University, Quellenstr. 51, 1100 Vienna, Austria*
[b] *(JSD Yale Law School) Researcher in Legal Philosophy and Technology Law, founder of the IT Law Programme at the University of Tartu School of Law, Näituse 20, 50409 Tartu, Estonia*
[c] *Postdoctoral Researcher, Copenhagen Business School, Porcelænshaven 18B, 2000 Frederiksberg*

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ABSTRACT

An important part of the criticism raised against the adoption of advanced contract automation relates to the inflexibility of automated contracts. Drawing on rational choice theory, we explain why inflexibility, when seen as a constraint, can ultimately not only enhance welfare but also enable cooperation on algorithmic markets. This illuminates the need to address the inflexibility of contracting algorithms in a nuanced manner, distinguishing between inflexibility as a potentially beneficial constraint on the level of transactions, and inflexibility as a set of systemic risks and changes arising in markets employing inflexible contracting algorithms. Using algorithmic trading in financial markets as an example, we show how the automation of finance has brought about institutional changes in the form of new regulation to hedge against systemic risks from inflexibility. Analyzing the findings through the lens of new institutional economics, we explain how widespread adoption of contract automation can put pressure on institutions to change. We conclude with possible lessons that algorithmic finance can teach to markets deploying algorithmic contracting.

1. Introduction

The considerable speed of digitalization and datafication in many areas of the economy and society, paired with analytics and developments in machine learning and artificial intelligence, theoretically allow for automating all stages of a contract's lifecycle: search, negotiation, formation, performance, interpretation, and enforcement. The reduction or outright removal of human involvement in the process of contracting and its replacement with algorithms can have all kinds of consequences - benefits, risks, and uncertainties. On the one hand, contract automation bears the promise of cost reduction, increased efficiency, creation of better contracts, new markets and more value. On the other hand, the use of technologies for contracting pose challenges that span from the redundancy of traditional jobs and expertise roles to technical errors and lack of transparency, resulting in risks related

* Corresponding author.
E-mail addresses: schmidt-kessenm@ceu.edu (M.J. Schmidt-Kessen), helen.eenmaa@ut.ee (H. Eenmaa), mm.law@cbs.dk (M. Mitre).

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to liability, accountability, and human autonomy. Some authors have considered these risks to derive from the inflexibility of algorithms. Given this context, the goal of this paper is, first, to explain how the inflexibility of advanced contract automation, viewed as a drawback or a benefit, relates to the underlying values of contracting and, second, to discuss what we can learn from algorithmic trading on financial markets when considering how to best accommodate inflexibility in advanced contract automation. In view of regulatory initiatives in this field, we suggest addressing the inflexibility of advanced contract automation by distinguishing between inflexibility of algorithms as a potentially beneficial constraint on the level of individual transactions, and inflexibility as a set of changes and systemic risks that arise on the markets as a result of employing contracting algorithms. This work contributes to the general discussion on algorithmic and smart contracts (e.g. Brownsword 2019; 2020; Scholz 2017; Werbach and Cornell 2017; Savelyev 2017; Mik 2017), and in particular, to the discussion of the issue of inflexibility in contract automation (Sklaroff 2017; McKinney et al. 2018; Finck 2019).

We start the paper by explaining how the inflexibility in advanced contract automation relates to the underlying values of contracting. Here, we highlight how the issue of the inflexibility of algorithmic contracts has repeatedly been pointed out in the literature as a drawback, if not a threat, to the foundational values of contracting. The third section introduces the reader to our conceptual framework that links the discussion around the inflexibility of algorithmic contracts to the concept of constraint as it is found in rational choice theory and in new institutional economics. In the fourth section, we introduce algorithmic trading and its regulation on financial markets in the EU as a case study to generate useful insights for discussing the possible need for regulatory intervention in other areas of contract automation. In the fifth section, we analyze how financial market regulation in the EU has dealt with the new risks deriving from inflexibility in algorithmic trading. This allows us to use an instructive real-life example of large-scale contract automation for discussing the problem of inflexibility within contract automation, a discussion that has been mostly theoretical in nature.[1] In the sixth section, we draw a connection between the reform of financial market regulation in response to algorithmic trading and the economic scholarship on constraints, summing up the lessons that these could teach for the broader discussion of contract automation across other sectors, in particular those related to blockchain ecosystems.

With this article, we make two original contributions. First, while a significant part of the literature claims that advanced contract automation (in particular smart contracts on blockchain) is of very limited applicability in practice, and harmful to the values of contracting, we discuss empirical evidence that goes against these claims: financial markets have already longstanding and wide experience with automating transactions of a contractual nature. Second, we use rational choice theory and new institutional economics as a theoretical framework that helps explain the intertwinement of advanced contract automation at the level of the individual transaction with its wider societal impact. In order to accommodate highly sophisticated transaction technology that may involve systemic risks, institutional changes need to happen, i.e. the set of rules (be it general contract law or sector-specific regulation) applying to a certain market that adopts automation is put under pressure to change.

2. The problem of inflexibility in contract automation

2.1. *Contract automation*

Contract automation has multiple meanings depending on the type and purpose of automation. Under the headings of ‘e-contracts’ (Governatori et al. 2018), ‘XML contracts’ (Cunningham 2006), ‘computable contracts’ (Surden 2012), ‘smart contracts’ (Szabo 1996; Staples et al. 2017), and ‘algorithmic contracts’ (Scholz 2017), scholars working at the intersection of computer science and law have engaged in theoretical and empirical work to foster the understanding of contract automation. In addition to its conceptualisation, this work has included experimentation with representing contracts and contractual relationships in a variety of computer languages and with the help of different algorithms (e.g. Governatori et al. 2018; Idelberger 2020). The latest academic wave on contract automation came with the rise and hype around blockchain technologies and smart contracts (e.g. Werbach and Cornell 2017; Savelyev 2017; Sklaroff 2017; Eenmaa-Dimitrieva and Schmidt-Kessen 2019).

The first wave in automating commercial contracts with the help of computers dates back to the late 1960s. Contract automation was meant to simplify contracting and to integrate it in companies’ information systems so as to reduce cost and increase efficiency in contracting (Goldfarb 1996; Sklaroff 2017). Computerized information systems and algorithms have already had a significant impact on contracting practice when it comes to drafting contracts with the help of text blocks and decision trees, and contract management software which facilitates monitoring and digitally analyzing contracts (Timmer 2019). These transformations are optimizing contracting processes and still require human involvement, but they do not fundamentally change contracting practice and the legal profession (Timmer 2019; Susskind and Susskind 2015).

At the same time, with technologies for contracting that almost entirely dispense with human involvement, the practice of various professions could change. The example of traders in financial markets is a case in point. Scholars at the intersection of sociology, technology, and law often point to the fact that, due to automation, traders can now “delegate a portion

[1] This is in particular true for the literature on blockchain-based smart contracts. Real-life applications of automated tools in other areas of contract law have been limited, too. Here, automation has been discussed mainly in academic literature and in particular on how automated tools could help in identifying contractual provisions that are in breach of regulations. See, e.g. Lippi et al., (2017) on automated tools for the recognition of unfair terms in consumer contracts, and Contissa et al. (2018) on AI tools to check whether privacy notices comply with the EU General Data Protection Regulation.

of the practice of trading to automats", something which develops "new kinds of market authors" (Lenglet 2011:47). Brokers, for instance, once "valued for their ability to provide insightful recommendations on financial instruments to their clients" (Lenglet 2011: 48), have now to sport the ability to navigate the world of algorithmic trading speedily and dexterously. Most importantly, automation, as all technological innovation, is not something externally imposed onto institutions and human actors. Instead, as established in the tradition of STS scholars such as Bijker and Law (1992), "social and technological change are better visualized as intertwined, codependent, mutually constructed trajectories" (Pardo-Guerra 2012: 570).

In the specific case of advanced contract automation, technologies would include machine learning algorithms that develop contracting strategies and identify ideal contracting partners. By "emulating" human intuition, they provide an avenue for automation to bring more fundamental change (Martins Pereira 2020).[2] Such algorithms take over decision-making functions and determine the contractual clauses or transaction parameters based on previous instructions from either humans or other algorithms. Algorithms and digital infrastructures can be increasingly used to automate the performance and enforcement of contracts without human involvement. For example, in the case of ride-hailing apps such as Uber, algorithms decide which drivers a user can choose from, set the price, monitor that the actual ride takes place, and transfer the payment from the user to the driver.

Within the platform economy, platforms act as algorithmic intermediaries for contracts that they enable to conclude (e.g. Mak 2016). Such automated transactions rely on a centralized system that sets the terms and conditions for transactions and automatically executes them. Advanced forms of contract automation that require little or no human involvement do not require centralized orchestration of transactions. Such disintermediated settings offer one of the latest frontiers for the transformative potential of contract automation. In such settings, the parties or their algorithmic agents (Sartor 2018) conclude machine-readable contracts leaving the precise content, interpretation of meaning, and execution to machines. Here, it is up to the machines to make and keep promises.

The term "algorithmic contract" has been proposed by Scholz (2017) to define "contracts in which one or more parties use an algorithm to determine whether to be bound and how to be bound" to an agreement. She specifies that "algorithmic contracts are contracts that contain terms that were determined by an algorithm rather than a person" (Scholz 2017).[3] As we will explain in Section 4, investment decision algorithms and sophisticated execution algorithms in algorithmic trading on financial markets would fall into the category of algorithmic contracts.

Algorithmic contracts need to be distinguished from smart contracts that have been defined as terms of an agreement drafted in computer language, which are executed automatically by transaction protocols without the need of any human intervention (Szabo 1996; De Caria 2019). In simple terms, a smart contract is an executable code: when specific conditions are met, it triggers a follow-on action. These encoded instructions do not necessarily amount to a legally binding agreement or contract, but they can be used to automate the execution of binding contractual conditions (e.g. Mik 2017; De Caria 2019). We regularly think of smart contracts as automating the performance and enforcement stage of a contract (Riehm 2019). For example, execution algorithms,[4] especially non-sophisticated execution algorithms can be considered a form of a smart contract.

Smart contracts are often associated with a specific infrastructure technology: blockchain (De Filippi and Wright 2018, 72; Tjong Tjin Tai 2017; De Caria 2019). Blockchain-based smart contracts are encoded in a suitable programming language, e.g. Solidity in the case of the Ethereum blockchain. Due to blockchain technologies relying on methods from cryptography, including the use of hashing functions, it becomes very difficult to tamper with a smart contract once it is placed on the blockchain. The execution of smart contracts is fully automated as protocols verify the conditions for performance and execute the smart contract protocol. In cases where the smart contract code contains both the agreement itself and the instructions for execution, the distinction between the agreement and its execution collapses, particularly considering that the agreement cannot be modified once placed on the blockchain (Sklaroff 2017; Diedrich 2016)

The potential of smart contracts to disrupt law, institutions, and commerce has been met with both enthusiasm (e.g. Fairfield 2014; Tapscott and Tapscott 2016) and skepticism (e.g. Mik 2017; Giancaspro 2017; Reyes 2016). While enthusiasts point out that smart contracts could significantly reduce transaction costs by eliminating the need for monitoring performance and litigation over non-performance, skeptics raise concerns about their inflexibility, claiming among else that smart contracts limit possible contractual relationships to whatever can be expressed in computer-readable instructions (Giancaspro 2017; Werbach and Cornell 2017). This is supplemented with concerns about their potential for being used for illegal or criminal causes as the execution of relevant algorithms is guaranteed without having to rely on law

[2] Here, we are extrapolating from Martins Pereira's (2020) fine categorization of the current stage of algorithmic trading and the likely future stage of algorithmic trading. While the former is characterized by "machines (..) that formulate and implement trading decisions within the limits of pre-coded rules" (2020, 277), the latter promises the replacement of the straightjacket of the rigid pre-coded rules by the capacity to adapt to and formulate new rules "on the go" - something that could be seen as similar to human intuition or learning.

[3] Scholz (2017) considers high frequency trading on financial markets to be a form of algorithmic contracting. We will explain how algorithmic trading on financial markets fulfills the definition of an algorithmic contract in our methodology section below. Using Scholz's definition, Martins Pereira (2020) adds that although in principle one could accept the idea of algorithmic trading comprising all trading that "follows a set of predetermined rules, regardless of whether these rules are then followed by a human being or, instead, a machine (2020: 278)", it is also true that given the current technological development algorithmic trading (and, by extension, algorithmic contracts) refers, in practice, to instances wherein machines deploy and perform algorithms transformed into computer code.

[4] Execution algorithms are a type of algorithm deployed in algorithmic trading on financial markets, see Sections 4 and 5 below.

or state institutions (ibid.). In the next part of the paper, we will focus on the inflexibility argument and the implications this has for the practice of contracting. While critics have been concerned about the inflexibility of smart contracts, the argument extends also to other forms of advanced contract automation.

2.2. *Inflexibility in contract automation*

One of the core challenges with algorithmic contracts is their inflexibility: the fact that the automation of some or all stages of a contract's life cycle, from search and drafting to performance and enforcement, limits subsequent adjustments or modifications. In the case of smart contracts, the problem of inflexibility derives from the fact that once the code has been placed on a blockchain and launched, it carries out the indicated tasks according to encoded instructions and its performance cannot be modified or canceled.[5] Even in instances where the code includes special intervention functions (Tapscott and Tapscott 2016), these are executed only at the envisioned moments based on the explicit and precise instructions foreseen at the moment when the code was launched, and as such are also inflexible. Both, (1) inflexibility in the contract performance stage of algorithmic contracts, especially with the use of smart contracts (parallelling with the relative inflexibility of financial trading algorithms), and (2) inflexibility of a contract as a whole if the code contains both the agreement itself and the instructions for execution, have been considered problematic and at the same time pertinent because of the intense interest in and need to accommodate fast-developing technologies in society.

There are two main ways in which the problem of inflexibility has usually been expressed. First, critics claim that flexibility creates important efficiencies in contracting practices, which are bound to be diminished or eliminated by the inflexibility of smart contracts (*limited efficiency argument, criticism 1*) (Sklaroff 2017). A second criticism lies in the argument that even when the inflexibility of contracts or contract performance creates benefits, the range of such application scenarios is very limited (*limited application argument, criticism 2*) (e.g. Levi and Lipton 2018).

There are various possible responses to these sets of criticism. Considering the limited efficiency argument, there are reasons to disagree with the claim that any application of smart contracts means a decrease or elimination in the efficiency of contracting due to the inherent inflexibility of smart contracts. Let us start with *response 1a* (disagreeing with the claim of the critics): considering the application at scale, we have plenty of examples wherein a small inflexibility in a system would serve greater flexibility and efficiency of the system (e.g., application of legal norms, use of standardized and thereby somewhat inflexibly built technologies or machines in large populations etc.). This is also something that the advocates of the limited application argument would agree with.

For responding to the different criticism presented by the limited application argument, we see two main options. Let us start with *response 2a* (disagreeing with the claim of the critics): we might reject the claim about the limited application scenarios. After all, this might be an overly static view. Given the large interest in technologies that rely on these inflexibilities (e.g. blockchain-based smart contracts), we are likely to see a much broader application in the future because industry is working towards it. It might well be that the range of applications is not so limited at all if we take a long-term perspective. Additionally, as *response 2b* (agreeing with the claim of the critics), we can just accept that the range of application of smart contracts is limited while considering that at the places where they indeed are applied their application does create important efficiencies in contracting practices.

Additionally, there is one more way to respond to the limited efficiency argument (*response 1b*, agreeing with the claim of the critics). Even if any application of smart contracts means a decrease or elimination in the efficiency of contracting due to the inherent inflexibility of smart contracts, this can be compensated by setting up a system of oversight on top of automated contracting platforms to deal with the problems arising from inflexibility. This, however, is not an ultimate response to the criticism as it gives rise to a further debate.

Pointing out the weakness of response 1b, some authors claim that such a system of oversight defeats the essence of smart contacts as tools of disintermediation[6] and makes smart contacts an evolutionary step on top of electronic data interchange (EDI), where conflict resolution is manual.[7] In other words, smart contracts would only amount to a marginal innovation.

While we might put forward *response 1c* (defending response 1b further) and argue that such an oversight would only partially defeat the purpose of smart contracts, these authors would nevertheless point out that the creators of smart contracts give the impression of resolving the issue of conflict resolution but they do not, as they simply ignore it (*wrong impressions argument, criticism 3*).

What is at stake here is the matter of whether the inflexibility of smart contracts needs to be compensated with a system of oversight (with responses 1a, 2a and 2b leading closer to the position that there is no such need) and whether all systems of oversight would defeat the purpose of smart contracts (with response 1c leading to think otherwise). However, if any of the critics' arguments nevertheless holds, it might appear that smart contracts could not lead to improvement in contracting or greater efficiency of markets as their proponents claim. These debates show that there is a need for a more comprehensive response to the challenge of inflexibility in algorithmic contracting.

2.3. *The many faces of inflexibility in advanced contract automation*

One way to provide a comprehensive and nuanced response to the challenge of inflexibility of contracting algorithms is to explore the possible foundations for such a response and to dis-

[5] This is accompanied with the transparency-increasing feature that each attempt to interfere with the code would leave a trace.

[6] In particular blockchain enthusiasts stress disintermediation as the single most important advantage, both for economic and political reasons, of blockchain systems.

[7] We are grateful to Marlon Dumas for pointing to this dilemma.

tinguish between the ways in which different types of inflexibility affect contracting. In order to do this, it is necessary to understand the changes that the use of algorithms (including the use of smart contracts) introduces to contracting and contract performance. These changes can entail both costs and benefits, but we will refer to them here in value-neutral terms: loss of linguistic ambiguity, loss of the ability to breach a contract, etc. It is worth noticing that the costs and benefits they pose affect, among other things, the human values related to private conduct, contracting, and relationships between individuals, e.g., making moral choices and exercising autonomy. As inflexibility has been put forward as a threat to the foundational values of contracting, we will describe the changes that the use of algorithms gives rise to in contracting along with notes on the foundational values these changes might affect.

Loss of the possibility of relying on incomplete contracts. When some or all stages of a contract's life cycle are automated without subsequently allowing for adjustments, the computer code representing the contract needs to be precise and fully defined to account for any contingency. As Sklaroff explains, "Computer code must be precisely and completely defined, because at root it is a series of if-then instructions that must all be resolvable by a computer. A smart contract cannot contain a term that has one meaning at the time of execution and takes on another meaning later." (Sklaroff 2017: 291) As with the ideal form of the complete contract in contract theory (Cooter and Ulen 2016; Solum 2012), one can expect such explicit and unambiguous contracts to be extremely costly to draft (Sklaroff 2017). Accordingly, they limit the real possibility of contracting, and *freedom of contracting* as one of the underlying values of the practice, especially in circumstances where algorithmic contracting is offered as the only contracting option.[8]

Loss of linguistic ambiguity and flexible interpretation. Even where algorithmic contracts are modifiable along the way, contractual "good faith" or "best-effort" duties, as well as the use of vague terms that would allow for flexibility in the interpretation of contractual clauses are and would continue to be difficult to translate into computer code.[9] Furthermore, it is a challenge to steer an algorithmic contract to reflect the commercial context and customs, and its broader societal embeddedness, all of which are generally core pieces of information for setting parties' expectations and allowing the system of contract law to work (Reyes 2016; Sklaroff 2017). Many consider this a significant loss, especially as *vague terms* and *consideration of social context* have been deemed essential features of contracts and contract law (Cunningham 2006; Mik 2017; Werbach and Cornell 2017; Sklaroff 2017).

Change in skills required for contract drafting and interpretation. Creation and interpretation of a code-based contract or contract performance requires not only legal drafting and interpretation skills but also skills in reading and writing code. This is accompanied by the ability to breach a contract with the help of a sophisticated understanding of the contracting software, thus creating new winners and losers in the power dynamic between the code-savvy and the code-naive contracting parties (Marino and Juels 2016). This can affect the *level playing field* among contracting parties, making the contracting environment less fair for those with limited computer skills or lower resources to use them. This might mean higher entry costs for those wishing to employ algorithmic contracts, requiring them to invest in building and studying them or to trust fee-charging platforms for using those built by others. In the long run, this makes the *principle of equality* in contracting less meaningful.

Loss of the ability to breach a contract. Automation sets limits on the choices we can make when performing our part in a contract and, by doing so, it can eliminate the possibility of breaching a contract. This is significant both where breaching a contract is efficient, and where it is the exercise of the right to do a wrong. The choice of simply not complying with a binding promise - unilaterally walking away from it or changing the manner of performance - disappears with smart contracts. In this way, as it happens also in the case of several "analogue technologies", such inflexibility may be considered a hindrance to *personal autonomy* (Yeung 2011), even where automation might amplify autonomy in other aspects of a contractual relationship at the same time (e.g., with higher transaction speed, effective search for suitable transaction partners, effective monitoring of performance).

Loss of the ability to adapt at a later stage and loss of enforcement discretion. The automated performance also eliminates flexibility in the enforcement dimension of contracts (Sklaroff 2017), depriving parties of resolving contract disputes informally or adjusting the terms of performance (ibid.). Among other things, it eliminates the autonomy of parties in jointly walking away from the contract irrespective of whether a mutually more beneficial alternative solution was to be found in the absence of automation. This affects the ways in which contracting can be a vehicle for the exercise of *personal autonomy*. When it comes to the formal resolution of algorithmic contract-related conflicts, traditional courts have a clear role.[10] In line with the idea that algorithmic contracts could potentially lead to greater decentralization, we also see the de-

[8] During the Algorithmic Law and Society Symposium at HEC Paris in 2021, Giovanni Sileno discussed a methodology for analyzing the regulation, design, and deployment of algorithmic decision-making systems. As he and his co-authors explain in this special issue, their work helps to see "how values are generated and distributed in concrete settings with regulatory consequences, where automatic and automated decision-making components encounter contextualized social processes" (Geoff et al., 2022). Their insights could be valuable for gaining a deeper understanding of how the use and regulatory setting of automated contracting that is reliant on algorithmic decision-making affects users' autonomy, choices, and behavior in mitigating risks arising from automated transactions.

[9] There are, however, possibilities to refine computer code to mimic the human approach to interpreting incomplete or vague legal provisions, see Fungwacharakorn & Satoh (2022) in this special issue.

[10] For an interesting example, see an account of a case at the Singapore Court of Appeal regarding a debate over a unilateral mistake in automated contracting by a financial trading party and its reversibility on the grounds of the benefitting party's knowledge about the mistake or the attributability of such knowledge to that other benefitting party (Low and Mik 2020). Authors revisit the need to adapt laws in response to the use of algorithmic programmes.

velopment of alternative, including online and decentralized, solutions for dispute resolution (Patterson 2016; Buterin 2016; Tapscott and Tapscott 2016). As expected, the solutions confront the challenge to meet *procedural justice* requirements in order to align with the foundational values of contracting.

Change in the relation-building environment. A considerable portion of contracting relies on peer-to-peer contract enforcement, long term relationship building and the related second party trust mechanisms characteristic of relational contracting environments (Eenmaa-Dimitrieva and Schmidt-Kessen 2019). While relational and traditional contracts availed themselves to parties as *relation-building measures*, algorithmic contracts employing automated performance and enforcement do not. They give parties less ability to build a responsive relationship and do so over a long period of time, thus leading to fragmentation among contracting and relation-building measures, as well as decreasing the value of contracting as a relation-building instrument.

3. Analyzing contract automation through rational choice theory and new institutional economics

3.1. *Two types of inflexibility*

When addressing the challenge of the inflexibility of algorithmic contracts and their performance in this paper, we combine a case study[11] with the conceptual framework offered by rational choice theory and institutional economics. The theory of rational choice explains the behavior of actors as constant optimization in light of given constraints, and institutional economics illuminates how institutions influence market results, including how legal rules steer parties' cooperation and economic growth (as explained in the economic analysis of law). Relevant for the discussion on inflexibility, the research in these fields helps to explain the mechanisms through which the pursuit of particular societal goals (macro-level) can be enhanced by the use of constraints on behavior or limitation of options for individuals (micro-level) (Coleman and Fararo 1992). We employ the conceptual framework developed for the study of constraints in these fields to draw a potentially useful distinction for addressing the challenge of inflexibility. As we will explain in this section, there is a difference between (1) evaluating the inflexibility of automated contracts as a constraint operational primarily on the level of individual transactions, and (2) evaluating inflexibility as a hypernym for the changes and systemic risks that arise on markets as a result of employing algorithmic contracting, for example, due to lower human involvement, higher speed, and interdependency between many trading environments. The distinction helps us raise the question of which type of inflexibility regulation has targeted in financial markets and whether the same approach would be appropriate for steering the design and regulation of advanced contract automation so that their inflexibility would present advantages rather than disadvantages.

[11] See the methodology (Section 4) below.

3.2. *Inflexibility as a (beneficial) constraint*

As the review of contract automation in the previous section has shown, the inflexibility of algorithmic contracts is generally seen as problematic. We argue, however, that this inflexibility, as part of a wider process of automation, can be advantageous in contracting. We do this by drawing on the experience of financial markets with automation. Moreover, we argue that algorithmic inflexibility, in the same way as institutions, social norms and other mechanisms that coordinate individual actions to achieve predetermined outcomes, can be seen as a (sometimes beneficial) constraint, due to its capacity to level the playing field and coordinate individual actions. Markets have been successful in employing the advantages of inflexibility. To think further about the market's use of inflexibility, it makes sense to depict inflexibility as a constraint.

Definition of constraints. The term constraint is usually associated with normative ethics, and describes 'things that one must not do'.[12] Constraints on one's behavior may take various forms as rules that one must observe, or as factors with significant weight to override others. Although we borrow the term from moral philosophy, we use it in a broad sense by reference to factors that limit action (e.g. legal norms, physical barriers, software architecture related boundaries etc.). Some of such factors have been described by the law and technology literature under the concept of "regulation" in the broad sense (see Browsword et al. 2017). We prefer to use the concept of constraints, instead of regulation, to make a clear distinction between the traditional command and control approach and the broader sense in which various factors can constrain (rational) choice and action.

Instrumental use of constraints. Based on rational choice theory, we know that some constraints lead to better outcomes. However, it is worth keeping in mind that constraints are not necessarily instruments, i.e. tools for achieving certain ends (certainly not in deontological morality where doing harm is intrinsically wrong), but they can be and are treated as such, for example, in law and economics scholarship. The benefits of inflexibility (e.g. that of algorithmic contracts) as a constraint could be explained with the help of ideas from the theory of constrained maximization (Gauthier 1986; 2013; Kraus and Coleman 1987). According to Gauthier, constraints allow individuals to secure gains unavailable when the conditions of perfect competition are not satisfied. This has been explained by modeling the conditions of imperfect competition according to the prisoner's dilemma. In the words of Coleman (1998: 317)

> "In the standard [prisoner's dilemma], individually rational action leads to a suboptimal equilibrium. By definition, a suboptimal equilibrium is not Pareto optimal. That means that there are gains to be had. *Ex hypothesi*, these gains cannot be secured by individuals acting narrowly self-interestedly. Precisely such behavior generates the suboptimal equilibrium. In order to secure the gains, that is, in

[12] We rely here on the works in normative ethics and legal philosophy. For example, John Oberdiek explains, "There are certain things that one must not do, according to deontology, even if doing so would produce better consequences overall." (Oberdiek 2008).

order to secure a Pareto optimal outcome, the parties must forego individually rational strategies in favor of a cooperative one. The cooperative strategy will require each individual to constrain his self-interest."

Only some cooperative strategies would work in these circumstances and one of these is that of cooperation-by-competition on markets (Coleman 1998). If we think of the market as a form of cooperation, we could view markets as institutional arrangements (or, using the terminology that we introduce below, governance mechanisms) that rational cooperators choose as the most appropriate for themselves, especially because they contribute to social stability "by allowing individuals to cooperate with one another over a broad range of areas without first having to share deep or controversial commitments about the nature of what is good or valuable in a life" (Coleman 1998: 319; Eenmaa-Dimitrieva 2019). Markets would not be valuable here because of their efficiency, but because they contribute to liberal stability: market competition is itself a form of cooperation-by-competition, where competition presupposes cooperation (ibid.).

There are constraints without which markets and their cooperation-by-competition model would not be possible — markets presuppose systems of property rights (Coase 1960). Although having a stable cooperation mechanism (and accordingly, a scheme of property rights) would be in each person's rational interest, it cannot emerge as a result of individually rational decisions or actions due to various structural problems as characterised by the prisoner's dilemma (Gauthier 1986; 2013; Kraus and Coleman 1987). Gauthier's constrained maximization theory suggests that the stability of peoples' property rights can be ensured with the help of constraints, e.g., principles of justice or norms that would protect people against various infringements of their property rights (Eenmaa 2019). These constraints would be instrumental for enabling and protecting the cooperative mechanism of the markets, and as such, be in each person's rational interest (Gauthier 1986; 2013; Kraus and Coleman 1987). Similar preconditions need to be met also for the operation of electronic and algorithmic markets.

Legal norms as constraints & instruments. Many legal norms can function as constraints and, when applied, lead to certain outcomes. By limiting the behavior of many, legal norms can create circumstances where legal subjects would be more free to conduct their business and form relations with one another than in circumstances where law would not limit their behavior. This is one way to formulate the understanding of constraints as instruments for certain outcomes like improved cooperation or a better-functioning society.

Just as property related constraints lead to better outcomes, e.g. via greater stability of peoples' rights, so do provisions and principles of contract law. For example, the inflexibility introduced by the principle of *pacta sunt servanda* inhibits contractual parties from walking away from their promises and accordingly provides support for their cooperation (Ganuza and Gomez Pomar 2016).[13] In fact, in specialized fields of contract law, constraining parties' behavior is one of the predominant methods for defending the parties and their ability to contract. For example, the regulation of employment contracts or consumer contracts uses additional limitations on contractual terms to ground stability in the potentially unequal relationships and bargaining positions (employer-employee, business-consumer). Such constraints on parties' options are more beneficial for the given market than the alternative of fewer safeguards and less stability.

Technological solutions as constraints & instruments. Drawing a parallel with the example of legal rules, we can view some technologies, e.g. those employed for advanced contract automation, or the inflexible components and properties of such contracts, as creating similar kinds of beneficial constraints. By limiting the options of everyone who uses the particular technology, the technology organizes and restricts their behavior with the help of its inflexibility. As such, the algorithmic environment could be considered regulated not only by legal norms, but also by technological tools. It remains to be argued, however, whether such constraints were implemented as a result of a conscious choice, and if so, whether they were chosen due to the advantages of inflexibility.

In the case of financial markets, automation was not a completely conscious choice made by a careful planner or designer. Instead, and to the dismay of those who appreciate the idea of "intentional agency", automation probably "just sort of happened", and was permeated by the "trials and tribulations of routine and surprise" carried out by the vast "organizational middleware" (Pardo-Guerra 2019: 4).

The idea of "messiness", i.e. that automation was not an agreed on project, however, does not tell the whole story either. After the 1987 crash, the United States regulators accelerated the process of automation on financial markets. This move was not explicitly articulated as an attempt to gain from the inflexibility of automation, but rather as an attempt to replace the subjectivity and fallibility of human decision making with objective computers (Lewis, 2015). To that extent, by bringing some "objectivity" or "predictability" to the trading process, automation was employed to function as a constraint, which was beneficial, at least for some actors. In other words, it helped organize individual action by creating a more predictable playing field.

Automation and algorithms have also functioned as constraints after replacing other more traditional coordination mechanisms. As Pardo-Guerra vividly describes, stock and commodities markets were once "densely social, communicative spaces" (2019: 3). Prior to automation, the "cacophony of the marketplace" and the "apparent randomness of trade" were "coordinated through shared norms and expectations, networks of competition and collaboration, and elaborate means for signaling, rewarding, and reprimanding the members of the trading floor's community" (ibid.). Once these more traditional social practices became obsolete, being replaced by cables, screens, and data streams, the electronic limit order

[13] We thank the anonymous reviewer for pointing out the vast literature on additional forms of inflexibility that can be introduced into contracts by parties to overcome commitment problems, and that are discussed e.g. in Katz (1991) in relation to precommitments and renegotiation in agency relationships. The issue of inflexibility also arises in the area of contractual remedies where the flexibility of damages is regularly contrasted with the inflexibility of specific performance, see e.g. Kronman (1978).

book became the new infrastructure for coordinating individual actions (ibid, 237). The architecture of those electronic order books became a new and important constraint for trading. The queuing mechanism inherent to order books, based on the first-in-first-out principle to structure transactions, was thought to foster more efficiency, fairness and equality compared to prior, “human”, infrastructures. On the other hand, it also enabled new forms of harmful practices such as spoofing (ibid., 240).[14]

The introduction of electronic order books made the use of algorithmic trading strategies the best strategy for traders to maximize predictability and their returns (Kumiega and Van Vliet, 2012). Thus, neither the inflexibility inherent in algorithms creating the queues in electronic order books nor in trading strategies hampered the rise and widespread use of algorithmic trading.

Still, it is worth keeping in mind the difference between evaluating the inflexibility of algorithms (together with the problem of inflexibility as we have framed it above) and evaluating the changes and systemic risks that arise on the markets as a result of employing algorithmic contracting (sometimes also discussed as the inflexibility of or constraints on algorithmic markets elsewhere). It is the latter that we will turn to now. Viewing both, the inflexibility of algorithmic contracts and the related changes on markets through the lens of this conceptual framework helps us to reflect on the normative implications of advanced contract automation.

Whether and how contract automation can help to pursue any goal in society is conditioned by the justification of the constraints arising from the particular technology. Such a normative inquiry can be based on various foundations such as deontological morality but also utilitarianism, e.g. in the form of welfare economics. If we think about the basic justification of the binding nature of contracts from a welfare economics perspective, contracts that promote the well-being of contracting parties without inflicting harm on third parties should be binding (Kaplow and Shavell 2002: 155–156). Societies are rich in contract enforcement mechanisms, relying on first-, second-, or third-party enforcement, e.g. by applying contract law together with the threat of coercion (Dixit 2009; Eenmaa-Dimitrieva and Schmidt-Kessen 2019). Enforcement systems can equally be achieved with technology, as the example of smart contracts shows. Thinking from a welfarist perspective, there might be comparative advantages between enforcement mechanisms and the choice between them depends on the cost of using each. Propositions that might arise from this could be, for example, that only contracts which increase net welfare should be binding, that contracting practices that increase net welfare, in the long run, should be binding, or that contract enforcement should occur in the most cost-efficient manner. Distinguishing between those agreements that should be binding and those that should not is a challenge for any enforcement system.

When it comes to advanced contract automation, finding the most efficient contract enforcement system depends on the interplay between multiple factors. New institutional economics can help shed light on the respective roles that technologies, various norms and parties play in institutional settings.

3.3. *Contract automation as an interplay between multiple normative systems*

Studies within the field of new institutional economics (NIE), explain factors that determine the sets of rules that govern political, social and economic behavior (i.e. institutions) and how institutions affect economic performance (Alston 2018). According to Williamson (2000) there are four levels of social analysis with which NIE engages (Williamson 2000; Joskow 2008): (1) Informal restrictions that have a pervasive and long-run influence on economies and that are very difficult to change in the short run, e.g., based on religion, culture, and traditions (North 1991); (2) Public ordering and formal rules, including laws and constitutions; according to NIE, these can be shaped and adapted by policymakers to “get the rules of the game right”, i.e. to design institutions which allow for reaping the benefits from trade that can lead to enhanced economic well-being or welfare; (3) Private ordering and governance concerned with the arrangements that economic actors devise in light of the institutional environment and its restrictions (this level covers the governance mechanisms for contractual relations and organizational choices at the level of individual transactions); and (4) Short-term adaptation to prices and output (Williamson 2000). NIE uses the neoclassical model of rational choice (also in the form of bounded rationality) to explain individuals’ behavior and the interdependencies between the listed institutions and individuals’ economic behavior.

Institutions have an important impact on transaction costs, which in turn influence governance mechanisms. Search and negotiation costs, monitoring costs, coordination of the physical factors of production in the production process, and the costs of enforcing contracts are some of the transaction costs that determine whether an economic actor engages in spot-market exchanges, relational contracting, or vertically integrating production (Coase 1937; Williamson 1985; Brousseau 2008). While the precise interplay between public and private ordering continues to be one of the unresolved questions in NIE, there is consensus that they influence each other. Changes in governance mechanisms can trigger institutional change and vice versa, e.g., a shift from community-trading to trading with complete strangers creates pressure to define and put into place institutions that enforce private property rights and contracts beyond one’s community (Brousseau 2008; Greif 1993).

Transaction costs are also affected by technological development (Alston 2018). Technology can reduce or increase the need for monitoring, allow for cheaper monitoring through surveillance, or improve the coordination of production. When considering computerized, disintermediated contract automation with little or no human involvement, the impact of transaction costs seems to be mixed: while negotiation, monitoring, performance and enforcement efficiencies should lower transaction costs considerably (Szabo 1996; Fairfield 2014), automation could also lead to increased trans-

[14] In finance, spoofing refers to a trading practice of entering orders that are meant to be canceled just before they can be fulfilled in order to manipulate markets.

action costs, as described above.[15] This raises the question of whether achieving a net gain in economic welfare from contract automation would necessitate institutional changes. We will approach this question with the help of a case study on algorithmic trading on financial markets, which helps us gain an insight on how the regulatory environment has reacted to the widespread use of algorithms on financial markets, in particular stock markets.

4. Algorithmic trading and its regulation in the EU as case study

Case studies are generally used to understand the dynamics of the studied subject within its setting or context, in contrast to lab experiments that try to isolate the phenomena from context (Eisenhardt and Graebner 2007). The goal is to try to identify what is happening and why, and to understand the effects of the situation and implications for regulatory actions, in order to develop or contribute to existing theory (Dubois and Gadde 2002; Ridder et al. 2014; Yin 2014). For this analysis, we use a case study on algorithmic trading on financial markets in the EU to contribute to the existing theory on contract automation and for studying the inflexibility in contract automation further. We will analyze how financial market regulation has dealt with the inflexibility of algorithmic and high frequency trading (HFT) and ask whether it addresses inflexibility as a constraint on transactional level or as a hypernym for factors (e.g., high speed, low human involvement, interaction between trading venues) that give rise to changes and systemic risks on markets. Departing from an understanding of algorithms as vehicles of change both in transacting on financial markets and in advanced contract automation in other contexts, the lessons from the case study will provide the ground for our suggestions regarding how institutions would need to adapt in order to address the concerns regarding inflexibility in advanced contract automation raised in the literature.

The reason for drawing parallels between algorithmic trading on financial markets and advanced contract automation more generally is that we consider algorithmic trading as one example of advanced contract automation. A trade on a financial market is a contract in the legal sense. A contract is a voluntary agreement creating legal obligations between two parties that intend to be legally bound (e.g. Article 2:101 Principles of European Contract Law). The governing principle in contract law is freedom to contract: parties are free to stipulate the content of obligations, and contracts do not have to take any specific form (e.g. Article 1.1. UNIDROIT Principles of International Commercial Contracts). The contractual freedom of parties is, nevertheless, not absolute. In order to ensure that agreements creating contractual obligations are indeed "voluntary", contract law contains rules regarding error, fraud, duress, and capacity that void contractual obligations. There are also rules that make contracts voidable due to *force majeure*. Contract law thus offers the flexibility to adapt contracts to changed conditions or new factual circumstances in contractual relations through open-ended concepts (e.g. good faith) and contractual interpretation. In addition, contract law does not allow for the creation of legally binding obligations by contract which are illegal, contrary to public morals, or other public interest. As mentioned above, some types of specialized contract laws have additional safeguards to protect weaker parties in contractual relations.[16] These include, for example, consumer contract law and employment contract law.

On financial markets, players buy and sell a variety of financial instruments, e.g. stocks, derivatives, or bonds, which are contracts in themselves (Pistor 2013). Transactions in financial instruments are voluntary and create legally binding obligations between the parties (Haar 2016). In addition, financial market regulation aims at protecting investors, which are usually considered to be the weaker party. The regulatory framework is there to ensure that exchanges are indeed voluntary and not subject to fraud or other unfair market practices. Along with that, it ensures the protection of the public interest as far as the stability of financial markets is concerned. Certain parts of financial market regulation can thus be considered a special form of contract law in as far as they govern voluntary transactions on financial markets.[17] Algorithmic trading, including high-frequency trading, is a form of automated contracting (Scholz 2017).

Accordingly, we justify our case study selection due to algorithmic trading on financial markets bearing many common traits with automated contracting. In algorithmic trading, algorithms collect data, make decisions, and execute trades on financial markets without the need for human intervention (Seyfert 2016). HFT is one type of algorithmic trading (Martins Pereira 2020), which "exhibits message rates of more than 2 per second per financial instrument or 4 messages per all instruments on a given trading venue" (Article 19(1) Commission Delegated Regulation (EU) 2017/565; Čuk and Van Waeyenberge 2018: 149–150). The deployment of algorithmic trading techniques has increased the speed of transactions and has also allowed the creation of ever more complex interdependencies between various financial marketplaces (Mattli 2018).

Traders on secondary equity markets[18] have made use of two main categories of algorithms (Martins Pereira 2020).[19] On the one hand, they use investment decision algorithms which, based on a model and real-time data, decide the type

[15] See Section 3.1.

[16] On the development of contract law from a system of private law proper to more of a social law system, see also in this issue Alper (2022).

[17] We take a position here in a long-standing debate (especially in Germany) on whether financial market regulation is a purely public legal framework that governs relationships between supervisory authorities and private market participants, or is capable of creating rights and duties between private parties, too. See, e.g. Grundmann (2013) on the various positions in the discussion.

[18] Secondary equity markets refer to markets on which already issued securities are traded. Stock exchanges are an example of secondary equity markets.

[19] EU Regulation mentions these two main types of algorithms used on financial markets, too. See e.g. Recitals 5 and 7 in the Commission Delegated Regulation (EU) 2017/589 of 19 July 2016 supplementing Directive 2014/65/EU of the European Parliament and of the Council with regard to regulatory technical standards specifying the organizational requirements of investment firms engaged in algorithmic trading.

of security, quantity, and the price at which to buy or sell. Once the investment decision is made, order execution algorithms optimize the decision by automatically generating and placing orders or quotes on the most suitable trading venue(s) (Martins Pereira 2020). More sophisticated execution algorithms might determine further parameters beyond the trading venue when optimizing the order execution process. In contrast, less sophisticated algorithms will be limited to deciding the trading venue without changing other order parameters.

In secondary equity markets, the extensive adoption of algorithmic technologies in trading and the massive increase in transaction speed have created new challenges compared to non-automated trading. In a similar way, smart contracts have created new challenges compared to those of other non-automated contracting practices. As Martins Pereira (2020: 282) remarks, certain cyber and systemic risks are “inherent in the very nature of algorithmic trading: they arise because (all) algorithmic trading is automated, disintermediated, and generally faster than manual trading”. She adds that both investment decision and execution algorithms are more vulnerable to machine-driven errors and biases than manual trading. The same is equally true for computerized, disintermediated contracting more generally. In addition, humans will not be able to intervene in real-time should any algorithms malfunction, which is true for all kinds of algorithmic trading, but even more so for HFT (Martins Pereira 2020; Yadav 2019). This allows us to draw a parallel to the loss of flexibility in performance, e.g. in smart contracts. Furthermore, algorithms on financial markets can accurately interpret and act on hard data (such as limit order book data), but have much more difficulty interpreting soft, unstructured data that might be equally relevant for making the best investment decision (Martins Pereira 2020; Yadav 2019). This is similar to the challenges related to automated contracts, e.g., their inability to interpret their commercial context, customs, and broader societal embeddedness. The structure of modern financial markets amplifies adverse consequences from malfunctioning algorithms thus giving rise to systemic risks, e.g., causing strain on venue infrastructure, absorbing liquidity, and spreading quickly to the sphere of other market participants across markets (Martins Pereira 2020; European Commission 2011, 9–10). This can lead to flash crashes, brief episodes of extreme volatility that lead to a temporary collapse of the market.

In the next section, we describe how automation has been accommodated in financial markets and how regulation has addressed the risks that have arisen from the use of inflexible algorithms. For this, we use the EU regulatory framework for algorithmic trading and HFT (impact assessments, EU Directives, implementing legislation, European Securities and Markets Authority (ESMA)[20] guidelines, etc.) as archival data. Compiling the case study based on these data allows us to identify themes in the data and connect these to the existing literature on contract automation to refine and extend existing theory, which is the ultimate goal of any case study (Ridder et al. 2014). Understanding how algorithmic trading has been influenced by regulation and vice versa helps us to build a narrative about how regulation facilitated a specific shift in private governance on financial markets, namely the increased use of algorithms, which in return triggered changes in the institutions governing financial markets. The findings will allow us to critically reflect on possible regulatory intervention needed in other trading environments where computerized, disintermediated transactions occur. These include transactions occurring in blockchain ecosystems.

5. Algorithmic trading and its regulation in the EU

5.1. *Financial market regulation and algorithmic trading*

The regulatory model employed for financial markets worldwide is a mix of private and public ordering, where either public regulators or self-regulatory organizations[21] set the rules of the game for securities markets and enforce them. While US financial market regulation has historically relied heavily on self-regulation, the European model has relied more on government-made rules enforced through public authorities (Carson 2011). Nonetheless, exchanges play an important role in supervising trading and setting codes of conduct for traders trading on their markets in the EU (ibid).

The shift to algorithmic trading on financial markets has brought benefits and new risks. On the positive side, it has been argued that it has brought greater liquidity, lowered transaction costs, led to tighter spreads between bids and asks, and increased competition between trading venues (Menkveld 2016). New risks have, in turn, included the above-mentioned cyber and systemic risks (Martins Pereira 2020; European Commission 2011). When devising risk-responding regulatory regimes for algorithmic trading on financial markets, lawmakers have chosen between three approaches:

- Regulating algorithmic trading as such, if the adoption of algorithmic trading poses risks in itself, irrespective of the trading strategy it implements;
- Imposing more stringent obligations on particular algorithmic trading strategies, e.g. in the area of HFT; or
- Regulating risk-taking behavior arising as a response to algorithmic trading but not constituting algorithmic trading itself (e.g., the regulation of trading venues that host algorithmic trading).

Financial market regulation in the EU is a mix of these three approaches (Martins Pereira 2020).

[20] ESMA was created under EU law in 2009, and began its operations in 2011. The main purpose of this independent authority is to contribute to the stability of the EU’s financial system by ensuring high investor protection and stable financial markets. For more information, please consult ESMA’s portal. https://www.esma.europa.eu/.

[21] Self-regulatory organization, can refer to a range of governance systems for financial markets. Carson (2011) defines formal self-regulatory or “SROs”as “private institution that establishes, monitors compliance with, and enforces rules applicable to securities markets and market participants”. He also explains how many jurisdictions do not have a legal definition of SROs, but most jurisdictions will understand regulated markets, i.e. exchanges approved by law, as SROs.

5.2. The eu regulatory framework

Today's system of regulating financial markets in the EU had its origins in 1999 when the European Commission proposed a new Directive (The Markets in Financial Instruments Directive, or "MiFID I") to harmonize the rules for trade in financial instruments across all EU Member States.[22] The MiFID framework aimed at guaranteeing satisfactory protection for investors, as well as opportunities for investment firms to offer their services across borders based on the principle of home country supervision (Article 1 MiFID I), thus creating "a single market for investment services and activities" (Kern and Loiacono 2019: 323).

The MiFID system developed on two main ideas: first, that the competition between execution venues (i.e., regulated markets, multilateral trading facilities, organized trading facilities, systemic internalizers, market makers, among others) needed to be enhanced, and second, that investors needed adequate protection from disproportionate risks they may encounter on markets (Lenglet 2011: 48). MiFID I introduced what is known as the "best execution principle" or "execution of orders in terms most favourable to clients".[23] This obliged stockbrokers to execute clients' orders in the best possible manner (to the highest price, as speedily as possible, etc.). The need to comply with this requirement gave technological development a significant push. Being able to build instant comparisons between venues soon became a major concern for brokerage firms, as this was needed to know where they could best execute their clients' instructions. Smart Order Routers were designed and developed in order to make those decisions within milliseconds, a lapse of time that made it impossible for a human to stand competition. It is then no surprise that, in trying to predict the impacts of MiFID I, Casey and Lannoo (2006) argued back in 2006 that the resulting significant rise in algorithmic trading would be almost a certainty.

Due to the increasing worries with the risks posed by algorithmic trading, the revised MiFID Directive (MiFID II)[24] introduced a definition of algorithmic trading for the first time, subjected any actor employing algorithmic trading techniques to additional regulatory obligations, and ensured that all firms employing especially HFT would be subject to requirements imposed on entities with investment firm status and be properly supervised (Article 2(1)(d) MiFID II).

5.3. The what, who, and how of the EU regulatory approach

The what. The current EU regulatory framework governing algorithmic trading is composed of a large number of secondary EU legislation and implementing instruments.[25] According to Article 4(1)(39) MiFID II algorithmic trading is defined as,

> "Trading in financial instruments where a computer algorithm automatically determines individual parameters of orders such as whether to initiate the order, the timing, price or quantity of the order or how to manage the order after its submission, with limited or no human intervention, and does not include any system that is only used for the purpose of routing orders to one or more trading venues or for the processing of orders involving no determination of any trading parameters or for the confirmation of orders or the post-trade processing of executed transactions."

The definition is both broad and narrow (Martins Pereira 2020). It is broad because it includes even forms of algorithmic trading that involve some human decision making (which is largely irrelevant in practice). At the same time it excludes unsophisticated execution algorithms from the scope of regulation, namely those that only take decisions in relation to which trading venue(s) to send an order to. Investment decision algorithms and sophisticated execution algorithms (determining more than one parameter of an order) are subject to regulation irrespective of which trading strategy is pursued (Martins Pereira 2020).

The who. The EU regulatory framework applies to traders that employ algorithmic trading techniques within the definition.[26] Differently from its predecessor, the MiFID I, MiFID II singles out traders that pursue a market-making strategy by using algorithmic trading, which are subject to more onerous obligations. Lastly, it regulates trading venues that host algorithmic trading, as well as investment firms that provide direct electronic access (DEA) to a trading venue (Article 17(5) MiFID II; Busch 2016).

The how. In connection to the target of the regulation (the "who"), MiFIDII also has stricter requirements of transparency, accountability and technical robustness. As an example, it imposes an ex-ante control of the applied technologies on algorithmic traders (Article 17). It is expected that algorithmic traders use efficient systems and risk controls as well as test their algorithms thoroughly. They need to ensure that their algorithms do not allow for abuse or violate the rules

[22] Directive 2004/39/EC of the European Parliament and of the Council of 21 April 2004 on markets in financial instruments amending Council Directives 85/611/EEC and 93/6/EEC and Directive 2000/12/EC of the European Parliament and of the Council and repealing Council Directive 93/22/EEC based on the European Commission's 1999 Proposal [COM(1999) 232 final - Not published in the Official Journal]. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3Al24210.

[23] According to it, "Member States shall require that investment firms take all reasonable steps to obtain, when executing orders, the best possible result for their clients taking into account price, costs, speed, likelihood of execution and settlement, size, nature or any other consideration relevant to the execution of the order" (Article 21 (1) MiFID I).

[24] Directive 2014/65/EU of the European Parliament and of the Council of 15 May 2014 on markets in financial instruments and amending Directive 2002/92/EC and Directive 2011/61/EU

[25] The core pieces of EU legislation are MiFID II, EU Market in Financial Instruments Regulation 600/2014 (MiFIR), EU Market Abuse Directive 2014/57, and the EU Market Abuse Regulation 596/2014 as well as a number of technical standards and delegated acts.

[26] We simplify a little here. There are certain exemptions from the application of the regulatory framework under Articles 2 and 3 MiFID II, but even in case of an exemption, some firms will still be subject to reporting and organizational requirements arising for algorithmic traders under Article 17 MiFID II.

of trading venues, and have to keep a log of all placed, canceled and executed orders.[27] When pursuing a market making strategy, they need to carry out that strategy for a certain amount of trading hours, and provide liquidity on a regular and predictable basis. Algorithmic traders are also subject to supervision by and informational duties to national authorities. Lastly, certain algorithm-driven forms of market manipulation have been explicitly prohibited in the Market Abuse Regulation (Article 12 (2) (c)),[28] a sister piece of legislation to MiFID II.

Implementing regulations require investment firms engaging in algorithmic trading to take measures that make their algorithms resilient.[29] These include, for example, building in a "kill functionality" which can immediately cancel any unexecuted orders submitted to trading venues and to build an automated surveillance system supervising the trading activities by the investment firm. Furthermore, algorithms need to have inbuilt maximum order values and volumes, as well as message limits, to prevent sending an excessive number of messages to order books in regard to the submission, modification, or cancelation of an order. All of these measures, together with many others laid out in Level 2 regulatory instruments provide vast ex-ante controls to make algorithmic trading safe.

To guard against possible negative consequences from algorithmic trading, MiFID II also regulates the trading venues that host algorithmic trading. The latter are required to have their own facilities, systems and procedures to test the algorithms of market participants, thus sharing the burden with algorithmic traders to ensure that algorithms do not "create or contribute to disorderly trading conditions on the market". Many regulated markets had these systems already in place before MiFID II came into force (European Commission 2011). According to Article 48 MiFID II and Level 2 implementing measures, the venues must also make it possible to flag orders generated by algorithmic trading, and enable the identification of different algorithms used for the creation of orders and the person initiating those orders.[30] In addition, trading venues are expected to have the capacity to reject orders that exceed predetermined volume and price thresholds or are clearly erroneous. They must also have the ability to temporarily constrain or completely halt trading (through the use of so-called circuit breakers) "if there is a significant price movement in a financial instrument on that market or a related market during a short period," and in exceptional cases, to be able to cancel, vary or correct any transaction. Trading venues thus have the power to counteract some of the risks that might arise from the use of algorithms in trading.

Lastly, MiFID II and Level 2 implementing measures regulate providers of DEA.[31] DEA providers are investment firms that provide their clients with direct electronic access to make transactions (Busch 2016), i.e. they make it possible for clients to directly access trading venues without having to use an intermediary. While these services do not constitute algorithmic trading in themselves, the clients may be using algorithmic trading techniques. DEA providers must therefore have internal systems and controls in place to monitor clients use of their system, they must ensure that their clients comply with the requirements of MiFID II and the rules of trading venues, and are also subject to a range of reporting obligations. EU financial regulation thus takes a comprehensive approach and regulates all entities where risk-taking behavior in response to algorithmic trading can arise.

These are some of the examples of how financial market regulation has responded to advanced automation on the markets. The heightened speed, lower human involvement and increasing interdependencies between trading venues have called forth regulation to step in for managing the systemic risks and changes arising from the employment of algorithmic trading and HFT. While on the level of individual transactions, parties' actions have been constrained by the inflexibility of algorithms, this has not been at the center of regulatory measures. Rather, it is reasonable to assume that traders have benefitted from these constraints. At the same time, the second type of inflexibility resulting from the employment of algorithms (systemic risks) has been something that the markets have not been able to manage without appropriate regulatory intervention. This situation is an instance of divergences between private benefits and costs and societal benefits and costs. While the inflexibility from the use of algorithms benefits the traders that employ them, it also causes costs at societal level, which justifies regulation. This is in line with the main theories of regulation in economics (Shleifer 2005),[32] according to which regulatory measures are most suitable in situations in which social costs cannot be internalized through market competition or private litigation.

[27] HFT traders have additional, special reporting obligations, see Article 28 in Commission Delegated Regulation (EU) 2017/589.

[28] Regulation (EU) No 596/2014 of the European Parliament and of the Council of 16 April 2014 on market abuse (market abuse regulation).

[29] This and further requirements are specified in Commission Delegated Regulation (EU) 2017/589 of 19 July 2016 supplementing Directive 2014/65/EU of the European Parliament and of the Council with regard to regulatory technical standards specifying the organizational requirements of investment firms engaged in algorithmic trading.

[30] Commission Delegated Regulation 2017/584 supplementing Directive 2014/65/EU of the European Parliament and of the Council with regard to regulatory technical standards specifying organizational requirements of trading venues.

[31] Commission Delegated Regulation (EU) 2017/589 of 19 July 2016 supplementing Directive 2014/65/EU of the European Parliament and of the Council with regard to regulatory technical standards specifying the organizational requirements of investment firms engaged in algorithmic trading

[32] These main theories are public interest theories of regulation based on (i) Pigou (1938), in which externalities are internalized through the taxation of harmful activities, (ii) Coase (1960), which is a critique to the public interest theory of regulation and argues for an internalization of externalities through tort or contract law and private litigation, and (iii) Stigler (1971) that points to the risk of capture of the regulatory process and the cost of government failure in regulation that needs to be taken into account when regulating against market failures. Exploring these three theories in relation to the regulation of automated finance would be a self-standing and interesting line of inquiry in itself.

6. Discussion: inflexibility in contract automation and the lessons from algorithmic trading

Having discussed the constraint-based understanding of the inflexibility of automated contracts as well as the NIE approach to the interplay of private and public governance mechanisms, some general lessons from algorithmic trading emerge. Through MiFID I, we observed an institutional change promoted by the EU lawmaker in the institutions that govern financial markets in the EU. The introduction of the "best execution principle", together with the technical development of algorithmic technologies and computing capacity, led to the spread of algorithmic trading throughout the industry, in a similar way to the United States. The change in public ordering thus triggered a change in private ordering and created the incentives for securities traders to shift their transaction governance to algorithmic trading. This, in turn, created new risks (such as errors in code, algorithms' difficulties to account for soft data surrounding a transaction, no possibility of real-time human intervention to stop the execution or enforcement of orders placed). As a result, we could observe another institutional change, namely the introduction of new stress-testing obligations on traders and venues that raised transaction costs for traders but reduced cyber and systemic risks, and recalibrated financial markets at a new equilibrium and leveled the playing field.

Whether the institutional environment has gotten the rules of the game right, and there is a net benefit in welfare, is still open to debate. Some argue that the regulatory burden on algorithmic traders is too great and greatly reduces the economic benefits from algorithmic trading (Yeoh 2019). Martins Pereira (2020), on the other hand, argues that the exclusion of simple execution algorithms leaves an important source of risk unmitigated.

Algorithmic trading on financial markets has been widely adopted despite new and systemic risks arising from the use of algorithms. From the empirical evidence that some markets have been able to accommodate widespread use of automated transactions, we can assume that the limited efficiency and limited applicability arguments against contract automation do not hold. On financial markets in the EU, the lawmaker has intervened to hedge against some of the risks or adverse consequences that have arisen from automation but has not barred it. In sum, despite ongoing debates on the societal benefits and drawbacks, algorithmic trading and its surrounding regulation have allowed for a successful adaptation of financial markets to this new technology.

These lessons provide insights into how the inflexibility of algorithmic contracts can be governed so as to become net beneficial. It is difficult to draw lessons from algorithmic trading at a very general level, as financial markets have a history of very tight regulation which minimizes transaction costs and makes markets as efficient as possible, while also taking precautions against fraudulent and rogue traders, and ensuring investor protection (Armour et al. 2016). We, therefore, suggest considering lessons for two of the closest examples of computerized, disintermediated automated contracting that bear similarity to algorithmic trading on financial markets: transactions on cryptocurrency exchanges and some smart contracts deployed in public blockchain systems.

Cryptocurrency exchanges. Cryptocurrency exchanges are platforms that exchange fiat for cryptocurrencies and enable trades between different cryptocurrencies. Cryptocurrencies can be considered digital assets,[33] and trades happening on cryptocurrency exchanges are functionally similar to those occurring on financial markets. Users of cryptocurrency exchanges can set the terms under which they are willing to buy and sell. Cryptocurrency exchanges, like stock exchanges, can employ algorithms that automatically verify market prices and execute trades according to the positions in the order books.

Currently, cryptocurrency exchanges are subject to lower levels of regulation compared to regulated financial trading venues (Bratspies 2018).[34] The trades concluded between users of cryptocurrency exchanges are subject to general contract law. In theory, general contract law could provide a remedy for inflexibility from algorithmic errors, e.g. in the case of erroneous performance of algorithms that inform the execution of orders on cryptocurrency exchanges. A recent case from Singapore,[35] which revolved around a malfunctioning algorithm of a platform that triggered unintended transactions by traders, shows, however, that the application of the contract law doctrine of mistake is unfit to capture the realities of contract automation (Low and Mik 2020). Thus, it would be interesting to discuss whether principles from the regulation of algorithmic trading could have avoided such situations.

Public blockchain systems. Public blockchain-based systems, such as Ethereum, allow for automated enforcement of smart contracts without the possibility of the interference of a "controller" as we can observe with financial market supervisory authorities, stock exchanges or operators of cryptocurrency exchanges. While public blockchain environments give as much freedom as a programming language can give to parties in setting the terms and conditions for their transactions, there are no compulsory ex-ante or ex-post correction mechanisms for any possible flaws other than the consensus protocols that register and execute transactions.

Bartoletti and Pompianu (2017) carried out an empirical study of a variety of blockchain-based platforms and showed that on the most popular platform for smart con-

[33] The rules to determine the exact nature of cryptocurrencies and possible already existing applicable regulatory frameworks are not yet established. The American Bar Association stated in its 2019 White Paper on digital assets that cryptocurrencies or tokens can be a means of payment, a key to getting access to an application, a (security commodity). See ABA (2019). *Digital and Digitized Assets: Federal and State Jurisdictional Issues*, available at https://www.americanbar.org/content/dam/aba/administrative/business_law/buslaw/committees/CL620000pub/digital_assets.pdf.

[34] Albeit some jurisdictions treat them as payment institutions (Nabilou, 2020), and in the European Union they are subject to Anti-Money Laundering regulation, see Directive (EU) 2018/843 of the European Parliament and of the Council of 30 May 2018 amending Directive (EU) 2015/849 on the prevention of the use of the financial system for the purposes of money laundering or terrorist financing.

[35] Singapore Court of Appeal (SGCA) in Quoine Pte Ltd v B2C2 Ltd [2020] SGCA(I) 2. We thank our anonymous peer reviewer for referring us to this case.

tracts, Ethereum, the largest part of smart contracts by far were of a financial nature. The authors understand smart contracts of a financial nature as those that “manage, gather or distribute money as preeminent feature” (Bartoletti and Pompianu 2017). These smart contracts have a variety of functions from facilitating and keeping track of transactions in real-world assets, to offering crowdfunding and insurance services. The consequences of errors in code and unforeseen contingencies can be severe. If and how general contract law doctrines could help remedy any risks still needs to be tested before courts, but applying any doctrines from contract law that are based on intent, i.e. a human decision-making process, might be equally difficult as in the above mentioned case of the cryptocurrency exchange. Adaptations of contract law doctrines or regulation might thus be necessary.

As we have argued above, the inflexibility of automated contracts could be considered a constraint that is beneficial to foster markets and trade at the level of individual transactions. At the same time, such technological changes in the way in which parties govern their transactions might necessitate an institutional change in order to reduce the systemic risks that arise from the widespread use of contract automation to the parties themselves and to society as a whole. In our case study on financial markets, we have explained how the introduction of algorithmic trading has led to a change in the institutions (rules and regulations) governing financial markets. EU lawmakers evaluated the risks from algorithmic trading, made decisions about which parts of algorithmic trading should be subject to further regulation, and imposed new obligations both on the users of algorithmic trading techniques, as well as the platforms that host and benefit from algorithmic trading.

When it comes to other forms of advanced contract automation, trades on cryptocurrency exchanges and blockchain platforms such as Ethereum being an example, it might be worth considering the possibility, feasibility, and desirability of institutional change. In relation to cryptocurrency exchanges, we can observe institutional change already. In September 2020, the EU Commission proposed a Markets in Crypto-Assets Regulation (MiCA) that aims at supporting innovation while protecting consumers and the integrity of cryptocurrency exchanges (European Commission 2020). Similar to MiFID II, MiCA has the central goal of creating a level playing field across the 27 EU Member States for trade in crypto-assets. Under the MiCA proposal, cryptocurrency trading platforms and exchanges will need regulatory approval to provide their services legally in the EU. In addition, issuers of crypto-assets covered by MiCA will have to submit a white paper in advance to national financial supervisory authorities. These authorities will have the power to prohibit the issuance of such crypto-assets if they do not comply with MiCA. As the proposal stands, and in contrast to the regulatory approach to algorithmic trading in traditional securities, crypto traders and their trading techniques will not be explicitly regulated. Only the provisions against market abuse similar to those found in the Market Abuse Regulation (MAR)[36] will apply to crypto-asset traders under MiCA (Articles 78–80 of the MiCA Proposal). MiCA will regulate, however, crypto-asset trading venues (see Art. 68 MiCA Proposal). EU regulation might also be coming for smart contracts on public blockchain platforms, in the form of a pan-European blockchain regulatory sandbox (European Commission 2020).

To a certain extent, the approach to regulating algorithmic trading on financial markets might thus be already in use as a blueprint for other types of regulatory frameworks for contract automation. It should, however, not be used uncritically. The heavy regulation of financial markets, including algorithmic trading, has imposed very high regulatory compliance costs for traders. It has been implemented through the already existing multilevel supervision system, including national financial supervisory authorities, exchanges, and traders themselves. The system is thus highly centralized, highly controlled, and highly exclusive. It is only accessible to privileged participants that have the resources and know-how to stem the technological and compliance costs. This runs to a considerable extent against the philosophy of a system of contract automation that is accessible to everyone and is not subject to control by powerful intermediaries, as envisaged by early generations of cypherpunks and later blockchain enthusiasts (De Filippi and Wright 2018).

7. Conclusion

We are at a crossroads where the full automation of contracting is predicted by some as the fundamental disruption of contracting and the legal profession, and by others as mainly hot air (Lipshaw 2020). An important part of the criticism raised against the unlikely widespread adoption of smart contracts in the literature relates to the inflexibility of automated contracts and particularly smart contracts. We explain that inflexibility in itself can be seen as a constraint that can ultimately be not only welfare enhancing but also necessary for enabling cooperation on algorithmic markets. By relying on the propositions of new institutional economics, we explain how a more widespread adoption, however, might require institutional change to hedge against the risks arising from automation on the algorithmic contract market. We use the example of algorithmic trading on financial markets to show how widespread adoption of automation has been accompanied by changes in the rules of the game, i.e. the institutional framework. The changes in institutions presuppose a risk assessment of contract automation, a determination which parts of automation need to be regulated, and a consideration of obligations both on the users of automated contracts, as well as the platforms that allow for the use of contract automation like cryptocurrency exchanges and public blockchain platforms. In this process, however, it is worth keeping in mind that there is a difference between addressing the inflexibility of algorithms and addressing the systemic risks and changes that arise on the markets as a result of employing the inflexible algorithms for contracting.

[36] Regulation (EU) No 596/2014 of the European Parliament and of the Council of 16 April 2014 on market abuse (market abuse regulation) and repealing Directive 2003/6/EC of the European Parliament and of the Council and Commission Directives 2003/124/EC, 2003/125/EC and 2004/72/EC

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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