An innovative RegTech approach to financial risk monitoring and supervisory reporting

Petros Kavassalis
Panepistemio Aigaiou, Chios, Greece

Harald Stieber
Harvard University Weatherhead Center for International Affairs, Cambridge, Massachusetts, USA

Wolfgang Breymann
School of Engineering, Zurcher Hochschule fur Angewandte Wissenschaften, Winterthur, Switzerland

Keith Saxton
KS Strategic, London, UK, and

Francis Joseph Gross
European Central Bank, Frankfurt am Main, Germany

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Abstract

Purpose – The purpose of this study is to propose a bearer service, which generates and maintains a "digital doppelgänger" for every financial contract in the form of a dynamic transaction document that is a standardised "data facility" automatically making important contract data from the transaction counterparties available to relevant authorities mandated by law to request and process such data. This would be achieved by sharing certain elements of the dynamic transaction document on a bearer service, based on a federation of distribution ledgers; such a quasi-simultaneous sharing of risk data becomes possible because the dynamic transaction document maintain a record of state in semi-real time, and this state can be verified by anybody with access to the distribution ledgers, also in semi-real time.

Design/methodology/approach – In this paper, the authors propose a novel, regular technology (RegTech) cum automated legal text approach for financial transaction as well as financial risk reporting that is based on cutting-edge distributed computing and decentralised data management technologies such as distributed ledger (Swanson, 2015), distributed storage (Arner *et al.*, 2016; Chandra *et al.*, 2013; Caron *et al.*, 2014), algorithmic financial contract standards (Brammertz and Mendelowitz, 2014; Breymann and Mendelowitz, 2015; Braswell, 2016), automated legal text (Hazard and Haapio, 2017) and document engineering methods and techniques (Glushko and McGrath, 2005). This approach is equally inspired by the concept of the "bearer service" and its capacity to span over existing and future technological systems and substrates (Kavassalis *et al.*, 2000; Clark, 1988).

Findings – The result is a transformation of supervisors' capacity to monitor risk in the financial system based on data which preserve informational content of financial instruments at the most granular level, in combination with a mathematically robust time stamping approach using blockchain technology.

Practical implications – The RegTech approach has the potential to contain operational risk linked to inadequate handling of risk data and to rein in compliance cost of supervisory reporting.

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Originality value – The present RegTech approach to financial risk monitoring and supervisory reporting is the first integration of algorithmic financial data standards with blockchain functionality.

Keywords Smart contracts, Algorithmic standards, Document engineering, RegTech

Paper type Conceptual paper

1. Introduction

In this paper, we propose a novel RegTech[1] approach for financial transaction as well as financial risk reporting, which is based on cutting-edge distributed computing and decentralised data management technologies such as distributed ledger (DL) (Swanson, 2015), distributed storage[2] (Chandra *et al.*, 2013; Caron *et al.*, 2014), algorithmic financial contract standards (Brammertz and Mendelowitz, 2014; Breymann and Mendelowitz, 2015; Braswell, 2016), automated legal text[3] (Hazard and Haapio, 2017) and document engineering methods and techniques[4] (Glushko and McGrath, 2005). Our approach also takes inspiration from the concept of the "bearer service" and its capacity to span over existing and future technological systems and substrates (Kavassalis *et al.*, 2000, Clark, 1988)[5]. The bearer service, as proposed here, generates and maintains a "digital doppelgänger" for every financial contract in the form of dynamic transaction documents (DTDs) that form a standardised "data facility" [6] automatically making important contract data from the transaction counterparties available to relevant authorities mandated by law to request and process such data. The sharing of certain elements of the DTDs on a bearer service based on a federation of DLs[7] makes this possible. Such quasi-simultaneous sharing of risk data becomes possible because DTDs maintain a record of state in semi-real time, and anybody with access to the DL can, therefore, verify this state in semi-real time.

The potential of the proposed approach for supervisors' enhanced capacity to monitor the evolution of risk in the system can hardly be overstated, and the same applies to financial institutions (FIs') capacity to monitor risk within the boundaries of their ever more complex (holding) groups. Our approach indeed addresses a data management and interoperability issue that is rather specific to FIs, and that gives rise to negative externalities (e.g. financial contagion) and a suboptimal provision of public goods (e.g. financial stability). FIs appropriate an economic rent for managing an informational asymmetry (Inklaar and Wang, 2013, Hertkorn *et al.*, 2015, Philippon, 2015). Project owners looking for funding tend to have better knowledge about their future capacity to repay borrowed funds as compared to those willing to fund such projects. The stronger the informational asymmetries between capital owners and owners of projects, the bigger are the profit opportunities for FIs in their role as financial intermediaries[8]. In this sense, and in stark contrast to a situation of complete markets à la Arrow–Debreu–Hahn, banks thrive on an informational market failure. As a result, they have little interest in sharing internally produced data on financial risk (contained on their asset side) or in increasing the technological capacity to share such data not only to the detriment of supervisors' capacity to monitor risk in the system but also to the detriment of their own internal risk control functions, as documented in the explosion of operational risk in recent years (Grimwade, 2016).

Moreover, at current levels of interconnectedness, this situation has led to the emergence of systemic risks in addition to FIs' idiosyncratic risk, and there are calls for additional capital buffers to at least partly internalise such risks (Acharya *et al.*, 2016). Economists have also pointed to the changing incentives of FIs in a financial environment characterised by at least two types of equilibria (Allen and Carletti, 2006). The non-crisis equilibrium exhibits informational asymmetries that are individually optimal for FIs but socially sub-optimal and require prudential supervision. However, in a context of financial contagion where black swan type risks materialise on the liability side of FIs in conjunction with increased risk on the asset side, FIs would actually prefer sharing data even with competitors they are lending to and borrowing from to avoid a situation of excessive "cost of complexity" (Battiston *et al.*, 2016). Bai *et al.*, (2016) even point to the possibility that increasing complexity has reduced overall (informational) efficiency of the financial system, which hints at a possible vicious cycle where complexity engenders additional informational asymmetries, in turn creating individual profit seeking by FIs, increasing the complexity of financial structures, etc.

In terms of system architecture, supervisors already monitoring FIs on a case-by-case basis have the mission to address the negative externality created by individually rational profit maximizing behaviour of FIs. However, they have little prospect of success unless they receive risk data in a timely manner and in an adequate format. While, in general, the aim of RegTech is to improve the monitoring of the behaviour of financial institutions in almost real time, to identify non-compliant behaviours and to achieve a high level of granularity in risk assessment, which did not previously exist (Arner *et al.*, 2017, 2016), *our proposed RegTech approach to risk monitoring and supervisory reporting is the first integration of an algorithmic financial data standard with DLT functionality*. The result is a transformation of supervisors' capacity to monitor risk in the financial system. At the same time, the present RegTech approach has the potential to contain operational risk linked to inadequate handling of risk data and to rein in compliance cost of supervisory reporting.

In this paper, RegTech is conceived as the innovative use and combination of several technology building blocks to both automate compliance tasks and deliver transparent monitoring of financial transactions mainly by the following:

- using a DLT approach together with modern algorithmic finance technology; and
- instantly publishing (under specific access policy rules) and processing real-time financial information, which is transferred directly, seamlessly and continuously from the information systems of FIs to regulators line-of-sight.

Our approach levers previous work to develop the Algorithmic Contract Type Unified Standard (ACTUS)[9], as well as important work on legal entity identifiers (LEIs)[10] for uniquely identifying counterparties. It is the combined use of all the above elements that distinguishes the work described here from previous efforts aimed at a more structured representation of financial contracts and the computation of their dynamical properties (including the calculation of realised and expected cash-flows based on ACTUS[11]), which have been developed in the context of the programming paradigm known as "functional programming" (Jones, 2001).

The new construct we propose, the DTD, is an instantaneous, *ad hoc* and comprehensive digital representation of a particular financial contract (specifically made for regulatory purposes), and as such has, in effect, similarities with a synthetic financial instrument. As such, the DTD remains synchronised, in near real-time, with the individual original financial contract it represents. Therefore, the DTD would make a significant contribution to the improvement of the capability of the regulation authorities to timely collect accurate reporting information, on a contract per contract level for all financial institutions (together with standard risk metrics for particular or aggregated financial instruments). Consequently, it will help these authorities to identify contracts that impose systemic risks, diagnose financial market failures early and possibly act and "stop crises before they start" (Cochrane, 2014) – as well as to eventually monitor in quasi-real time the relative positions of financial institutions and their inter-dependencies.

Furthermore, implementing DTDs could also provide a testing and debugging environment before actually attaching legal value to future full-fledged digital contracts (smart contracts) executed on a shared ledger where reporting and contracting would largely collapse into one and the same operation (Pinna and Ruttenberg, 2016). This testing environment could be expected to create already important feedback to regulatory design as well as risk management approaches, both within FIs and with regulators. As legacy financial contracts are progressively replaced by newly created algorithmic contracts with automated reporting features, this trend would only accelerate further[12]. The outline of the remainder of the paper is as follows: Section 2 briefly reminds the economic policy background and current regulatory challenges. Section 3 introduces the idea of the DTD as a "digital doppelgänger" of the legal financial contract, while Section 4 is devoted to details of the architecture and components of the system, explaining the role of DL, Smart Contract DTD, deep DTD and ACTUS, and how the interaction of these components will create the RegTech environment that we envisage in this paper. Section 5 concludes the paper.

2. A proposal how to develop a new layer of algorithmic regulation functionality

The Great Financial Crisis of 2007-2008 has put the issue of financial stability at the top of global economic policy agenda. At the Pittsburgh summit, G20 leaders decided to create the Financial Stability Board (FSB)[13] with the mission to promote global financial stability by coordinating the development of regulatory, supervisory and other financial sector policies. The FSB operates to monitor and assess systemic risks of the global financial system, draft and propose the policy actions that address these risks and monitor the implementation of the recommended policies. The FSB has a particular focus on increased financial transparency and addressing policy-relevant data shortcomings and gaps through the development of a globally coordinated process of financial data collection (including price and volume of trades), storage in local trade repositories (TRs), dissemination and analysis for a large part of over-the-counter (OTC) derivatives transactions (FSB, 2011; FSB, 2015a; BIS and IOSCO, 2012a; BIS, 2012b; Massarenti, 2016). Specific recommendations for disclosure of FIs' risk exposures and risk management practices have been also part of this policy (Banco de Espana, 2012; EDTF, 2015). The newly created centralised financial infrastructures, as well as the progressive generalisation of reporting obligations, are to produce a meaningful view over the functioning of previously opaque OTC markets and help regulators to assess FIs' business-related risks. These policies have led to a significant increase in the number of derivatives contracts being centrally cleared, and most derivatives transactions are now reported to TRs (Sheets, 2017). By 2016, the number of reported contracts outstanding had more than tripled to more than 30 million contracts compared to under 10 million contracts in 2013 (FSB, 2016).

However, in practice, complex and heterogeneous multi-level hierarchical reporting systems, such as those practiced in the context of TRs, may induce significant organisational inefficiencies, which often appear as data fragmentation, quality and consistency problems. There are frequent reports about difficulties in collecting all the necessary data, especially prices and trade execution timestamps, comparing data coming from different sources, aggregating similar data, etc. (FSB, 2015b; Chen *et al.*, 2011; Gordon, 2017). In addition, the current financial reporting system raises serious concerns about high compliance costs for the industry. The new financial reporting rules would require a radical re-engineering of in-house IT systems of financial institutions (as it happens, for example, with the BCBS239 principles for risk data aggregation and reporting). Such "native inefficiencies" in the emerging institutional architecture for financial stability monitoring[14], and a slow industry adaptation path as a result, may delay and undermine the benefits of the regulation, as it usually happens in this industry (Houstoun *et al.*, 2015). Moreover, owing to the continuously increasing automation in financial markets, the global reach of trading and exposures of many market participants make for an increasingly complex financial system with decreasing frictions. Scenarios of very fast global spread of surprising types of crises become less improbable. That makes speed and timeliness, flexibility and global scale of risk monitoring a major feature of an effective regulatory response to potentially dangerous events in the financial system. Current reporting and analytical processes experience considerable difficulties to deliver such performance, both for their data architecture and organisation and for their technical infrastructure.

As we design a new infrastructure for financial reporting, we need to better explore the potential of emerging and established financial, computational and information technologies, to "optimize by design" (Doyle and Csete, 2011) the application of new regulation. The current legal framework[15] requires that a report should contain trade details specifically relating to a particular transaction. Regulation is silent on how this plethora of information could be managed and consolidated[16]. We conceive the financial reporting system as a new *layer* of algorithmic regulation functionality that *spans over* existing financial technology systems, processes and data formats. In such a perspective, the thriving infrastructure of TRs could develop into a RegTech reporting infrastructure, i.e. an ultra-distributed document management and storage system that virtually penetrates the current in-house IT systems of financial institutions. We propose to create a standardised data facility that automatically transfers important contract data from the transaction counterparties to supervisors, regulators and other competent authorities designated by law. The same facility interprets data using a standardised cash flow generation process inferred from the contractual obligations. Such an automation of the financial risk reporting system could track and monitor single financial contracts and institutions almost in real time[17]. This approach would also make it possible to automate at a deep level compliance tasks of regulated financial institutions, thus allowing them to reduce operational risks and costs related to compliance requirements.

Most importantly, the reporting system we propose as a decoupled layer of regulatory functionality from the FinTech infrastructure offers to regulators new possibilities for identifying and fixing deviant behaviours that induce negative externalities and risks at a large scale, including possibly removing particular types of financial contracts from the market. Hence, we can progressively build the mechanisms to accurately assess the build-up of financial risk at the instrument level and trigger alarms long before a full-blown crisis has time to develop (Cochrane, 2014). This "narrower" regulatory approach should increase the overall efficiency of regulation and create feedback to new data science-driven regulatory responses previously conceived as not feasible[18]. Finally, as we envision a significant portion of this RegTech reporting space to become open (under specific privacy-respecting restrictions) to all organisations and citizens, it will allow society at large to acquire a role in the discovery and revealing of potential shortcomings for the financial system (Hardjono *et al.*, 2016).

A necessary condition for the implementation of such a RegTech infrastructure covering the whole financial system is the availability of an infrastructure that would offer globally unique identification of all parties to contracts, thus providing a critical *global public good*. Following the 2007-2008 crisis, the FSB has designed the Global Legal Entity Identifier System (GLEIS), built on a G20-endorsed charter, for exactly that purpose. The GLEIS has a global presence with over 30 LEI issuers managed by the Global Legal Entity Identifier Foundation (GLEIF), and it has, meanwhile, registered over 520,000 entities. The GLEIS is supervised by the public-sector Regulatory Oversight Committee[19]. The use of the LEI code remains to be mandated by legislation to reach the universal coverage, which would enable it to deliver its full potential, creating value in many more fields than regulation.

3. The dynamic transaction document: a close-to-real-time "digital doppelgänger" for each financial contract during its entire life span

At a high level, we propose a unified goal for a RegTech financial reporting infrastructure. It requires the design of a "bearer service" on top of the existing financial system that generates and maintains a DTD for each financial contract. While, at an abstract level, a DTD is close to a synthetic financial contract, it is not a contract itself and it *cannot* transfer value. It is a coded replication of all relevant features of the actual contract on which the firm needs to report, and it must be kept in sync with the actual contract. To be informationally efficient, the DTD will isolate the minimally required information for the financial contract it represents. It can be used over the entire life of a financial contract, including for, but not limited to, all sorts of regulatory reporting purposes. The DTD will store a "digital doppelgänger" for every financial contract together with every relevant state of the world[20] that has materialised. Workable solutions need to overcome differences of legal text (to be read and interpreted by humans) and algorithmic code (to be read and executed by machines) (De Filippi and Wright, 2018).

This paper proposes a unique algorithmic representation of a contract essentially for regulatory purposes. The DTD would track and monitor the evolution path of the actual contract during its whole life-cycle, at each stage providing updated quantitative information and helping relevant users (in accordance with legally determined levels of data access) to level the playing field with FIs with respect to data-driven insights. From this perspective, the proposed DTD infrastructure produces a *public good*, potentially producing important insight at the macro- and micro-supervisory levels while containing legacy systems' drag and eventually allowing FIs to manage their own data and monitor risk more efficiently and in a more secure manner[21]. As explained in the introduction, this public good cannot be expected to be provided in sufficient amounts by FIs left to themselves, creating a need for regulation. At a first approximation, a DTD will be composed of a number of distinct components according to the specific requirements for the construction of transaction and risk reports (as defined by relevant legislation, technical standards, industry standards, etc.)[22], and by following the principles and methods of automated legal text and document engineering (Hazard and Haapio, 2017, Glushko and McGrath, 2005).

In the case of transaction reporting, each time a financial transaction takes place, the IT systems of the transacting counterparties produce a standard electronic message that is captured and processed by the RegTech infrastructure. This can be done via smart contracts. The latter guarantee, as their main feature, a strict order of message commitments, and they guarantee execution. The execution is essentially their calculation of state. After updating its state, the doppelgänger is in accord with the real world, and its state is verifiable by anybody with access to the DL. The state creates a standardised "trace", or audit trail, that a financial transaction must leave behind to inform the competent authorities about all significant circumstances under which this transaction took place. Traces related to the evolution of the same financial contract will be automatically bundled together within a DTD. To ensure the availability of such DTD features at every point in time, we propose a multi-component system structure with a Smart Contract DTD at its core. This will live in a (permissioned) DL infrastructure and act as a proxy for the DTD, as the complete DTD document (the so-called deep DTD) will be stored off-ledger (for a similar approach, see (Zyskind *et al.*, 2015a, 2015b). Essentially, the Smart Contract DTD records the relevant financial events and stores only essential financial data that affect the (evolving) state of a financial contract. It also organises the interaction with the external environment, for example, to retrieve relevant market data.

4. RegTech system architecture and components: Algorithmic Contract Type Unified Standard algorithmic functionality, distributed ledger, distributed storage

To remain a truthful digital representation of the actual financial contract across changing states of the world, a DTD should follow a state-transition evolution similar to the logic of the actual financial contract. In this context, the information to be contained in a DTD has an immutable and an evolving part. The immutable part carries the contract terms proper (counterparties, obligations and commitments, default provisions, etc.). The contract terms are stored in different DTD components assembled into a document component model that captures the reporting standards and the requirements of use. The ACTUS algorithms compute the time-evolving part from the immutable part and the relevant states of the world[23]. The time-evolving part consists of cash flows and some non-cash flow events (together called *contract events*). Thus, the time-evolving part can be considered a transition path involving a finite number of contract evolution states, defined, for example, as the chain of contract events. According to the two types of operational modes of ACTUS, two types of time-evolving outputs exist: Firstly, ACTUS creates the history of the contract, expressed in terms of the *realised* contract events, which are deterministic because computed from known realised states of the world. Secondly, ACTUS needs forecasts of the relevant future states of the world as input to create *expected* future contract events (mainly cash flows), which are probabilistic in nature. The future expected cash flows provide the input for financial risk analysis needed for reporting risk data.

4.1 The structure of a dynamic transaction document

More precisely, information stored in a DTD include the following three types of data:

(1) Contractual information required by the financial reporting guidelines, which includes the following:

- DTD component C1 – contract identity data (indicative)
  - unique transaction identifier
  - product information
  - underlying information
  - reporting date and time 0
  - order date and time
  - trading date and time trading capacity
  - indicators (such as short selling and waiver)
- DTD component C2 – counterparties identity data (indicative)
  - reporting entity ID {LEI of reporting FI and country}
  - contract parties ID {LEI and country}
  - reporting party ledger address contract parties
  - distributed ledger address

- DTD component C3 – contract financial data (indicative)
  - contract type
  - contract parties roles
  - contract deal date
  - effective start of date, maturity date
  - value (notional principal and currency)
  - cycle of interest payment
  - cycle anchor date of interest payment
  - nominal interest rate

(2) All data needed to reconstruct a contract's history during its life cycle (along the evolution of the contract as reflected in the DTD transition path), which mainly includes data from external resources, e.g. interest rates during the transitions from one state to another and other market conditions external to the contract, which affect not only the mutual obligations of the counterparties, but also changes in the legislation, etc. (DTD Component C4).

(3) Standard DTD input for financial analytics (DTD Component C5). This input mainly consists of the contract events, in particular cash flow events, and implies that the DTD should also incorporate algorithmic finance technology needed to generate this information out of the data contained in Components C1-C4. More specifically, the algorithmic part consists of ACTUS algorithmic functionality, ACTUS methodology and its contract types taxonomy (Brammertz *et al.*, 2009, ACTUS Financial Research Foundation, 2016, ARIADNE Business Analytics, 2017). Together, these components, by processing information contained in C1-C4, generate the contents of C5.

The DTD document will encapsulate the contract events generated by the logic of the underlying financial contract in the form of transition states[24]. This is why DTD can be written as a state-transition system where:

- the initial state S_0 represents the initiation of the underlying contract;
- a finite set of intended states, denoted $Si_1, \ldots, Si_N$, outline the expected evolution of the DTD along the intended contract path as defined on the basis of the input received between the time of the initial state S_0 and the state Si_n under consideration;
- a small set of non-intended states $Sni_1, \ldots, Sni_K$ define a major departure from the intended contract transition path (owing to external actions that change the intended path of evolution, such as a re-selling decision, which affects the ownership of the contract, a modification in the duration of the contract, in the product configuration, as in the case of a mortgage, a "cancel" or a "default" decision taken by the counterparties, etc.); and
- triggering events (normal and exceptional) necessary to define the transition from one state to another (Flood and Goodenough, 2017).

The input to define S_0, and states $\{Si_1, \ldots, Si_N\}$ and $\{Sni_1, \ldots, Sni_K\}$, will be received directly from the counterparties. Once the transition path is generated, the DTD will successively calculate, in reference to the actual evolutionary trajectory, the "deterministic" (part of the) value of the contract at each state based on the data provided by separate DTD components. Specifically, a contract's (realised and expected) cash flows will be derived from DTD states by incorporating ACTUS algorithms in the structure of a DTD component of type C5, which, in this context, integrates transaction reporting with risk reporting – providing to its recipients the complete basis for financial analysis and risk assessment.

The document engineering part comprises five distinct functional features:

(1) DTDs replicate (a subset of) the legal financial contract for the needs of financial reporting and monitoring.

(2) DTDs enable both transaction and risk reporting at the most granular level (the individual financial contracts).

(3) DTDs use ACTUS algorithms for calculating evolution states and cash flows (based on the contract rules) and provide input for financial analysis.

(4) DTDs allow for automatic aggregation of different cash flows according to metrics and levels of aggregation according to user needs. This allows automatic computation of critical (prudential) indicators about the position of particular financial institutions and/or their inter-dependencies.

(5) Users with access to DTDs can reconstruct the image of each individual contract, as well the image of an entire institution through cash-flow aggregation based on information provided by individual DTDs[25].

Therefore, they will be more powerful in discovering early run-prone contracts or other market shortcomings, and act to "stop crisis before they start" (Cochrane, 2014).

4.2 The network implementation of a dynamic transaction document

To ensure these DTD features at every point in time, we propose an environment for financial reporting with a smart contract version of the DTD at its core. This will live in a (permissioned) DL infrastructure (Swanson, 2015; Pinna and Ruttenberg, 2016; Boucher *et al.*, 2017). Smart Contract DTDs act as a proxy for DTDs (the deep DTD) stored off-ledger[26]. Obviously, access to data included in both DTD versions (both the Smart Contract and the deep DTDs) will need suitable access policy frameworks that are beyond the scope of this paper[27]. The Smart Contract DTDs record the relevant financial events and store essential generic data (such as realised and expected cash flows) that impact the (evolving) state of a financial contract. They also organise the interaction with the external environment, e.g. by retrieving and fetching market data. Once a new transaction reported (separately from each counterparty), it should be validated by a limited number of DL participants responsible for this task, added to the most recent version of the ledger and automatically and irrevocably stored in the DL, and then transferred into the deep DTD. This "handshake" mechanism, very tailored to the reporting use case discussed here, needs to be designed carefully to ensure a fair representation of the evolution of the actual (underlying) financial contract at any time while keeping validation efforts as low as possible.

Why might a dual DTD identity be preferable? This choice is owing to (cost) efficiency and scalability considerations. Smart Contract DTDs essentially work as a proxy for deep DTDs. They provide deep DTD location identification, at the same time making publicly available, through the DL, the essential transaction and risk reporting information while keeping resource requirements on the DL structure within feasible limits. At the same time, the deep DTD structure effectively stores the complete reporting data and the calculated cash flows for each transition state of a contract. The Smart Contract DTD will suffice for most purposes of risk monitoring, and, if legislation allows so, for frequent reporting tasks.[28] Simultaneously, supervisors will access deep DTDs for, more resource-intense, case-by-case inquiries, including for the purpose of auditing or stress-testing system requirements.

Essentially, Smart Contract DTDs encode the logic, conditions and basic rules regarding the financial transactions generated by financial contracts, they orchestrate the interaction with external systems and third party resources (for example, with IT systems providing market data, sometimes referred to as oracles) and generate inputs for financial analysis. The code of Smart Contract DTDs will execute functions such as *DTDcontractCreate, DTDcontractUpdate, DTDcontractStore, DTDcontractGet* and *DTDcontractCancel.* A specific function (*deepDTDsetURL*) allows for initialising the longer version of the transaction report (i.e. the complete transaction report) in a distributed data store, with (off-ledger) storage nodes being co-located with the principal nodes of the distributed ledger. A combination of functions will be responsible for transferring the complete reporting information from the financial contract counterparties to Smart Contract DTDs and then to deep DTDs. Smart Contract DTDs may run at every node of the distributed ledger, or at specific (principal) nodes, depending on the design architecture chosen for the deployment of the DL. The specific access rights over Smart Contract DTDs' data and functions and the access policy rules are also stored directly on the DL.

A private DL stores and manages the Smart Contract DTDs to ensure information imitability, instant update and transparency. It supports system-wide, transparent, consistent and timely risk assessment and automatic compliance control while effectively organising access control and assigning permission rights. However, because of the limited size of the data store provided by a DL (Xu *et al.*, 2016), it is necessary to complete the DL network of nodes with an (underlying) off-chain data storage infrastructure (where the deep DTDs are stored). Distributed storage technologies using fragments that are placed at a number of storage network peers (Caron *et al.*, 2014) and/or decentralised edge cloud architectures (Chandra *et al.*, 2013) may provide the performance and local placement data policies (eventually imposed by the Central Banks' data protection policies) required. However, both DL and distributed/decentralised storage are emerging technologies, and there is still a lot of uncertainty as far as the economics, standards and adoption strategy, performance and scalability of the proposed architecture. Yet, it is clear that global financial players, such as DTCC, one of the biggest Clearing Houses and a Global Trade Repository, are seriously considering the use of DLTs in the post-trade financial services. The automation of financial transaction and risk reporting will have great advantage for both the industry and the successful implementation of the new regulation, and this automation essentially depends on the deployment of cutting-edge innovative technologies as proposed in this paper.

In the meantime, some of the authors were involved in successful proofs of concept (POCs) including live demonstrators (Sel *et al.*, 2017). One such demonstrator[29] makes use of Ethereum smart contracts that implement a basic model of a bond (modelled after an ACTUS "Principle at Maturity" or "PAM" contract type) and an interest rate swap (modelled after an ACTUS "SWAP" contract type). Smart contracts execute on a private network using Raspberry PI's and laptops as DL nodes. The demonstrator produces reports in the case of a merger of two counterparties and a default of counterparty. Having close-to-real-time reports in quickly changing market environments as represented by these two scenarios is precisely what the concept discussed in this paper aims to achieve. Selective elements of COREP, MIFID and EMIR reporting have also been implemented allowing seamless machine-to-person as well as machine-to-machine reporting at any point in time. A second demonstrator[30] makes use of a Hyperledger DL[31] that interacts in real time with an external ACTUS server. The demonstrator creates and maintains automated transaction and financial risk reports in the context of a simple economy consisting of three inter-related banks and a regulatory authority.

5. Conclusion: the proposed dynamic transaction document enables close-to-real-time, end-to-end regulatory reporting based on granular data

The DTD provides a unique presentation of each financial contract to be used at every step in the processing chain, including, but not limited to, all varieties of regulatory reporting. In terms of process logic, the reporting takes place *only once* and it is the different users of the DTD (mainly regulators, possibly research institutions and other representatives of "society at large") who decide how information will be aggregated (applying a suitable document access policy). The granular data on transactions are broadcast to the DTD supporting infrastructure where it is automatically aggregated and made available for analytical purposes. Essentially, consistent transaction processing and nearly instantaneous regulatory reporting of financial transactions and their associated risks would become possible.

The DTD supporting infrastructure will be designed end-to-end (e.g. from FIs to supervisors). The benefits of such a "narrow regulation" approach, enabled by a DTD, will become obvious for all partners involved in the complex financial system as soon as the system is in place (the analogy to the invention of the wheel applies). Already today, FIs are legally required to report on transactions as well as on the evolution of risk aggregates. DTDs would integrate in a fully consistent manner both risk views for monitoring and reporting purposes; as a result, they could help reduce compliance costs and progressively close the gap between the operational and the analytical departments, i.e. integrating front, middle and back office. Overall, transparency of the global financial system will increase – firstly, benefitting supervisory authorities and regulators, secondly, financial research and legislation and, last but not the least, society at large.

Notes

1. RegTech is a blend word (Regulatory Technology) that signifies a targeted use of technology to improve efficiency and introduce data processing innovation and automation in the delivery of regulatory procedures and tasks, e.g. in the control of compliance of financial institutions with applicable regulation in the area of reporting (of risk data) and risk monitoring (FCA, 2017).
2. The term "distributed storage" denotes "a computer networking scheme in which the primary objective is to pool the storage capacity of all the connected devices" (see: www.businessdictionary.com/definition/distributed-storage.html).
3. "Automated legal text" refers primarily to a "data model for (legal) text" (Hazard and Haapio, 2017), or more generally to (legal) text represented as computer code that can be executed in an automated manner at virtually zero marginal cost; a sub-set of such automated legal text is a "smart contract" where the (automated) execution of the computer code is guaranteed by the fact that instructions are executed on a possibly large number of machines in a decentralized manner as described in (Diedrich, (2016).
4. "Document engineering" (Glushko and McGrath, 2005, refers to "techniques for analysing individual transaction patterns and the role they play in the optimization of a related overall business process"; in the case where, as in the present context, such techniques are used to help a business comply with regulatory requirements, we consider this as being part of RegTech where "(. . .) (m)achine-readable regulation allows more automation and can significantly reduce the cost of change, ensuring greater consistency between regulations and implementation" (PWC, 2017).
5. A "bearer service" refers to a layer within a hierarchical (data transmission) technology stack that provides certain basic functions in a standardized manner while allowing users to define more specialized functionality in higher layers of the technology stack.
6. We chose the term "data facility" rather than the very tempting term "data container" due to the vastly richer functionality of the present approach; however, as with containers and the bar code,

the role of standardization occupies a central place, the discussion of which, however, is beyond the scope of this paper.

7. For the sake of simplicity, we discuss the architecture as if there was a single DL; in reality, there will be several DLs that communicate with one another.
8. See Hertkorn *et al.* (2015) for a discussion of related measurement issues.
9. www.actusfrf.org
10. www.gleif.org
11. ACTUS, the algorithmic data processing component of DTD, provides two modes of operation: a real-time mode for determining the cash flows to be transacted (realized CF) and a simulation mode for computing future cash flows contingent to the future relevant states of the world (expected CF). The real-time mode only uses states of the world that have already realized and yields deterministic results. The simulation mode, on the other hand, needs as input forecast of future states of the world as, e.g. future interest rates. Thus, the outcomes, i. e. the expected cash flows, are probabilistic in nature. In this sense, ACTUS can allow for a wide of financial assessments that are important for risk management, financial regulation (Braswell, 2016), much beyond the particular use of ACTUS standards described in this paper.
12. Technology adoption is expected to be disruptive in the sense that once the wheel is invented it is almost impossible to stop people from using it.
13. www.fsb.org/
14. As an example of the issues financial institutions currently face with reporting, we mention the enforcement fines received by some of them for transaction errors, due to the submission of inaccurate and incomplete reports (Bannigan, 2016, Gordon, 2017). This proves the complexity and the business risk associated with reporting.
15. Transaction reporting is an important part of the existing MiFID II and MiFIR framework (www.esma.europa.eu/policy-rules/mifid-ii-and-mifir) which specifically favours transparency and targets market abuse (Bannigan, 2016, Clifton *et al.*, 2017).
16. For a long time, regulation was expected to be technology neutral; while this expectation has not been adjusted, at least since the mid-1990s with the successive arrivals of electronic and automated form of financial trades, high frequency trades and finally big data in finance, technology neutrality has been emptied of its empirical content. Under present circumstances, any form of regulation will qualify some technologies and disqualify others. At the same time, different technologies create different feedbacks to the effectiveness of any particular regulation, i.e. both directions of the feedback loop need to be understood, measured, and monitored constantly.
17. In product tracking and tracing in logistics and distribution systems this is already the case.
18. Our approach is in line with the concepts of adaptive financial regulation and Regulation-as-a-Services, proposed by Baxter (2016) and Piechocki 2016), respectively.
19. www.leiroc.org
20. Relevant states of the world are those that (directly or indirectly) affect some (expected) cash flow of the contract. This includes, but is not limited to, market information such as interest rates and information about counterparty behaviour.
21. Even a major security breach at the level of the DTD could not hurt the actual contracts (data) that have legal value.
22. The proposed system incorporates generic legislation guidelines, such as MiFID, EMIR and specific transaction reporting rules as defined for example by FSB and ESMA (ESMA, 2016).

23. At a conceptual level, the ACTUS algorithms resemble the state-transition machine suggested by Flood and Goodenough (2017).

24. The legal text of a financial contract contains the business rules that determine the generation of financial events. In fact, a financial contract is a set of successive events, such as capitalizations of accrued interest, interest payments and rate resets, which create cash flows during the lifeline of the contract. As defined by Brammertz *et al.* (2009), financial events are the execution of the mutual promised between the contact counterparties on the time line, depending on the external environment (market risk, counterpart risk, etc.) and other conditions defined in the contract. These events are either explicitly mentioned, or are intrinsic, in the actual contract in the sense that their generation depends on the execution rules of the contract. ACTUS algorithms calculate the financial events for each contract and generate the cash flow. The DTD interacts with ACTUS to get these automated calculations to reconstruct the image of each individual contract (as s series of evolution states) at the RegTech reporting space – specifically adapted to the needs of financial reporting and monitoring. We should also notice that ACTUS algorithmic functions are tied to so-called contract types (CT), which standardize the state-contingent contract payoff. A given ACTUS CT implements a family of these standard cash flow patterns. All contracts reported through the DTD mechanism are mapped on ACTUS CTs (Brammertz *et al.*, 2009, ACTUS Financial Research Foundation, 2016).

25. As explained above, the DTD incorporated ACTUS two-fold function: the real time mode and the simulation mode. This means that DTD will provide cash flows on two levels: firstly, realized cash flows, namely, the actual transactional cash flows occurring during a financial contract's life; secondly, future expected cash flows conditional to models of the relevant states of the world as analytical raw results that are a suitable input to any kind of financial analysis conducted by the DTD users. Progressively, as the process of contract automation will gain momentum, other elements can be added to the DTD structure, to create a larger framework of contract variables within which such calculations may take place.

26. Our approach is similar to Zyskind *et al.* (2015 a, b), Xu *et al.* (2016) and the internet of trusted data vision outlined in Hardjono *et al.* (2016).

27. On privacy and access management-related issues and perspectives, see Lane *et al.* (2014) and Hardjono *et al.* (2016).

28. Once the system is in place, due to the high degree of automation, running costs can be expected to be very low and cost-benefit considerations could lead to higher reporting frequencies, if not overnight reporting. In this case, the Smart Contract DTD would be the better format.

29. An explanatory video is available at: www.pwc.be/fismablockchain

30. This is based on a joint initiative of University of the Aegean and Zurich University of Applied Sciences.

31. See www.hyperledger.org

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About the authors

Petros Kavassalis is an Associate Professor with the University of the Aegean (Department of Financial and Management Engineering – Information Management Lab, i4M Lab) and a Senior Researcher at the Computer Technology Institute & Press, Greece. Previously, he did research at L'École polytechnique, Paris (Centre de recherche en gestion), at MIT, Cambridge, Massachusetts (Research Program on Communication Policy – now part of SSRC) where he contributed to founding the MIT Internet Telecommunications Convergence Consortium (MIT–ITC), and at ICS–Forth, Greece. Petros Kavassalis holds a degree in civil engineering from the National Technical University of Athens (NTUA) and a PhD from Dauphine University in Paris (economics and management). His research focuses on information management, identity and privacy management in federated environments, business process modelling and automation, applications of distributed ledgers, document engineering and communications policy. Petros Kavassalis is the corresponding author and can be contacted at: pkavassalis@atlantis-group.gr

Harald Stieber is a Senior Economist in the European Commission department responsible for EU policy on banking and finance (DG FISMA). Since 2013, he has followed research in the area of complex and global systems science, agent-based computational models, global financial data standards, blockchain technologies and digital currency. Previously, he worked on financial programming, macro-modelling and measurement of potential output, public sector productivity measurement and economic forecasting. He holds a doctorate in economics from Vienna University of Economics and Business (WU Wien), and he is currently a Fellow in the WCFIA scholars program at Harvard University. His current research interest includes the role of blockchain technology and digital currency in regulated markets, for compliance (RegTech) and for government services (GovTech).

Wolfgang Breymann is the Head of the Group Finance, Risk Management and Econometrics at Zurich University of Applied Sciences, Institute of Data Analysis and Process Design. After a career in theoretical physics, he turned to finance in 1996 as one of the early contributors to the field of econophysics. Since 2004, he is a Professor at the Institute of Data Analysis and Process Design at Zurich University of Applied Sciences, where he developed the activities in financial mathematics and quantitative risk management. He is one of the originators of project ACTUS and member of the board of directors of ACTUS Financial Research Foundation. His current research interests include automation of risk assessment to improve the transparency and resilience of the financial system.

Keith Saxton is an Independent Director and Advisor engaging with multiple organisations, from new entrants to large established players, helping with business strategy, technology imperatives, FinTech initiatives and risk management. Previously, he was the Director Financial Services IBM Research and held a number of industry focused leadership positions at a country, regional and global level. Before IBM, Keith worked in executive management of the front office of various major global banks covering trading, sales, capital markets, risk and long-term strategic business planning.

Francis Joseph Gross is a Senior Adviser in the Directorate General Statistics of the European Central Bank (ECB). He holds an engineering degree from École Centrale des Arts et Manufactures, Paris, and an MBA from Henley Management College, UK. Before the ECB, Francis spent 15 years in the automotive industry. His research interests include developing vision and strategies for managing the dual disruption of rapid globalisation and digitisation. His focus is on the "real world – data world" interface, primarily object identification. He serves on the Regulatory Oversight Committee (ROC) of the Global LEI System (GLEIS), and he has been instrumental in the emergence and development of the GLEIS.