Incentivizing Data Quality in Blockchains for Inter-Organizational Networks – Learning from the Digital Car Dossier

Zavolokina, Liudmila ; Spychiger, Florian ; Tessone, Claudio J ; Schwabe, Gerhard

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Completed Research Paper

Liudmila Zavolokina
University of Zurich
Binzmühlestrasse 14
8050 Zürich, Switzerland
zavolokina@ifi.uzh.ch

Florian Spychiger
University of Zurich
Binzmühlestrasse 14
8050 Zürich, Switzerland
florian.spychiger@uzh.ch

Claudio J. Tessone
University of Zurich
Andreasstrasse 15
8050 Zürich, Switzerland
claudio.tessone@business.uzh.ch

Gerhard Schwabe
University of Zurich
Binzmühlestrasse 14
8050 Zürich, Switzerland
schwabe@ifi.uzh.ch

Abstract

Recent research reports the need for consistent incentives in blockchain-based systems. In this study, we investigate how incentives for a blockchain-based inter-organizational network should be designed to ensure a high quality of data, exchanged and stored within the network. For this, we use two complementary methodological approaches: an Action Design Research approach in combination with agent-based modelling, and demonstrate, through the example of a real-world blockchain project, how such an incentive system may be modelled. The proposed incentive system features a rating mechanism influenced by measures of data correction. We evaluate the incentive system in a simulation to show how effective the system is in terms of sustaining a high quality of data. Thus, the paper contributes to our understanding of incentives in inter-organizational settings and, more broadly, to our understanding of incentive mechanisms in blockchain economy.

Keywords: Blockchain, inter-organizational networks, incentives, data quality, Action Design Research

Introduction

Many industries struggle to solve problems and improve processes which involve interrelationships (in some cases not apparent) between different untrusted, heterogeneous organizations. In many sectors (e.g. education, healthcare, automotive industry), there is no way an individual organization (including a governmental body) is able to resolve emerging problems of high complexity acting on its own (Hoberecht et al. 2011). Nowadays, organizations establish relationships with others in nearly every step of the execution of their business transactions (Powell et al. 1996). An inter-organizational network can be described as a structure which includes actors (organizations) and relationships between them (Popp et al. 2013). Trust is the basis of inter-organizational relationships which makes them possible, and enhances the effectiveness of the network (Popp et al. 2013). Thus, organizations build up inter-organizational networks in order to address emerging problems and profit from the resulting improved performance (e.g. efficiency gains, new business models) and cooperation (e.g. innovations, knowledge sharing).

To resolve trust issues, such mechanisms as legal contracts, regulations, and incentive alignment are traditionally established. Recently, with the emergence of blockchain technology, organizations started experimenting and building up specific consortia, and this became a popular means of working cooperatively to attain certain business goals (Gratzke et al. 2018). More than 40 such consortia were established by the year 2017 (ibid.). Though the potential of blockchain technology for inter-organizational relationships has not been fully explored yet, it is claimed to be an enabler of business relationships in many fields (the financial sector and logistics currently being the most prominent of these). Organizations involved in blockchain consortia opt for secure and transparent data exchange and storage, which is promised by blockchain technology. However, to be able to generate value from this exchange and storage (which is the ultimate goal of such inter-organizational relationships), these consortia should achieve a high quality of stored data.

One of the important dimensions of blockchain governance (which comes from the literature on IT governance) is incentives (Beck et al. 2018). Incentives motivate agents (network participants) to act in such a way that they freely choose their behavior so that it is consciously or subconsciously aligned with the system goals (Beck et al. 2018). These incentives may have monetary (e.g. earnings) or non-monetary character (e.g. reputation, opportunities for new business models, beneficial cooperation). While incentives are widely explored in research streams on IT governance, for blockchain technology there is a breadth of questions that remain open. Recently, Beck et al. (2018) called for exploration of incentive mechanisms[1] in blockchain-based systems and proposed the related research agenda. In our study, inspired by Beck et al. (2018), we focus on an incentive mechanism placed in a blockchain-based inter-organizational network, which ensures a high quality of exchanged and store data within the network. By 'data quality' we mean the correctness of the stored data (if the data is accurate, valid and error-free) as well as its completeness (none of relevant data is missing). The problem of poor input data (also often called "Garbage In, Garbage Out") is widely known. In the context of blockchains it becomes even more relevant to ensure high data quality because, once recorded, the data cannot be changed any further due to the immutability of blockchains. Therefore, to ensure that an inter-organizational network can extract value from data exchanged and stored in a blockchain-based system, the data quality must be assured in the first place. Consequently, in this paper we address the following research question:

RQ: How can we incentivize data quality in blockchains for inter-organizational networks?

We assume that achieving high data quality is a necessary factor to reach the goal of the inter-organizational network and to foster prosperity within the network. Under this assumption, we specify the question to be addressed as follows:

Sub-RQ: How can an incentive mechanism make a blockchain-based inter-organizational network consistent[2] and self-sustaining[3]?

In this paper we use two complementary methodological approaches: an Action Design Research (ADR) (Sein et al. 2011) approach in combination with agent-based modelling (Epstein 2006; Macal and North 2007). The contributions of this study are two-fold. Firstly, we create a parsimonious model (describing agents, their behavior, interactions, and the environment in which they operate), which is aimed at resolving incentivization problems related to the quality of exchanged and provided data on the basis of learnings from an existing blockchain project (further described as Car Dossier). In order to evaluate this model, we run extensive simulations to show what effects it has on the blockchain-based inter-organizational network. Secondly, we discuss what implications the results of our study have in terms of design of incentives in blockchain networks, therewith bringing value to practitioners. In doing so, we make

[1] Here and further in the paper we use terms 'incentive model', 'incentive system', 'incentive mechanism' inter-changeably though we acknowledge their conceptual differences.

[2] An incentive system is said to be consistent, if a rational actor's best strategy is to act according to the goals of the incentive mechanism.

[3] An incentive system is called self-sustaining with respect to a given framework, if it fosters the prosperity of this framework and is attack-resilient.

a step towards better understanding of mechanisms of incentive systems in blockchain-based inter-organizational networks, blockchain governance, and blockchain economy in general.

The paper is structured as follows: In the second section, *Car Dossier*, we describe the project this work is built upon by using methods from the Action Design Research approach (Sein et al. 2011). The project description gives an overview of the built-up consortium and the inter-organizational network of the Car Dossier project. In the third section, *Related Work*, we review the relevant literature on inter-organizational networks and general blockchain-based incentive systems. Fourth, the section *Methodology* describes the approach taken in this study. Fifth, we describe the *Results* of the study, in particular those emerging from the proposed model for a blockchain-based incentive system in an inter-organizational network. Then, in the *Discussion* we reflect on the results, their meaning and the implications for research. Finally, we draw *Conclusions* from our study, outline its limitations and propose future research directions.

Car Dossier

A consumer study, conducted in 2017 in Germany, reports that the automotive market is in the top 3 markets with the least trust from consumers (followed by banks/insurances and the telecommunications industry) (Lades 2017). In particular, in the second-hand car market consumers suffer from such problems as: the car being in worse condition than initially indicated, accident damage which was not previously disclosed, limited documentation provided, fraud, etc. (European Union 2014). In a consortium of companies from the automotive market, the Car Dossier project addresses and aims to resolve problems of mistrust, intransparency and process inefficiency by creating a blockchain-based solution. The involved parties are companies (an insurance company, an importer and official car dealer, a car-sharing company) and public authorities (the Road Traffic Agency). The goal is to collect various data over a car's lifetime in order to create a valuable "Car Dossier" and a shared platform to exchange data and increase efficiency of operations. As there are multiple parties involved who do not fully trust or know one other, the participants opt for a blockchain-based solution. The blockchain technology serves as an enabler for such inter-organizational relationships. From the technology point of view, centralized technologies may solve those issues, but they are legally and organizationally not acceptable. Legal issues (not the least because of data protection issues and the limited task of a public administration) prevent governments from running such systems. Furthermore, the participants do not trust any single provider to run a platform for them. So, the 'distributedness' of blockchain governance is a major driver for consortia to rely on blockchain technologies.

The Car Dossier solution is built on top of Hyperledger Fabric, a modular open-source platform providing a permissioned blockchain infrastructure ("Hyperledger Fabric" 2018), and is driven by a consortium of the above-mentioned companies with the further goal of being open for all players in the Swiss automotive market. The permissioned framework is ideal for a business application in which the participants require some means for identification but do not necessarily fully trust one another (Vukolić 2017). Such a system creates an inter-organizational network of companies which calls for well-established governance mechanisms (we explain the notion of inter-organizational networks later in *Related Work*). One of the governance mechanisms is an incentive system, which should ensure the consistency and the self-sustaining operation of the system in terms of quality of provided data, gains and losses participants experience through participation in the network, and their behavior (e.g. how active the participants are, how to identify and avoid malicious behavior).

The blockchain stores data associated with vehicles: accidents, servicing, technical issues and transfer of property. The complete set of records for a specific vehicle is the Car Dossier. The data is saved, encrypted on the blockchain, and customers (e.g. private or organizational) can buy access to a relevant Car Dossier they may be interested in. A system based on smart contracts, ensuring payment for data suppliers or payment of a fee for data consumers upon fulfillment of certain conditions, provides a financial incentive for participation in the network. Overall, this is a system in which multiple parties are enabled to do business together without necessarily trusting one another. For such a decentralized and automated solution to be effective, an appropriate incentive model must be in place such that all participating parties contribute the necessary amount of high-quality data to the system. Such an incentive model can again be implemented and operated autonomously in the setup described above. Ultimately, a self-functioning system should emerge within which all agents are motivated to contribute car data without the need of a centralized authority to organize the information flow. This should also show that the incentives are consistent, meaning that the effect of the incentives are as desired[4].

Related Work

Inter-organizational Networks

Even though inter-organizational networks are a well-established phenomenon, there is no agreement on a single definition to be used equally in organizational studies, IS research or social sciences. However, a common understanding of inter-organizational networks posit that they all incorporate "social interaction (of individuals acting on behalf of their organizations), relationships, connectedness, collaboration, collective action, trust, and cooperation" (Provan et al. 2007). In our study, we adhere to the definition that suggests inter-organizational networks consist of actors (individuals or organizations), relationships between them (connections) and the meaning of their relationships (Popp et al. 2013). We acknowledge that the term "inter-organizational networks" is often used in relation to supply chains. In our study, organizations interact through the platform, where they exchange data and are financially rewarded for it. Therefore, they are naturally intertwined and networked with one another.

Previous studies acknowledge that trust is the basis for inter-organizational relationships, which makes cooperation between actors possible. The higher trust is, the more successful the cooperation results (Popp et al. 2013). With the rise of blockchain technology[5], which can be built in trust-free environments (Beck et al. 2016), such inter-organizational ties should be reconsidered in terms of governance of inter-organizational networks. Blockchain systems can play the role of facilitator in inter-organizational networks by minimizing (or possibly eliminating) the need for control over others in risky situations (Das and Teng 2001), thus giving rise to more trusted relationships. Though blockchain technology brings certain value for service systems due to its design and underlying concepts (like immutability, transparency, integrity of data, etc.) (Seebacher and Schüritz 2017), the technology itself is not a holy grail which is able to resolve any emergent issue. Therefore, it is mandatory to study how such a system should be designed to bring the promised value. In particular, in our study we focus on the incentive mechanism which, if correctly set up, should ensure a high quality of data in a blockchain-based inter-organizational network.

Incentive Systems for Blockchains

Reasonable and well-aligned incentives play an important role not only in the digital economy, but also in the blockchain economy (Beck et al. 2018). Without a consistent and self-sustaining incentive mechanism, a blockchain economy would not be possible. Though Beck et al. (2018) do not provide a definition of an incentive system for blockchain economy, they identify three levels on which incentives should be aligned: digital processes in peer-to-peer exchanges for value creation of blockchain-based digital goods; incentives to create private goods, club goods, and public goods; and new network-based processes that incentivize the peer-to-peer nodes to reach consensus. Beck et al. (2018) propose numerous research questions to be explored on all three levels to develop deeper understanding of incentive systems. In our study, we look at how an incentive system may be designed to overcome the challenge of insufficient data quality in a blockchain-based inter-organizational network so that creation of a public good, a valuable car dossier, may be possible.

There are a limited number of studies that address incentives in blockchain systems. Xu et al. (2016) found that for systems where a permissioned blockchain is a more feasible solution than a permissionless one, and some data may be stored off-chain (for example, for achieving privacy), "an additional economic incentive is required for the participants to be honest." This incentive may include security deposits, reputation or rating mechanisms. Okada et al. (2017) distinguish blockchain systems on the basis of the

[4] There is a famous term for the case when incentives make the situation even worse: "The cobra effect". It is based on an anecdote set at the time of the British rule of colonial India. The Britons were concerned about the high number of dangerous cobras in Delhi. They decided to offer a bounty for every dead cobra to the people of India. As a result, the Indians started to breed cobras at home which eventually led to a larger population of cobras.

[5] We believe that the reader is familiar with foundations of blockchain technology. Therefore, we do not provide any further explanation on its basics.

nature of incentives in place: market- and non-market-based. Market-based incentives are tightly bound to a token or cryptocurrency, its pricing mechanisms and its market price. In contrast to those, consortium blockchain systems need non-market-based incentives. In this case, there is no need for participants to engage in an energy-consuming and competitive processes (such as mining), they can instead agree on an appropriate mechanism (Okada et al. 2017). However, in these situations there should be additional incentive mechanisms (like legal measures, e.g. contracts or regulations), which will ensure appropriate behavior of participants in the network. Okada et al. (2017) conclude that there should be further exploration of how such incentive systems should be designed, evolve and change over time.

Finally, we look at the literature on cases similar to the one we have in the Car Dossier project. Notheisen et al. (2017) address the problems of information asymmetries in the car market by implementing proof-of-concept prototype to gather history of a real-world asset (a car) in a public blockchain-based system. In their study, Notheisen et al. (2017) show the feasibility of the case for utilizing blockchain technology. However, the questions regarding incentives in this system remain undiscussed and still open: How is high-quality data achieved? How can the system be protected from the misbehavior of its participants, i.e., prevented from inserting incorrect data? Some visionary solutions include the integration of sensors in processes related to collection of data or related to physical objects; or the usage of oracles - so-called gatekeepers - to approve the data to be entered into the network. In our study, we take a step further and address these questions.

Methodology

Action Design Research and Project Setting

In order to define requirements for the design of incentives in blockchain-based inter-organizational networks that ensure data quality, and further to propose a model for an incentive system, we follow the ADR approach (Sein et al. 2011). ADR allows for the design of an IT artifact embedded in an organizational context. It encompasses proven methods from both Design Science Research and Action Research. The problem and the proposed solution addressed in this study call for close collaboration with a consortium of companies that build up a blockchain-based inter-organizational network. This requires continuous examination of the specific organizational setting by intervening and evaluating (Sein et al. 2011). The ADR methodology is the right means not only by which to design and build an innovative IT artifact (Hevner 2004), but also to embed it into and learn from the organizational context while addressing a problematic situation (Sein et al. 2011). The ADR project is conducted within the Car Dossier project described above. Table 1 summarizes how ADR was set up for this study in terms of its stages and principles.

Stage 1: Problem formulation in the ADR project. In order to gain an overview of the state of the art in the field, extensive literature research was conducted as a starting point (Vom Brocke et al. 2009). The focus was put on existing incentive models in current blockchain implementations as well as in other peer-to-peer networks. Four semi-structured interviews (Myers and Newman 2007) with each of the business project partners in the Car Dossier, conducted between April and July 2017, were analyzed in order to understand the business activities of organizations. Furthermore, the group of researchers involved in the project attended tri-weekly project meetings that took place between August and November 2017. These meetings and discussions served as targeted observation sessions to determine specific problems in terms of data quality and incentives.

Stage 2: Building, Intervention, and Evaluation: we formulated the early requirements for the incentive system, and these were verified on 5th October 2017 in a focus group with the project partners. A scenario-based design (Rosson and Carroll 2009) approach helped us in building up a link from abstract examples, where incentive mechanisms are needed; to more specific examples (two scenarios were identified: car birth and logging in the blockchain; car usage and case of an accident). After that, inspired by the modelling approach for complex adaptive systems (Nan 2011) (see a more detailed description in the *Modelling Approach* section), we designed the first version of the model for the incentive system.

Stage 3: Reflection and Learning: the model was evaluated in the follow-up focus group on 16th November 2017. The focus group provided constraints for the model. Furthermore, several rounds of workshops within the ADR team, conducted between February and April 2018, helped in refining the model (e.g. including specific roles in the model).

<table>
<tr><th colspan="4">Table 1. ADR process</th></tr>
<tr><th colspan="2">Stages and Principles</th><th>Method</th><th>Artifact</th></tr>
<tr><td colspan="4">Stage 1: Problem formulation</td></tr>
<tr><td>Principle 1: Practice-Inspired Research</td><td>Research is driven by the need for a consistent incentive system for a blockchain-based inter-organizational network in the Car Dossier project.</td><td>Semi-structured interviews (Myers and Newman 2007)
Participation in the project meetings</td><td rowspan="2">Recognition:
Problem exploration in terms of data quality for the Car Dossier network.</td></tr>
<tr><td>Principle 2: Theory-Ingrained Artifact</td><td>The academic literature on inter-organizational networks and on incentive systems for blockchain applications is used as the theoretical basis.</td><td>Literature review (Vom Brocke et al. 2009)</td></tr>
<tr><td colspan="4">Stage 2: Building, Intervention, and Evaluation</td></tr>
<tr><td>Principle 3: Reciprocal Shaping</td><td>Early requirements are formulated in collaboration with practitioners.</td><td>Focus groups (Liamputtong 2009)
Scenario-based design (Rosson and Carroll 2009)</td><td rowspan="5">Car Dossier specific model:

1st Version:
The first proposal for the model, incorporating actors of the network and the early requirements in the model.

2nd Version:
The model incorporates Car Dossier specific roles and constraints, and includes additional mechanisms to address occurring problems.</td></tr>
<tr><td>Principle 4: Mutually Influential Roles</td><td>The ADR team includes researchers and practitioners in order to include theoretical, technical, and practical perspectives.</td><td></td></tr>
<tr><td>Principle 5: Authentic and Concurrent Evaluation</td><td>The incentive system is first designed and then evaluated within the ADR team.</td><td>Complex adaptive systems (Nan 2011)
Focus groups (Liamputtong 2009)</td></tr>
<tr><td colspan="3">Stage 3: Reflection and Learning</td></tr>
<tr><td>Principle 6: Guided Emergence</td><td>A better understanding of the organizational context is gained in the 2nd iteration for model refinement. The incentive system is examined in the simulation, ensuring that the model fulfills the set goals (consistent and self-sustaining incentive system for the Car Dossier network), corresponds to the emergent requirements (network-specific characteristics), and is formally valid.</td><td>Complex adaptive systems (Nan 2011)
Agent-based simulation (Epstein 2006)</td></tr>
<tr><td colspan="4">Stage 4: Formalization of Learning</td></tr>
<tr><td>Principle 7: Generalized Outcomes</td><td>A generalized model is created to show how an incentive mechanism can make a blockchain-based inter-organizational network consistent and self-sustaining, positioning the Car Dossier platform as an instance.</td><td>Complex adaptive systems (Nan 2011)
Agent-based simulation (Epstein 2006)</td><td>Generalized Model:
The final version that can be applied to blockchain-based inter-organizational networks.</td></tr>
</table>

Stage 4: Formalization of Learning: we generalized our Car Dossier specific model to a general one to show how such an incentive model might be designed in heterogeneous inter-organizational networks. In the paper, the concepts from the model are presented together with the instance solution for the Car Dossier project.

Modelling Approach

One way to describe an inter-organizational network of high complexity and changing dynamics, is to treat it as a complex adaptive system (CAS) (Choi et al. 2001). CAS describes "interplay between a system and its environment and the co-evolution of both the system and the environment" (Choi et al. 2001). CAS can be referred to as "a system that emerges over time into a coherent form, and adapts and organizes itself without any singular entity deliberately managing or controlling it" (Choi et al. 2001). One important characteristic of CAS is that there is no central governance mechanism put in place. This type of systems is not controlled by a single rule, but by different distributed interacting parts that have little or no central control over them. Each of these parts has its own governance rules, but altogether they influence the system by various means. This enables CAS to be highly adaptive to its surroundings (Holland 1992). This property closely resembles the spirit of decentralized blockchain-based systems, and thus we argue it is a natural fit for the design and analysis of an incentive system for a blockchain-based inter-organizational network. Furthermore, originating from studies on biological systems and later applied to numerous socio-economic systems, "CAS have the ability to self-organize and dynamically reorganize their components in ways better suited to survive and excel in their environments, and this adaptive ability occurs, remarkably, over an enormous range of scales" (Macal and North 2007). These factors, self-organization and adaptation, correspond to the requirements for designing the incentive system we propose in this study.

Though there is no single definition that researchers agree on, as the concept is still developing and changing depending on the research field (Nan 2011), three components of CAS are established and commonly recognized. These concepts are agents, environment and interactions (Nan 2011). We use the three basic concepts of CAS as a tool to describe the building blocks of the incentive system we design. First, *agents* are actors or single entities in the system. They may have certain attributes, which reflect the internal state of agents, and behave according to specific rules. Second, *environment* is a medium for agents to operate and interact. Environment may be characterized by its structure. Third, *interactions* are behaviors of agents that may be characterized by connections between agents and flows of resources between them. During the modelling process, activities within the ADR project gave input for the definition of certain attributes of agents (like their roles and behaviors). Beyond this, the activities helped define the agents' interactions in the systems aligned to the idea of creating a data market within the Car Dossier project.

In order to analyze interactions of the agents in the environment of a CAS upon a certain set of rules, researchers use agent-based modelling (Epstein 2006; Macal and North 2007) as a powerful tool for computational simulation. We keep the modelling approach parsimonious, intending to reduce the set of parameters to a bare minimum, which allows us to disentangle their role in the overall system properties. Then, following the approach of Nan (2011), we conduct extensive simulations to measure global properties and the influence of certain parameters in the system. More specifically, we measure how certain quality factors of the dossiers may be achieved within the network. Thus the simulation tests the effectiveness of the incentive system. Later, under *Simulation*, we describe what and how parameters for the simulation were set.

Results

Problem Formulation

In this section, we explain the problem addressed and define the high-level requirements for the incentive system. Our research is driven by the need for a consistent and self-sustaining incentive model for a blockchain system that mediates inter-organizational relationships in the form of data exchange on cars' history transactions. As the ADR team was actively involved in the creation of the system, the process of problem analysis was highly iterative and included feedback from the project partners (from the Car Dossier project) in interviews and project meetings (as described in *Methodology*). The quality of provided data is difficult to control. Though blockchain technology, thanks to its characteristic of immutability, ensures that entered data cannot be altered, it is still not clear how to ensure the initial input of data is correct (in cases of unintentional error or intentional misbehavior) and its supply is constant.

Data quality may be hindered by technical challenges (e.g. incorrect manual input of data, no visual interface or not enough competence to use the system), strategic considerations (e.g. an organization does not wish to reveal any critical business information, and thus changes the data), data protection and privacy (e.g. how to deal with the private data of car owners in such a distributed system, and clarity over who owns the data records), regulations (e.g. in cases when state organizations such as the Road Traffic Agency need to be enabled by law to use such systems as the basis for car registration checkups). Moreover, organizations may act maliciously, providing incorrect data on purpose. Thus the first requirement we set for our incentive system is to ensure *data correctness*, meaning that the records entering the blockchain are correct.

Another issue in the Car Dossier refers to missing records in the history of a car. This may happen due to the factors described above, or simply because organizations which could provide the needed data are not a part of the network and thus do not contribute. Furthermore, the quantity of provided data should be taken into consideration as organizations, depending on their roles, may have different amounts of available data to provide. Thus one should distinguish data which may be provided constantly in large portions (e.g. telemetry data) and data which can be provided only once (e.g. car production data). However, when considering the quantity of provided data, it is important to take into account that the key is not to achieve large amounts of data, but high-quality data that guarantees the informativeness of a dossier. All in all, this provides us with the second requirement for the system – to ensure *data completeness*, meaning that none of the possible data records in a dossier are missing.

These two factors (incorrect and missing data) decrease the overall quality of dossiers and threatens the prosperity of a system in which the goal is to ensure a high quality of exchanged and stored data.

The Car Dossier Incentive Model

We propose the incentive model in order to ensure the high quality of dossiers (in terms of data correctness and completeness) in the system. We describe concepts in the model, i.e., its building blocks, and show how they are associated with one another within the incentive model. We describe the model (following the basic concepts of CAS) from two perspectives: a general perspective and a case-specific one. From the general perspective, we introduce the concept and give a conceptual definition for it. From the case-specific perspective, we provide the definition in relation to the Car Dossier project. Table 2 gives a concise overview of the main concepts constructed and used in the model. The model is not intended to give a full description of reality, which would be an unattainable task; instead, it focuses on aspects which are crucial and relevant for the emerging problems discussed above.

Agents

In the Car Dossier project, agents are different organizations within the automotive sector in Switzerland that are involved in the network. These organizations provide data about the history of cars throughout their lifecycle: from the moment a car gets produced to its utilization. An example of an organization may be a specific insurance company or a repair shop. Agents are grouped according to their roles (e.g., the role of insurer includes all insurance companies in the network). *Roles* are attributed on the basis of business activities, responsibilities and rights in the network. Some roles provide more data than others; however, this lies in the very nature of the respective industries. Therefore, the revenues of a dossier should be distributed equally if all involved partners put the same relative effort into providing data. We also differentiate between *sizes* (Pareto distributed (Lucas Jr 1978), as known in the literature as an empirical fact) of agents to ensure full market inclusion: smaller players in the market should not be discriminated against while providing and consuming data in the system (e.g., small repair shop vs. large insurance company). Organizations may act maliciously or behave well. By malicious *behavior*, we mean provision of incorrect data (e.g., a repair shop which falsifies data on repair works) or the act of hiding data. There is a proportion of malicious agents in the system ($\Delta_{malicious}$), who act with a probability p_m maliciously. *Roles*, *sizes* and *behaviors* constitute the three necessary attributes we use to define agents in our model. We take a frequentist approach to describe behaviors (maliciousness of agents, how often they add wrong data, etc.), because this is a variable that can be obtained from observations, irrespective of any assumption of the decision-making process by the agents. Therefore, this is the most minimalistic approach that can be taken. The goal of the proposed incentive system is to validate and demonstrate whether or not it is able to resist malicious behaviors of agents and thus keep the high quality of data. We want to show that by means of this incentive system we increase the rate of the correct data, even in presence of many malicious agents. We also identify what agents to target to increase the completeness of dossiers.

As suggested by the literature (Okada et al. 2017), we introduce a rating mechanism. The rating mechanism influences the revenues an organization gains from its participation in the system. The rating of an organization should prevent it from providing incorrect data (incorrect data results in a lower rating, which subsequently results in lower revenues) and incentivize quality control (reporting of incorrect data leads to a higher rating and thus to higher revenues). As a result, each organization gets its *rating* in the system. The global rating measures the organization's behavior as a data provider (we call it a dossier rating) and a reporter of incorrect data (we call it a system rating). For simplicity reasons, we do not weight the impact of the ratings differently in relation to the global rating. However, this should be considered in more detail when developing the model further.

Table 2. Description of the Concepts

Concept	Conceptual definition	Case-specific description
1. Agents		
Organization	Organizations are participants in the blockchain network that interact with the network in a certain way.	In the Car Dossier project there are several organizations from the automotive sector in Switzerland involved in the network. All of them are agents in the network.
2. Environment		
Data	Data is the single records provided in the blockchain from different organizations.	Data records are provided on car events such as car registration, insurance contract, services, repair works, and collection of driving behavior data.
Dossier	Each dossier is a digital representation of a physical entity in the system. A dossier incorporates data from the blockchain, provided in different time periods from different organizations.	The dossier holds data related to the specific car throughout its lifecycle.
3. Interactions		
Organization's activities	Organizations in the network perform the following activities: - join/leave the network - provide data - purchase data (associated with money flow) - govern the network (report for correction)	An insurance company may enter the network or leave it due to several reasons. It may provide data on insurance policies and accident reports. It may purchase usage data to make more individualized offerings for its clients. It may report incorrectness of purchased information.
Correction mechanism	Once an organization reports a data record in a dossier, a committee votes on whether the issue is to be corrected or not. Depending on the origin of the information, the committee may include external party, regulator, and be built up of one or more organizations. There might also be additional regular checks of an amount of stored the data (depending on its type, amount, origin, or time spent in the system).	1. Reported issues are checked by: - the Road Traffic Agency in case of security-related data - an independent committee in case of non-security-related data 2. Regular checks may be performed by The Road Traffic Agency, e.g., for 1% of all security-relevant data.

The dossier rating for each organization reflects the correctness of the data supply from this organization to the given dossier. The dossier rating is calculated per dossier. The *dossier rating* is determined as follows:

$$dossierrating = \left(\frac{1+q}{1+Q}\right) \times exp\left[-\lambda\left(\frac{t-t_{last}}{1+N}\right)\right],$$

where λ is the decay factor of the dossier rating (the higher it is, the more data the role needs to supply); q is the actual number of static[6] data units, which the agent provides; Q is the maximum number of static data units, which the role should provide; t is the current time; t_{last} is the timestamp of the last data unit added; and N is the total number of dynamic data units, which the agent provides.

The system rating for each organization reflects their activities in the correction mechanism depending on whether or not they report incorrect data to be corrected. This rating increases if the reported data was corrected (meaning that it was reported correctly). This is a part of the correction mechanism that helps to maintain a better quality of data in dossiers. The *system rating* is determined as follows:

$$systemrating = \frac{\exp\left(\beta_0+\beta_1 x_1+\beta_2 x_2\right)}{1+\exp\left(\beta_0+\beta_1 x_1+\beta_2 x_2\right)},$$

where x_1 is the number of reported errors, x_2 is the number of confirmed misconducts, β_0 is the intercept parameter which defines the initial value of the system rating, β_1, β_2 are consequently the reward and punishment intensity of the correction mechanism.

Consequently, the *global rating* is determined as follows:

$$rating = 0.5\ x\ systemrating\ +\ 0.5\ x\ avg.dossierrating$$

Depending on its dossier rating, an organization is rewarded for the provided data. Thus an organization i gets a *dossier revenue*:

$$dossierrevenue = p_s \times P\ \times \frac{R_i^d}{\sum R^d},$$

where p_s is the sale probability, P is the price of the dossier, and R^d is the dossier rating. The total revenue of an organization is thus a sum of all dossier revenues for which the organization has contributed.

Environment

Following the definition of environment (an environment is a "medium for agents to operate on and interact with" (Nan 2011)), we consider data and the dossiers, incorporating this data, to be the environment of our system. *Data* units single records in a car's history (events such as car registration or a car accident) provided by organizations inside the system. These data records are then grouped into dossiers. Each *dossier* is created per car and includes all records for the specific car. We differentiate between correct data, incorrect data (provided with or without bad intention), and missing data (which could have been provided, but was not). Data may be missing for two reasons: the agents participate in the car dossier system but do not add data to it (for any reason), or the agents do not participate in the car dossier system. Data can be categorized into two types. The first type of data is *static data* that is only added to a dossier once (e.g., the technical characteristics of a car). It is assumed that the role-specific static data for a dossier is known per role. Each role has a fixed amount of static data which they should provide once they add a car (in their role) to the blockchain. The second type of data is *dynamic data*. The distinguishing feature of dynamic data is that it is changing data that should be provided constantly (e.g., change of mileage).

The average quality of a dossier may be computed, depending on the amount of incorrect data within it. We consider a dossier to be correct when all data in it is correct or has been corrected (even if there is data missing). We consider a dossier to be complete when no data is missing (all involved agents have added data to the blockchain), even though some of the data might be incorrect. In our simulation, we measure for the fraction of correct and complete dossiers in the system.

Interactions

Organizations within the system interact with one another and with the system itself. They may *join* or *leave* the network. For example, in the car dossier, new organizations may enter into the network to benefit from

[6] Static and dynamic data is described next under *Environment*.

it, as well as leave it if they do not get expected value or it does not correspond to their business strategy. Organizations *provide* or *purchase* data. These two interactions are crucial as the value that provided data contributes, combined with monetary reward, creates an incentive for organizations to participate in the network. The interactions are included in the proposed *correction mechanism*. Once an incorrect record is noticed, it may be reported in order to be checked and corrected if needed (as explained below in the scenario for correction of wrong data). The proposed model covers two scenarios: data provision and consumption, and correction of wrong data. Figure 1 gives a visual representation of the proposed model. Interactions are numbered to give a better overview of the actual sequence of actions for both scenarios. We show in these two scenarios how the model works to ensure a higher quality of data inside the system.

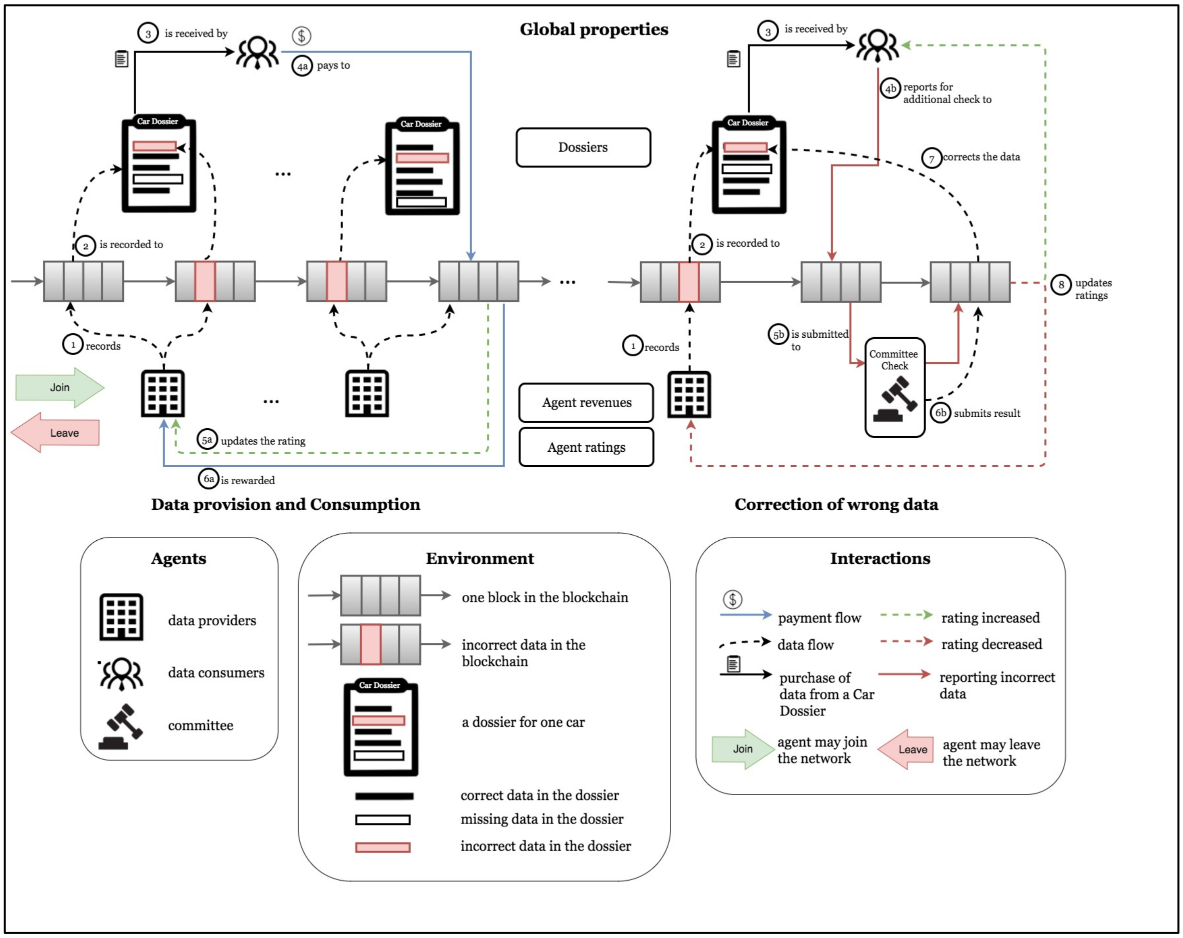

Figure 1. Overview of the Incentive Model

Scenario: "Data Provision and Consumption"

(1) An organization (e.g., a repair shop) makes a record of an event in the car's lifecycle (e.g., repair work) which is stored in the blockchain. (2) The record from the blockchain is available in the Car Dossier (on an application level) for the specific car to be accessed by other participants for a fee. (3) The record is purchased and received by another organization (e.g., an insurance company, an individual or even an external party). (4a) The payment (from an insurance company in this specific record) is secured in the blockchain. (5a) The rating of the repair shop in the system is updated. (6a) Upon a successful purchase, the repair shop receives a monetary reward.

Scenario: "Correction of Wrong Data"

Here we describe how the incentive mechanism works to keep the quality of provided data high. For this we introduce a simple correction mechanism. Important to note: any correction involves adding a new record and making the old record invalid, maintaining the transparency of all changes in the blockchain.

Steps 1 to 3 remain the same, as described in the data provision and consumption model above. (4b) If the insurance company (following the scenario above) notices that a record is incorrect, it reports the record for an additional check. This report is stored in the blockchain. (5b) The record is then sent to the Committee Check. Assuming the reported issue is relevant for the car's security, the Road Traffic Agency verifies the record. (6b) The agency makes a decision regarding whether the data needs to be corrected or not. (7) If the data needs to be corrected, it is corrected in the blockchain. (8) Depending on the decision, the rating of both the repair shop and the insurance company is updated.

Simulation results

To show the effects of the proposed incentive system, we conduct three numerical experiments. We determine the correctness, completeness of dossiers in the system, and the revenues of the agents (behaving lawfully or maliciously while incorporating the data). All parameter details are described in Table 3.

Each simulation is run of T=300 timesteps where the first 100 serve as a stabilization period for the system. For each parameter set, the simulations are repeated 100 times. The parameter setting is done for agents (including rating and revenues), dossiers, data in the system, and the correction mechanism. The parameter combinations used are summarized in Table 4. In the first experiment, we run the simulation to show the effect of the correction mechanism. Thus we compare two states of the system – with it and without it. The latter two experiments are done with correction to show the influence it has on measurements in the system. The parameters we vary in the experiments are different, so the experiments analyze different aspects of the response of the system to changing conditions. To be precise, we:

Experiment 1: we vary the share of malicious agents with full participation fixed, ceteris paribus.
Experiment 2: we vary the fraction of agents writing to the blockchain (in other words, participation rate) with the $\Delta_{malicious}$= 0.2 proportion of malicious agents fixed, ceteris paribus.
Experiment 3: we run the simulation for one particular parameter combination of the above variations (full participation, $\Delta_{malicious}$= 0.2 proportion of malicious agents).

<table>
<tr><th colspan="3">Table 3. Parameter Setting</th></tr>
<tr><td rowspan="2"><u>Agents</u></td><td colspan="2">• There are $n = 100$ agents with sizes $\sim Pareto\ (2, 1)$
• The agents are split up in $r = 10$ roles (every role is taken by at least one agent)
• $p_m = 0.5$</td></tr>
<tr><td>• Rating: ○ $\beta_0 = 3$
○ $-10\beta_1 = \beta_2$
○ $\lambda = 0.25,\ \beta_1 = 0.1$</td><td>• Revenue: ○ $p_s = 0.1$
○ $P = 10$ currency units</td></tr>
<tr><td><u>Dossiers</u></td><td colspan="2">• There are c = 3000 dossiers (cars) that enter the system in regular batches (10 dossiers per timestep)
• The dossier's (equal to vehicle's) life-span ~ $exp(1/32)$ → expected life = 32 timesteps.</td></tr>
<tr><td><u>Data</u></td><td colspan="2">• If a new dossier enters the system, one agent from each role is selected with a probability of $p_i = \frac{s_i}{\sum s_R}$ (proportional to agent's relative size within the role). Non-malicious agents add $Q = 4$ static data units to the car, whereas the malicious agents only add with a probability of $(1 - p_m)$ the correct amount of Q data units to the car; and with a probability p_m they add less than Q data units to the car.
• In each timestep, each agent receives new data (dynamic data) to add to the blockchain. This happens with a probability of $p_d = 0.2$ for each dossier the agent is involved in.</td></tr>
<tr><td><u>Correction mechanism</u></td><td colspan="2">• In each round, each agent checks a maximum number of dossiers and reports an error if they find one. The maximum number is set to D_{max} =40. The expected number of dossiers checked per timestep depends on the size of the agent and can be calculated as follows: $\frac{s_i - \text{x\_min}}{\max(S) - \text{x\_min}} \times D_{max}$, where x_min is the minimum value of the size distribution.</td></tr>
</table>

Experiment 1 – Correctness of dossiers. In the first experiment, Correctness of Dossiers, we run simulations to show if an introduced *correction mechanism* helps to increase the quality of dossiers in terms of their correctness (fulfilling the first requirement for *correctness*). Within this experiment we show to what extent the correction mechanism can increase the correctness of dossiers in the system. We vary the proportion of malicious agents in the system. For this, we measure the fraction of correct dossiers (meaning there is no incorrect data in a dossier) before and after application of the correction mechanism. We also look at the average fraction of correct data (again, as opposed to incorrect data) per dossier.

The results of the simulation are shown in Figure 2. The system without correction can provide a relatively high quality of dossiers (above 70%) only when the proportion of malicious data is very low (under 0.05). The most important result from this experiment is the calculation of the fraction of correct dossiers, with and without the correction mechanisms. Strikingly, with this parameter set, the fraction of correct dossiers without correction in place drops to zero when the number of malicious agents is larger than 0.5 - in what is a tipping point. With the correction mechanism in place, however, for the tipping point the rate of correct dossier reaches 0.5. Even when the proportion of malicious agents is 1, 20% of the dossiers are correct. We conclude that the correction mechanism proposed is very effective for the task proposed.

Experiment 2 – Completeness of Dossiers. In the second experiment, Completeness of Dossiers, we look how many market players of different sizes should participate in the system to ensure completeness of dossiers (fulfilling the first requirement for *completeness*). Here, we calculate average completeness of data per dossier for varying participation of organizations. Organizations are selected following three different procedures: either the largest, the smallest or randomly selected organizations participate in the data provision for the blockchain. This reflects three market scenarios in which the Car Dossier consortium attracts, respectively, the largest, smallest or random players to take part of the system. We fix the $\Delta_{malicious} = 0.2$ proportion of malicious agents (which we arbitrarily assume to be a realistic scenario). It is important to note that 1 means the whole coverage of the network, while 0.1 represents the largest 10% of companies (sorted in descending size order) for the blue line, and the smallest 10% (sorted in ascending size order) for the red line.

The results of the simulation are shown in Figure 3. In order to achieve 80% completeness of the dossiers, the system should include at least half of the largest organizations; in order to achieve a similar result attracting the smallest organizations, 95% of the smallest firms should be included. Having only 50% of the small organizations results in under 20% completeness of dossiers. The graph also shows that with higher fractions of organizations, having large organizations quickly results in a high completeness of dossiers (above 90% when including more than 65% of agents), and having small organizations high completeness (above 80%) with fractions above 0.95.

Experiment 3 – Revenues of agents. In the third experiment, Revenues of Agents, we investigate how the revenues of agents, orchestrated by the *rating mechanism,* keep incentives to behave well in the system higher (by being better rewarded) than to behave maliciously or not to participate at all (by not being able to profit). This experiment shows if we could achieve our ultimate goal in creating a consistent and self-sustaining system by demonstrating how the proposed incentive system influences the revenues organizations get for data provision. Here, we fix the $\Delta_{malicious} = 0.2$ proportion of malicious agents (as in the previous experiment) and assume full participation. The Y-axis shows currency units.

The results of the simulation are shown in Figure 4. The revenue each agent receives from the sale of accesses to the dossier depends on the dossier rating. The results show that malicious agents have lower revenues than good agents (892 and 1964 currency units respectively). Good agents generate significantly higher total revenues than malicious agents (on average, almost double for the parameters selected).

Discussion

Blockchain technology is on in the rise. In the last few years, IS researchers started to approach such topics as design, adoption, governance, and use of blockchain systems. This research is intended to develop deeper understanding in the emergent field of blockchain governance and, more specifically, in its incentive mechanisms. We investigate incentivization problems related to data provision in blockchain systems for inter-organizational relationships and propose an incentive system that helps to resolve it. The design of incentive mechanisms for blockchain systems is not a trivial task; it highly depends on design properties (such as if it is public or private, permissioned or permissionless (Okada et al. 2017)), the purposes of participants in the network, their activity and behavior, business context, and exogenous factors such as regulation. We see that there is an existing problem related to data provision and data quality in the context of inter-organizational data exchange and storage: how we get data inside the network, and, once there,

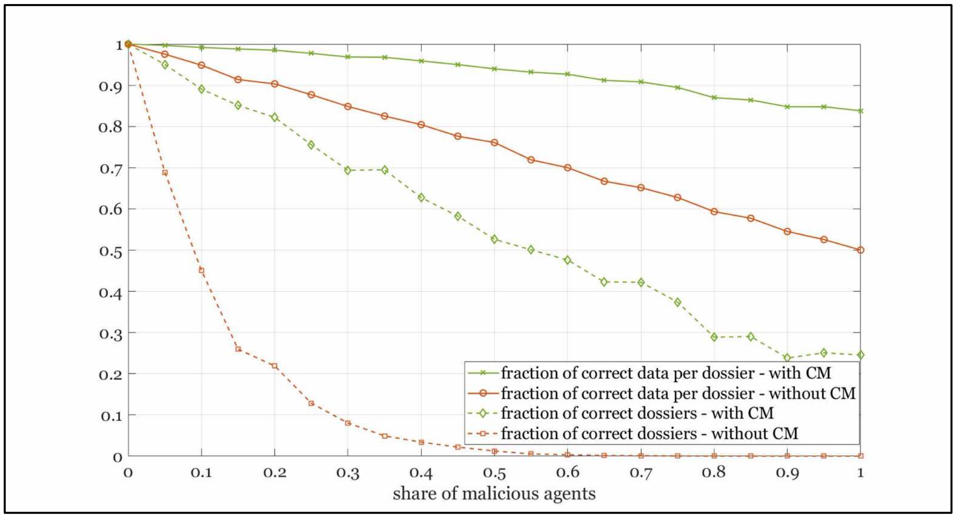

Figure 2. Correctness of dossiers

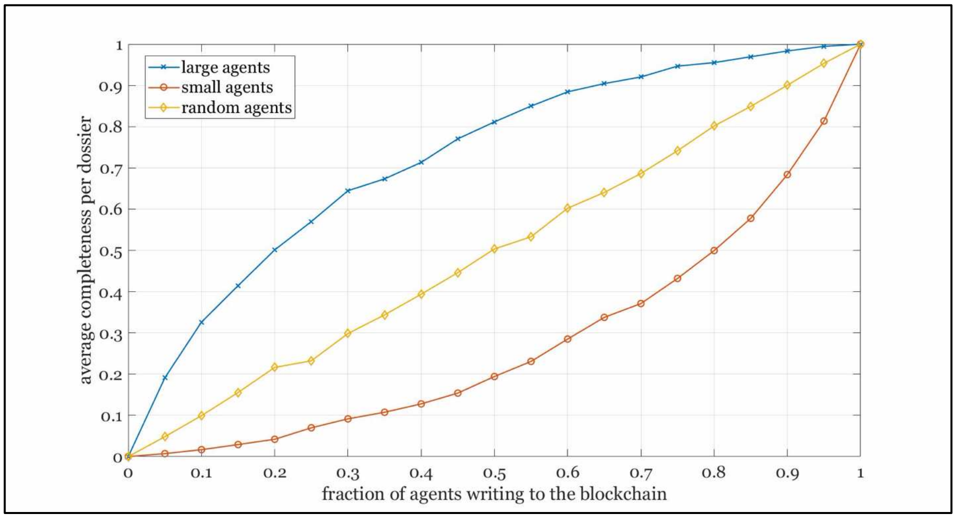

Figure 3. Completeness of Dossiers

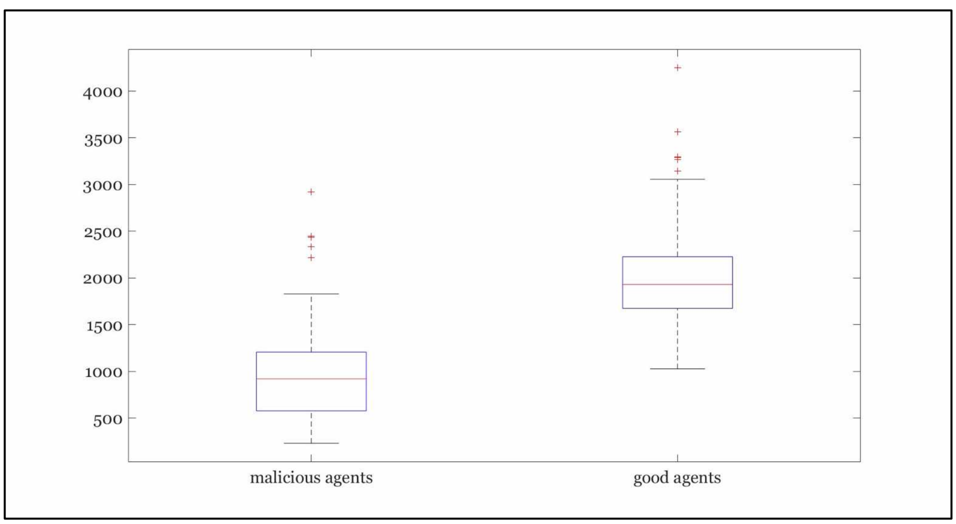

Figure 4. Revenues of agents

we ensure the quality of this data. So far, literature suggests that Internet-Of-Things solutions (sensors for tracking physical measurements) combined with oracles (a third-party services to verify data) may be a feasible solution (Notheisen et al. 2017); however, to our best knowledge, none of the existing studies have shown how and to what extent they are useful. We look in more detail at how such a quality-enhancing mechanism may function and how effective it is.

Referring back to the *Sub-RQ (How can an incentive mechanism make a blockchain-based inter-organizational network consistent and self-sustaining?),* we suggest that a purely price-based incentive system (an organization gains revenue for the amount of data it contributes to the system) is neither adequate nor sufficient to solve the identified problems. Therefore, another approach is necessary. For this, we introduced a rating mechanism (Okada et al. 2017), influenced by measures for data correction (correction mechanism). Therewith, the incentive model does not merely focus on the data providing process but rather on the well-being of the whole system. The rating mechanism either gives malicious agents no incentive to participate in the system (as they cannot profit from it) or encourages them to behave well (providing correct and complete data). The incentive model values the contributions of each participant (role-dependent) with a feature to control data quality. This ensures high-quality dossiers and supports consistency of the system overall. The incentive model acts as a strong immune system for the blockchain system as it punishes bad behavior and encourages the correction of errors. It thereby actively fosters the well-being of the system. As a consequence, the incentive system can be called self-sustaining since it promotes the longevity of the blockchain network. However, we are assured that exploration of the rating function (for both dossier and system ratings) should be continued in future to find an optimal solution.

With our model, we show that in the absence of the correction mechanism, the quality of the dossiers produced in such a system deteriorates in the presence of malicious agents up to a point where a limited number of malicious agents is enough for the system to produce dossiers that contain at least some wrong information. Our correction mechanism is enough to allow the system to produce a sizeable proportion of dossiers with correct information, even in a case where only malicious agents take part of the system. Furthermore, market penetration should be considered in blockchains, where completeness of history data is crucial. In the example of Car Dossiers, the blockchain brings value only when there are no gaps in the provided data. At the same time, if the data is complete, it brings high benefits to each of the organizations in the network. Thus onboarding measures should be pushed forward. Our results show that though coverage of the whole market is necessary, in order to increase completeness of dossiers in the system, the focus should be first put on onboarding the largest players. This will increase completeness of dossiers in the system considerably in comparison to having the smallest players alone. To achieve full coverage of the market (having all necessary players), there should be additional, exogenous measures. First, one of possible measures would be creating a standard to be used in a country or on the market, which might be effort-consuming and also take considerable time to establish. Furthermore, possible benefits for market players (e.g., efficiency gains, possibilities for new business models) should be demonstrated. For this, it is important to address the key players of the industry first. They not only bring volume to the system but also have far-reaching connections within the industry. This also includes players that do not act as partners but rather have a supportive role (e.g., governmental agencies or software firms). Interestingly, blockchain may also change the way organizations cooperate within inter-organizational networks (Popp et al. 2013; Provan et al. 2007), bringing competitors together and allowing them to benefit from mutually created good. However, to ensure the full participation of the market (including smaller organizations), technical hurdles (e.g., integration of existing systems in blockchain infrastructure) should be minimized.

Going beyond the blockchain hype, together with several organizations and a state institution on board, we have shown how an incentive system (as an important part of blockchain governance) can be designed for a real case. It is important to highlight that an incentive system is much more powerful if incorporated in the existing reality with existing governance mechanisms. In our incentive system, we do not reinvent institutions or governments. We rather let them do their daily activities (like security checks for the Road Traffic Agency), benefitting from efficiency gains, trust, and information quality a blockchain network is able to provide. We believe that this realistic approach strengthens our model, and it also calls for hybrid forms of governance. Such hybrid governance should incorporate existing governance mechanisms (e.g., those set by the government) in combination with blockchain-related incentives (e.g., to operate the network), as Beck et al. (Beck et al. 2018) suggest. These mechanisms can be incorporated into the design of a blockchain system in the form of the proposed correction mechanism. The simulation demonstrated that such a mechanism keeps data quality high and makes the system resistant to malicious behavior.

Furthermore, in the case of the Car Dossier, checks of data records in general (but especially by a state authority) may enhance trust in the quality of data. Finally, the existence of such a correction mechanism itself makes organizations behave with integrity under the threat of a possible penalty (like a decrease of rating and therewith revenues, and also legal measures that may be introduced in the system). Thus we conclude that a hybrid governance will help to enhance trust between participants in an inter-organizational network (Provan et al. 2007): first, due to incremental blockchain characteristics which offer immutability and transparency of transactions (Seebacher and Schüritz 2017); second, due to existing trust-enhancing mechanisms, as verification of data by known competent established institutions incorporated in a trust-free blockchain system (Beck et al. 2016).

Conclusion

In this study, we report on an ADR project conducted in collaboration with a blockchain consortium that builds up a blockchain-mediated inter-organizational network. This paper addresses the need for a consistent and self-sustaining incentive system which should be built on top of the existing technological layer. Therewith, we answer the call for more extensive research on incentive systems in blockchain economy (Beck et al. 2018) by outlining a specific incentivization problem, on the basis of a real-world case, and proposing an incentive model to address it. The contributions of this study are two-fold. First, we provide knowledge regarding how an incentive system may be constructed in a blockchain-based inter-organizational network to resolve problems of insufficient data quality. With this, we complement growing literature on blockchain technology (with specific focus on incentive systems for inter-organizational networks). Second, we contribute to the practice, showing how such a model can be applied in a real case application. This knowledge is valuable for blockchain practitioners in early and mature phases of design and development: from the initial idea of building up such a network to actual use and operations.

This study has several limitations which also offer directions for future research. First, dynamic change of the network: we did not consider that agents (organizations) may enter and leave the network dynamically. This leads to additional data gaps due to missing partners and variable rates of information in the blockchain. Thus, future studies should consider the adaptive behavior of agents. Second, though mathematical modelling and simulations are an effective means of studying complex problems, it is still necessary to observe such systems operating in real-world situations. We assumed that agents act rationally and there are no external factors influencing the system. However, real-world situations could bring both additional requirements for organizations to act, and also additional requirements for the system to function. For example, further study of the payments, provided as one of the incentives, and their influence on the behaviors and trustworthiness of actors (e.g., a mechanic checking the technical qualities of a car). Further observation is needed to give more practical insights on operation of such a platform. Third, we did not simulate the complexity of market-based pricing for data in dossiers. This calls for extension of the model in terms of data supply and demand (to incentivize agents to provide the most demanded data). Furthermore, the correctness of the data in the system is highly dependent on the number of malicious agents. The next steps would be to check multiple incentive mechanisms and find the optimal one, either by providing formal proof, or by searching existing incentives schemes. In addition, a comparison of the proposed system with the status quo, or with a system controlled centrally, both in terms of costs of operation and in terms of percentage of correct information, could be insightful. We hope that this study sheds some light on the design of incentives for blockchain-based inter-organizational networks and inspires follow-up studies in the growing research field on blockchain technology.

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