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# Evaluating blockchain as a participatory organisational system: looking for transaction efficiency

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**Abstract**

The article presents a decision-making model that can be used with blockchain technology. Blockchain is used as an alternative transaction mechanism to authority and the market, where the decision is decentralised within the organisation. Thus, the process is parameterised around the acceptance or not of a project, depending on individual levels of expertise, consensus level and including deliberation time. In addition, commission and omission errors are also evaluated. We show that this technology should be imposed naturally because, at the same level of information, it can obtain better results than any other decision mechanism in a systematic way. In addition, the blockchain ensures that both commission errors and omission errors are reduced with decision times that do not increase the expected opportunity loss on omission errors.

*Keywords:* blockchain; group decision making; hierarchy; omission and commission errors

## 1. Introduction

From the perspective of efficiency, socialisation has important benefits over individual autarchy. The specialisation that results from the division of labour allows gains in efficiency to be made thanks to better use of individual skills and abilities. However, socialisation requires coordination and motivation among specialists, which is the role of the market and organisations (Arrow, 1974). Decisions are traditionally made in an organisation under the principle of authority and centralisation, which differentiates it from the market, where purchase and sale relationships concur through the price system, under the principle of consensus and decentralisation.

Organisations are a structure of relationships that improve, under certain circumstances, the efficiency of the market in collaboration and exchange, which is essential for specialists to access the consumption of goods and services produced by others. A well-accepted hypothesis in

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organisation theory is that individual behaviour is intentional but bounded rational (Simon, 1947); that is, the cognitive limits of the brain lead decision-makers to make errors of judgement. When they are aware of these limits, organisations can be designed with the aim of minimising the collective negative consequences of errors (Burton and Obel, 2013; Cyert and March, 1992; Daft and Lengel, 1986; March et al., 1993).

Blockchain technology is a decentralised ledger system that allows organisational improvements to be made by replacing the authority or improving some of its functions (Amini et al., 2022; Yan and Zhou, 2023). Consequently, there have been many studies of the advantages of blockchain, among which are greater transparency in transactions (Song et al., 2022), which reduces opportunistic behaviour within organisations (Yavaprabhas et al., 2022) and with its external stakeholders (Chaudhuri et al., 2021); generating greater speed, security and traceability of transactions (Chen, 2023; Xu et al., 2023a); reinforcing its compliance with smart contracts (Dai, 2022), which generates greater confidence in all the agents involved (Chittipaka et al., 2022); fewer risks (Zheng et al., 2021); and greater price competition that favours the consumer (Zhang et al., 2022; Petratos and Faccia, 2023).

Blockchain technology also has other advantages that have been less examined, including establishing decision rules that allow the use of the organisation's human capital and decision making. Specifically, this technology allows the participation problems that are found in large groups to be solved (Wu et al., 2023), allows the recommendation that it be a structured and reproducible system (Sakka et al., 2023), and the decentralised resource can be allocated in different ways to the traditional methods (Yang, 2023).

This study examines the under-researched question of how new technologies, and specifically blockchain as a technology that allows an algorithm to be applied as a decision rule, can affect an organisation's decision-making mechanisms, understood as management information and decision-making processes (i.e., innovations that can improve the performance of the *status quo*). The efficiency that can be provided by technology will also impose decision mechanisms on organisations in a process of natural selection (Goldfarb and Tucker, 2019). Overall efficiency is measured here by the expected opportunity loss (EOL) of errors in the organisation's decisions.

The new information technologies and measurement devices (e.g., sensors of the Internet of Things [IoT]) have allowed organisations to gather considerable knowledge about the labour factor, which has discouraged investment in human capital and generated large monopolies that distort the remuneration balances deteriorating the productivity growth (Alvaredo, 2018; Akcigit and Ates, 2021). This study is justified by some of the qualities of the new technology (i.e., the blockchain), which can change the current domain of authority in organisations in favour of participatory mechanisms. Specifically, we evaluated how blockchain's ability to keep information accessible to all, its reliability and speed in voting systems, its maintenance of anonymity and its permanent record of information can alleviate the main problems that have limited participation in organisational decisions.

The proposed model considers two main organisational decision mechanisms: The first corresponds to a traditional organisation with a concentration of power (authority), and the second corresponds to a participatory organisation in which blockchain technology manages the experts who must participate in each decision. The decisions are dichotomous between continuing with the *status quo* or accepting a new project whose performance cannot be accurately anticipated *a priori*. In a traditional organisation, the authority makes the final decision on the project.

Meanwhile, in the participatory organisation individuals are automatically chosen by the blockchain to evaluate the projects, and the final decision is reached according to the established decision rule applied through an algorithm (simple majority, three-fifths, etc.). Each contribution of the blockchain is studied separately and is compared with the results of the authority and traditional voting for different levels of difficult decisions.

The rest of this paper is organised as follows. Section 2 reviews the literature on information, authoritarian decision making and how new technologies have brought about substantial changes in organisational relationships, which affects their efficiency. Section 3 explains the essential organisational aspects of blockchain technology. Section 4 describes the model, the elements of the organisational design problem and the general configuration of participation. Section 5 presents the main results and simulations. In Section 6, we discuss the managerial implications and describe a practical situation. Finally, Section 7 summarises this article, highlights the contributions and makes some recommendations for future research.

## 2. Literature review

### *2.1. Authority, its relationship with information and shortcomings in its management*

Coase (1937) finds that the probability that the authority commits errors as part of the management costs will increase with the spatial distribution and the disparity of the transactions. Innovations in information and communication technologies have had a considerable impact on the organisation's costs, with implications on the ways of governing collaboration and on the design and organisation of workstations. This has reduced an important part of the uncertainty of evaluating the quantity and quality of the resources, for whose action the authority is rewarded.

An organisation has advantages over the market when transactions are complex (Williamson, 1979). However, in a society in which the establishment of communications has a cost, recurring transactions have incentives to be carried out under authority. For example, suppose that a society in which $N$ specialists participate. Coordination in the market through the price system results in $N(N-1)/2$ relationships (network structure). However, if each specialist relates separately to the authority to achieve the same goal, then $N$ relationships and $N+1$ people in total will suffice (hierarchical structure). If the cost of establishing a relationship is zero or insignificant, then the number of relationships would be irrelevant. However, when there are costs, the time lost to interact between agents matters for the final efficiency (Sáenz-Royo et al., 2022b). Although the authority's ability to direct is limited by time and managerial ability, there are diminishing returns to scale as the activities and resources to be directed increase in number and/or complexity. To grow, the function of directing and coordinating must be delegated to others. This means that when the transaction is simple, the organisation makes the necessary internal structure too costly and the market is more efficient. This gives rise to management costs, which explains why a single organisation does not replace the entire market in managing resources. To reduce management costs, dominant governance presents a hierarchical structure (authority) in which decisions fall to a limited number of individuals, who are delegated by the actors that are legally granted this power, those who contribute the capital to the capital company or the workers in cooperatives.

New technologies have allowed organisations to appropriate the knowledge of the individuals that comprise them. Management systems (i.e., enterprise resources planning [ERP]) are databases that collect the knowledge of workers. This allows the organisation to become the owner of the actions aimed at generating information. The knowledge of customers, suppliers and production is systematised and stored. This simplifies cognitive processes and gives power to whoever manages the information (i.e., the authority). Malone (2013) explains how the new advances in information technology and in the company's relationships with customers, mainly data and artificial intelligence, are moving companies towards network structures. The development of information technologies that present significant economies of scale has favoured multinational companies that operate as natural monopolies (Tirole, 1988). This trend has led the authority to manage a large volume of assets, which gives it a greater capacity for economic (control of certain markets), social (influence and control over the media) and political influence (through lobbying and *quid pro quo* behaviours). The concentration of authority over a large amount of resources allows the establishment of strategic behaviour networks that destabilise the distributive rules. Mayer (2021) argues that there is a gap between market efficiency and regulatory effectiveness, which increases as technology development accelerates, assets become more intangible, corporations affect broader segments of society and economies of scale grow to global proportions.

The authority needs to gain the trust of the individuals with promises that this expropriation will not take place; otherwise, they will be left without investment and without a competitive advantage. Relinquishing authority by shareholders and substituting other, more inclusive mechanisms instead can help to build trust. This situation may seem paradoxical: Shareholders can increase their profit by renouncing actions that limit the ability to appropriate higher profits *ex-post*. Edmans (2020) finds that by giving up *ex-post* opportunities, which would allow them to access a greater portion of the value generated, the shareholders can win because the resignation encourages other stakeholders to make greater investments and finally the generated value size that is distributed is greater. This behaviour is perfectly explainable from the point of view of individual rationality, and there is no need to introduce morality elements. Given that levels of information have increased considerably, the specialisation of the authority in its management is less necessary, and the risk falls entirely on the resource owners. Consequently, Piketty (2020) proposes to increase participation in decisions by establishing a legal obligation to incorporate the members of the organisation into the organisation's councils. These initiatives are close to self-management, where the risk due to uncertainty about the final production is shared among the resource owners.

### *2.2. Participation versus authority*

The capital lender facilitated the accumulation of tangible assets when they were the strategic asset of organisations. The keys to reformulating the internal organisation structure with new forms of governance are now being explored. The result would improve productive efficiency by improving decisions, favouring the accumulation of intangible assets and trying to align productive efficiency with private gains, competitiveness and benefits.

Ownership of non-human assets, and more specifically of information, ends up conferring more or less power and influence over individuals. Given that ownership is distributed, it influences the incentives to make investments in human capital specific to the transaction, which affects wealth creation. The existence of private information makes less informed individuals present less expertise, and its incorporation into the organisation's decisions deteriorates the hope of group performance. This justifies the concentration of authority in organisations (Chakraborty and Yılmaz, 2017; Dessein, 2002; Harris and Raviv, 2010). The information and property relationships are jointly determined. The form of internal organisation will result from the interaction between them (Nault, 1998). Participation is expected to act as a coordinator. In the economy of intangible assets, the organisation's renunciation of authority may be justified as a way to build trust in collaborative contexts where it is necessary to combine incomplete and implicit contracts at the same time. Participation attempts to make decisions different from prices but is similar in that uninformed criteria are not imposed. It tries to avoid the asymmetric information of the authority giving transparency to the decision process.

Freeman et al. (2020) argue that the purpose of an organisation is to involve all of its stakeholders in the creation of shared and sustained value. An organisation serves its shareholders and employees by creating this value, and ultimately all of its stakeholders: customers, suppliers, local communities, and society at large. The best way to understand and harmonise the divergent interests of all stakeholders is through a shared commitment to decisions, which strengthen an organisation's pursuit of long-term prosperity. However, the coordination mechanisms must be efficient in the consumption of resources, including time. Participatory systems require more time and their improvement in decision performance should compensate for this handicap.

Mutual influence allows strategic behaviour, allocating resources to non-productive redistributive aspects and generating incentives to influence the decisions of others. Even without taking these resources into account, the quality of the collective decision deteriorates with the influence of trials (Salas-Fumás et al., 2016). Therefore, if influences are reduced or neutralised, then there are no stakeholders *per se* because no one influences or is influenced by decisions made by others (we exclude the impact of an actor's decisions on their own results) to improve collective performance.

Although the relationship of equality between individuals in the organisation ensures that the shareholders have sufficient income to maintain the incentives to finance investment, the system must overcome the inefficiencies of participation in decisions. Human capital is, by definition, specific to collective action. Therefore, increasing participation in decisions generates incentives where it is more complicated because its ownership is not transferable. If the tangible assets are not very important, then the efficient solution may be that the individuals who invest in the specific human capital become the main source of decision through participation if the information conditions allow it. To improve efficiency, mechanisms that control access to tangible assets on a non-equal basis or deliver tangible assets to a third party that can block access to them should be avoided. Intangible assets are attributed to the following particular characteristics (Haskel and Westlake, 2017): investment costs are sunk costs, there are significant synergies (complementarities) between them, excluding third parties is difficult or impossible and they must be scalable. The sunk costs of the investment mean that there is a greater specificity, and therefore a greater difference between the value of the assets in the transaction for which they are initially dedicated than outside it (Williamson, 1979). More complementarity means that there is a greater sensitivity of the productivity of each individual to the endowment of the rest. Finally, the difficulty of appropriation means that the rest take full or partial advantage of the output generated with the investment in intangibles.

Efficiency to evaluate decision mechanisms is listed below because proposals such as 'the capital company must be managed for the benefit of all interest groups' are empty of content. Without specifying the circumstances in which the relationship will occur, the method of making decisions and the efficiency that the system presents, nothing can be said about the behaviour or the final results.

### 2.3. Decision mechanisms

Sah and Stiglitz (1986, 1988) demonstrated for the first time the relevance of architecture in decision making as a system of judgements that adds information to improve the performance of organisations where individuals are fallible. Their contribution was to show an evaluation system that allowed for different collective decision mechanisms to be compared, distinguishing between the types of error that can be made; that is, type II error (commission error) and type I error (omission error) (Sáenz-Royo and Lozano-Rojo, 2023). Our study also quantifies losses due to errors of omission and commission, although with several important differences. The EOL of the voting blockchain technology is compared with the authority and with the traditional voting system. The gains from shared versus private information and the diversity in the ability to process information are also studied. Participation in joint decisions generates incentives to know the activity of the organisation and because trying to improve it is the task of all individuals not only of the authority, coordination is also an element that individuals internalise in their behaviour. There is no directed flow because judgements do not occur sequentially and communication is open. Decision times are relevant, which penalises participatory processes because the performance of new projects is delayed. Finally, the inefficiencies that are generated from the possible mutual influences between judgements of individuals are also analysed.

Organisation theory has also investigated the relationship between organisation design and type I and/or type II decision errors in group decision making (Christensen and Knudsen, 2002, 2010; Csaszar, 2013; Knudsen and Levinthal, 2007; Salas-Fumás et al., 2016). Our study uses the model that was developed by Sáenz-Royo et al. (2022b), which resembles those of Knudsen and Levinthal (2007) and Csaszar (2013), in which each member of the organisation is fallible in the probabilistic decision. The model has two main contributions: On the one hand, the fallibility of individuals comes from their intentional bounded rationality (i.e., errors of judgement are not purely random); and on the other hand, in the calculation of the EOL, the time necessary to obtain a firm collective decision is considered.

This study is motivated by the research opportunities that are offered by new technology (i.e., the blockchain), whose combined characteristics can spur a new concept of participatory organisation (Yaga et al., 2018). The evolution towards network organisations that was predicted by Raab and Kenis (2009) has materialised with the development of the blockchain. The network structure was defined by van Alstyne (1997) as an organisation that acts like a computer in which decisions are modelled based on the capacity of individuals, establishing rules that minimise errors and optimise the decision-making capacity of its members. The blockchain provides public information that is distributed among individuals while maintaining anonymity, minimising management costs and giving reliability to the process thanks to metadata and cryptography (Holbrook, 2020; Chod et al., 2022). We explore the performance of blockchain features in group decision making, where the provision of information and the form of participation generate different levels of efficiency within the organisation. The combination of these characteristics can favour new governance in an organisation, which faces the uncertain opportunities of change with greater reliability.

## 3. Blockchain

Blockchain is a comprehensive information technology with tiered technical levels and multiple classes of applications for any form of activity and asset exchange, which manages information in a transparent and accessible way for tangible and intangible assets (e.g., votes, ideas, reputation, intention, information, etc.) (Dutta et al., 2020; Iansiti and Lakhani, 2017; Kassen, 2021; Yaga et al., 2018). The concept of the blockchain is a new paradigm of organisational information for the evaluation and remuneration of value contributions, which is managed in a decentralised way as a coordination system with transparent rules of any activity between individuals applied through algorithms. The rules are accepted in a participatory manner while establishing the remuneration obtained at each step of the value chain.

Li et al. (2021) find that the value of this technology lies in the fact that it does not require a central authority. It establishes an automated consultative process between individuals in the network, which does not require trust because it creates an algorithmic self-monitoring that rejects any malicious attempt to defraud the system. The blockchain establishes a public ledger, where relevant events and the participation of individuals are unalterably recorded. Information is shared in files between peers (peer to peer [P2P]) with public-key cryptography (Biais et al., 2019; Choi et al., 2019).

Blockchain technology could become a management layer that may be seamlessly embedded in an organisation, serving as the technological foundation for payments, decentralised exchange, invocation and transfer of intangible assets, issuance and execution of smart contracts and decision making (Nosouhi et al., 2020). Blockchain is a mode of decentralisation that may become the foundation of the global information paradigm, with the potential to reshape all human activity as pervasively as the Internet did.

### *3.1. Blockchain elements*

#### *3.1.1. Decentralised information system, synchronised through P2P technology*

Nobody is the owner of the information because the group information is obtained from the transfer of the individual information of the operations, all those involved can access said information, it is non-private and non-proprietary, and stays distributed in all the devices of all the individuals in the organisation. This avoids the temptation that whoever supports the information has some advantage that provides them with arguments to acquire greater authority than the rest (Biais et al., 2019; Liu et al., 2021).

#### *3.1.2. Maintains a record system by unalterable blocks that are ordered temporarily*

Each block of the chain has a timestamp, which allows anyone to have a perfect traceability record of any process that they want to monitor (Tang et al., 2019; Xu et al., 2023b), assigning unalterable responsibilities to those who have participated in it. The importance of the information recorded will establish the form of its verification (Biais et al., 2019; Chod et al., 2020; Dutta et al., 2020). Every piece of information added to the blockchain has to be corroborated in some way, usually by a level of the individual's agreement, whose verification work needs to be rewarded. The notaries of each process are known as miners. The reliability (i.e., times that it has confirmed information that has been accepted, and *vice versa*) of each miner is their letter of introduction, and their reward can be linked to this characteristic (Asgaonkar and Krishnamachari, 2018; Eufemio et al., 2018; Nosouhi et al., 2020).

#### *3.1.3. Transparency about operations (assessments, transactions and validations) and their anonymity*

The entire organisation can see the transactions, but the participants can be encrypted so that only each of them can see their participation. The incentive system assigns prizes and penalties to those involved in the process, and it can be verified that the payment rules are met. However, it is not possible to see who has participated in the process. Each individual is encouraged to manage their own behaviour through rewards and penalties and not by social pressure or authority (Catalini and Gans, 2020; Sunny et al., 2020; Yermack, 2017).

### *3.2. How the blockchain works*

Singhal et al. (2018) report that in the blockchain, each operation carries with it a file attesting to the action of an individual. A standard algorithm is executed on this file to compress it into a 64-character shortcode, which is called a hash, that is unique to that document. No matter how big the file is, it is compressed into a secure 64-character hash that cannot be computed backwards. The hash is then included in a blockchain transaction, which adds the timestamp. This is proof that that digital asset exists at that time. The hash can be recomputed from the underlying file, which is stored privately on the owning individual's computer, and not on the blockchain, confirming that the original content has not changed. This standardised mechanism allows the registration of intellectual property in any part of the process, which represents a level of transparency in information that has never been seen before, and eliminates the problems of moral hazard and adverse selection, registering the value generation of intangibles as a verifiable cost (Biais et al., 2019; Chod et al., 2022; Saleh, 2021).

Rewards can be recorded in each block for processing work, in which individuals offer their ability to generate value or to verify and record that information is true before it is added to the blockchain (Sheth and Dattani, 2019). The blockchain is constantly growing as individuals add new blocks to it to record actions in a linear chronological order. Each individual has a copy of the blockchain, which is automatically downloaded when they join the network. The blockchain has complete information on actions, from the genesis block (the first operations executed) to the most recently completed block and is easy to see from any block explorer (Chod et al., 2020).

This system is a self-reliable testing mechanism for all of the organisation's operations. It resembles a database that records all of the processes. This verification process can usefully include IoT sensor technology, smartphones, tablets, laptops, quantified self-tracking devices and so on. The blockchain is a cheap, public record of the transfer of information and the effective allocation of resources in the operations of any organisation (Choi, 2020; Dutta et al., 2020).

### *3.3. Adoption and application of the blockchain to a participatory decision system*

Despite the benefits of the blockchain and its possible application in numerous fields (Lu, 2022), its adoption seems to be less prolific than its media impact. One of the main obstacles that organisations encounter when using the blockchain is trust in the system by adopters (AlShamsi et al., 2022; Li et al., 2023; Taherdoost, 2022; Xu et al., 2023c), followed by factors such as high investment (Esmaeilian et al., 2020), high energy costs (Böckel et al., 2021; Pawar and Sachdeva, 2023), resistance to change due to organisational culture (Shojaei et al., 2021) and lack of knowledge in its implementation (Bekrar et al., 2021). Therefore, its adoption can be improved by investigating added benefits to increase the perceived benefit of its implementation (Giri and Manohar, 2021; Garg et al., 2023), decrease the costs of its use and improve the knowledge and ease of use (Kamble et al., 2020; Giri and Manohar, 2021), which would allow a greater introduction of the technology and participation in it (Taherdoost, 2022).

Once the technology is adopted, blockchain can lead to a profound participatory revolution. Perhaps the most immediate benefit is that it can overcome the efficiency problems that have been detected by the literature for participation in decisions (Zhao et al., 2022). The involvement of stakeholders in executive decisions not only has implications for their commitment but also represents a recognised system for improving the quality of authority decisions (Christensen and Knudsen, 2002, 2010; Csaszar, 2013; Knudsen and Levinthal, 2007; Salas-Fumás et al., 2016). Simon (1947) studied the problems of uncertainty in decision making, establishing a theoretical framework that differs from the classical rationality framework, where individuals can make wrong decisions. For Simon (1947), uncertainty is an endogenous problem of the decision-maker whose base is in their cognitive and time limitations. Sáenz-Royo et al. (2022a) model this idea, calling this conceptual framework the intentional bounded rationality of individuals. This approach assumes that individuals are aware that they make erroneous decisions (which are not the best) while assuming a reasonable error given their limitations.

It is assumed at the social level, thanks to historical evidence, that participation in decisions obtains better returns than the concentration of authority (i.e., democracies vs. totalitarian regimes). This participation contributes to avoiding the appropriation of *ex-post* rents, but it has not presented evidence in smaller organisations. The accumulation of tangible assets required for the organisation to be more efficient has given capital the ability to decide, but this does not justify its delegation to a small group of managers in an authoritarian and hierarchical manner, and other factors have prevented more participatory decision systems. There are three main arguments that have justified authoritarian decision making in organisations.

The first and perhaps most important argument is private information. Organisations have developed closed management systems (ERP) in which each functional department only has the information necessary to carry out its specialised activity. This has entailed an approach in which the authority has privately disposed of all of the information. Information asymmetry makes fewer expert individuals present more fallibility in their judgements, and their incorporation into the organisation's decisions deteriorates their group performance, which justifies the concentration of authority in organisations (Dessein, 2002; Harris and Raviv, 2005, 2008, 2010; Chakraborty and Yılmaz, 2017). The blockchain avoids this problem because the information is shared among all of the members of the organisation, and therefore the differences in judgement are a consequence only of the individual capacity to assimilate said information.

The second argument is that the time spent to get participation is the cause of its inefficiency. Sáenz-Royo et al. (2022b) analyse the performance of an authoritarian system, compared to other participatory decision-making structures where the time required for decision making is an important source of inefficiencies that justifies the concentration of authority, even when the information is shared, and all individuals have the same processing capacity. Traditional voting systems require specific times to carry out voting because of the coordination and management of the process. In contrast, the blockchain allows a secure voting system while working, without the need for meetings or systems for the dissemination of ideas. Voting is unalterably recorded on a shared blockchain, and decisions are made based on the decision mechanism established by the organisation using a specific algorithm. In this sense, Christensen and Knudsen (2010) show how the simple majority decision rule (as a combination of hierarchy and polyarchy) is the most efficient when individuals are fallible.

The third argument is that the lack of independence in the judgements shown by the individuals impairs the performance of collective decisions (Salas-Fumás et al., 2016). Traditional voting systems take place sequentially, and normally are not secret (to avoid time costs), which notably conditions the voters' judgements due to the social relationships between members, thus generating strategic behaviours. Blockchain technology makes it possible to alleviate moral hazard frictions (Chod et al., 2022) while maintaining the anonymity of voters and guaranteeing the functioning of the system without the need for an authority to organise the consultation (Bolton et al., 2004).

Finally, blockchain provides an immutable record of the decisions made, the judgements of the individuals involved in the decision and of the difference in collective performance with respect to the *status quo* that each decision has entailed. The system can obtain a reliability coefficient for each individual from this information. This is very relevant when decisions are delegated to small groups of experts to improve group efficiency (Moral et al., 2018; Pérez et al., 2018).

## 4. The model

The model uses a general conceptual framework of the organisation where individuals have intentional bounded rationality and where the elements for analysis are the impact of the independence of the judgements of the individuals, the information asymmetry and the decision time. The key question is to determine which decision mechanisms are more efficient than authority and under what assumptions.

### *4.1. Intended bounded rationality*

Sáenz-Royo et al. (2022a) propose an exhaustive functional representation of the concept of intentional bounded rationality, where the probability that the individual expresses a correct judgement depends on their capacity for information processing and the difficulty of the problem. We present a simplification of the proposed formulation of Sáenz-Royo et al. (2022a). In this work, many alternatives are not evaluated, only the decision to accept or reject a project that can improve the performance of the *status quo* is considered. In addition, individuals do not have prejudices regarding the evaluated project, and the judgement about the project can be conditioned by other individuals. In this conceptual framework, individuals face projects whose latent performance ($V$) is unknown *a priori* and must be compared with the performance of the current *status quo* ($V_0$). The inverse of the difference between the value of the new project and the value in the *status quo* represents the complexity of the choice, which decreases as the performance difference increases. The expertise of individual $i$ is represented by the parameter $\beta_i$. Its value increases with the general ability of the individual to process information and the specific experience and knowledge that they have about the information to be processed. A higher value of $\beta_i$ increases the probability that the project will be accepted when its net performance is positive. The probability that an individual $i$ accepts a project whose performance $V$ is synthesised in $p_i(V)$:

$$p_i(V) = \frac{1}{1 + e^{-\beta_i\left(\frac{V-V_0}{V_0}\right)}}. \tag{1}$$

Its complement, $1 - p_i(V)$, is the probability that the individual rejects the new project and prefers to continue with the *status quo*. Individuals can make two types of errors in their judgements: First, a commission error arises when a favourable judgement is shown for a project that must be rejected because its latent performance is lower than the *status quo* ($V < V_0$); and second, an error of omission arises when an unfavourable judgement is shown to a project that must be accepted because its latent performance is superior to the *status quo* ($V > V_0$). Commission errors are visible because the organisation presents a lower performance than that obtained with the previous *status quo* by accepting the project, while omission errors represent an opportunity cost (this is a benefit that has not been earned due to having chosen wrongly). Therefore, according to the model, an unlimited rational individual only supports projects with $V > V_0$ and rejects the rest. The type II error probability (commission error) is $p_i(V)$ when $V < V_0$. Meanwhile, the probability of committing the type I error (omission error) is $1 - p_i(V)$ when $V > V_0$. In this approach, $p_i(V) = 1 - p_i(V_0)$ and $1 - p_i(V) = p_i(V_0)$. The final choice of individual $i$ will be denoted as $E_i(V)$ if they consider that the new project should be accepted or $E_i(V_0)$ if they consider that the organisation should reject it.

Equation (1) is bounded between the values 0.5 when $\beta = 0$ and 1 when $\beta = \infty$; that is, whenever the project presents a latent performance higher than the *status quo* ($V > V_0$) for any $\beta > 0$ probability of accepting the project is higher than the probability of remaining with the *status quo*. Likewise, the probability of showing a favourable opinion of the *status quo* is higher than that of showing a favourable judgement of the project when the latent performance of the *status quo* is higher than that of the project ($V_0 > V$). When the individual is unable to process information ($\beta = 0$) due to a total lack of experience, then the probability of choosing the project or the *status quo* is 0.5, and the individual is indifferent between the two alternatives regardless of their latent performance. If the individual has the maximum possible expertise ($\beta = \infty$), then they will choose the alternative with the highest performance, even if the difference between the performance is minuscule.

### 4.2. Decision mechanisms

The way in which an organisation decides is called a decision mechanism. The collective decision criterion can range from accepting the judgement of a single individual to make the collective decision (i.e., authority) to requiring the unanimity of all of its members (i.e., total consensus) (Goers and Horton, 2023; Guo et al., 2023). There are many alternatives between these two options, which depend on aspects such as the number of individuals involved, their level of consensus (decision rule) and their level of expertise. The combination of these three variables represents what is called a decision mechanism ($s$), and the probability that the organisation accepts a new project of latent performance $V$ is represented in $p(V \mid s)$.

#### 4.2.1. Authority

In the authority mechanism (we denote by $a$), an individual has the power to make the decision to adopt the project and finalise the group decision process or not. A new project is accepted or rejected with the probability function (1) with the expertise of the individual who holds the authority ($\beta_a$), and their decisions become group decisions. Therefore, for $s = authority$, $p(V \mid s) = p_a(V)$. Any new project must be communicated to the authority. One of the strengths of this mechanism has been its agility in decision making. The time required by the authority to make a decision is considered to be one period because it does not require any coordination, and the justification for this time is merely deliberative ($T_a = 1$).

#### 4.2.2. Participation

In participation, the adoption of the project by the group requires the information aggregation mechanism in a group of $N$ individuals to be determined. In this work, two technologies are considered, the traditional consultation technology in which individuals are summoned to express their opinion (denoted by $b$), subsequently carrying out scrutiny, and the blockchain technology (denoted by $c$), which allows us to computerise (while working) the judgements of individuals in an anonymous and unalterable way. Participation also requires the decision rule to be established; that is, determining the minimum number of individuals out of the total that is required to accept the project (denoted as $h$). The combination of decision rule, technology and the number of individuals consulted determine the decision mechanism(s).

*Decision rule.* A simple decision rule in participation is to require the unanimity of the individuals ($h = N$) and if the technology is traditional $s = b_N$.

$$p\ (V|b_N) = \prod_{i=1}^{N} p_i(V) \ = \prod_{i=1}^{N} \frac{1}{1 + e^{-\beta_i\left(\frac{V-V_0}{V_0}\right)}}. \tag{2}$$

Suppose a group of 100 homogeneous individuals with the same expertise. The probability of accepting the project unanimously is limited by the two extremes, which depend on the number of experts:

1. A group of 100 total inexperienced ($\beta = 0$) individuals with a probability of accepting each one is 0.5, regardless of the latent performance of the project ($p_i = 0.5$). The probability of

unanimously accepting in this group (Equation 2) is ($0.5^{100}$)—that is, (7.8861E-31)—which is much lower than the minimum individual probability of accepting a project that has higher latent performance than the *status quo* ($V > V_0$), which is 0.5, and therefore omission errors increase (i.e., projects that should be accepted are rejected). However, it is also very difficult to accept a project that performs worse than the *status quo* ($V < V_0$), thus reducing commission errors.

2. A group of 100 rational experts ($\beta = \infty$) individuals. If all are rational, then they would effortlessly distinguish the best alternative ($V > V_0$) and would choose the project with probability 1. The probability of unanimously accepting the project in Equation (2) is 1, given that there are no opportunistic behaviours.

Consider some counter-intuitive properties of unanimity in a project that exhibits a latent performance superior to the *status quo* ($V > V_0$). Suppose that it has 100 experts who can be wrong once in a thousand, given the latent performance differential of the alternative project above the *status quo*. The probability of choosing correctly for each of them is 0.999, and the probability that a group of 100 experts unanimously accept is 0.90479 ($0.999^{100}$). The unanimity mechanism presents a probability of omission error, rejecting a project with performance higher than the *status quo* ($V > V_0$) of 0.09520785, which is much higher than the probability that each of the experts has separately (0.001). Meanwhile, the project presents a latent performance that is lower than the *status quo* ($V < V_0$) (i.e., the individual probability of accepting is 0.001), while the unanimity mechanism presents a probability of commission error of 1E-300 ($0.001^{100}$), which is much lower than that of each individual separately (0.001). Therefore, unanimity guarantees not making commission errors in exchange for increasing omission errors, the performance of this balance depends on the objectives of the organisation.

Suppose that there is a group of 99 high-level experts ($p_i = 0.999$) given the latent performance differential in favour of the alternative project ($V > V_0$) and one total inexperienced individual ($p_i = 0.5$). In this case, unanimity presents a probability of correctly accepting the project of 0.45284892, which is well below the 0.90479 that would have been obtained if they were all high-level experts, thus increasing the probability of making an omission error to 0.54715108. The probability of accepting a project with a latent performance differential in favour of the *status quo* ($V < V_0$) (individual probability of accepting is 0.001 for 99 experts and 0.5 for the inexperienced) from the unanimity mechanism is 5E-298 ($0.001^{99} \cdot 0.5$). Therefore, the probability of committing a commission error, accepting having to reject, is much lower than the individual probability of committing this error by the experts (0.001).

The unanimity mechanism increases, *ceteris paribus*, the omission errors. In other words, it rejects projects that present a better performance than the *status quo* in exchange for reducing commission errors. In short, it is immobile.

Another possible rule is the simple majority, in which it is required that $h = (N + 1)/2$ of the individuals manifest themselves in favour of adopting the new project to adopt it; otherwise, the *status quo* continues. The participatory system allows errors of commission or errors of omission to be limited as desired in group decisions (Christensen and Knudsen, 2010). If the aim is to reduce the errors of commission, then it is enough to require a large majority for acceptance (3/5 parts, etc.) increasing the errors of omission. Meanwhile, if the aim is to reduce the omission errors, then it is enough to reduce the requirement of majority acceptance (2/5 parties, etc.). The objectives of the organisations require personalised management of the error. Catalani and Clerico (1996) argue that if a company makes a mistake and adopts a project that generates significant losses, then its reputation will be negatively affected and it could even close. Meanwhile, Yu and Lai (2011) show how errors of omission in emergency management can have fatal consequences. In fact, the simple majority decision rule, when the number of individuals is even, is a rule that reduces the commission error to a greater extent than the omission error because it requires $N/2+1$ individuals to be approved and $N/2$ to be rejected. The gains from participation in simple majority rule blockchain technology are analysed in this paper.

A counter-intuitive example in the majority mechanism is when we have two groups of individuals, one group with great experience and another group with very little experience. Suppose that a project whose performance is lower than the *status quo* ($V < V_0$) assumes that there are three super-expert individuals ($p_i = 0.001$) and four super-inexperienced individuals ($p_i = 0.499$), where $p_i$ is the probability of accepting. The probability that the group will accept by majority a project with latent performance below the *status quo* ($V < V_0$) is the sum of the following combination of group votes:

Expert group (GA) and inexperienced group (GB):

Option 1: GA: 0 acceptance votes or more ($p_A = 1$) and GB: 4 acceptance votes ($p_B = 0.0620015 = 0.499^4$)

Probability Option 1:

$$P_1 = p_A\, p_B = 0.061815679$$

Option 2: GA: 1 acceptance vote or more ($p_A = 0.002997001$) and GB: 3 acceptance votes or more ($p_B = 0.3110015$)

$$P_2 = p_A\, p_B = 0.000932072$$

Option 3: GA: 2 acceptance votes or more ($p_A = 0.000002998$) and GB: 2 acceptance votes or more ($p_B = 0.6859985$)

$$P_3 = 2.05662E-06$$

Option 4: GA: 3 acceptance votes ($p_A = 0.000000001$) and GB: 1 acceptance vote or more ($p_B = 0.9369985$)

$$P_4 = 9.36998E-10$$

The total acceptance probability for the majority mechanism is $P_1+P_2+P_3+P_4 = 0.062749809$. The case described here is a super extreme situation in expertise. In general, the possible gains from the weights are expected to be lower than in this case. The deterioration with respect to the individual experts (0.001) is important, but the result of the majority is closer to the experts than to the inexperienced, which leaves little room for improvement through weighting. It must be taken into account that to date the weighting of the experts is difficult and expensive (Tetlock, 2000), which the blockchain can help to change.

*Decision technology*. Decision technology has implications for the time required for the query, for information asymmetry, for the independence of the judgements made by individuals and for the

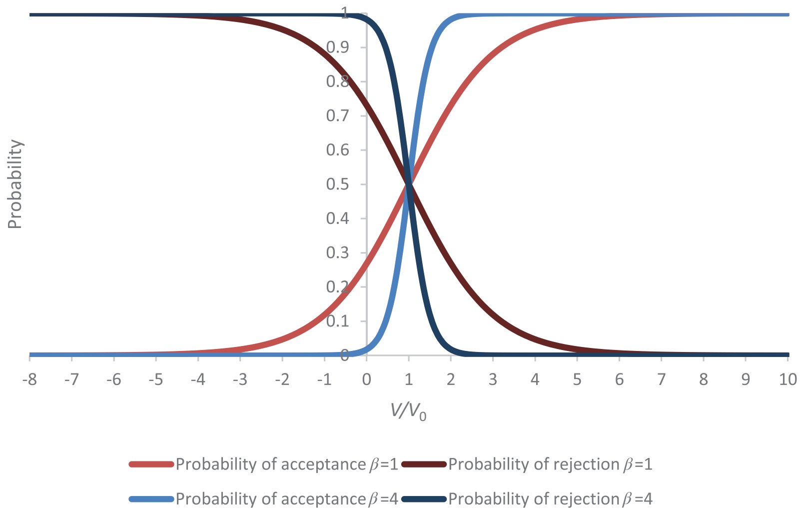


Fig. 1. Probability of acceptance and rejection for $\beta = 1$ and $\beta = 4$.

management of expertise as a possible consideration. Two technologies are considered traditional voting versus blockchain.

*Time*. The time required for the group decision will be measured proportionally to the number of individuals participating in it. The efficiency of each participation technology provides a coefficient of time needed per person. Although in this work, it is considered that the votes are not sequential, they can occur in parallel. There are necessary adjustment times in the coordination, call, meeting and scrutiny, and therefore each technology will have a necessary time. We will assume an additional time for the deliberative one ($T_a = 1$) with a high-efficiency coefficient (0.1) in the case of the blockchain ($T_c = 1 + 0.1N$) and medium (0.6) in the case of traditional voting ($T_b = 1 + 0.6N$).

*Private information.* Traditional vision assumes that the authority is the owner of all the information of the organisation, which generates a great asymmetry with respect to the rest of the individuals. However, the blockchain ensures shared information, including its location among all the individuals in the organisation. It also allows reward systems for correct voting and facilitates the establishment of generalised incentives for investment in human capital.

Information asymmetry supposes that a discretionary cost is imposed when processing information, which ensures greater expertise for those who have private information. Therefore, there are greater probabilities of choosing correctly. In the model, private information is represented with a higher parameter $\beta$, assuming a lower cost of searching for information for the individual who has it. When the information is the same for all, the differences in the $\beta_i$ parameters represent the ability of each individual to internally process said information and provide a correct answer. In intentional bounded rationality, the errors in assessing the performance of the alternative with respect to the *status quo* follow a logistic distribution function (Ren and Huang, 2018; Canbolat, 2020), whose mean is the true value and whose dispersion is determined by the parameter $\beta$ because its variance is $\pi^2/3\beta^2$. As can be seen in Fig. 1, the probability of correctly evaluating the difference $(V - V_0)$ increases when the parameter $\beta$ increases, which reduces the area of error. The type II error is represented by the area between the abscissa axis and the probability of accepting up to $V = 1$; that is, when $V < V_0$. The type I error is represented by the area between the abscissa axis and the probability of rejecting from $V = 1$; that is, when $V > V_0$.

*Independence, conditionality and heterogeneity.* Traditional technology has paid little attention to ensuring that the identity of assessments remains anonymous. Social relationships and hierarchical dependencies create obligations by establishing links of dependency, conditioning individual evaluation, and creating what we will call a leader (whose evaluation is a reference for others) and a follower (who presents an evaluation conditioned by the leader). Meanwhile, blockchain technology is based on two principles: the unalterable record of the evaluations and their anonymity.

Once independence is guaranteed, it is reasonable to assume that there is heterogeneity in the ability to process information in the search for the underlying best project, which is reflected as a different $\beta$ for each individual in Equation (1). When all individuals face the same decision, the difference between the latent performances $(V - V_0)$ does not change; that is, the difference between the probabilities of accepting in Equation (1) lies solely in the $\beta$. However, the mean group acceptance probability $(p_N(V))$ can be calculated as $p_N\,(V) = 1/N \sum_{i=1}^{N} p_i(V)$. If all individuals have the same expertise $(\forall\ \beta_i = \beta)$, then the probability of the decision rule follows a binomial and its formula is closed; otherwise, the probabilities must be obtained by simulation.

*Weighting and efficiency.* Blockchain technology has several important gains over traditional evaluation technology. On the one hand, the reliability of the judgements of each individual is historically recorded, which allows for a weighted group evaluation that presents better results than the traditional method. On the other hand, the incorporation of weighted evaluations makes it possible to reduce the number of individuals that is necessary to obtain reliability. Partial counts of the generated appraisals can be obtained because the technology has a record of the reliability of the appraisers. The technology makes it possible to establish a rule to stop voting when a certain level of the reliability of the evaluations has been reached. For example, if the first six evaluations are unanimously in favour of accepting the new project, then the probability that the evaluation is wrong $p_N = 0.51$ (with totally inexperienced evaluators) is 0.014; and if the first seven evaluations are unanimously in favour of accepting the new project, then the probability of being wrong is 0.007. The question is: knowing that $X$ evaluators $X - k$ have provided a positive evaluation, what is the reliability of the evaluation at that moment, knowing that the probability that $p > 0.5$?

## 5. Evaluation of aspects of organisational efficiency

### *5.1. Superiority of independence over conditionality*

The error reduction of participation increases as the number of independent participants increases. This result is basic to Condorcet's jury theorem and has been widely used in crowd wisdom theory (Berend and Paroush, 1998). When the relationships between individuals imply a total conditioned evaluation, the criterion of the follower ($i$) coincides completely with the leader ($j$); that is, $p_i(V|E_j(V)) = 1$ and $p_i(V_0|E_j(V_0)) = 1$. When all of the individuals in a group have the same reliability and there are $M$ individuals who are totally dependent on one of them (i.e., the judgement of one condition that of $M$ individuals), participation works as if the member who conditions the others had $M + 1$ votes, and the probabilities of the group are the same as those of a group with $M$

fewer components. Therefore, its reliability is equal to that of a group with $N - M$ individuals (i.e., reliability less than with $N$ individuals). When the conditional relationships are not total but are symmetric (i.e., the leader's evaluation always conditions the follower with the same probability) in the errors of commission and omission, $p_i(V|E_j(V)) = p_i(V_0|E_j(V_0))$, its probability distribution is the same as the total conditional. This happens because the mismatched evaluations are equal, $p_i(V_0|E_j(V)) = 1 - p_i(V|E_j(V)) = 1 - p_i(V_0|E_j(V_0)) = p_i(V|E_j(V_0))$, and therefore the result is the same as with total conditioning.

Asymmetric conditional relationships allow a wide range of judgement combinations but their interpretation in project evaluation cannot be justified. An individual could choose probabilities of intersection with another individual (i.e., probabilities of commission and omission error) that would maximise the group performance, provided that the probabilities and the final result were known. This is a contradiction in its own terms because if the probabilities and the result are known, then the individual's choice should be unique and should be the alternative with the highest performance. For this reason, asymmetric conditional relations are not studied in our case. These results show how traditional technology has worse results than blockchain technology, where the anonymity of the evaluation is a mechanism to ensure the independence of individuals.

### 5.2. *Superiority of heterogeneity versus homogeneity under the same mean reliability*

A comparison of systems with the same average probability of acceptance is possible through their entropy. The entropy of Shannon (1948) is used as a measure of uncertainty. Systems with heterogeneity in their set of probabilities present less uncertainty because the more informative elements overcompensate the uncertainty of the less informative, as long as the average probability of acceptance is maintained. Thus, if the individuals are homogenised by assigning the average probability of accepting to all of them, then the group probability of accepting is underestimated. Therefore, it can be guaranteed that the reliability of participation is at least that provided by its homogenisation. Moreover, the greater the dispersion of the expertise, the greater the gain with respect to its average probability of acceptance. Therefore, the probability that the participants will accept a project with latent performance $V$ with a decision rule of at least h favourable members is:

$$p\ (V|s) = \sum_{h=m}^{N} \binom{N}{h} p_N(V)^h (1 - p_N(V))^{N-h}. \tag{3}$$

The rate of convergence to the asymptote of the binomial is very fast. For example, $p_N = 0.8$, $N = 13$ and $m = N/2 + 1$, the probability of accepting a new positive project is $p(V|s) > 0.99$. If a situation of heterogeneity occurs (with the same average probability of accepting that homogeneity and independent individuals), then it is ensured that the group results of homogeneity improve.

### 5.3. *EOL evaluation of different decision mechanism*

Some aspects of the performance of the different group decision mechanisms are evaluated by the $EOL(V)$. In the simulated process, different performances of the new project $V$ are evaluated.

Consequently, its visualisation allows us to identify the best decision mechanism based on the possible distribution of $V$. The model presents three central equations:

$$EOL\left(V\,|V\rangle\,V_0\right) \;=\; \left(V - V_0\right)\left(1 - p\left(V \mid s\right)\frac{Ve^{-rT_s} - V_0}{V - V_0}\right), \tag{4}$$

$$EOL\left(V|V < V_0\right) = \; p\left(V \mid s\right)\left(V_0 - Ve^{-rT_s}\right), \tag{5}$$

$$EOL\left(V|V \;= V_0\;\right) = \; 0. \tag{6}$$

An important contribution of this model is that time is important; the EOL of each decision mechanism is expressed in terms of the present value calculated with a positive discount interest rate, $r$. During the time spent until reaching the collective decision, the group continues to operate in the *status quo* and obtains a payment $V_0$. The EOL of a project with $V > V_0$ increases with the time used to reach a collective decision because the time needed to make the group decision is the time in which the benefits of a project that has better performance than the *status quo* have not been obtained. Meanwhile, for projects with $V < V_0$, the EOL decreases with the decision time because the commission error is delayed.

The base case for the simulation considers all the values of $V$ from $-8$ to 10, a *status quo* value $V_0 = 1$ and some $\beta = 1$, 3 and 5. Initially, the participation values are presented for a different number of evaluators, to finally show the different decision mechanisms when there are seven possible evaluators. Likewise, once what it means to improve the evaluators' expertise is established, the decision mechanisms are analysed for a $\beta = 2$. The time needed to evaluate the project is different between the decision mechanisms.

The EOL performance measure, Equations (4), (5) and (6), weights the losses from errors of commission and omission. Values of $V$ between a lower limit, $-8$, and an upper limit, 10, are obtained in a simulation exercise. The overall performance of a decision mechanism is equal to the EOL of wrong decisions. The discontinuity at $V = 1$ occurs because there are no error costs when $V = V_0$. The decision-making process and the equations used in each stage can be seen in Fig. 6 (Section 6).

### *5.3.1. Evaluation of private information*

Figure 2 shows the expected errors of commission and omission of the group in the range of the value of the project variable, $V[-8,\ 10]$. The private information of the authority, compared to the rest, is represented with a $\beta_a = 3$ for the authority, while the rest of the individuals have a $\beta_{bi} = 1$. Authority versus participation is compared with traditional technology with seven and 13 individuals (because blockchain technology assumes shared information and all individuals must present similar $\beta_{ci}$) and a simple majority decision rule ($h = (N + 1)/2$). The symmetry between costs of commission and omission of participation happens because the time required to group the information is not penalised (this aspect will be addressed in the next subsection), establishing in this section an interest rate $r = 0$.

In this assumption, the authority shows a smaller area of commission and omission errors for low differences between the project and the *status quo*, while participation does so for significant differences in performance. The participation of at least 13 individuals is necessary for participation

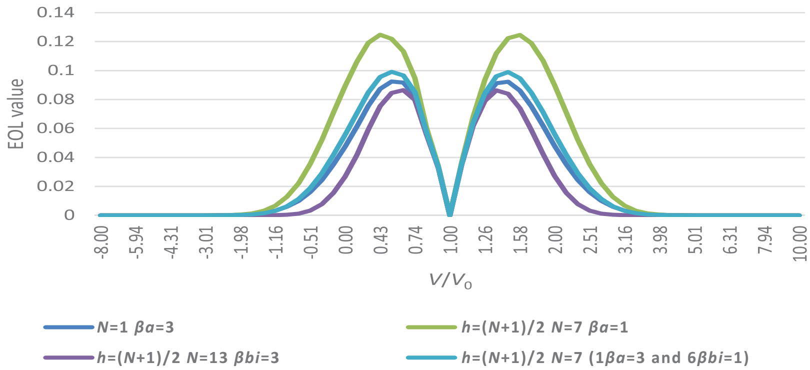


Fig. 2. Expected opportunity loss (EOL) of commission ($V < V_0$) and omission ($V > V_0$) errors for private information in different decision mechanisms ($r = 0$, and range of $V$: $-8$ to 10).

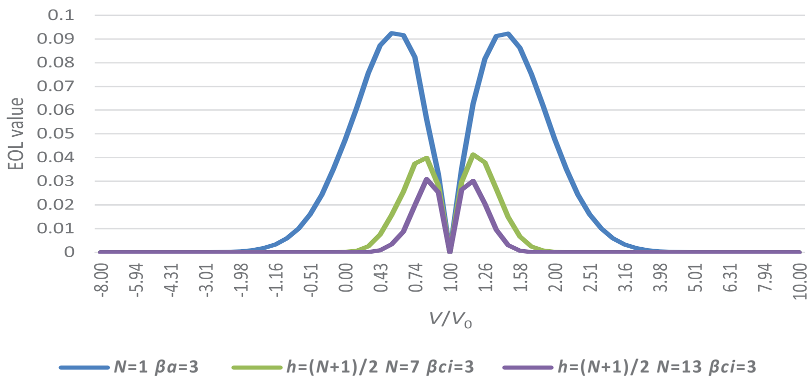


Fig. 3. EOL of commission ($V < V_0$) and omission ($V > V_0$) errors without private information in different decision mechanisms ($r = 0$, and range of $V$: $-8$ to 10).

to compensate for the difference in expertise with the authority due to private information. We call 'combination' the incorporation of the authority (i.e., an individual with greater expertise than the rest) in a group of seven individuals, with equal voting weights. However, not even this evaluation mechanism manages to improve the EOL of the authority alone, although it comes very close; that is, when the authority has private information, it establishes a participatory decision-making group with the authority, and six low-expertise individuals (this mechanism requires more decision time) obtains practically the same performance results as when the authority decides unilaterally. The results of $EOL(V)$ from simulations are presented in Figs. 2 and 3 for interest rate $r = 0$.

Private information makes sense when the information is processed and compiled by an individual who specialises in this work. The authority internally processes and structures the information. Its advantage is that it has very short decision times. The development of information technologies allows the organisation's information to be grouped and complete management reports to be presented, together with a higher level of training in current societies. This suggests that the differences between individuals when processing well-structured information are insignificant (Tetlock, 2000).

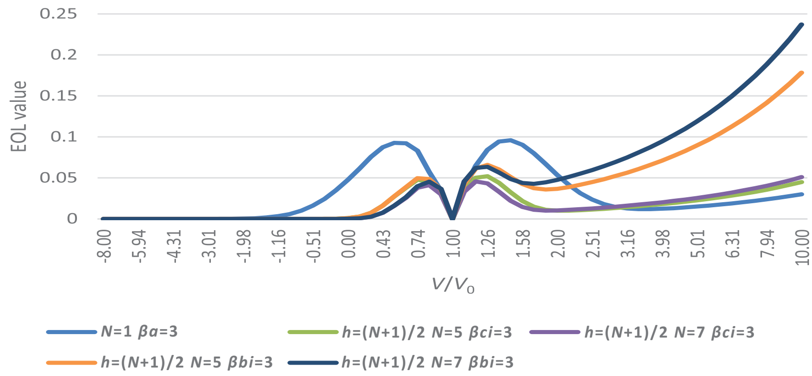


Fig. 4. EOL of commission ($V < V_0$) and omission ($V > V_0$) in different decision mechanisms ($r = 0.3\%$, and range of $V$: $-8$ to 10).

Figure 3 shows a situation of shared information, where all individuals present a $\beta = 3$. In this case, participation represents significant reductions in EOL as the number of individuals increases. Another aspect to highlight is that the incorporation of the first individuals reduces EOL to a greater extent than the latter, which makes it more informative to study the participation of small groups.

The function $EOL(V)$ is convex for $V < V_0$ and $V > V_0$, while its value is 0 for $V = V_0$. It has an interior maximum for a value of $V$ in the ranges between $V_m$ and $V_0$ and another between $V_0$ and $V_M$. Different values of $V$ affect the EOL with two opposite effects: when the difference between $V$ and $V_0$ increases in absolute value, the probability of a wrong decision of the decision mechanism decreases by Equation (1). However, as the difference in project values increases, the opportunity loss from the wrong decision simultaneously increases. At the maximum EOL, the two marginal effects are equal in absolute value.

### 5.3.2. *Time until the group decides adoption*

The time needed to reach a decision by participation depends on the number of individuals and the technology. The penalty with the blockchain is significantly lower than traditional participation. Time incorporates asymmetries in the EOL of commission errors and omission errors. When the time has a cost and the project has a lower performance than the *status quo*, increasing the decision time reduces the EOL because the organisation continues with the *status quo* during the evaluation stage, and the periods in which a project has been accepted are reduced with lower performance than the *status quo* (commission error). When the project presents a higher performance than the *status quo*, increasing the evaluation times increases the EOL because the superior performance that can be obtained by accepting is lost during the group decision times. This effect favours participation on the side of commission errors and harms it on the side of omission errors. The results of the EOL calculation from simulations are presented in Fig. 4 for an interest rate $r > 0$.

For values of $V < V_0$, the EOL of the different decision mechanisms is convex with an interior maximum. This is similar to what happens when $r = 0$. When $V > V_0$ the EOL functions have a maximum and a minimum in each decision mechanism. This means that when time counts, there is a value of $V$ beyond which the marginal increase in EOL of the opportunity cost of the wrong decision dominates the marginal increase in EOL of the lower probability of error. The lowest EOL of participation with traditional technology occurs for values of $V$ lower than with blockchain technology and both occur for values lower than for authority. These points mark the efficiency zones of each decision mechanism.

Figure 4 shows that participatory systems with traditional technology penalise projects have a performance that is much higher than those of the *status quo* due to the time required to decide, which makes them inefficient. However, participation shows important gains with respect to authority with blockchain, thus becoming a competitive decision mechanism that reduces both the EOL of commission errors and the EOL of omission errors. Participatory mechanisms are more efficient in difficult decisions when the differences between the performance of the status quo and the project are small. Authority mechanisms dominate easy decisions where performance differences are apparent. However, even on these occasions, they do not present important differences with the blockchain.

### 5.3.3. Diversity and reliability-weighted assessments

To achieve participation in management, a vote can be taken on project decisions. Specifically, these decisions are made based on votes weighted using governance tokens and aggregated through intelligent contracts (Singh and Kim, 2019). The price of the governance tokens is expected to increase as a result of the extra profits that the organisation obtains thanks to making good decisions and supposes a payment for the participation in expensive evaluations. This represents an incentive for the accumulation of human capital of the participating individuals. In short, the system tries to improve the organisation's efficiency, assign efficient voting weighting mechanisms and align individual and organisational interests. Some previous works have studied weighted voting systems for high-quality recommendations in advertising, prices and others (Asgaonkar and Krishnamachari, 2018; Papanastasiou et al., 2018; Tsoukalas and Falk, 2020). However, given the complexity of the subject, in this paper, we will limit ourselves to outlining some technical conditions that help improve organisational efficiency with this instrument.

The problem of how to improve committee evaluation performance has been addressed in group decision-making theory (Bacharach, 1975; Dong et al., 2016; Gong et al., 2015). In this line of work, various simulation exercises have been carried out in a scenario in which the evaluators have small reliability differences of less than 10% (between the best and the worst evaluator). The results show that the contributions of diversity and the incorporation of weights among the evaluators make few contributions to the performance of participants with media expertise. There is barely any diversity in small groups, while in larger groups the enormous improvement resulting from participation means that the effect of diversity or weighting has an impact of less than 1%.

The accuracy of each evaluator's $p_i$ can be recorded in blockchain technology using historical information. If $k$-registered historical evaluations are available and the performance of the projects accepted by evaluator $i$ is known, then an estimate of $p_i$ can be determined based on how many times it has been correct. Mathematically, the estimate $\hat{p}_i$ is equal to the number of correct answers with respect to the number of evaluations ($k_i$). Of course, there is estimation error that statistical theory, under moderate conditions, prescribes as $[\hat{p}_i - z\sqrt{(\hat{p}_i - (1-\hat{p}_i))/k_i}; \hat{p}_i + z\sqrt{(\hat{p}_i - (1-\hat{p}_i))/k_i}]$ as a $(1-\alpha)\%$ confidence interval for $p_i$, where $z$ is the $(1-\alpha/2)$

percentile from a standard normal distribution. Although we could increase $k_i$ to get a more precise estimate of $p_i$, this is a burden for a single appraiser. For example, if we want the estimate $\hat{p}_i$ to be within, say, 1% of the true value $p_i$ with, say, 99% confidence, then, noting that $\hat{p}_i\,(1-\hat{p}_i) < 1/4$, the confidence of the interval can be manipulated to show that $k_i >= 16,587$ is required. Alternatively, we suggest instead of increasing the number of appraisers by choosing a relatively small value of $k_i$ and using the lower bound of the confidence interval, $\hat{p}_i - z\sqrt{(\hat{p}_i - (1-\hat{p}_i))/k_i}$, be the proxy of $p_i$. For example, if $k_i = 100, z = \phi^{-1}(0.995) = 2.576$, and say $\hat{p}_i = 0.80$, then the lower bound is equal to $\hat{p}_i - z\sqrt{(\hat{p}_i - (1-\hat{p}_i))/k_i} = 0.7$. In this way, the accuracy of the evaluator is underestimated, and more evaluators are needed for each project. However, evaluators should not be eliminated due to lack of reliability, contributing to the collective evaluation assuming the minimum training that each one can present to 95%, the blockchain requires a greater number of evaluators to neutralise this supposed lack of expertise; for more details see Wagner (2020).

We will assume a symmetric decision rule in which it is intended to reduce commission and omission errors in the same proportion. The distribution function that determines the errors is a binomial with $n$ evaluators and the probability of success $p_N$ belongs to [0,1], establishing a relationship between $p_N$ and the number of evaluators $n$ needed to get a given level of reliability. To know the probability $p_N$ from the observations, the random walk can be using Stirling's formula (Rudnick and Gaspari, 2004),

$$E(x) = n(p_N - (1-p_N)),$$

$$Var = 4np_N(1-p_N).$$

Thus, this system allows sequential evaluation to reduce the number of individuals based on the coincidence in the initial evaluations. The evaluators with the greatest expertise can be chosen first then and added in case the evaluations do not coincide. In this way, a weighted evaluation is not carried out but the individual experience is considered, assuming a saving of time, especially in projects that show significant differences in performance, which are where participation is most penalised.

## 6. Discussion, managerial implications and illustrative example

The development of organisations as an alternative to the market depends on their ability to improve the efficiency of coordination and their ability to establish sustainable incentives for the accumulation of human capital (management of intangibles), where decision mechanisms are an element that directly affects both. This happens because participation in decisions guarantees to increase the information of decisions and establishes incentives for the accumulation of human capital; the difficulty is the income appropriation *ex-post* from the property.

Participation has been shown empirically to be the best form of organisation in countries, but it has hardly been used in firms because the private information, the non-independence of voting due to mutual influences and the time required have made it inefficient. However, the emergence of the blockchain is an opportunity for this decision mechanism to prosper in the coming years. Errors in organisational decisions are costly from the private and social points of view. In addition, evolution decisions largely depend on the decision mechanisms and the effectiveness of the implementation stage.

Participation makes it necessary to align individual interests with collective interests, avoid mutual influences, make the lawful way of achieving individual objectives by obtaining collective objectives and reflect these interests through the decision algorithm. The quality of decisions depends on the information that decision-makers have and can generate, and on their ability to process the available information, while avoiding private information. The review of decisions and implementations depends on the interaction with the environment in which the involvement of all is a value. Establishing mechanisms that reduce potential errors requires further studies at a theoretical level to allow both commission and omission errors to be taken into account.

The classical organisation operates in an authoritarian hierarchical system, where there are hardly any incentives to develop human capital, and in a lack of collective action, where information flows in a direction where people do not feel part of the organisation. The consequences are the continuous failure in the implementation of technological projects by companies (Porras and Robertson, 1992) and the abandonment of the job for no apparent reason (Klotz and Bolino, 2016). Consultants show that 85% of bid data projects that companies undertake fail (Asay, 2017). The reason for failure is often organisational resistance to internal politics, lack of skills and inability to address security and governance challenges. The solutions proposed to reduce failure rates focus on the active participation of the components of the organisation treating the projects in a more bottom-up manner.

The theoretical arguments pose three fundamental drawbacks to participation in organisations. The first is the existence of private information; the extraordinary technological developments have made the collection and processing of information a simple task, automating indicators and reports. However, the problem is that this information is managed in a proprietary manner, attributing enormous power to its owner, and this can be used in favour of individual interests. The second is the time required for participation, which may entail unaffordable opportunity costs for the organisation because long group decision times entail significant losses when the projects present significant gains with respect to the *status quo*. The third is the mutual influence that allows individuals to behave opportunistically (Boje and Murnighan, 1982), establishing *quid pro quo* relationships, controlling votes and spending resources to obtain greater personal income instead of putting efforts into improving the performance of the organisation.

The theoretical results show that blockchain can neutralise the problems of participation in decision making, providing information in a transparent way, granting independence in votes thanks to its anonymity and reducing voting times, which have been problems that participation has traditionally shown. In addition, it seems logical that participation brings fluidity to the implementation stage because the members of the organisation will not resist the implementation of the innovation projects that they supported in the collective decision process.

From a managerial perspective, the results of this study indicate that the expected blockchain opportunity loss tends to be lower in (i) low-interest rate organisational environments that do not severely penalise the time needed to reach a collective decision; (ii) when risks from environmental shocks around the *status quo a*re moderately low (low dispersion of the probability distribution of project values challenging the *status quo*) and (iii) in organisational environments that expect worse results in relation to the *status quo* (i.e., the mean of the distribution of the economic values of the projects is lower than the economic value under the *status quo*); that is, when the organisation is in a

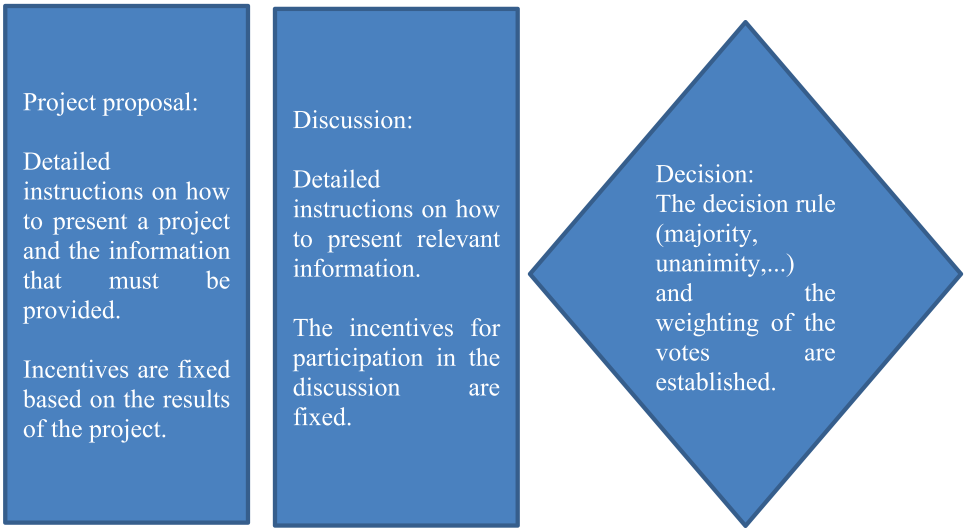


Fig. 5. Participatory blockchain scheme.

leading position. In addition, the authority mechanism will be preferred in the opposite conditions to the previous ones, particularly when organisations anticipate flows of innovation projects from a distribution of values with a mean much higher than the value in the *status quo* and high variance or when the expertise level of all members is very low.

This article was motivated by the signs of overheating of traditional authoritarian organisations that are leading to an accumulation of wealth by a few people and showing signs of exhaustion in productivity improvements, which is an undoubted strong point of this organisation type. Although some authors such as Piketty have advocated participation in decisions as a solution, no evaluations have been provided to measure the improvement in the quality of organisational decisions, perhaps due to the practical difficulty of adequately identifying the reasons for success and failure in making decisions. The theoretical exercise that was carried out in this study is framed in the intentional rationality of the individuals that determines the final result of the decisions. This stage can rarely be observed directly. The exercise reveals the relevance of accounting for EOLs due to omission errors in decision making (which are unobservable to the external observer) to explain decision mechanisms. This reveals the power of blockchain participation versus authority in reducing *ex-ante* EOLs.

The model presented here and the aspects that are discussed around it can be visualised with a practical example. Suppose that a professional office decides to establish a blockchain participation system for improvement projects. In the traditional system, the manager unilaterally proposes improvement projects, discusses them with the individuals that they deem to be appropriate and finally decides whether the project is implemented or not. All members of the unit participate in the implementation phase. This approach concentrates the responsibility and impact of the project on the unit head. An alternative is presented to transform this system into a participatory blockchain process. Three sequential operations are proposed: the project proposal, discussion and decision (Fig. 5).

In the participatory blockchain, a virtual space with P2P technology is enabled so that anyone can propose a new improvement project, discuss it and vote on it prior to its implementation. Participation in each operation is assigned some automatic incentives. Normally the incentives and the estimated payback are established based on the percentage of profit over the *status quo*. The project proposal process is the most encouraged and later the discussion process. In the decision phase, the vote and the final result are usually compared to evaluate the expertise of each member.

Projects can be proposed by anyone and discussed by all members, allowing information to be shared, to finally establish a voting system (weighted or not). The entire pre-deployment process can be done anonymously and independently.

A possible concrete example is detailed in Operation 1, where one of the members proposes to acquire invoice recognition software for automatic accounting (which is made known to all through P2P technology). The accounting supposes 30% of the time of the members of the organisation and the software ensures automation of 80% (the proposal is anonymous thanks to the encryption of data). According to the proposal, salary costs will be reduced by 24% (30% · 80%). In Operation 2, another member objects because they consider 10% of the accounting to be personalised and cannot be automated (because they are used for their cost analysis, and this makes them different) and corrects their improvement forecast to 16% (the discussion is anonymous and independent thanks to encryption and anonymity). Another professional contributes a possible change in legislation within two years that will force all accounting to be personalised (the discussion is anonymous and independent thanks to encryption and anonymity). In Operation 3, all members assess the proposal and vote according to their evaluation of the available information (more information is presented in voting than in the traditional method because individuals have incentives to share it thanks to traceability, improving the expertise of members, individuals are independent and anonymous to vote thanks to encryption). The final results of the project if implemented will determine the payments of the participants.

Blockchain allows the information to be shared in a decentralised way (P2P) while maintaining the independence and anonymity of the participants in the operations (hash encryption) and maintaining the traceability of the contributions, which allows the payment of incentives for results. This is done in real time, which reduces the communication times giving the necessary efficiency to the process. The complete chart flow of the process modelled can be seen in Fig. 6.

## 7. Conclusion

This paper analyses a decision-making process that can be implemented with blockchain technology. The main and general contribution of the article is the modelling of a decision-making system that allows its advantages to be used with blockchain technology. This is done from a singular approach: Blockchain is used as an alternative transaction mechanism to authority and the market, where the decision is decentralised within the organisation. Thus, the theoretical approach allows us to relate the characteristics of the blockchain with the intra-organisational problems that it can solve.

The second contribution is derived from the previous general contribution: We parameterised the process around the acceptance or not of a project, depending on certain rules or mathematical expressions that are directly related to blockchain technology. Thus, among these advantages is the

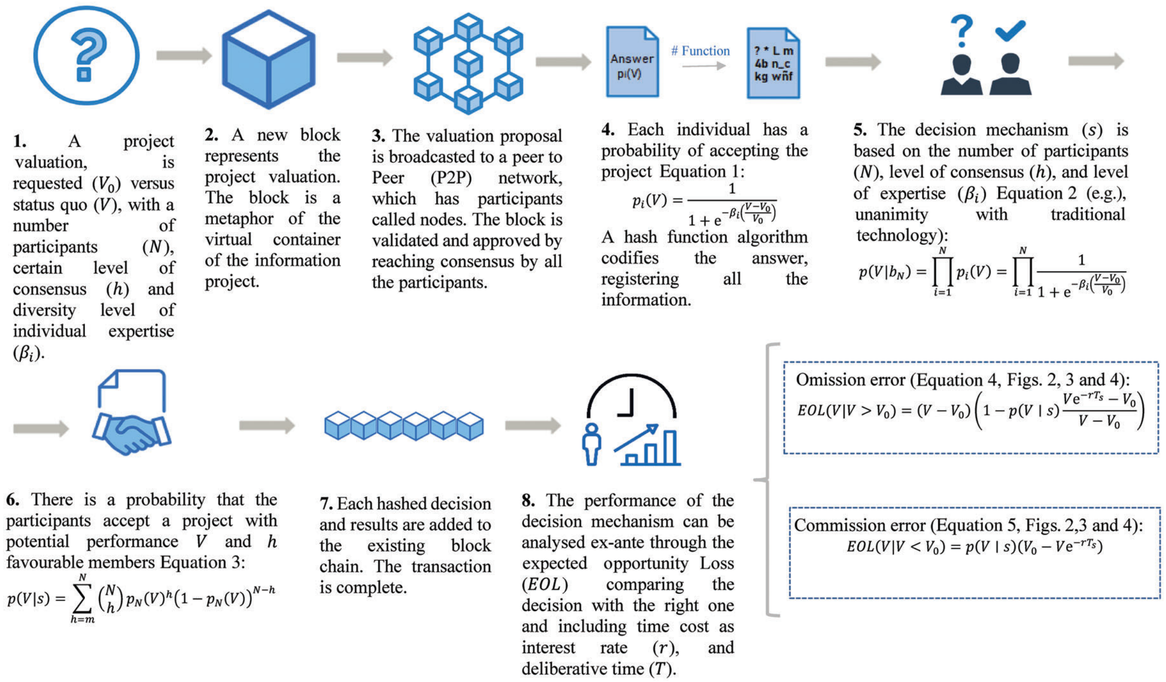


Fig. 6. Chart flow of the process.

use of individual human capital ($\beta$), with different levels of expertise ($\beta s$—nodes), parameterisable consensus levels ($m$—acceptance protocols), and including deliberation time ($T$—time processing information) as a cost through the interest rate ($r$—costs of energy and processing), without external pressures (anonymity–decentralisation and encryption). This allows us to unravel the black box of decision making and integrate realistic and compatible decision rules with blockchain technology, beyond the benefits of its known advantages such as anonymity or traceability.

The third contribution is related to the less friendly or darker aspects that are dealt with in blockchain technology (i.e., error evaluation): These are commission and omission errors, as well as their modelling. Thus, the blockchain ensures that both commission errors and omission errors are reduced with decision times that do not increase the EOL on omission errors. The result of the model is that this technology should be imposed naturally because it allows us to obtain better results than any other decision mechanism in a systematic way at the same level of information. In addition, this technology allows us to establish incentives for the accumulation of human capital and for sharing information, which should further improve the performance of its decision mechanism.

Based on these contributions, some recommendations for future work can be made. The first recommendation is related to extensions of some functional forms with different parameters, as well as the consideration of the functions of the decision maker's attributes in the decision rules. The second is related to the implementation and evaluation of the model with respect to other possible models to make aspects of improvement visible. Finally, another line would be related to the incentives of adopting and participating in the decisional system by the economic agents.

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