Representation and Intensity of Preferences: A Public Economics Analysis of Liquid Democracy

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Abstract

Following an increasingly large corpus of literature championing blockchain-based voting systems and, in particular, Liquid Democracy, this paper proposes a theoretical analysis based on public economics on the issue completing the current literature which focuses more on technical issues. Differentiating between Liquid Democracy as a voting tool and as a new form of democracy, I argue that the former offers the opportunity to vote for more inclusive decisions and to better reflect voters's intensity of preferences delegation and logrolling. However, the latter does not benefit from these positive outcomes as it faces major limitations at large scales because it fails to provide a framework for bundling and for legislative work. In this paper, I conclude that reaches the conclusion that, for now, Liquid Democracy is more suited to local democracy or small-scale homogeneous groups than to larger-scale systems (such as national constitutions). Along the paper, I discuss blockchain-based examples of Liquid Democracy to illustrate the analysis and link it with recent literature.

1 Introduction

Democracy relies on the people expressing preferences over policies. To express these preferences, citizens (or at least those allowed to do so) have the right (and sometimes the obligation) to vote regularly for local, regional or national elections either directly or, more frequently in Western democracies, for candidates who become their representatives. However, the way the voting system is designed can influence how these preferences are accounted for through two mechanisms that might be entrenched. The first one is the long-known Condorcet Paradox (Condorcet, 1785), later on refined by Black (1958), and the Arrow Impossibility Theorem (Arrow, 1951) that states that it is impossible to design a voting system that is "fair" (in the sense that it meets five basic principles).

Beyond how votes are counted, the way votes are casted may also influence the outcome of an election. This has been illustrated in the recent US elections (see for instance Salame ("Texas Closes Hundreds of Polling Sites, Making It Harder for Minorities to Vote")) and has triggered research on voter suppression (Hajnal, Lajevardi, and Nielson, 2017) or on the recurring issue of gerrymandering. Many factors may influence the voting capacity of citizens; adopting the language of the 'pathetic dot theory' (Lessig, 2006), these factors can pertain to the domain of the law (who can vote), the architecture (where polling stations are located) or norms (whether voting is perceived as being important by members of your community). Therefore, every voting system must choose an aggregating and a decision-making function that has consequences for the country's political dynamic. Such voting systems must make trade-offs in terms of costs and efficiency that may not be considered optimal by all.

Consequently, there have been numerous works studying or advocating voting systems reform. In particular, with the emergence of digital technology, remote voting through digital systems (or e-voting) became possible and was experimented in various settings (Gibson et al., 2016). The reasons to do so included cutting down the costs of elections, generalizing access to votes (reduce voter suppression) as well as technology enthusiasm. E-voting comes with considerable challenges and risks — the most famous controversy being the 2000 US Presidential Elections in Florida (Lobo, 2004) — and there has been a continuing research to overcome these challenges (Gibson et al., 2016).

Since the emergence of blockchains in 2009, there have been many calls for Blockchain-based E-Voting (hereafter called BEV). Blockchains are a way of ensuring distributed, reliable and immutable data storage between nodes. An increasingly large number of people believe they represent a major opportunity for e-government (Batubara, Ubacht, and Janssen, 2018) and in particular e-voting. On Scopus, the abstract and citation database, the number of papers including the words "blockchain" and "voting" increased from 1 in 2015 to 190 in 2020 (Scopus, 2020). Although there are still numerous unanswered questions and challenges concerning the adoption of such a technology (Taş and Tanrıöver, 2020), many publications promote blockchain-based e-voting systems. Some even go beyond a purely technical proposition and argue that BEV could enable a radical shift in democracies towards more direct forms of representation. In particular,there has been a resurgence of interest in Liquid Democracy (first described by Carroll (1884)), a form of voting where representation is either direct or delegated transitively in a very liquid manner, in the hope that it would yield better representation and more participation.

Considering the radicality of these propositions, there is still relatively little research on the political consequences of such changes. Yet, throughout history, numerous scholars have studied why and how people vote, providing us with methodology and framework to analyze organizations and constitutions. Among the most prominent scholars to have used economics tools to analyze constitutional structures are James Buchanan and Gordon Tullock in *The Calculus of Consent* (1962).

While some of the conclusions drawn in their book are rooted in the technological context at the time of writing, the methodology remains relevant and proves to be extremely informative about BEV and Liquid Democracy (LD). This paper aims to initiate this field of research. Neither E-Voting nor LD depend on blockchains — nor on any particular technological implementation for that matter— and the issues addressed in this paper pertain to theoretical public economics rather than applied economics. Nonetheless, the discussion will focus on the example of blockchains for two reasons: (i) blockchains are natural candidates to illustrate the voting mechanisms that are explored in this paper and (ii) they are a hot topic and this paper contributes to ground the discussion on more formal and scientific grounds.

Using a public economics framework, I analyze the effect of LD on voting costs and representation focusing on the question of the intensity of preferences and representation structures. I show that, as a voting system, LD could effectively reduce costs and allow for more inclusive decision-making and may help reflecting the intensity of preferences of voters through logrolling. Blockchain-based systems may automate the process and create a transparent and auditable vote-trading marketplace, thus reducing the risks of manipulation or corruption. However, even if people are better represented under LD, there are no guarantees that delegating votes to more informed citizens will lead to better decision-making for the group. Extending the analysis to LD as a new form democracy reveals serious shortcomings in the capacity of voters to engage in direct or indirect vote-trading. Moreover, I recall that we are yet to find a system that is faithful to the ideal of LD and offers institutional room for independent legislative work. I then study small-scale communities and argue that, e-voting is more suited for local democracy than for national issues. Finally I discuss blockchain-based implementation to add a discussion of practical governance issues to the theoretical analysis carried out in the paper.

The remainder of the paper is structured as follow: in section 2, a literature review presents the major works in the field of institutional economics that influenced this research. An extensive review of LD is also carried out before presenting blockchains and in particular BEV with its *caveats* and unresolved issues in the hope to familiarize the reader with these fields. Section 3 is devoted to applying institutional economics analytical tools to LD as a voting tool and as a new form of democracy before discussing implementation in terms of scale and technology. Finally the results are summarized and discussed in the Conclusion.

2 Literature Review

2.1 Public Economics

Analyzing voting dynamics through formal mathematical modelization dates back to the 18th century with Condorcet (1785) who showed that majority voting was not transitive. In the founding *Social Choice and Individual Values*, Arrow (1951) completed this paradox with the impossibility theorem that states no rank order voting system can meet the five following criteria: (i) Non-dictatorship (no single voter can decide) (ii) Unrestriced domain (be deterministic and not context-dependent) (iii) Independance of irrelevant alternatives (preference between two choices should not depend on third choices) (iv) Monotonicity (social preferences are monotonous with respect to each individual's preferences) (v) Citizen Sovereignty (every outcome of the vote is theoretically achievable). Yet, most democracies rely on rank order voting as the conditions of the impossibility theorem are rather restrictive. Black (1958) showed that, under reasonable assumptions on preferences (unidimensional and single-peaked), majority voting meets all of the five criteria.

In *The Calculus of Consent*, Buchanan and Tullock (1962) retain the hypothesis of unidimensionality and single-peaked preferences and discuss voting rules under these conditions. Among the numerous discussionspresented in the book, I concentrate on two arguments particularly important for our discussion. The authors mostly consider votes between two alternatives and can therefore ignore the impossibility theorem which does not stand in that case. However, unlike Black, they do not give particular importance to the majority rule. In turn, they discuss the optimal ratio $K^\star = \frac{R}{N}$ required for a motion concerning the whole group to pass where $N \in \mathbb{N}^\star$ is the size of the group and $R \in \{1..N\}$ is the number of voters supporting the motion. Note that the group will decide on a political constitution in the perspective of sustained cooperation, collaboration and provision of public goods. Inspired by Neumann and Morgenstern (1947), they rely on a game theory approach and build on the notion of equilibria of repetitive games.

When $R = 1$, anyone can propose a motion that will be automatically voted and will entail a group action. In that case, all the other members of the group are expected to bear the cost of a policy that will most likely only benefit its originator. On the contrary, if $R = N$ then unanimity is required for a motion to pass. In that case, the motion will benefit all members of the group, otherwise they would not vote for it.

However, when unanimity is required for a motion to pass, the cost of reaching consensus and cooperating is high as bargaining with all the members is required. In turn, when $R = 1$, no bargaining at all is required. Therefore there are two costs to be expected :

External Costs imposed by decisions taken by and benefiting other members. These costs $C_E(R, N)$ are decreasing with respects to R

Decision Making Costs imposed by the costs of bargaining. These costs $C_{DM}(R, N)$ are increasing with respects to R

Thus, there is an optimal $\frac{R}{N}^\star$ that minimizes the total costs $C_{Tot}(R, N) = C_E(R, N)+C_{DM}(R, N)$ and it is this ratio that the authors try to identify given the type of decisions the voters have to make. Note that, since N is a characteristic of the group, only R can vary. This optimal ratio depends on costs structure and will therefore be higher if external costs are likely to exceed decision-making costs. This is why a higher proportion of voters is often required to modify a constitution than to pass a bill.

Following this analysis, Buchanan and Tullock conclude that there are no reasons why $\frac{R}{N}$ should be 0.5. They also contend that a simple majority only makes sense under the assumption that all agents have equal preferences on all matters, in which case the majority should be chosen because that will yield the highest social output. However, they recall that most people have strong interest for some questions and a lesser one for others issues.

Suppose for instance that $N = 2$ and the individuals (n_1 and n_2) need to agree on two issues A and B. There are cases where n_1 is always better off with $\overline{B}$ rather than B (same goes for n_2 and A) but both are better off with (A, B) rather than $(\overline{A}, \overline{B})$. This is an example of the famous prisoner's dilemma. However, contrary to the original prisoner's dilemma (Flood, 1952), there is room for negotiation and agents can coordinate to ensure that both A and B are passed. n_1 renounces to block B if n_2 does so for A. More complex examples with $N > 2$ are presented in the book but it is enough for this discussion to limit ourselves to this simplified version.

What follows is that most people would be willing to renounce their favoured outcome on the issue of least interest to guarantee their preferred outcome on the most important one. This leads to one of the major conclusions of *The Calculus of Consent* which is a call for *logrolling*. Indeed, according to the authors, the prisoner's dilemma emerging in political settings can be solved through vote tradingk, as shown above. In this case, achieving an outcome more favorable than the Nash equilibrium of $(\overline{A}, \overline{B})$ is possible because there are successive votes on different issues instead of a one-time choice and because vote trading (either direct or indirect) can be undertaken. More specifically, it only works if the horizon of votes is long enough so that any betrayal in the cooperation will be offset by losses in future collaboration. Although this conclusion is rather different from the Arrow's Theorem, this somehow echoes the limitations of rank order voting where voters are unable to express the intensity of their preferences.

In a later part, Buchanan and Tullock explore representation structures for unicameral and bicameral parliament to avoid manipulation by a small group and ensure that a ratio of K at the parliament faithfully represents the same ratio in the total population. It is also the concern for good representation that gave birth to LD as discussed later.

Lastly, among the various fields of research building on *The Calculus of Consent*, one is particularly important for us: discussing the vote market. While Buchanan and Tullock champion vote-trading, they do acknowledge that vote-buying might raise moral questions. Specifically, they insist that vote-trading offers must be completely transparent in order for the voters not to be and feel manipulated and that vote-buying might not offer such guarantees. This central argument of the book has laid the ground for further political liberalism, such as Parisi's Political Coase Theorem (Parisi, 2003). Extending Coase's conclusions (Coase, 1960), he claims that if there are no transaction costs and if the market for votes is complete, then a socially Pareto-optimal equilibrium will be achieved independently of the voting system. This stance has been challenged (Munger, 2019) but provides an interesting extreme position to consider in mind when thinking about vote markets.

Other libertarians authors (Posner and Weyl, 2015) have explored alternatives to express intensity of preferences and a market for vote-buying, such as Quadratic Voting (QV). Under QV, people would be able to buy more votes on subjects they feel more concerned about, with the price being a quadratic function of the number of votes. This is of importance for us because blockchains scholars such as Allen et al. (2017, 2018) claim that blockchains can implement new forms of democracy, in particular QV. While very close to the subject of this paper, QV is already extensively discussed, including by economists, and this paper will not address it.

2.2 Liquid Democracy

Liquid Democracy (LD) is a relatively recent concept and, consequently, is still not consensually defined which makes it hard to specify exactly what is being discussed. Inheriting from delegative and proxy voting strands, and sometimes still called under these names, LD can define either a voting mechanism, a evolution of participatory democracy or a new form of democracy (Paulin, 2020). Another difficulty comes from the fact that there is relatively little academic research dedicated to the subject and a lot of the documentation comes from gray literature (Ford, 2014). Nonetheless, I here attempt to provide a definition and contextualize LD.

Although they can be traced back to Carroll (1884), the principles of LD were firstly conceptualized by Miller (1969) when proposing a method for "direct and proxy voting in the legislative process". The idea was to make the best of the (then relatively new) computers to foster more direct democracy,allow for better representation and increase participation. In such a system, each citizen could decide to delegate their vote to anyone who would effectively become a representative. Those entrusted with the most votes would become legislators. People could, at anytime, decide to withdraw their delegation and vote for themselves.

According to Miller (1969), it is impracticable for everyone to be an expert on all issues and it is more efficient to delegate votes to more knowledgeable persons that one believes to be aligned with her ideas. What is more, representative democracy does not reflect the mantra *one person, one vote* and LD would reflect more faithfully the will of the citizens. As recalled by Green-Armytage (2015), this paper remained relatively unnoticed, with the notable exceptions of a discussion by Shubik (1970) and a similar contribution by Tullock (1972). It is only with the boom of computerization that the idea of proxy voting gained significant momentum.

Tullock (1992) made a proposal rather close to the one by Miller (1969) based on a device linked to a television to follow parliament debates. Citizens could then decide to give their vote to any representative or vote directly. This work was extended by Alger (2006) who demonstrates that his proposition allows to overcome the tradeoff between "the representation of a legislature stemming from a voting system and either constituent services or government stability" (p.2) and that, provided that the system follows a few ancillary rules, it is a better form of representation. Interestingly, Alger (ibid.)'s proposal is explicitly designed to be implemented when voting for a legislature and for operating the said legislature, as the two are too entrenched to be designed independently.

Parallelly, Ford (2002) and Green-Armytage (2005) introduced a new element in proxy voting: transferability of proxies. Not only were people allowed to delegate their votes to an expert, but that expert could, in turn, delegate her vote and all those she had received to someone else. Adding this aspect, it is time to turn to and adopt the definition of Blum and Zuber, 2016, p.4 :

> Liquid democracy is a procedure for collective decision-making that combines direct democratic participation with a flexible account of representation. Its basic model consists of four components that can be stated as follows: All members of a political community that satisfy a set of reasonable participatory criteria (adulthood, baseline rationality) are entitled to:
>
> (I) directly vote on all policy issues (direct democratic component);
>
> (II) delegate their votes to a representative to vote on their behalf on (1) a singular policy issue, or (2) all policy issues in one or more policy areas, or (3) all policy issues in all policy areas (flexible delegation component);
>
> (III) delegate those votes they have received via delegation to another representative (meta-delegation component);
>
> (IV) terminate the delegation of their votes at any time (instant recall component).

Besides the meta-delegation, Blum and Zuber (ibid.) mention another aspect of LD: delegation per topic. Originally mentioned by Miller (1969), delegation per topic is now widespread in the literature (Ford, 2020; Green-Armytage, 2015). While this aspect is usually connected to LD as a voting method, but Blum and Zuber (2016) link it to a broader political system that I discuss in subsection 3.2.

Implementations of LD and academic literature on the subject remain rare. Paulin (2020) reviews them and proposes to differentiate LD as a voting tool and a new form of democracy. According to him, very few initiatives are considered to truly amount to LD.

Blockchains are one of the reasons that explain the ever-increasing initerest in LD. If the idea of proxy voting stemmed from the development of novel communication processes, blockchains offer a very promising platform for LD. Indeed, proposals are now flourishing (Berg, 2017; Fan et al., 2020; Kashyap and Jeyasekar, 2020) but most remain rather technical and focus on implementation issues but, to the best of my knowledge, a theoretical political economics analysis of such a proposal is still to be undertaken.

2.3 How Blockchains Work

Blockchains are peer-to-peer distributed ledgers —generally referred to as Distributed Ledger Technology (DLT)— recording transactions in an append-only way. Transactions are grouped into "blocks" and then added to the "chain" of previous blocks. The specificity of blockchains is that they are, by design, transparent, verifiable and permanent in the sense that it is extremely hard to modify their records. This high security is achieved through encryption and hash of the data and of the blocks; this ensures that tampering attempts can be detected by various members of the network (Vujičić, Jagodić, and Ranđić, 2018). The processus of adding and encrypting blocks relies on a lottery that guarantees decentralization and that consensus is achieved without the any form of central authority.

Decentralization, transparency and security through encryption were the main features of the blockchain technology as devised by Nakamoto (2008), created to support Bitcoins, a decentralized cryptocurrency. At the time, the information recorded in the blocks was mostly a financial ledger. But the establishment of the consensus mechanisms design for DLTs has since fostered for the development of new ideas about decentralized governance.

Increasingly complex forms of interactions over blockchains have been made possible over time with the development of new blockchains. For instance Ethereum was the first blockchain with the capacity to compile a Turing-Complete programming language (Wood, 2014a), opening ways for distributing virtually anything that carries value through blockchains. In particular it made it possible to code smart contracts that had first been described by Szabo (1997) but were impracticable at the time. Smart contracts are self-executing chunks of code that are recorded into a block. Once they are on the blockchain, they are as immutable as the blockchain is.

However, this security can also be a weakness. Blockchains are tamper-resistant when the attacking parties have less than 50% of the stake (depending on the consensus mechanism, it may be value, hashing power etc.), but when nodes reach consensus on a modification, the whole structure and protocol of the blockchain can be amended. Therefore the governance of the blockchain (as an infrastructure) has consequences for all the ecosystem living on top of the blockchain. The governance of blockchains takes place both *on-chain*, through code implementations, and *off-chain*, by the means of formal and informal institutions (De Filippi and McMullen, 2018).

2.4 Blockchain-Based Organizations

As the technical opportunities offered by blockchains increased, the field of applications widened and has been considered to revolutionize virtually every field of society [1]. It includes classical and

[1]a significant overview can be found in De Filippi and Wright (2018)

new forms of economic organizations (Davidson, De Filippi, and Potts, 2018) either in the market economy or for more commons-oriented organizations (Troncoso and Ultratel, 2020). Blockchain-based organizations can either rely on blockchains for coordination, automation and decentralization of off-chain processes or live fully over a blockchain. In all cases these blockchain-based or blockhain-enabled organizations require a rather complex set of smart-contracts. That necessarily raises many coordination challenges and entrenched difficulties (Howell and Potgieter, 2019b).

More importantly, blockchains bring up challenges and opportunities for government. Atzori's account of these issues remains one of the most complete to date. She notes that:

> Broadly speaking, the advocates of decentralization tend to have in common the same dissociative attitude towards centralized institutions [...] Many enthusiasts simply promote the blockchain as a more efficient, decentralized and consensus-driven public repository, which can have a number of applications in order to make citizens less dependent on governments, yet within a society that is ultimately founded upon the State authority. (Atzori (2017))

This dichotomy is found in particular in the literature around Blockchain-based E-Voting (BEV). Indeed, among the champions of voting on blockchains are crypto-anarchists (De Filippi and Wright, 2018) but also many who could be characterized as "reformists" for whom BEV is to be used in our democracies just as a tool. Most of the papers presented in the following section belong to the reformist strand. BEV could merely be a voting tool but it could also be a first step to creating institutions outside of the State framework and new forms of democracy. These two approaches have very different consequences that this paper lays out to analyze their implications within a framework of institutional economics.

Whichever purpose it serves, a blockchain-based organization will necessitate governance of the organization and of the technology it relies on (De Filippi and McMullen, 2018). Governance of blockchains can be either distributed, decentralized or, in practice, rather centralized in the hands of foundations or central parties (Howell and Potgieter, 2019a). As I discuss later, ignoring the challenges of governing the blockchain leaves an significant blind spot in the analysis. This is all the more true as the term "blockchain" covers various implementations in terms of consensus mechanisms and publicness in particular. Each implementation yields its own governance challenges and the choice of the type of blockchain to host a blockchain-based organization, let alone a voting system, entails assumptions and specific challenges.

2.5 Blockchain-based E-Voting

Gibson et al. (2016) provide an interesting history of online voting and its challenges and recall that "As the internet evolves, then so also do the remote voting systems built upon it" (p.280). It is, therefore, not a surprise that blockchains, which have been dubbed as the Web 3.0 (Wood, 2014b) are considered for e-voting.

E-Voting and Blockchain-based E-Voting (BEV) must solve the same problems as other technologies. As underlined by Lessig, 2006, pp. 141-143, there are extremely challenging difficulties. In particular, the system must simultaneously ensure anonymity in the vote (discussed in subsection 3.2), transparency and verifiability to ensure that the vote is not modified not to forget the issue of digital identity, detection of fraud or coercion. Additionally, the issue of unique and singular digital identities is a challenge in and of itself (Siddarth et al., 2020)

Osgood (2016) cites Norden and Famighetti (2015), a report showing that "43 out of 50 states used EVMs [Electronic Voting Machines] that were at least ten years old [and] notoriously easy to hack and tamper with". However, despite these well-known and unresolved issues, Osgood (2016) is optimistic about the potential of BEV to solve these issues. By design, blockchains are difficult to tamper with and offer a level of security and transparency that may revolutionize collaboration between actors. An interesting nuanced and extensive account of using blockchains for e-voting is provided by Dhillon et al. (2019).

Osgood (2016) is not the only optimistic scholars as numerous authors such as Hanifatunnisa and Rahardjo (2017), Hardwick et al. (2018), Hjálmarsson et al. (2018), Kshetri and Voas (2018), Takabatake, Kotani, and Okabe (2016), and Yavuz et al. (2018) have proposed designs and implementations of BEV. The booming interest in BEV all around the world is, thus, undeniable.

Despite its challenges, at least in practice, great hopes lie within the blockchains-enthusiasts community. My goal is not to discuss these propositions nor BEV but rather to apply the analytical framework of institutional economics to BEV, as it gathers significant momentum worldwide at the time of writing.

2.6 Institutional Economics and Blockchains

While a fairly recent and developing field, the foundations of an institutional economics analysis of blockchain-based organization have been laid out by a few recently-published papers. Wagner (2019)'s work is, perhaps, the most comprehensive when analyzing the legacy of Buchanan and Tullock in the field.

In chapter 17, Rajagopalan (2019) focuses on the technical aspects of blockchains. He follows Lessig (2006) and De Filippi and Wright (2018) in their conclusions that the code entails "constitutional constraints" and recalls that distributed ledgers are mostly a new way of reaching a consensus.[2] He then applies their framework to cryptocurrencies, a form of club goods. In this paper I seek to extend this work to other applications of blockchains, specifically voting platforms.

In chapter 18, Berg, Davidson, and Potts (2019), following the definition of crypto public choice (Berg, Berg, and Novak, 2018), go beyond cryptocurrencies and explore the possibilities of "institutional cryptoeconomics", claiming that blockchains offer the opportunity to try new constitutional orders. Blockchains thus constitute methodological tools to explore potential arrangements and new sets of rules. I will attempt to further this work by proposing a first analysis of a Liquid Democracy constitutional order relying on a blockchain.

By extending the conclusions of the above-mentioned papers to a concrete constitutional proposal, this paper contributes to furthering the field of institutional economics analysis of blockchain implementations.

3 A Political Analysis of Liquid Democracy

According to Allen et al. (2017), every institution is situated within the technological context of its time. When constitutions were drafted, no one could have possibly imagined the advent of the Internet and blockchains, which have since opened tremendous possibilities. Nonetheless, the analytical framework devised by political economics at the end of the 20th century remains relevant for addressing new technologies in relationship with politics and voting matters.

[2] which is exactly the problem Buchanan and Tullock (1962 addressed

This section analyzes Liquid Democracy in the light of the issues presented in the literature review. It first concentrates on Liquid Democracy as a voting mechanism without changing the way the legislature works before extending our discussion to a modified institutional context. The discussion addresses both general LD and its blockchain-based applications, focusing on the new governance challenges that a shift towards LD could entail.

3.1 Liquid Democracy as a Voting Tool

Let us first consider the case of LD used as a voting mechanism. To be clear, let us take the case of a group of person who need to vote on different issues and make decisions that are binding for the group. Such a group might, for instance, be a parliament or more simply a group of shareholders for a company. Closer to the blockchain world, it can also be token holders of a DAO.[3]

In that group, voting rules follow the four principles described by Blum and Zuber (2016) and reviewed in subsection 2.2: (i) citizens can vote directly, (ii) they can delegate their votes on one, some of all areas to a representative, (iii) delegation is transitive, (iv) delegation can be terminated at any time.

Reassessing the Epistemic and Egalitarian Arguments

Blum and Zuber (ibid.) propose a "normative democratic theory" framework to assess the advantages of a voting system through 2 criteria: (i) the epistemic account assesses how good a system is at discovering the best solutions and (ii) the egalitarian account refers to how well citizens are represented in this system. For instance, enlightened absolutism would rank very high on the first account, and very low on the second one. They argue that LD outperforms traditional representative democracy on both accounts. I retain the two-pronged framework but I propose to complement their analysis and discuss their conclusions. According to the analytical elements of *The Calculus of Consent*, some points seem to back their position.

First off, for a given voting rule (a ratio of voters required to pass a bill) decision-making costs are likely to be reduced through delegation and concentration of votes while external costs should not change. Indeed, LD allows a citizen to delegate her vote to an expert she "trusts" to be more informed and aligned with her views. Classically, an expert receiving votes is called a "guru". Everyone can have 0 guru (vote directly for each subject), 1 guru (delegate all her votes to one guru) or several (1 for each area for instance). Let us assume that each guru votes on average for p ($p-1$ voters delegated her votes to her); then to represent a ratio of K, only $\frac{R}{p}$ gurus out of $\frac{N}{p}$ need to agree before a decision. In that case, the costs structure becomes $C_{Tot}^{LD}(R,N,p) = C_E(R,N) + C_{DM}(\frac{R}{p}, \frac{N}{p})$. Because $C_{DM}(\frac{R}{p}, \frac{N}{p})$ is increasing w.r.t. both R and N, $C_{Tot}^{LD}(R,N,p) \leq C_{Tot}(R,N)$ for $p > 2$.

This does not necessarily imply that the optimal ratio will increase [4] but it is possible to increase the chosen ratio while still reducing total costs meaning that LD will pass more unanimous bills. This therefore validates the egalitarian argument: if the voting rule is closer to unanimity then everyone's interest is better taken into consideration.

[3] DAOs are communities of blockchains users managing an asset made of smart contracts and relying on participative governance processes.

[4] Proving this requires making assumptions on the second derivatives of the costs functions. To keep the spirit of Buchanan and Tullock, the mathematical proof is not included here but is available upon request.

On the contrary, the epistemic argument has faced strong drawbacks from recent literature. Research from Caragiannis and Micha (2019) suggest that local delegation algorithms might not be good at selecting "better" alternatives. In other words, if there is a vote between two alternatives and that one is objectively better than the other, LD might not be better for selecting it than direct democracy and there are cases in which LD fares worse than the alternative. Even when delegation only goes towards more qualified gurus, worse outcomes could be reached. What is more, Escoffier, Gilbert, and Pass-Lanneau (2018, 2019, 2020) have shown that reaching an equilibrium is NP-hard under several forms of networks (along which delegation can happen). A NP-hard problem is a problem for which we cannot compute a solution in a polynomial time[5] and we do not know if it is theoretically possible to do so. It is thus computationnaly difficult to achieve optimal delegation networks and that poses *caveats* for chosing LD. Finally, Bloembergen, Grossi, and Lackner (2018) try to measure the efficiency of LD and evaluate the gain (previously defined in Kahng, Mackenzie, and Procaccia, 2018) that represents "the group accuracy after delegations versus the group accuracy achieved by direct voting". This proves to be inconclusive as the gain can take all the values possible, which means that the accuracy can either increase or decrease, making the epistemic argument precarious.

In the language of Public Choice used in this paper, these complexity results translate as follows: it is unsure that a LD vote will result in a Pareto-dominant situation.

Blockchain-Based Vote-Trading Platforms and Logrolling

Another reason why blockchain-based LD could help the group adopt more socially efficient bills is through logrolling and vote markets. I mention in the subsection 2.1 that *The Calculus of Consent* argue that trading votes is necessary, in particular for minorities to still be represented on the subjects that concern them most thus avoiding a "tyranny of the majority". However, vote trading remains subject to conditions. Voters will be extremely reluctant to trade votes when opportunities are not clearly announced and that there are risks of manipulation. In particular, most voting systems have the essential requirement of preserving vote secrecy which makes it impossible to verify that votes have been casted according to the contract. Nonetheless, for some parliamentary votes or small groups decision-making, secrecy is not required nor even desirable. This applies to holding representatives accountable, for example. In these cases, open vote-markets could be beneficial. *The Calculus of Consent* do discuss the conditions necessary to engage confidently in logrolling. Two of them are transparency and certainty of execution.

Blockchains create new opportunities in that regard: they allow for the organization of a transaction platform for votes as blockchains are appropriate for the markets of "complete contracts" (Davidson, De Filippi, and Potts (2016)). Vote trading can be considered to be as complete as possible: all the states of the future world pertaining to the contract can be considered and logically described within the code of the contract. So, we could imagine a platform on the blockchain on which voters would openly advertise their votes enabling open logrolling with a guarantee that there will be enforcement of the trade.

Suppose two votes on subjects A and B are planned and voter i publicly announces that she is willing to redeem or vote on A against a vote for B. Voter j sees this and engages in the vote. A smart contract is used to ensure that j holds two votes on the first issue and i two for the

[5]In polynomial time algorithms,the solution is found in a time that depends polynomially on the complexity of the input. They are considered to be reasonably scalable algorithms, opposed to exponential ones.

second. Voter secrecy could still be preserved with i and j voting confidentially (as if there was no vote-trading) but with two votes on their respective subjects. Note that, in this case, transfer of vote is different from vote delegation as defined in LD democracy. Indeed, delegated votes are revocable while votes in vote-trading contracts are not. Vote-trading smart-contracts should thus be designed specifically if authorized by the constitution.

This two persons/two subjects situation could soon be generalized. Smart-contracts could be designed to automate vote-trading. We could even imagine a platform where people could identify other people with non-aligned strong interests and start trading campaigns advertising for vote-trading opportunities. If that was to be implemented, that would, once more, back the egalitarian argument. Indeed, not only would everyone's voice be heard but it would also be heard in proportion to the intensity of their opinions. However, it would require everyone to rank their preferences on all subjects. Literature on Single Transferable Vote (STV) which also requires to rank all the preferences always recall that it is rather complex to ask voters to rank all the options when the list is long (Endersby and Towle, 2014; Tideman, 1995).

The Calculus of Consent also state that (monetary) vote-buying is an efficient way of revealing social preferences at the scale of the group. Vote-buying raises more social concerns than logrolling and vote trading but is not condemnable *per se*. If public advertising of vote trading opportunities and automation of such exchanges are possible, a market for votes could emerge, either implemented within the voting platform or parallelly. In this case, the issue of complete ordering of preferences may raise another type of issue: arbitrage.

Suppose i identifies an arbitrage opportunity: she trades votes with j on subjects A and B, that is to say i gives her vote on A to j against her vote on B and x in a currency (most presumably a cryptocurrency). If i later trades votes with k, yielding her vote on subject B and $y < x$ for a k's vote on A, then i made money ($x - y > 0$) and j's preferences are not taken into account (and j lost x). In the case of a market with perfect information, which is the case of a blockchain platform, equilibrium should be reached revealing aggregated social preferences. However, although vote-trading opportunities are complete contracts, it is unsure that an equilibrium similar to swap markets for cryptocurrencies can be achieved. Voters do not always act rationally and the market for vote-trading is may therefore not be competitve and rational and it may not lead to Pareto-efficient situations (Caplan, 2003; Casella, Llorente-Saguer, and Palfrey, 2012; Frey and Eichenberger, 1991). This calls for caution in the design of the vote-market raising serious concerns about monetization of votes.

Should vote-buying and marketplace be illegal, one of the advantages of blockchain-based platforms is that they are transparent, making it possible to monitor forbidden transactions. On the contrary, automation and decentralization on blockchains make it virtually impossible to prevent smart contract from being executed or illegal market places from running thus making enforcement challenging. In the case of accountable members of parliament, it is likely that social pressure and the risk of losing their position would be enough to deter them from engaging in illegal activities. However, these safeguards might be less efficient in the case of larger communities with fewer guarantees, making it hard to effectively ban vote-buying.

For parliamentary groups, the transparency of blockchain-based platforms is also useful to hold its members accountable to their constituents. Transparency helps to reduce the risks of corruption and lobby-induced logrolling increasing the moral legitimacy of vote-trading.

In conclusion, adopting blockchain-based Liquid Democracy as a voting mechanism could help reduce decision-making costs between actors thus favoring a more inclusive threshold to pass bills.

Contrarily to direct democracy where the intensity of preferences is not taken into account and logrolling is difficult, LD allows to trade votes and structurally enables vote-trading. Recourse to blockchain-based platforms offers technical solutions to ensure that vote-trading is made openly with the possibility to offer auditable logrolling smart-contracts while still preserving vote secrecy when necessary. The risk of a monetary market for votes raises important theoretical and moral issues that must be carefully addressed should a group decides to adopt a blockchain-based LD voting system.

Algorithmic theory warns us that recourse to LD does not guarantee a more efficient outcome than direct democracy, making virtually impossible to compare the two systems under the epistemic account. Nonetheless, our analysis proves that the egalitarian argument does hold and that not only more unanimous decisions are made but that intensity preferences are also better accounted for.

3.2 Liquid Democracy as a New Form of Democracy

I now extend the analysis to the cases where Liquid Democracy is not only a voting mecanims but also a new form of democracy. There is no consensus yet on what it means to adopt Liquid Democracy as a new form of democracy. Almost every author discussed in the literature review proposes different alternatives, but they all share one common features: LD is used as a voting mechanism by all citizens who can express their votes on all issues. Therefore the group is much larger than those previously discussed and, contrary to the examples presented above, voters have to deal with many different issues and do not have the capacity to become experts in all of them, making delegation more necessary and likely[6]. Along with LD, some institutions remain necessary (to draft laws, to vote on a budget. . .). This is where the variations are most significant.

Logrolling in Liquid Democracy, Is Bundling Still Possible?

The previous section underlined that logrolling would be easier in the context of LD as a voting method. However the rationale for engaging in vote-trading when LD is a new form of democracy would be unclear.

Suppose a guru g_i receives $p_{i,A}$ votes for her field of expertise (domain A) but does not vote (or not with as many votes at least) on subject B ($p_{i,B} \ll p_{i,A}$). Therefore a guru g_i has little to no negotiating power and cannot weigh in to push forth her expertise. She is also extremely unlikely to sacrifice the vote she holds for domain A because she might lose these delegations at any time. Consider two votes on domain A and B planned to happen on two consecutive days and gurus g_i and g_j wishing to engage in vote trading, g_j lending her votes today for g_i's votes tomorrow. Because one key feature of LD is that delegation withdrawal can happen at any time, g_j has no guarantee that she may receive enough votes tomorrow and will not rationally engage in vote-trading. This echoes the point made in the previous section: it is necessary for vote-trading transfers not to be recallable. This should also be the case for all votes held by a guru, but this would contradict the fourth feature of LD as defined in subsection 2.2.

Without sacrificing that feature, what will happen is that for each subject, votes will take place independently from other domains. A guru has no way of knowing the intensity of the votes she received and has nothing better to do than to vote according to her expertise. Whichever

[6] In the case of parliament discussed above, representatives must also vote on many issues but this is their main activity with more time to do research on the issues.

decision-making rule is chosen (apart from unanimity), a (qualified) majority with weak views could impose a choice to a strongly interested minority. In the current forms of democracy, vote-trading takes place through political parties. They propose election programs that are bundles of varied proposals in the hope that they will gather voters from different sides who consider the bundle in accordance with the issues they value most although different voters might not agree on which parts are positive. Parties are a way of knowingly trading votes: an agent will vote for an ensemble in which there are motions they oppose (lightly) and motions they champion (strongly). As discussed in this section, LD would make political parties obsolete because people would be represented directly and bundling and *de facto* vote-trading would also be out of the question.

Another difficulty would be the chronology of different votes. Buchanan and Tullock typically did not cover transaction and organization costs in their analysis but organizing elections and voting itself is costly for both the institutions and its members even if LD reduces costs. It therefore impossible to continually consult citizens on different issues and an agenda would have to be devised. It is unclear how election frequency affects turnout (Garmann, 2017) and election frequency impact on logrolling has not been studied extensively. However it seems safe to assume that if an agent believes the issue she cares most about will not be subject to a vote before long, her interest might be discounted. The question of discounting factor in logrolling calculus has been introduced, although in a somehow different context, by Carrubba and Volden (2000).[7] This adds another difficulty for gurus and voters to engage in vote trading on the behalf of those who confide in them.

To the best of my knowledge, the literature on LD has identified its shortcoming in terms of bundling but has never formally analyzed it in terms of its difficulty to reflect the intensity of preferences. For instance, Blum and Zuber (2016) mention briefly the question of bundling and political parties (p.18) but do not provide a detailed analysis. What is more, the solution they propose —delegating votes on broad fields and not just on single issues— does not seem to solve this issue as cross-domains trades would still be difficult.

Institutional Structure and Representation in Liquid Democracy

In the previous section, I asserted that the capacity for gurus to engage in logrolling will depend on the constitutional framework for LD. For instance we have noted that the issue of the political agenda will be crucial and that whether gurus can lock in the votes they hold in a logrolling contract strongly influences the outcome of the different votes. To further the analysis, let us now focus on what the literature says about different institutional structures in a LD democracy in particular regarding representation of minorities and expression of intensity of preferences.

First off, Miller (1969) proposed to use LD to delegate voting power to representatives, maintaining the concept of a parliament. In practice, if the House has N representatives, the N gurus with the most votes would be Members of Parliament (MPs) and their mandate would last for a given period of time to ensure stability (2 years in the original paper). Citizens would then be able to choose between the different MPs currently "elected". This proposal does not meet the 4 criteria of LD democracy because votes can only be transferred to a very restricted set of gurus. It would, however, solve the issue of vote trading, as MPs receive the votes on all matters. However, as the number of votes a given MP holds at a given time is not guaranteed, engaging in vote trading on votes discussed later in the agenda could not happen as seen above.

[7] Notably, they are interested in logrolling in parliaments and reach the conclusion that the more frequent the elections, the higher the discount factor for MPs as they face the risks of not being reelected.

Blum and Zuber (2016) propose a solution that is closer to the spirit of LD which is based on “trustees”. Instead of continual delegation of votes and immediate recalls, they propose a delegation phase and then a debate phase. During the debate phase, the gurus keep all their votes, and after pondering over the arguments of different sides, vote for all the delegations they hold. Interestingly, a period in which delegations are guaranteed would allow for vote trading but only if the agenda regroups issues pertaining to different domains. One could contemplate mixing this “trustee” proposal with a sort of imperative mandate. A voter could fix objectives to her guru, delegate her vote (on a group of themes or all her votes) unquestionably and without the possibility to withdraw votes within a period, but at the end could automatically recall her vote if the objectives are not met. This would incentivize gurus to take into considerations the preferences of her “trusters”.

Smart contracts are natural candidates for such a delegation although this would require being able to formally codify the expectations which may be complex. This idea could be compared with Ford (2020) micro parties who strongly support one priority. Contrarily to Miller’s proposition (1969), this does not explicitly address the issue of parliamentary work which goes well beyond just voting for laws. MPs are also responsible for legislative work, drafting bills, commission work… and there are no control mechanisms in their proposition to ensure these tasks will be done. Finally and very questionably, Blum and Zuber (2016) propose to put gurus deliberation under the oversight of the executive, which would virtually put an end to the separation of powers.

Green-Armytage (2015) proposes a mixed system between direct and proxy voting, close to the one proposed by Alger (2006). Voters elect legislators through an ordering method (he proposes STV) and, on each issue, can either decide to vote directly or to delegate their vote to a “public voter”, another name for a guru, of their choice (the gurus can overlap with legislators). The gurus then vote either directly or delegate their voice to another one. This effectively addresses the issue of legislative work including the management of a national budget. However it does not address the issue of logrolling and vote-trading since voters can always decide either to vote directly or to change the guru they delegate their votes to.

We see that, so far, no proposition for a LD based democracy has managed to simultaneously address the issue of how to maintain the legislative work and reflect the intensity of preferences of the citizens. In their chapter 16, *The Calculus of Consent* discuss one more question concerning parliamentary representation. They show that a bicameral system makes decision rules more inclusive (closer to unanimity) as long as constituencies between the two houses are different enough. When voters can chose which representative to delegate their vote to, this condition of separate constituences cannot be respected anymore. The argument of *The Calculus of Consent* was that with representation and only one house, 51% of the representatives, each elected by a short 51% of their constituencies could pass laws that effectively favor only 26% of the total population. Arguably, the possibility to withdraw votes and delegate them to another guru nullifies this risk and makes the parliament a faithful mirror of the society. However, it seems unlikely that every citizens will constantly monitor what their gurus do — otherwise they would be better off voting themselves — and there might be cases where a bill is passed that is only supported by less than a majority.

Even if that is not the case, there is another argument for a bicameral parliament: not only does it prevent the formation of minimum winning coalition inferior to $R^\star$ but it also helps pass more unanimous proposals, only marginally increasing decision-making costs and significantly reducing external costs. Among the work reviewed here, only Miller (1969) proposes to have two houses but with voters being able to freely choose their representative in both houses. This essentially makes them redundant and duplicates their costs without bringing significant improvements over a unicameral parliament. One could consider the possibility of combining a traditional Senate with a LD democracy. This would not address the issue of logrolling mentioned numerous times in the LD House but, as mentioned by Green-Armytage (2015) about the legislators, it is likely that the Senate would still rely on political parties. This would reintroduce a form of bundling, although it is unclear how that would interact with the other House.

This section has revealed limitations in LD as a new form of democracy. In contexts where a large community is consulted on many different topics, there are no propositions[8] of a constitution that guarantees a proper framework for legislative work and that allows to reflect the citizens' intensity of preferences through logrolling. Some proposals present adjustments to facilitate logrolling or to resemble representative democracy, but this is always made at the expense of important features of Liquid Democracy. This paper contributes to the literature in the hope that these issues will be taken into consideration in the new solutions that will undoubtedly be proposed in the future.

3.3 Liquid Democracy for Local Democracy

The previous sections identified issues that may occur when scaling up LD and using it as a new form of democracy. Most of them, either finding an efficient delegation pattern of trading votes or keeping voting costs low, only get worse with the size of the group. For small groups voting on a small number of consistent issues, it is possible that the drawbacks mentioned above would be outshone by the improvements enabled by LD. Unsurprisingly, all the examples reviewed by Paulin (2020) concern small scale communities. This section moves away from the conceptual standpoint adopted thus far and discusses the practical costs and benefits of local LD.

Let us look at the municipal scale which, in many cases, constitutes the smallest scale for elections. Depending on the country, cities have different prerogatives but they cover only a rather limited and local scope of higher interests for the voters. This is exemplified by a higher turnout in local elections and in smaller cities (Dahl and Tufte, 1973; Frandsen, 2002). The relatively small number of subjects to decide upon, the denser network of constituents and the small size of the group can make the limitations less stringent.

Rather, LD in this setting could allow for more participatory democracy. Voters could be asked to vote more regularly replacing the municipal council on some or all issues. Having a system with both a municipal council and LD could bring some of the security assurances provided by the bicameral system. Direct democracy at a local scale has existed in Switzerland for a long time and the previous section has shown that LD can work in settings where direct democracy is possible. Thanks to delegation, the general turnout for direct sollicitations is likely to be higher while making it possible for people to engage in local vote-trading.

Even more so, in smaller communities, people are more likely to know well and be aligned with their gurus on several issues, thus reducing the risks of not being aligned with their vote-holder. That would make it easier for gurus to engage in formal or informal logrolling as they could provide more guarantees about the votes they hold.

Unfortunately, there are no examples of local governments relying on Liquid Democracy (yet) but this indicates that LD is more promising as an extension and improvement of local direct democracy than an alternative for large scale representative democracy. There are increasingly more examples of groups delegating governance over blockchains exploring their potential and

[8] as of the end of 2021

limitations in practice. A blockchain-enabled smart city whose governance would rely partly on LD would be a good way to test the conclusions of this paper.

3.4 Governance of Voting Platform and Implementation Challenges

Beyond the electoral dynamics, recourse to digital tools for voting purposes challenges the control of the process. While it is not the scope of this paper to extensively discuss implementation and technical issues, it would be a large blind spot not to acknowledge and identify them.

Some of these difficulties concern e-voting in general while some are more specific to blockchain systems. Among the former, we should note digital identification, non-coercion, trustworthiness, reliability and management of the platform. They have been underlined frequently, in particular by Lessig, 2006, pp. 141-143 who calls for transparency in the voting process, a transparency that, he claims, can only be achieved through open source code so that citizens can verify the election process. But this leaves open the question of the structure of the voting platform; it could be centralized and managed by a state or it could be completely distributed and managed by the community. An election can only be as trustworthy as the tool used to vote. Centralized solutions make sense when there is high confidence in the State. Today, all the states who have implemented a digital identification system have done so in a centralized way with IDs being recorded in central databases (Sullivan and Burger, 2019, p.240). This allows for privacy and control of the rights inasmuch as the States is considered a trustworthy of this data.

However, if the goal of LD is to refocus the democratic process on bottom-up participation and horizontal organization, it is only natural to question this centralized approach and discuss alternatives. Blockchains could provide a distributed solution to some of the aforementionned issues (transparency, monitoring, reliability, horizontal governance) but would raise a new one: governance of the tool itself.[9] A blockchain is either a club good or a public good following Samuelson (1954)'s typology[10] managed by its users. However, how the power is distibuted among them may significantly vary.

Howell and Potgieter (2019a,b) have shown that although blockchains can sometimes be managed as commons, most of the time there is concentration of power in the hands of a small set of users (the founders, the largest miners, a foundation t name a few). In public Proof-of-Work[11] blockchains such as Bitcoin or Ethereum, block validators grouped in a "mining pools" representing more than 50% of the computing power could theoretically boycott some information and record on the blockchain fraudulent information. Concentration of power poses challenges when blockchains are being used for financial purposes (influent agents of Bitcoin have tremendous economic and strategic power), but the consequences could be even more dangerous in the case of political matters.

Among the possible solutions let us mention using semi-public or permissioned blockchains where only pre-approved agents are authorized to validate the data for instance. This way, one could achieve a level of transparency, involving anonymous and potentially malevolent actors. There is also increasing research to promote alternative and less environmentally nefast consensus mechanisms (such as Proof-of-Authority) but it is unlikely that they will be more tamper-resistant. Another solution might be to rely on side-chains of other large blockchains. For instance, gover-

[9]Such an issue would arise for any kind of distributed platforms but, consistenly with the rest of the paper, only blockchains are discussed.

[10]In both cases it is non-rivalrous but exclusion may be easy (private blockchains) or impossible (public blockchains)

[11]the first consensus mechanism which relies on trying to solve difficult algorithmic puzzles

nance of these side-chains could be permissioned to allow for control while the state of the side-chain would be committed to the public blockchain to benefit from its security.

There are countless possibilities, depending on the requirements of the situation. A State-backed election will more likely choose a rather centralized permissioned blockchain, while some groups might needs more decentralization. But the discussion need to go further as, when using an external blockchain, the group implicitly relies on the governance of the blockchain itself thus giving power to agents that might not even have a right to vote in this election. Somehow, this challenges the assumption that blockchains eliminate the need for third parties as the blockchain (both the infrastructure and the governance process) becomes an intermediary in the voting process.

In any case, this will result in a trade-off between security, decentralization and trust. To carefully consider the outcome of this trade-off, we should note that the way people perceive their state is highly dependent on the technology that the public service relies on (Bodó and Janssen, 2021). Once again, the question of scale is highly relevant. A form of distributed ledger without strong technical security (such as a private blockchain) might make sense in small communities with reputation mechanisms and low risks of freeriders while the situation is wholly different for large groups. This is another illustration of Olson (1965)'s results on the difficulty of avoiding freeriders depending on the size of the group. Conversely, governing collectively the voting platform could increase the level of community involvement and strengthen participation through a sense of increased agency. Technical implementation decisions are thus strongly conditioned by the homogeneity and the size of the community.

As a continuation of this research, classification of blockchain-based governance or e-voting solutions discussing potential implementations depending on the requirements of the community would be extremely useful.

4 Conclusion

New technologies make it possible to imagine new forms of governance, governments and decision-making processes. Currently, Blockchains and DLTs are the technologies receiving the most attention and dedicated research, resulting in many propositions for blockchain-based e-voting or constitutional reforms. None of the processes analyzed in the paper are absolutely dependent on blockchains or DLTs and it is possible that LD could be implemented on other technological platforms or that new forms of government derived from blockchains will emerge in the future. However academic and activist literature currently focuses on the topical issues of LD and BEV. While these proposals extensively discuss feasibility and technical implementation, analytical studies of the political consequences are quite rare. This paper contributes with an instituional economics analysis from a Public Choice's perspective.

I first focus on LD as a voting mechanism and find that it is likely to reduce decision-making costs as less people need to agree thus creating room for a more inclusive decision rule. However it is uncertain whether the optimal ratio will actually increase. Moreover, LD naturally offers vote trading opportunities which favors a better representation of the intensity of preferences of the citizens. The paper then extends the analysis to a LD constitution where not only are vote conducted via LD but citizens also engage in legislative decision-making. I argue that LD as a political system does not offer, for now, solutions for vote-trading because delegation by themes and possibility to withdraw delegation at any time make it particularly difficult to engage in logrolling. Additionally, current propositions do not offer satisfying answers to the issue of conducting the legislative, commision and budgeting work that is done by parliaments in present day democracies.

Most of the limitations identified in the paper would not be prohibitive in small homogeneous communities required to govern, say, a public good such as a city. Blockchain-based governance for a community is best exemplified by Democracy Earth, whose goal is to propose a governance model to move "beyond the territorial boundaries of Nation-States" (*Democracy Earth* 2021, p.3) confirming that LD might not be suited for replacing current constitutions *per se* but could be efficient in other settings. Note that the example of the vote on national matters (the Peace Plebiscite in Colombia in 2016) mentioned in Cossar and Berman (2020), concerns a single vote isolated in time and does not capture the issues of vote-trading and intensity of preferences. As such, it cannot constitute a proof of concept for large scale Liquid Democracy. Blockchain-based governance for public good is also consistent with literature on blockchains and the governance of the commons (Poux, de Filippi, and Ramos, 2020; Rozas et al., 2018) which proves that it is appropriate for small to medium communities.

The contribution of this paper to the literature is twofold: firstly, it provides a theoretical institutional economic analysis of Liquid Democracy in terms of capacity to reflect the intensity of preferences. Although this issue has been mentioned in the state of the art literature, it had never been formally analyzed. Secondly, it builds on the existing distinction between LD as a voting tool and as a new form of democracy to disentangle classical arguments and highlights that some of the benefits of a voting mechanism could actually be counterproductive in a large scale constitutional setting.

It would be interesting to develop this analysis further to other possible forms of democracy. In particular, this research only scrapped the idea of reconciling Liquid Democracy and parliaments and much work on that issue is required. How could moving away from the "one person-one vote" paradigm make it possible to better account for intensity of preferences, for instance via quadratic voting? Further research on the topic should include an extended discussion of blockchain-based voting tools, focusing specifically on the affordances of blockchains and their particularities. The possibilities are countless and blockchains offer a fascinating sandbox to design new governance models. Some are already relevant for the relatively small communities governing a public or common good but national governments raise other issues not yet adequately addressed by the proposals discussed in this paper.

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