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Blockchain in Public Goods Allocation

Unlocking Economic Value and Equitable Distribution Through Token-Based Markets

Lewis Cohen,
Co-Founder, DLx Law

Dr. Andreas Freund,
The Blockchain Swiss Army Knife, ConsenSys

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Introduction

Naturally occurring public goods (e.g., water, forests, beaches) are often thought of as "free" public utilities—something with a virtually unlimited supply that can be consumed without any direct economic cost. We are all considered the "owners" of these public goods. In most cases, we do not expect to be "charged" for their consumption. Because we tend to think of these public goods as abundant, we do not worry too much about their limited supply or the need to provide equitable access and fair allocation.

There is a general acknowledgment of an economic cost to many human-made public goods (such as highways, airports, and libraries), which must be recovered through some sort of fee, toll or charge. However, we suspect that the general public gives little thought to the policy decisions embedded in cost recovery schemes or the impact of cost recovery methodologies on the efficient allocation and utilization of these resources for the assets.

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Pure vs. Impure Public Goods

Economists also talk about "pure" and "impure" public goods. A "pure" public good is one where an individual's consumption of the good does not in any way impact others' opportunity to consume the same good and where, as a practical matter, individuals cannot deny each other the opportunity to consume the good. An example of a "pure" public good is street lighting: one individual's enjoyment of the lighted street does not in any way detract from that same enjoyment of others. Likewise, it is not possible to light a street for some individuals while excluding others.

What interests us here are "impure" public goods—those where at least to some extent the consumption by one individual negatively impacts the ability of others to do so (i.e., there is some level of scarcity). Additionally, with impure public goods, it may be possible to some extent to exclude a number of individuals from consuming the good while allowing others to do so (excludability).

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Challenges with the Current Impure Public Goods Fee Structure

When it comes to "impure" public goods, there can be a strange dichotomy in our thinking. On the one hand, we often do not want to be charged simply for the "usage" of the public good; nevertheless, we recognize the scarcity of the resource and are aware of general maintenance costs incurred regarding these resources. This fundamental dissonance makes it difficult to construct a market for many impure public goods. There are economic costs involved, and limitations in access (not everyone can visit a park, bask on a beach, or simultaneously enter a congested downtown area). Additionally, many practical frictions limit how available resources are allocated and how costs can be recovered. As a result, the true economic value of impure public goods and their optimal usage can be difficult to determine.

Fees for accessing and maintaining public goods be it tolls or admittance fees, tend to be structured as flat amounts that do not reflect the complex dynamics of both supply and demand. This is particularly true when a public body or governmental entity sets the fees. This leads to a situation where both the usage and pricing are typically suboptimal. Until recently, we lacked the technological means to let markets address the cost allocation problems of public goods at scale.

At present, a handful of public goods have been allocated based on market processes. Examples include wireless broadcast spectrum and vertical property development rights (also known as "air rights"). However, these goods are generally allocated using a single auction mechanism in which the bidding is limited to a small number of pre-qualified large-scale entities. Given the limited number of approved participants in these processes, the outcome often resembles monopolies or oligopolies, which leads to rent-seeking behavior from the entities controlling resource access. In addition, following the initial auction, competition may be limited, which leads to suboptimal allocation and usage of the resource. Market-based allocation of public goods has not yet been made available to the general public at large.

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A Market-Based Pricing Architecture For Impure Public Goods

What would happen if we were to view a much wider variety of public goods as being susceptible to market-based price discovery, for instance, in the way that commodities such as gold or petroleum are traded in both spot and futures markets? Further, what if every individual or business who has the right to a public good is issued a finite supply of free usage receipts at regular intervals? What if participants interested in public goods could freely buy and sell usage receipts in open marketplaces? What if public goods marketplaces were not only frictionless and transparent but also prohibited rent-seeking intermediaries who often manipulate resource prices? What if these usage receipts could be used to construct new instruments to hedge the risk of market volatility, such as through a futures contract?

In this paper, we seek to conduct such a thought experiment and investigate if markets for enumerable but finite usage rights for a wide variety of freely exchangeable "impure" public goods can be created using blockchain technology and "tokens." Can revised pricing structures lead to better, more efficient, and safer usage of impure public goods while avoiding the "tragedy of the commons" -- where individual users acting in their self-interest deplete a shared resource to the detriment of all interested users?

We will use the example of congestion pricing in an urban city to illustrate market-driven prices for impure goods. Congestion pricing itself is nothing new; the City of London has utilized it to great effect since 2003. While the pricing of the public good, "vehicle access to central London" under the current framework is dynamic, it is not market-driven. Moreover, a London resident is not treated any differently than a visitor from the US. This set-up produces friction as the visitor is using the Londoner's public good, and it forces Londoners to pay for the usage of a public good that they already pay for through their taxes. While the current system might be economically beneficial for the City of London, it is not beneficial for the individual Londoner. In fact, it is similar to asking someone to pay rent for the apartment they own. Hence, such an arrangement does not incentivize citizens to be mindful of how they use the public goods they own, as there is no direct connection between public good, usage, and economic outcomes.

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Examples of Congestion Pricing as a Fractional, Scarce Public Good

In our example of a token-based market for impure public goods, we will discuss the following areas to demonstrate the theoretical viability of our suggested approach:

- *Why congestion pricing?*
- *Token model, distribution, and usage*
- *Market description and dynamics*
- *The potential for market manipulation and the oversight of market integrity*
- *Attack vectors and mediation*
- *Implementation considerations – mobile, blockchain, tokens, AI and algorithmic usage*

WHY CONGESTION PRICING?

Congestion pricing is an instructive example of an "impure" public good. There are a finite number of vehicles that can safely occupy a geographic area at a single point in time (scarcity), and, with some effort, access to that area can be limited, or at least observed (excludability).

Congestion pricing would be a net new allocation structure in most cities. In addition, it has the benefit of applying to the existing infrastructure for which inhabitants are already paying and would not be expected to be conflated with other city services on both the cost and revenue side.

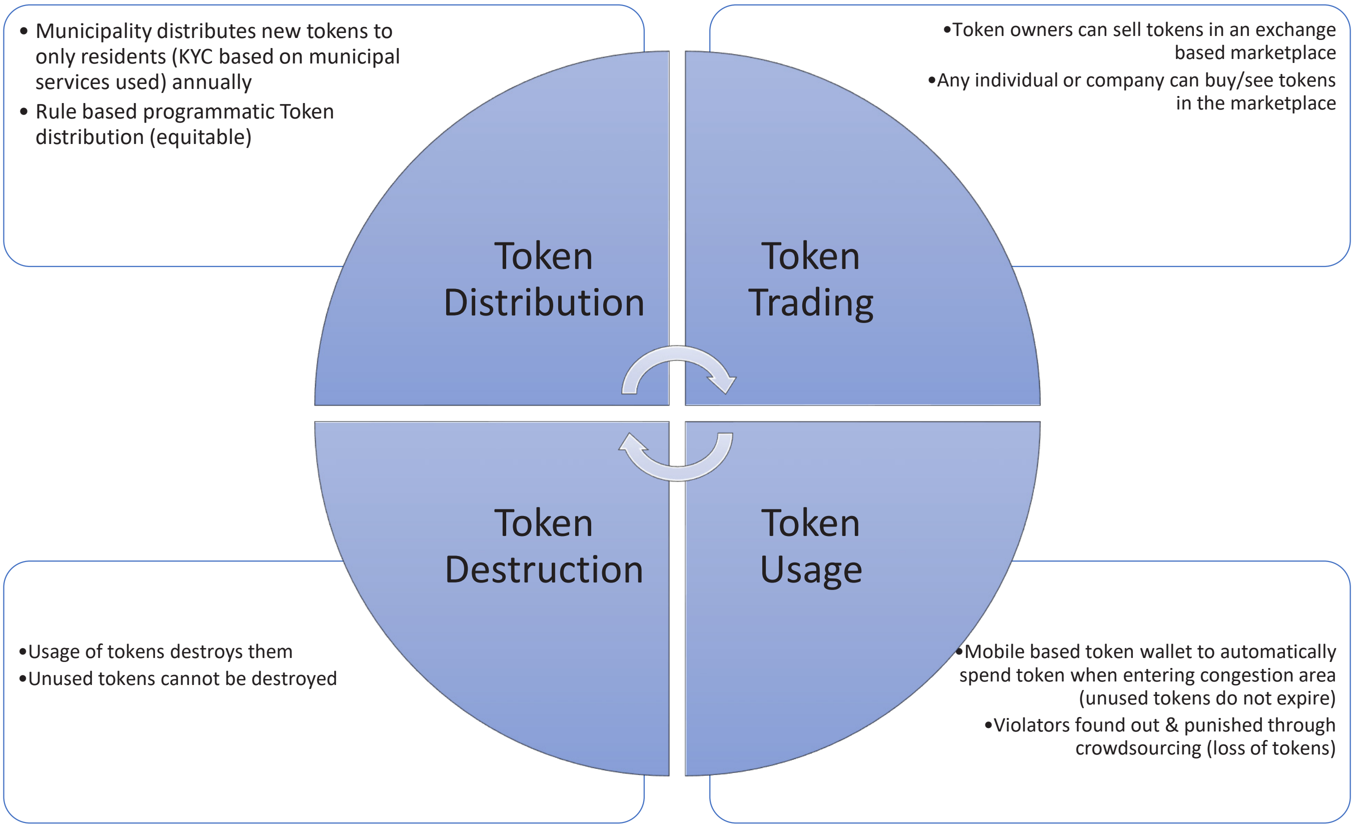
TOKEN MODEL, DISTRIBUTION AND USAGE

Potential models for market-based congestion pricing are straightforward to construct:

- *Every resident of a city is issued a finite number of digital access receipts for the congested area free of charge. In this exercise, we'll say one access receipt per day for a year for simplicity. Let's call these receipts "tokens" – this term will be familiar given how mass transit systems have used physical tokens in the past.*
- *Those tokens are valid for an agreed period (say, one year), and new tokens are issued periodically to eligible citizens.*

- *Every driver of a vehicle needs to pay (i.e., transfer to the municipality), say one token, upon entering the congestion zone of the city during certain hours of the day. The access right of the token expires once the driver and vehicle leave the congestion zone.*
- *Tokens are destroyed once used.*
- *Drivers of vehicles can buy one or more tokens in an open marketplace.*
- *Token prices are set in the marketplace based on supply and demand (perhaps at least initially with government-set minimum and maximum prices).*
- *Algorithmic tools could be developed to allow travelers needing access but without tokens to simplify purchases by pre-setting parameters to various preferences (e.g., minimize cost, plan-ahead as far as possible, prioritize travel flexibility, etc.).*
- *The token can only be used to access the city's congestion zone and nothing else.*
- *The city may reserve the right to issue additional tokens as a "safety valve" if the demand for tokens is significantly outstripping token supply at any one point. Minting supplemental tokens avoids the potential for excessive "surge pricing"—similar to what ride-sharing providers use to incentivize drivers to come online to increase the supply of drivers when the demand for rides significantly outstrips supply. We recognize that a completely unchecked market can create undesirable short-term pricing distortions. These distortions would need to be managed either centrally through a third party such as a municipal agency subject to appropriate oversight and transparency, or programmatically through rules embedded in the exchange protocol. This is an important point with far-reaching consequences, and we will discuss it in more detail when we explore the economic and social implications of our model.*

Congestion Pricing Token Lifecycle Process



Since impure public goods by definition have some level of scarcity, they could become expensive to access. If a marketplace for that access is established, some market participants can be expected to attempt to game the system to gain an "unfair" advantage, as is seen in almost all open marketplaces. We will discuss examples of potentially malicious behavior of participants and how to mitigate it once we have discussed the functioning of the marketplace itself.

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Marketplace Description and Dynamics

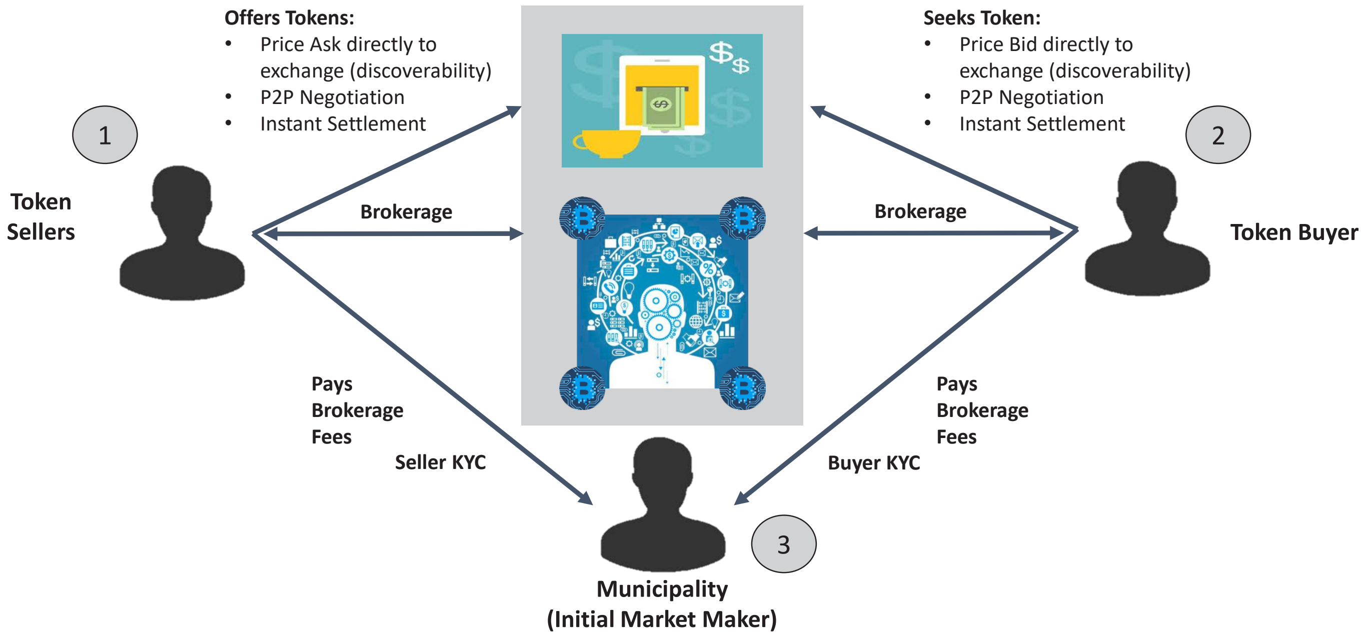
A marketplace for these tokens to be exchanged is simple to imagine:

- *All persons interested in accessing the congestion zone would first need to register their identity. Registering identity could be a simple process handled through a mobile app (for those from outside the region who may be entering for the first time). Anyone would be able to register with the marketplace. There will, however, be a certain level of automated "know your customer" (KYC) checks such as validation of a credit card (to buy tokens) or verification of a participant's local utility account (for token issuance).*
- *Every registered participant could buy or sell tokens in an easy-to-use online marketplace.*
- *Bids and asks for tokens would be registered with the marketplace and matched based on the rules set by buyers and sellers in the bid/asks. Properly constructed, these transactions could, in theory, take place on a peer-to-peer basis without a need for third-party intermediaries.*
- *Each trade could be subject to a small fixed trading fee deducted programmatically that would go to the municipality to support the maintenance of the system.*
- *A variety of other rules could be implemented, such as a rule requiring that no registered participant can hold more than two to three times the number of tokens regularly issued to an individual at any point in time. A rule of this type would avoid token concentrations in the hands of a few individuals.*
- *Trades between buyers and sellers could be settled with a 100% cash-collateralized stable settlement coin (the "coin") pegged to, e.g., the USD (or the EURO, if in the Eurozone, etc.) to avoid complicated bank transfers between individuals.*

The coin could work as follows:

- *A buyer pays $100 with their credit card to obtain 100 coins plus a transaction fee, which are issued once the credit card payment is received. The first currency paid could be held with a bank or other regulated entity. The 100 coins could then be used to purchase more tokens.*

Token Marketplace Mechanics



- *Coins could be converted to a relevant fiat currency such as USD, at which point a conversion fee would be due. Alternatively, registered participants may use the coins to pay for other city-owned services or charges. Examples of such services and charges are parking fines, municipal business license fees, utility bills, or public transportation tickets.*
- *Participants can "gift" tokens and coins to other registered participants. Only the standard trading fee would apply to gifted transactions.*
- *Marketplace fees etc. must be paid in the coin.*

The expectation is that with enough participation and liquidity in the market, a highly dynamic price picture will evolve. When demand is high, prices will rise, and when demand is low, they will sink. Participants may devise a plan to save their tokens through rideshares and sell them in the market for a profit to pay, for example, for a vacation or other discretionary items.

ATTACK VECTORS AND MEDIATION

Malicious behavior intended to game the system is to be expected in any open marketplace. We will discuss the two most anticipated attack vectors and token usage non-compliance.

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Anticipated Attack Vectors

Value extraction attacks from market participants:

Potentially Malicious Behavior: Market participants could choose to hold their tokens and not sell under any circumstances. If enough participants join such an effort, there would be insufficient liquidity in the marketplace, rendering it impossible to purchase tokens. Only current token holders could enter the congestion zone leading to potentially high disruption of business in the congestion zone.

Potential Mitigation: The city could become a market maker and inject liquidity into the marketplace by minting new tokens, easing liquidity concerns.

Extortion attacks:

Potentially Malicious Behavior: Participants force other participants to sell their tokens at a steep discount or give them their tokens for free.

Potential Mitigation: The city could limit the total token balance in a single account, which would discourage users from centralizing tokens, and thus power, to formulate an extortion attack. The municipality could also limit the number of gifted tokens and coins by a participant to a certain number of participants in a set time frame.

Token usage non-compliance:

Potentially Malicious Behavior: Drivers attempt to not pay the token as they enter the congestion zone.

Potential Mitigation: Crowdsourced tipping with economic incentives and disincentives may be used. Every individual registered and legally verified with a "whistleblower" service could provide a digital proof of a suspected violation with a digital signature of the whistleblower. This process could be as simple as taking a picture of the license plate of the suspected violator with a mobile device. If a breach is identified, the driver is fined, and the fine would be split with the whistleblower. Once a violation is recorded, subsequent whistleblower reports of the same violation will be ignored. Given that whistleblowers have identities associated with a digital signature, the possibility to attack the system through, for example, a Distributed Denial of Service or DDOS attack is remote.

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Implementation Considerations and Recommendations

LEGAL CONSIDERATIONS

Determining whether the tokens and/or coins would be considered “securities,” “financial instruments” or something similar under applicable law (and, therefore, subject to trading constraints and other restrictions) will likely require engagement with the securities regulatory bodies in the marketplace’s jurisdiction in which the municipality is located. We believe that the aforementioned tightly constrained token and marketplace construction will likely not be viewed favorably by the relevant securities regulators; however, any such analysis will be based on the specific facts and circumstances of the structure as actually deployed under applicable law.

Considerations such as “money transmission” regulation and banking laws would be relevant to the construction of the marketplace as well. Federal and local regulations would affect, among other things, how the system would address applicable anti-money laundering (AML) and KYC regulatory requirements. Although the way in which financial regulations are being applied to open, peer-to-peer marketplaces using tokens is currently in flux, we believe that a marketplace of the type contemplated in this note can be constructed in a manner consistent with applicable regulations in most jurisdictions.

Lastly, we acknowledge the critical importance of applicable municipal law, and that certain municipalities might have to implement significant changes before the above scheme could be implemented. Applicable municipal laws will need to be considered on a case-by-case basis.

ECONOMIC AND SOCIAL CONSIDERATIONS

The initial and recurring token distributions are not trivial and will determine the overall market size and its liquidity of markets for access. Token distribution could be based on multiple factors, such as age, location, and socio-economic factors. This aspect of the design of the marketplace will require extensive modeling to ensure both a liquid market and a fair distribution of tokens that do not further cement current economic imbalances.

For members of economically disadvantaged groups, a free tokenized distribution of scarce public goods could enable a basic income stream, which could, in turn, stabilize the economic situation of these persons. Having direct access to additional economic and educational activities could strengthen the earning potential of economically disadvantaged groups. This would yield a positive effect on the social costs of a municipality, such as welfare, housing, etc. Entirely new service sectors could evolve around the marketplace, providing services to the participants, e.g., how to save tokens, how to use tokens to offset other costs.

Although giving away tokens to its residents would impact the municipality's direct revenue potential, the transaction fees would still be a net new direct revenue source. The above-mentioned social cost savings will be more significant in the long run than the municipality's short-term revenue potential, also given that congestion pricing will generate net new revenue for most municipalities.

In a fully transparent market, as described above, there will be no information asymmetries; in other words, no arbitrage opportunities. This forces capital to be allocated to the actual economic resource allocation problem rather than gaining an unfair advantage due to information imbalances, which will enhance the efficiency of the market itself.

An example of information asymmetry in today's equity markets is the minimal price differences of assets on the same exchange. This asymmetry has given rise to the phenomenon of high-speed trading, which is seeking to exploit these small and only brief price differences for arbitrage trading. In order for differences in token price to disappear before trades are settled and thus avoid information asymmetry scenario two things need to happen:

1. Transactions must be economically finalized in a specified, finite time which is significantly longer than the time it takes to form a token price based on bid/asks, e.g., sub-seconds.

2. The order of transactions must be randomized within the finite settlement timeframe.

This approach will render high-speed trading irrelevant for this token marketplace and significantly increases equal opportunity for marketplace participants. This, in turn, will improve the marketplace and, therefore, resource allocation efficiency.

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Considerations for a Monetary Token Policy

Lastly, we want to return to a municipality's ability to "print" new tokens and make them available for sale in the marketplace. In many ways, this is equivalent to the monetary policy of a central bank, which can increase or decrease the amount of "cash" in the system. The primary purpose of monetary policy is generally to create "price stability." In our case, the reason a municipality may be permitted to issue new tokens from time to time would be to avoid the token price surging to socially untenable levels due to relatively brief periods when demand dramatically outstrips supply. There are, however, significant differences which need to be considered and which often complicate the token monetary policy of the municipality:

- *Only a finite number of vehicles can be in a specific area at any given time and still avoid the reason for congestion pricing in the first place, namely traffic gridlock. A municipality cannot "print" an arbitrarily large number of new tokens, as a Central Bank in principle can since this would run counter to the original intent to improve the traffic situation in the congestion zone.*
- *Consequently, the original distribution of free tokens to residents cannot represent 100% of the total possible supply such that a municipality has a "token cushion" it can print to reduce market prices.*

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Managing Large Token Price Fluctuations

In contrast to a Central Bank, a municipality has several options to handle large token price fluctuations. In order to better control large token price fluctuations, marketplace administrators could, for example, institute a token price freeze or prohibit additional vehicles from entering into the congestion zone.

DISALLOWING MORE VEHICLES INTO THE CONGESTION ZONE

While not optimal, from a market point of view, disallowing additional vehicles into the congestion zone is a relatively benign intervention as the current tokens in use will expire at the end of the day, and vehicles will have to leave the congestion zone. This will reduce overcrowding, and the municipality can accept new tokens the next day, and markets can resume normal trading. The ability to implement such a solution will, of course, be highly dependent on the infrastructure available to the municipality.

INSTITUTING A TOKEN PRICE FREEZE

A token price freeze could be set at a discount to the last token price in the marketplace, equivalent to a token devaluation, until the number of vehicles in the congestion zone have decreased enough that people are willing to sell new tokens at a price point below the fixed price. This is an extreme measure from a market point of view since market participants who do not have to sell will withdraw from the market since the price is perceived to be no longer attractive.

While such a quick fix seems appealing, instituting a token price freeze will not directly stop token holders from entering the congestion zone, nor will it forbid token-holders from selling their excess tokens (at the frozen price point). Sellers will remain in the market for one of two reasons, because they are still operating at a profit relative to their original token acquisition price or because they need to liquidate their token positions. Until this liquidity is drained out of the market, the number of vehicles in the congestion zone will remain higher than intended.

When disallowing additional vehicles to enter the congestion zone, the market will return to a normal trading pattern within 24 hours. However, it will take possibly significantly longer than 24 hours to return to a situation where the price freeze could be lifted, thereby extending the period of economic resource misallocation and, thus, a real net economic loss.

TECHNICAL CONSIDERATIONS:

- *Given the highly distributed nature of the token and the marketplace, we believe that it would be preferable to implement such a system using a public permissioned blockchain platform. Public, because everyone would be able to participate in the system yet permissioned since there will need to be a KYC process for both the participants and the blockchain nodes. The token and the stable settlement coin can be readily represented as Ethereum ERC-20 tokens and used with open source blockchain wallets such as MetaMask. The marketplace could be readily implemented utilizing open source software for decentralized exchanges such as 0x, Airswap, or Uniswap.*
- *Given that participation in such a system would be based on participant permissions such as legal residency and identity, anonymity is not required. However, privacy must be maintained. This can be most easily achieved utilizing a Blockchain-based Decentralized Identity, leveraging decentralized identifiers and verifiable credentials standards as defined by the W3C organization. Additionally, the system operator must not retain any personally identifiable information (PII) in the system itself. Decentralized identifiers and verifiable credentials can be kept PII neutral, ensuring non-repudiation through public key infrastructure (PKI) based digital signatures. In addition, the usage of trusted execution environments as cryptographic "black boxes" can secure all operations not executed on a Blockchain and can add additional layers of privacy protection.*
- *If credit/debit cards were allowed in the marketplace, the congestion pricing system could utilize existing municipal infrastructure, such as payment gateways and banking relationships to implement non-blockchain payment rails.*
- *End-users would interact with a mobile-first interface. A mobile app would allow registration/KYC, payments as well as account management, including trading.*
- *Together with the GPS of the mobile device, the app could determine the position of a driver and whether the driver must pay a token or not. The app could automatically execute the required transaction.*

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Other Examples of Fractional, Scarce Public Goods

Congestion pricing is not the only impure public good that could benefit from our described model. This basic approach could be applied to other similar public goods such as:

- *Municipal neighborhood parking rights*
- *Local area CO2 emissions*
- *Regional fishing quota management systems*
- *Special-access highway travel lanes*
- *Broadband spectrum allocations*

To show the broad applicability of the concept, we will briefly discuss the example of municipal neighborhood parking rights, focusing on the differences from the congestion pricing model, rather than the many similarities.

MUNICIPAL NEIGHBORHOOD PARKING RIGHTS

Another mobility-related public good is municipal neighborhood parking. Today, residents in urban neighborhoods can purchase parking permits from the municipality for their vehicles to park at any time in their neighborhood. Non-residents are typically not allowed to park except for marked parking spaces, such as metered parking. This arrangement can result in an overabundance of parking for local residents and a shortage for non-residents. This problem is particularly troublesome in mixed business-residential communities. The impact of the current approach is that the scarce public good of a neighborhood parking space is inefficiently allocated; this is similar to the congestion pricing issue we discussed above

When taking a closer look at the situation, one realizes that a similar model could be employed for municipal neighborhood parking. In fact, the same technology infrastructure, marketplace architecture, incentive model, and mitigation steps against malicious behavior could be used as described above. This also means that the same benefits and regulatory considerations, as discussed above, apply here as well. The main difference to congestion pricing is how the parking permit token is structured. Here we will briefly discuss how a parking permit token can be structured and traded:

- *Congestion price tokens are typically valid for a day once activated. Yet, there is a more fine-grained time structure to consider for municipal neighborhood parking rights. Parking tokens are needed in variable time increments. This means that rather than using a fungible token for the fractionalization, we should be using a non-fungible token for the parking permit that has a primary owner and secondary owners. Note that secondary ownership is time-bound, and the time segments cannot overlap.*

- *From a trading point of view, participants would bid on time segments, say in ten-minute increments, with a fixed start and end time. The owner sets a price for those increments.*

- *Given the complexity of evaluating bids—since they could be for a different number of time segments with different starting and end times—it is worth considering using a transparent auction system for each parking slot. The time dimension also allows a market participant to auction off larger time blocks over an extended time period, such as Monday through Friday, from 9 am to 5 pm on a monthly basis. This system allows for greater flexibility to adjust to the market requirements.*

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Conclusion

In conclusion, the current allocation of, and cost of access to, both natural and human-made "impure" public goods are often suboptimal. The flat pricing structure leads to inefficient economic outcomes, as we have examined above when discussing scarce public goods use cases—congestion pricing and municipal neighborhood parking.

Implementing market-driven pricing and exchange structures as described in detail for congestion pricing, we see the following benefits:

- *Efficient resource allocation based on supply-and-demand for a public good resource can be achieved:*
- *if there is a free and equitable distribution of a public good, or rights to its usage, at the beginning of a use cycle in the form of tokens;*
- *a transparent, non-information asymmetric marketplace where these tokens can be traded without transaction front-running; and*
- *programmatically enforced token and marketplace rules that prevent malicious and rent-seeking behaviors.*
- *Besides a more efficient resource allocation, a market-based structure also:*
- *avoids aggregation of resources with few participants.*

- *enables the potential of an efficient form of basic income for low-income participants with direct positive cost impact on public spending for social services; and creates new service sectors to service the new marketplace.*
- *A clear elaboration of a non-security use case for tokens and decentralized marketplaces with programmatic rules.*

From a technical point of view, we demonstrated how such a model could be implemented with today's technologies, including Blockchain and Mobile Applications. Lastly, we listed additional use cases where our model is applicable to showcase that these considerations are generally relevant to a variety of scarce public goods.

We hope that this paper may inspire vigorous discussion among citizens, politicians, businesses, and technologists. Working together, we can begin strategizing and implementing innovative methods to effectively preserve and equitably allocate scarce public goods not only locally but also globally.

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