Design of a Market Exchange for Climate risk

by

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ABSTRACT

Significant scientific research has been performed that shows human activities are the primary contributor to a warming climate, but disagreement exists in the likelihood and impact of this change. For example, projections for sea level rise (SLR) have been developed by certain cities, and the mitigating costs related to managing this risk can be estimated. Still, there exists disagreement between the true probability of change, rise and impact. This paper proposes a real-time pari-mutuel market based on a blockchain to capture this disagreement and manage SLR risk more cost-effectively for the City of Boston.

Keywords: Climate risk, pari-mutuel, marketplace, blockchain, sea level rise, insurance.

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Dedication

I dedicate this thesis to the women in life – Suzanne, Amélie and Yvonne. I hope you dream big and pursue your dreams.

1 Introduction

In 2021, the World Economic Forum identified the top three global risks to all be related to climate change. They are (1) extreme weather, (2) climate action failure, and (3) human environmental damage (World Economic Forum, 2021). These risks have been on the global risk radar since 1988 when climate change due to human impact (i.e. anthropogenic) first emerged on the public agenda (Moser, 2010). The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 by United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), specifically to provide policymakers with regular scientific assessments on the current state of knowledge about climate change.

Irrespective of this area being scientifically researched for more than thirty (30) years, significant uncertainty remains regarding the probability and impact of climate change. Even the IPCC has stated that greenhouse gas (GHG) emissions result from very complex systems and that their future evolution is highly uncertain (IPCC, 2021). The IPCC modelled five (5) scenarios in their most recent report, without attaching any likelihood to each scenario occurring. This uncertainty makes it difficult to plan, develop, fund and mitigate climate risk for the specific scenario that will prevail in the future.

Studies also found that people with different political views (Brenan & Saad, 2018) and from different generations (Pew Research Center, 2021) have divisive views on climate change. These different views compete with one another, and create a need to separate falsehoods from fact (where the fact is the actual outcome of specific climate events over a period of time) through the creation of a "marketplace of ideas" (Schultz & Hudson, 2017) where different ideas or views can be traded against each other.

In addition, financial losses due to natural catastrophes are expected to continue to rise, since global warming is predicted to increase the frequency and severity of extreme weather events (Botzen, Deschenes, & Sanders, The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies, 2019). In Boston specifically, several physical coastal resilience projects (e.g. the construction of sea walls, elevated waterfront parks) have been identified to protect the city's shoreline from severe storms and sea level rise (SLR) related to climate change (City of Boston, 2020). These defenses are insufficient and financial instruments such as insurance are recommended, to complement such hard infrastructure solutions by limiting losses and spreading risks (Botzen & van den Bergh, 2008). Insurance can contribute to "climate proof" communities via effective risk sharing mechanisms. Due to the escalating nature of climate risk (both from a frequency and severity perspective) insurance companies themselves are also increasingly exposed to this risk, which requires that climate risks be included in premiums and risk management. The economic and insured losses caused by natural disasters are expected to increase as well (Botzen & van den Bergh, 2008), which should increase the respective insurance premiums as well as the cost to society. Also, the demand for natural disaster related insurance requires new capital to be made available to reinsurance companies (Polacek, 2018).

This thesis explores a new risk sharing mechanism to protect against specific climate outcomes. It introduces an alternative and non-conventional funding mechanism that addresses different stakeholder views on climate change at a possible lower cost. For such an alternative financial instrument to become a mainstream risk mitigating financial instrument, it is essential that the solution is perceived as fair, efficient and is trusted by its stakeholders. Therefore, the solution is proposed to be built on a blockchain technology that is not reliant on a central authority figure and can reduce inefficiencies (Werbach, 2019).

2 Background

2.1 Boston climate change

Boston (the City) is a coastal city and the capital of the Commonwealth of Massachusetts, United States of America, with a population of 675,647 people (United States Census Bureau, 2020).

The City is vulnerable to flooding and rising sea levels. For example, the Blizzard of 1978 resulted in a 100-year coastal flood of the Massachusetts shoreline and caused damages of $550 million, including $95 million being required in emergency costs (Kirshen, Knee, & Ruth, 2008). In 2013 the City was ranked as the world's eighth most vulnerable to floods among 136 coastal cities (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013).

Boston's sea levels have been rising for the past century, as shown in Figure 1 (Center for Operational Oceanographic Products and Services, 2020). SLR *is driven by a combination of the melting of land ice, the expansion of water as it warms, and changes in the amounts of water extracted from below ground or stored behind dams* (City of Boston, 2016).

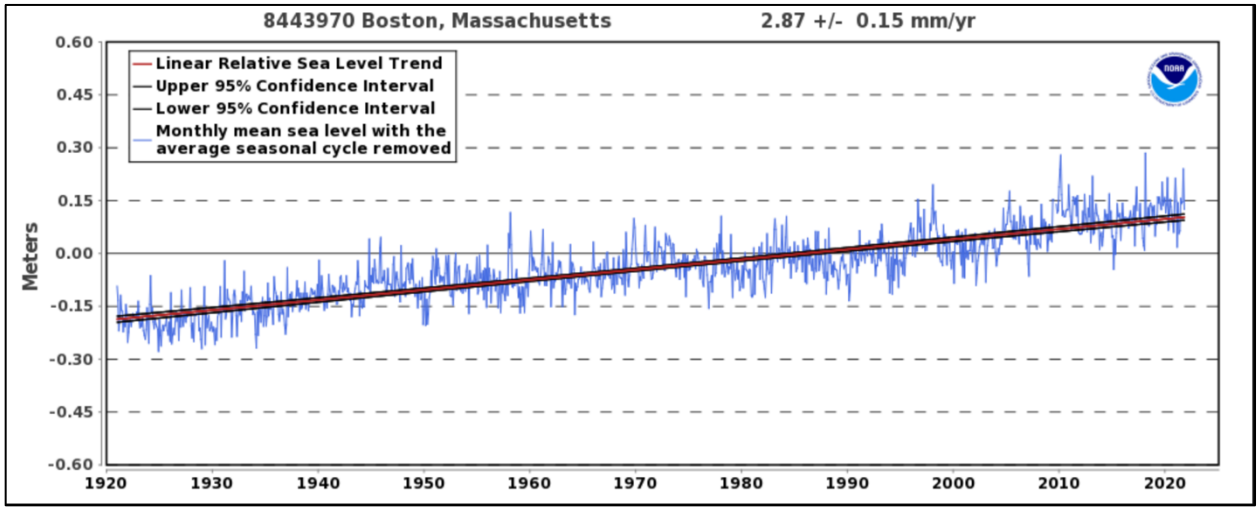

Figure 1: Boston relative sea level rise (SLR) trend (Center for Operational Oceanographic Products and Services, 2020)

Higher sea levels will result in more frequent high-tide flooding, which can be disruptive and expensive. Higher sea levels also result in deadly and destructive storm surges, such as those associated with Hurricane Katrina, "Superstorm" Sandy, and Hurricane Michael—pushing farther inland than they once did (Lindsey, 2021). Finally, a rising sea level also means that any storm will cause more flooding in the future than it would today (City of Boston, 2020).

In response to all of the City's climate change challenges (higher temperatures, sea level rise and more severe floods), the City launched the project Climate Ready Boston. As part of this initiative, several physical coastal resilience projects have been identified (e.g. the construction of sea walls, elevated waterfront parks) to protect Boston's shoreline from an increased risk of severe floods (City of Boston, 2021). In support of this project, the City[1] modelled three scenarios to determine possible SLRs (City of Boston, 2016):

1. An aggressive "low-emissions scenario" in which net global emissions are reduced to less than a third of their current levels by 2050 and are brought to zero by about 2080 through *major emissions reductions;*
2. A "medium-emissions scenario" in which emissions remain around current levels through 2050 and then are slowly reduced in the second half of the century through *moderate emissions reductions*; and
3. A "high-emissions scenario" often characterized as a continuation of *business as usual*.

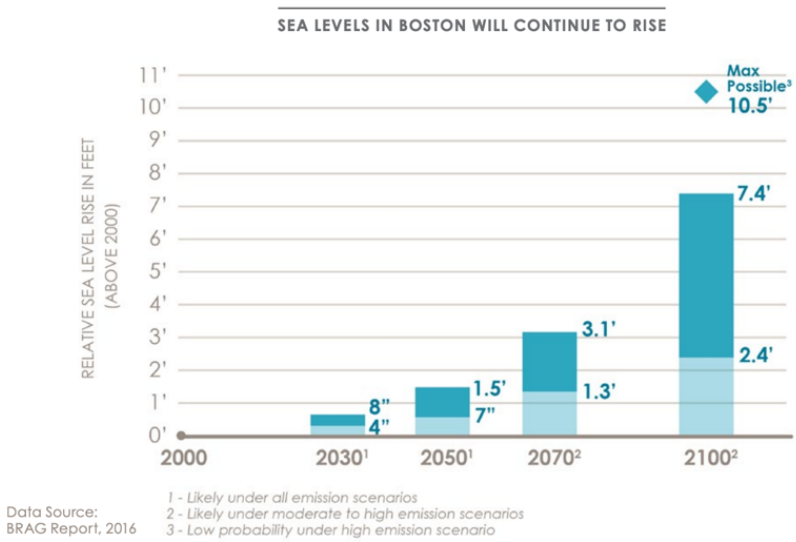

Figure 2: Boston SLR scenarios (City of Boston, 2016)

Figure 2 compares expected SLR scenarios against the level from the year 2000. To give context, over the entire 20th century, Boston sea levels rose about 9 inches relative to land. The figure shows that by 2030 another 8 inches of SLR may happen, which is three times faster. By 2050, sea levels may be as much as 1.5 feet higher than in 2000, and by 2070, they may be more than 3 feet higher than in 2000.

[1] Other forecasts are available (e.g. by the US Army Corps of Engineers), but as the City is the primary entity responsible for addressing and mitigating climate change within Boston, their scenarios are used.

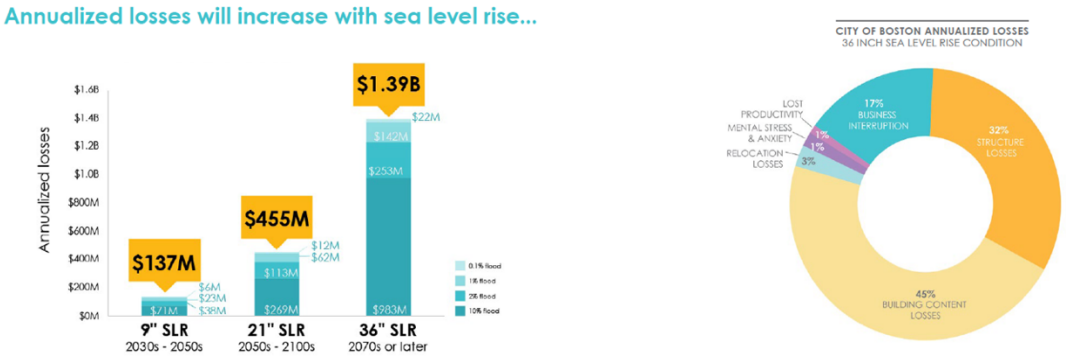

Figure 3: Expected Annual losses because of SLR (City of Boston, 2016)

These projected sea level changes are also expected to significantly impact the Boston way of living. Annualized losses from higher sea levels are expected to range between $71m and $1.39bn, exposing between 0.2% and 23% of the City's population. Severely damaging flood events will become more common over time. As flood risk increases, not only does the total expected annualized losses increase, but the share of these losses attributable to high probability floods (10 percent chance of occurring in any given year) also becomes much more significant as the size of these floods increase. Between 2030 and 2050, the City estimates that a severe flood with a 1 percent annual chance of occurring[2] would flood 2,100 buildings and cause an estimated $2.3 billion in physical damages to buildings and property and other economic losses, including relocation and lost productivity. Over a 30-year period, there is almost a one in three chance that a 1 percent annual chance flood will occur at least once. In the late century (the 2070s or later), a significant portion of Boston's current land is forecasted to be inundated every month by such an extreme flood (City of Boston, 2016).

The City aims to protect its constituents against these climate risks, with funding already being made available. The City committed to spending at least 10% of its 5-year budget to defend the city against the effects of climate change (City of Boston, 2021). This equates to approx. $330 million for the period from 2022 to 2026. Not protecting its stakeholders from severe climate events can negatively impact the city's ability to generate revenue to provide services to its citizens, as property values may fall. For example, in 2022, the City is budgeting to generate 73.3% of its income from property taxes (City of Boston, 2021). If extreme flood events materialize, it can result that the City enters a "death spiral" where costs required to pay for damages associated with extreme climate events (such as floods) are unable to be recovered from higher property rates, due to people also facing economic hardship and being unable to pay such taxes, and even leaving the city. Once the City is caught in such a "spiral" where increased costs cannot be recovered, it can lead to bankruptcy.

Project Climate Ready Boston identified specific projects in Boston Harbor, Downtown/North end, Dorchester, East Boston, Charlestown, and South Boston that would

[2] A "1 percent annual chance flood" is a flood event with a 1 in 100 chance of occurring in any given year, also known as a "100-year flood".

raise small parcels of land and *use temporary barriers in key locations to prevent flooding during storms* (City of Boston, 2021). In addition to such hard infrastructure solutions to mitigate the impact of climate change, financial instruments, including insurance, can complement such hard infrastructure solutions by limiting losses and spreading risks. Insurance can contribute to "climate proof" communities via effective risk sharing mechanisms (Botzen & van den Bergh, 2008).

2.2 Opposing climate change views

People from different backgrounds and demographic profiles have different views on climate risk.

For example, in the United States, Democrats feel a greater sense of urgency about the issue while Republicans are increasingly skeptical of the dominant scientific views on the topic. Independent voters fall between these two views (Brenan & Saad, 2018).

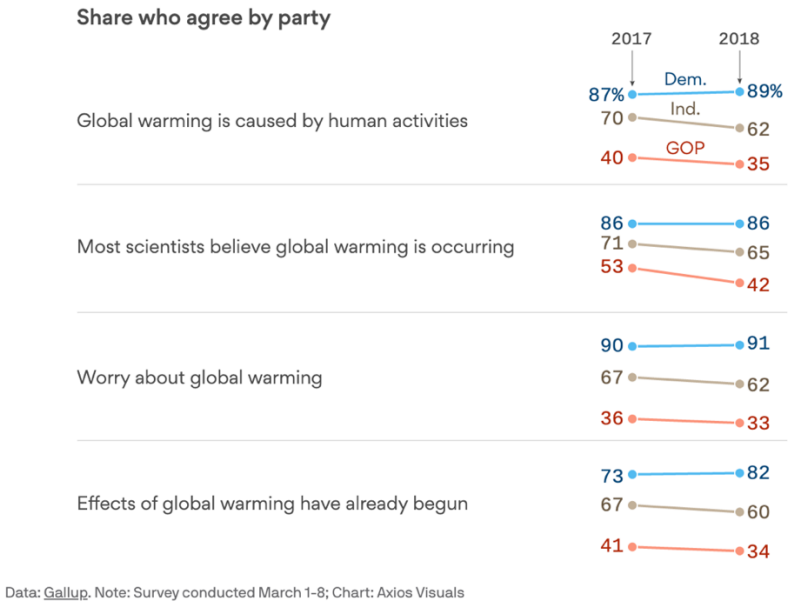

Figure 4: Different climate change perspectives based on political views (Brenan & Saad, 2018)

Another recent study found that younger people are more interested in addressing climate change than their older counterparts, and are also actively taking action to address climate change. Young people are also more likely to favor moving away from fossil fuels (Pew Research Center, 2021).

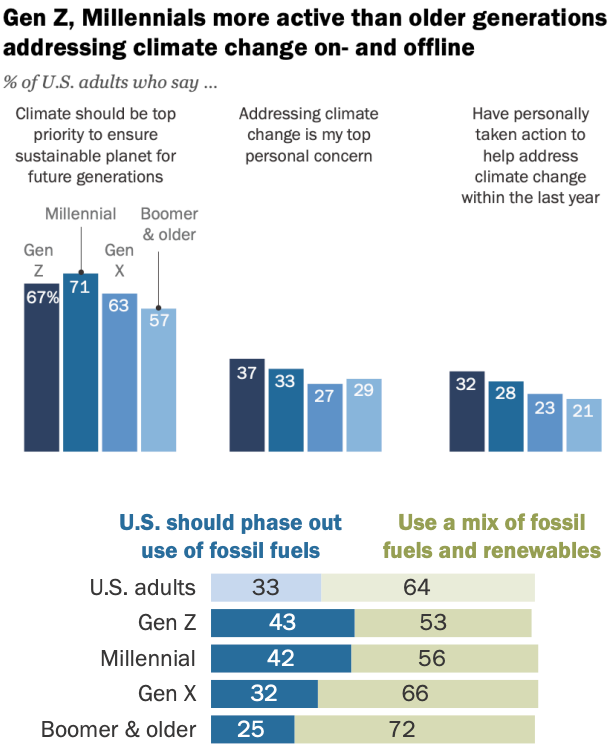

Figure 5: Different climate change perspectives based on generation / age (Pew Research Center, 2021)

These different views on climate change highlight different needs and concerns on how it should be addressed. The differences also create tension between the respective stakeholders.

It is worth noting that the generations most concerned about climate change, also have the least financial resources to address it. The Boomer & Older generation currently accounts for 65.2% of US wealth in the US, followed by Gen X who owns 28.9%. Gen Z and Millennials combined only account for 5.9% (US Federal Reserve, 2021). For the younger population, this highlights a need for generational wealth transfer required from older to younger generations to address the concerns of the youth who will live the longest with climate change.

2.3 Insurance

Insurance can benefit companies and households in managing losses that result because of specific events, including climate change. Well-designed instruments can limit total economic losses and catastrophic impacts for individuals (Botzen & van den Bergh, 2008).

Damages that result from flooding may just be too significant for the affected parties to repay, resulting in bankruptcy if compensation is not provided in a timely manner. The Federal Emergency Management Agency (FEMA) data indicates that approx. 40% of small

businesses never open their doors after a disaster, and another 25% fail within a year (Scott, 2014). Insurance spreads the risks of such events across many policyholders. In this way, the potentially catastrophic consequences for individual businesses and households are transferred to insurance companies. Insurance companies collect premiums from many policyholders to carry this risk and repay the policyholder when they are affected by that risk. By spreading the risk, insurance companies can reduce this risk to the individual. In addition, insurance contracts reduce the uncertainty faced by individuals, which increases their welfare and is beneficial to stimulating business activity and economic stability (Botzen & van den Bergh, 2009).

Insurance is also used to segregate risks. Insurance companies can price policy premiums differently, based on the respective risk characteristics of the policyholder, for example, the location of the property, height above sea level, individual or business risk exposure, etc. This practice of "discriminating" against policyholders is how insurance companies segregate their risks. Effectively insurance exploits different views on the same risk by the two different parties (the insurance policyholder and the insurance provider).

2.3.1 Current flood insurance for Boston

In 1968, the US Congress created the National Flood Insurance Program (NFIP). The NFIP is a public-private partnership between the federal government, the property and casualty insurance industry, states, local officials, lending institutions, and property owners (Department of Homeland Security).

This program offered homeowners more affordable flood insurance because private insurance companies were unwilling to cover the risk of damage caused by floods. FEMA administers the program. While private companies sell flood insurance, all rates are subsidized by FEMA. Property owners in Boston qualify to buy and maintain federally subsidized flood insurance through the program (City of Boston, 2020).

Two kinds of flood insurance are building coverage and contents coverage. The respective rates may vary depending on:

- The flood zone the property is located in;
- Its height above sea level; and
- The building's characteristics.

In "high risk" flood zone areas, flood insurance is required by law if the property owner carries a mortgage from a regulated or insured lender. Owners who have received federal disaster assistance for flood damage also need to buy flood insurance to be eligible for future aid (City of Boston, 2020).

2.3.2 Tail risk of climate insurance

Hurricane Andrew that hit Florida (1992) and the Northridge earthquake of California (1994) revealed that the global reinsurance industry - the backstop of traditional insurers -

was severely undercapitalized to deal with catastrophic events of that magnitude (Cantrell, 2018).

Historically, insurance companies relied on past data to price future risks. However no data existed to quantify the likelihood of a catastrophic event occurring in a specific area. Such extreme events are called tail risk events and are believed by markets to have a one (1) percent chance or less of happening (Lewis, 2007).

Post Hurricane Andrew and the Northridge earthquake, Hurricane Katrina landed in 2005 and caused $41 billion in insured losses and $108 billion in total economic losses in the United States (Johsnon, 2015). The major storm damaged homes and businesses in a concentrated area at the same point in time. A catastrophe on such a significant scale threatened the insolvency of various insurance companies and highlighted the devastating effect that natural disasters such as flooding can have (Kok, van Gelder, JK, & Vogelsang, 2002). Katrina also highlighted an insufficient supply of reinsurance to cover coastal catastrophe risk (Braun & Kousky, 2021).

2.3.3 Catastrophe Bonds

After Katrina, the insufficient supply of reinsurance cover led to the increased development of instruments that use the financial markets for enhancing risk transfer, such as catastrophe (CAT) bonds.

A CAT bond is a security that pays the issuer when a predefined disaster risk is realized, such as a hurricane causing $500 million in insured losses or an earthquake reaching a magnitude of 7.0 on the Richter scale (Polacek, 2018).

The CAT bond market reflects the growing demand for protection against major natural catastrophes. Climate change is contributing to this demand, as well as the increasing number of properties located in coastal areas. A CAT bond transfers insurance risk to the capital markets (Braun & Kousky, 2021).

The first CAT bonds were issued in 1997, where insurers accessed broader financial markets. CAT bonds offer institutional investors, such as pension funds, hedge funds, and mutual funds, an opportunity to earn attractive returns on investment uncorrelated with other financial market instruments in exchange for assuming catastrophe insurance risks (Polacek, 2018). CAT bonds generate high returns by investing the deposit into safe securities such as US Treasuries and the premiums paid by the issuer of the bond (Edesess, 2014).

Correlation of monthly returns, 2002 – 2020

	CAT Bonds	U.S. Treasuries	High Yield	U.S. Equities
CAT Bonds	1.00			
U.S. Treasuries	-0.03	1.00		
High Yield	0.27	-0.24	1.00	
U.S. Equities	0.20	-0.34	0.72	1.00

Figure 6: Low correlation of catastrophe bonds with other financial assets (Difiore, Drui, & Ware, 2021)

Summary Statistics

	Cat Bonds	U.S. Treasuries	High Yield	U.S. Equities
Annual Return	7.00%	1.30%	8.00%	8.70%
Standard Dev	3.20%	0.40%	9.40%	14.80%
Sharpe Ratio	1.8	0	0.7	0.5
Highest	3.10%	0.50%	12.10%	12.80%
Lowest	-6.50%	0.00%	-15.90%	-16.80%
% Positive Months	89%	86%	71%	67%

Figure 7: Returns of different financial asset classes (Difiore, Drui, & Ware, 2021)

Typically, CAT bonds are structured as floating-rate, principal-at-risk fixed income instruments. They range in size between $50 million to $500 million, although the market has supported deals as large as $2 billion. Duration tends to be between one-and five-years, with three to four years being the norm (Difiore, Drui, & Ware, 2021).

2.4 Marketplace

2.4.1 "The marketplace for ideas"

In 1859 John Stuart Mill argued against censorship and favored the free flow of ideas (Mill, 1864). The "marketplace of ideas" holds that the truth will emerge from the competition of ideas in free, transparent public discourse and concludes that ideas and ideologies will be culled according to their superiority or inferiority and widespread acceptance among the population (Schultz & Hudson, 2017).

This concept draws on an analogy to the economic marketplace, where economic competition results in superior products selling better than others. Thus, *the economic marketplace uses competition to determine winners and losers, whereas the marketplace of ideas uses competition to judge truth and acceptability* (Schultz & Hudson, 2017).

This is a fundamental principle underpinning the MECr that is proposed in this thesis, where the truth emerges at the conclusion of the investment period, but beforehand different ideologies create friction within society.

2.4.2 Pari-mutuel markets

Pari-mutuel markets require two or more investors to make bids on mutually exclusive (and exhaustive) outcomes that will occur in the future. After the actual outcome of the event is known, all the money that was bid on the incorrect outcomes is transferred to the bidder(s) who predicted the correct outcome, in direct proportion to the amount he/she wagered (Peters, Yinyu, & So, 2007).

By paying the winners with the losers' money, a pari-mutuel market does not expose the market maker to any financial risk (Peters, Yinyu, & So, 2007).

Significant shortcomings with traditional pari-mutuel markets include:

- Investors cannot exit a position within the market before its conclusion;
- A strong disincentive exists to invest early, as investors are best rewarded when all information is revealed immediately prior to the closure of the market (Pennock, 2004).

2.4.3 Continuous Double Auction markets

Another market type considered here is the Continuous Double Auction (CDA) market. CDA involves creating and maintaining an order book where buy and sell orders for shares are registered. The auction is "double" because traders can either place buy orders (bids) and/or sell orders (asks). The term "continuous" means that the orders could arrive at any time and be placed on the book after the auction starts. If the bid price is greater than or equal to the ask price, an order is matched, executed and ownership of the investment transferred (Zhang, Bi, & Shen, 2017).

A recent study found that these CDA markets are used to manage the risk associated with an increasingly warmer climate over short periods (Schlenker & Taylor, 2019).

2.4.3 Prediction markets

Prediction markets use trading contracts that yield payments based on the outcome of uncertain events in the future. There is mounting evidence that these markets produce forecasts of event outcomes with a lower prediction error than conventional forecasting methods, such as statistical forecast methods used by the National Weather Service (Arrow, et al., 2008).

An example of a prediction market is the IOWA Electronic market. Students can trade in contracts whose eventual payoff depends on a future event, such as an economic indicator,

a corporation's stock price returns, or even a movie's box office ticket sales (The University of Iowa, 2021).

Some prediction markets may create controversial incentives. For example, a market predicting the death of a world leader might be quite helpful for those whose activities are strongly related to this leader's policies. Still, it also might turn into an assassination market (May, 1992).

The mechanism proposed here is a new form of a predictive market. Due to more than one, non-binary outcome being utilized, the occurrence of such perverse incentives should be mitigated.

2.4.4 An existing climate risk exchange

The Chicago Mercantile Exchange (CME) offers futures contracts for certain cities on two main weather products: "cooling degree days", which measure how much cooling is necessary during hot temperatures in summer, and "heating degree days", which measure how much heating is required during cold temperatures in winter. The payoffs from these contracts depend on the observed temperatures over a specific month. The contracts are traded before the month in which the weather is realized, and thus provide a direct measure of the market's view on future climate. Effectively weather can be traded like other commodity index products (Sutton-Vermeulen, 2021).

An exchange to mitigate against SLR risk is not yet available.

2.5 Blockchain, Distributed Ledgers & Data Exchanges

2.5.1 Blockchain and Distributed Ledger Technology (DLT)

Distributed Ledger Technology (DLT) makes use of independent computers (referred to as nodes) to record, share and synchronize transactions in their respective electronic ledgers, instead of keeping data centralized as in a traditional ledger (Krause, Natarajan, & Gradstein, 2017). DLT is, in principle, a simple technology, but the interactions and dependencies amongst various small processes result in a complex and dynamic system. A DLT system needs to ensure the following properties within a system (Rauchs, et al., 2018):

- Shared recordkeeping: multiple parties must be collectively able to create, maintain and update a shared set of records;
- Multi-party consensus: a pre-determined permissionless or permissioned consensus mechanism to agree on a shared set of records;
- Independent validation: each participant must be able to independently verify the state of transactions and integrity of the system;
- Tamper evidence: each participant must be able to detect non-consensual changes to records; and
- Tamper resistance: no single party can independently and unilaterally change past records.

Blockchains use DLTs that track and collate the execution of digital transactions. Every executed transaction within the chain of transactions is verified and validated by the consensus of the members/nodes within the chain (i.e., without a central repository). The verification and validation processes performed are executed in a tamper-evident and tamper-resistant manner, in a distributed fashion and usually without a central authority (i.e., a bank, company, or government). At their basic level, they enable a community of users to record transactions in a shared ledger within a community, such that under normal operation of the blockchain network no transaction can be changed once published (Yaga, Mell, Roby, & Scarfone, 2018).

A significant benefit of distributed systems such as blockchain is that their power and decision-making are distributed among the stakeholders, instead of being concentrated in the hands of a few (Pentland, Lipton, & Hardjono, 2021). Blockchain is a preferred technology for this marketplace due to its trustless, secure, and reliable technology characteristics required for digital transactions. Being trustless means that involved participants do not need to know or trust each other or a third party for the system to function.

The insurance industry has deep expertise to identify, quantify and price risks, but is finding it challenging to understand distributed ledger technology and to develop a design/blueprint of how to adopt this technology within the industry (Popovic, et al., 2020).

IBM noted that blockchain could improve catastrophe bonds *by replacing the human interventions which are currently embedded throughout the entire risk transfer process, frictional delays and the risks of human error are completely removed – with a radical effect on the speed and efficiency of the process and, in the case of bonds, on the tradability of such securities* (IBM Global Business Services, 2019).

Another benefit of using a distributed ledger mechanism is that it increases transparency and fairness in the process. Transparency is improved in that the trigger event is dependent on data generated by an independent, third party and transaction ledgers are visible to all participants. Fairness is also enhanced, as policyholders receive the same coverage, depending on the physical risk characteristics of their property and their assessment and need for SLR risk coverage.

DLT enables the instantaneous peer-to-peer exchange of value to realize the highlighted benefits. By incorporating smart contracts into this structure, business logic can be automated, reducing operational friction and costs and ultimately realizing operational efficiencies.

Ricardian contracts

"A Ricardian Contract can be defined as a single document that is a) a contract offered by an issuer to holders, b) for a valuable right held by holders, and managed by the issuer, c) easily readable by people (like a contract on paper), d) readable by programs (parsable like a database), e) digitally signed, f) carries the keys and server information, and g) allied

with a unique and secure identifier. In the simplest possible terms, a Ricardian Contract is a document defining a type of value for issuance over the Internet. It identifies the Issuer, being the signatory, and any terms and clauses the Issuer sees fit to add in to make the document stand as a contract" (Grigg, 2004).

Contracts are put into electronic form and signed using digital signature technologies. This captures a reasonable and acceptable representation of the paper and ink contracts, bolstered with cryptographic integrity. With the hash as the identifier, the software can uniquely identify a given financial arrangement and confirm a strong signatures chain. The hash strongly implies that the contract is available to a user at all times, and it cannot be changed without being noticed (Grigg, 2004).

The Ricardian Contract delivers one great benefit to the issuer - clarity in many legal and customer support questions. The user benefits from convenience, lower overall costs, and better presentation of information within a more consistent framework.

2.5.2 Data Exchanges

A data exchange is a platform that has the *permission to gather, curate and aggregate data from many different sources to allow third parties to gain insights from such data*. They act as a layer between individuals or organizations that own the data and third parties that only want to use the results from data analysis performed on such data (Pentland, Lipton, & Hardjono, 2021).

A need for more open and user-friendly climate data access has been identified to reduce vulnerabilities resulting from climate change (Overpeck, Meehl, Bony, & Easterling, 2011).

Banks are incorporating and pricing climate risk into their credit risk portfolios (and, to a lesser extent, their market risk portfolios). Specifically, they include the economic costs and financial losses that may arise from the "increasing severity and frequency of the longer-term gradual shifts of the climate such as changes in precipitation, extreme weather variability, ocean acidification, and rising sea levels and average temperatures" (Basel Committee on Banking Supervision, 2021). Climate data is required to quantify these costs.

There is generally climate data available on the past and future predicted occurrence of physical risks at a given location or across a set of locations. These data sources do differ in terms of their scope, incl. the breadth of locations, the types of physical risks they incorporate and their spatial granularity (Financial Stability Board, 2021).

There exists a need for climate data exchanges to be developed, for financial institutions and their clients to use and better understand their climate risk exposures.

2.5.3 Oracles

An “oracle” is a trusted mechanism to access, validate and transmit data from external systems to blockchain systems (Mammadzada, Mubashar, Milani, García-Bañuelos, & Matulevičius, 2020). The smart contracts used within blockchains cannot interact with external sources. Oracles are required by these smart contracts and act as a bridge between the blockchain and the external world.

Implementing oracles provides considerable conceptual challenges as they can be regarded as a central point of failure that may introduce security and trust concerns. Oracles are required to validate the data it provides to the blockchain, as once this information is recorded, it cannot be deleted. Oracles should ensure that data written into the smart contract is legitimate and correct.

3 System concept

This section describes the stakeholders of the system to address the divergent climate change views and how they will interact with it.

3.1 Stakeholder Needs Analysis

The different stakeholders in the system and their needs (in order of priority) are:

Stakeholder	Their potential output that would meet our need	Our potential output that would meet their need	Degree to which the need is currently met
Citizens (incl. juristic entities)	Funding	Defend against or profit from actual climate change outcomes	Low – additional climate risk mitigant mechanisms required
	Investment	Liquid, uncorrelated, high investment returns linked to actual climate change outcomes	Low – limited number of instruments available
	Negative publicity (reputational risk)	Privacy protection	Low – major listed entities and public personas are currently not protected from public scrutiny
City	Mitigating climate change impact within the city	Additional, cost-effective source of funding to implement climate risk mitigant projects	Low – insufficient funding available to mitigate extreme climate scenarios
	Monitor climate change risk	Climate data exchange for SLR	Low – data not conveniently accessible in a user-friendly manner
Research institutions	Skills and technology	New, alternative data sources and technologies that supports additional research in climate science, governance and funding	Medium – Boston based universities are globally renowned institutions with strong networks. Climate data skills can be improved.

3.2 Solution Problem Statement

To manage actual climate risk outcomes by trading mutually exclusive climate forecasts on the same climate risk against each other, using a fair, trustless, private and auditable marketplace.

3.3 Boston SLR measurements and outcomes

"Average monthly sea level change (%)" (AMSLC) is proposed as the metric to determine the outcome of Boston SLR. AMSLC takes high tide measurements per day and averages it by month.

This approach determines long-term trends and is less dependent on the final year value (that can have a deciding influence on "compounded annual growth rate" or the "actual rise quantum in the final year" measurement methods). AMSLC removes the effect of higher frequency phenomena to compute an accurate sea level trend and aligns with the National Oceanic and Atmospheric Administration (NOAA) methodology (Center for Operational Oceanographic Products and Services, 2020).

Using scientific modelling, the City predicts the following SLR scenarios at high tide that could happen by 2030 (City of Boston, 2016)[3]:

- "Low" rise scenario – a rise of less than or equal to 4 inches, which is equivalent to an AMSLC less than or equal to 0.037 inches;
- "Medium" rise scenario – more than 4 inches, but less than or equal to 8 inches, is equivalent to an AMSLC more than 0.037 but less than or equal to 0.074 inches;
- "High" rise scenario – more than 8 inches is equivalent to an AMSLC of more than 0.074 inches

3.4 Participants

The main investor stakeholders and participants in this system are citizens (incl. juristic entities) that want to protect against specific climate events or profit from mutually exclusive and opposing views on SLR within the Boston area. For example:

- "Sceptics" will invest in the "Low" scenario shares;
- "Optimists" will invest in the "Medium" rise scenario; and
- "Catastrophists" will invest in the "High" scenario.

3.4.1 Sceptics

A climate Sceptic believes that most of the past warming is not "only" man-made and that the amount of climate change is natural and cyclic (Meyer, 2012). Climate sceptics promote the continued use of fossil fuels, incl. coal and/or oil as an energy source, as the monetary cost of "green energy" sources does not justify the climate benefit. For example, Climate Intelligence (CLINTEL) is a foundation that fits in this category, as they believe that today's warmer weather should be appreciated, as it is likely in the future that the climate will become colder again and may even transition into the next "ice age" at some stage. CLINTEL sent a message to politicians and world leaders at COP26 where they

[3] The City identified different scenarios for 2030, 2050, 2070 and until 2100. For the purpose of the initial system design, the 2030 scenario is used. The year 2000 is used as the baseline.

supported this view, including that the "facts show that global warming is not catastrophic, and therefore, there is no climate crisis" (Berkhout, 2021).

Climate Sceptics' motive to participate in this structure is profit driven, as they deem this an opportunity to prove the opposing views wrong while increasing their wealth. It may be required to protect their identity from possible adverse publicity.

CLINTEL is an example of a sceptic that may want to participate in this structure. Historical coal and oil companies that are not planning to change their environmental focus (possibly due to continued demand from consumers) also fit in this category. This includes major companies that continue to invest in coal and oil production, such as Glencore (Denina, 2021).

3.4.2 Optimists

Optimists believe in climate change and that it can be appropriately managed through active participation and transformation. For example, they believe oil and coal are bad for the environment and should be retired, but natural gas is a suitable and pragmatic solution to meet climate change needs.

Optimists' incentive to participate is two-fold; they can access more capital to invest in climate change mitigating projects while simultaneously earning a profit.

Examples of optimists include Bill Gates (Dolan, 2021) and Bernard Arnault (Dawkins, 2019), who promote increased investment into climate friendly technologies whilst simultaneously taking a cautious approach. Certain oil & gas companies also fall in this category, for example TotalEnergies who is pivoting from "oil & gas" towards "gas only" sustainable fuel solution (GlobalData Energy, 2021).

3.4.3 Catastrophists

Younger people believe that the climate crisis continues to escalate and not enough is currently being done to address the issue. They view that their generation will carry the cost for climate change in the future (Hassan, 2021). Greta Thunberg, the young environmental activist, challenged global leaders about their climate change achievements at the United Nations summit in September 2019 when she said, "How dare you? You have stolen my dreams and my childhood with your empty words" (Vaughan, 2019).

Their incentive to participate in this project is to gain access to funding from two other types of investors that were previously unavailable, that can be used to build or enhance climate change mitigating projects.

Greta Thunberg is an example of a Catastrophist. Crowd-funding can be considered by this investor class, as this is a younger generation with little wealth. Some companies who aligned themselves to only invest into and develop climate friendly technologies, such as Enel Energy and Breakthrough Energy Ventures, also fall in this category.

3.5 Concept of Operations

A "Real-time Pari-Mutuel" (RPM) market is a decentralized marketplace that allows participants to invest and trade in different views on the outcome of the same climate risk event. The marketplace provides transparency, privacy and trust to the system stakeholders regarding their investments. A description of its operations within MECr is provided here.

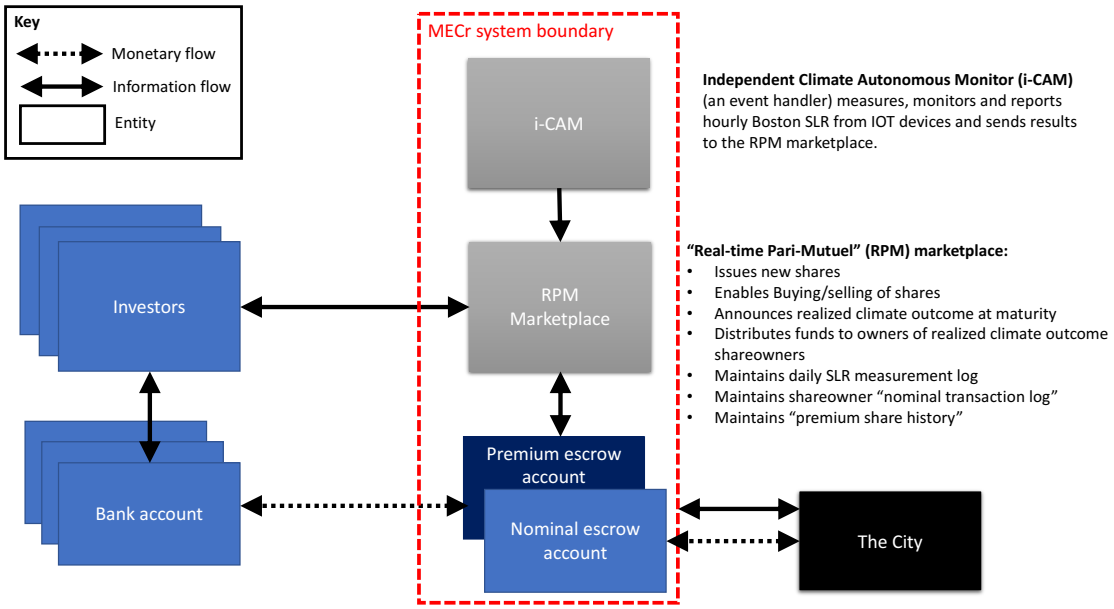

Figure 8: MECr and RPM system overview

STEP 1: Investors agree on outcomes and time horizon

1. Before launching a specific climate risk product, the mutually exclusive views\outcomes on the same climate risk are identified and agreed on by respective anchor investors, including the exact date by which the outcome will be determined and how the outcome is measured. For example, the different SLR outcomes identified by the City will be pursued by respective investors as follow:
    - "Low" scenario by climate Sceptics;
    - "Medium" scenario by Optimists; and
    - "High" scenario by Catastrophists.

STEP 2: System setup, investor registration and fund transfer:

1. The system is setup with specific investment parameters (e.g. different climate outcomes and the respective i-CAM).
2. Anchor investors will register on the system and receive a private/secret key to trade with, depending on their privacy needs.

3. Anchor investors buy the initial nominal shares issued and transfer funds into a nominal escrow account in exchange for founding shares in each climate outcome. Each share carries the same nominal value (e.g. $ 1,000 per share).
4. Each investor registered on MECr must own at least one share in any outcome to be able to trade on the system. This requires that a new share is issued to and purchased by the investor for a specific scenario(s).
5. The "nominal escrow account" is ring-fenced to the legal entity created explicitly for this scenario (a special purpose vehicle (SPV)).
6. The ownership of these nominal shares is created in the "nominal transaction ledger/log".

STEP 3: Infinite liquidity:

1. MECr, via the RPM, allows new shares to be issued and purchased at any time during the investment period, thereby allowing more capital to be introduced into the investment structure by new or existing shareholders. New shares are issued and purchased at the New Share Issue Price (NSIP), as determined by the RPM marketplace.
2. If the NSIP is greater than the nominal value of the share:

2.1 the difference in value is a premium that is paid into a separate "premium escrow account" owned by the SPV; and

2.2 a record of the entire nominal share ownership in the "nominal transaction ledger" immediately before this transaction is recorded and appended to the "premium history log".

3. The nominal value of the shares is paid into the "nominal escrow account". A corresponding entry is made in the "nominal transaction ledger" reflecting the newly created share and its ownership.

STEP 4: Managing climate view and exposure throughout investment period:

1. Investors can change their exposure to different climate views by either selling their shares or buying shares in other outcomes on the RPM marketplace via a Continuous Double Auction (CDA).
2. Money flows associated with buy/sell directions are directly between the respective investors and do not impact funds within the MECr escrow accounts.
3. Each buy/sell transaction results in a corresponding update in the "nominal transaction log" and "premium history transaction log" that captures the change in ownership of the respective share(s).
4. Investors can view all transactions and utilize the "premium history log" to price the claims of a specific share on the premium escrow account.

STEP 5: Independent climate outcome monitoring:

1. The independent Climate Autonomous Monitor (i-CAM) monitors SLR in Boston throughout the investment period, by capturing the following measurements on an hourly basis at different locations around the city:

    - Tide gauges; and
    - Satellite altimeters (Lindsey, 2021)
2. The NOAA Center for Operational Oceanographic Products and Sources (CO-OPS) can be used as the data source (Center for Operational Oceanographic Products and Services, 2020).
3. I-CAM sends each hourly measurement through to the RPM that appends the respective value, date and time to the "SLR measurement log".

STEP 6: Result and fund disbursement:

1. When the investment maturity date is reached, the RPM calculates the AMSLC for the entire period.
2. The RPM will automatically announce the actual SLR outcome.
3. The RPM will disburse all funds to the owners of the correct outcome shares in which this outcome resides. Funds are disbursed as follow:
    - Funds in the "nominal escrow account" are paid to each winning share owner, directly proportional to the number of shares they own per the "nominal transaction ledger". Each share is entitled to the same amount;
    - Funds in the "premium escrow account" are disbursed proportionally to the cumulative number of shares owned by a respective shareholder as reflected in the "premium history log". All shares in the "premium history log" are added up and the total amount of funds in the "premium" escrow account is divided by this total. After that, the funds are disbursed proportionally according to the shareholders' cumulative representation within the "premium history log".
    - Suppose no shareholders are available in the "premium history log". In that case, any available funds in the "premium escrow account" are distributed according to the "nominal transaction ledger" directly proportional to the number of shares each winning shareholder owns.

[OPTIONAL]: City support

1. The City can support this structure and use it as an insurance instrument to protect against specific climate outcomes (e.g. the medium and high SLR outcomes).
2. If the City provides support, they commit to paying insurance premiums to the structure for them to access a portion of the funds of specific scenarios, for example the "Medium" and "High" scenarios. If the insured scenarios are the ultimate climate outcomes, these funds can be re-directed to immediately fund the principal of a newly issued bond for the City to build climate risk mitigating infrastructure. These insurance premiums are paid to the "nominal escrow account".
3. The City will design climate risk mitigating infrastructure solutions for the "Low" scenario. But these designs will also be scalable and can be extended to address the risks of the higher risk scenarios, if required (e.g. build a higher sea wall).
4. Each successful outcome investor will receive at least their initial investment plus the insurance premiums back. The available funds are to be distributed as follow[4]:

[4] This is an example and the percentages are subject to change as required.

4.1 In the “low” scenario outcome:

4.1.1 the City did not insure and receives no funds;

4.1.2 the investors that invested in the actual outcome immediately receives 70% (seventy percent) of all the funds in the “nominal escrow account” and 100% (one hundred percent) of the funds in the “premium escrow account”;

4.1.3 the investors that invested in the scenario that was second (2^{nd}) closest to the actual outcome immediately receive 30% of the funds in the “nominal escrow account” (i.e. incurs a loss but does not lose all of their investment).

4.2 In the “medium” scenario outcome:

4.2.1 33% (thirty-three percent) of the funds in the “nominal escrow account” is to fund the principle of an infrastructure bond issued by the City that the winning investors own in proportion to their shareholding. The coupon of this bond will be priced lower for the City, by deducting a portion of the insurance premium that has already been paid to the investors from the annual interest rate;

4.2.2 the winning investors receive 50% (fifty percent) of all the funds in the “nominal escrow account” and 100% (one hundred percent) of the funds in the “premium escrow account”;

4.2.3 the investors that invested in the scenario that was 2^{nd} (second) closest to the actual outcome receives 17% (seventeen percent) of all the funds in the “nominal escrow account” (i.e. incurs a loss, but does not lose all of their investment and benefits from the infrastructure that is being built).

4.3 In the “high” scenario outcome:

4.3.1 50% (fifty percent) of the funds in the “nominal escrow account” is to fund the principle of an infrastructure bond issued by the City that the winning investors own in proportion to their shareholding. The coupon of this bond will be priced lower for the City, by deducting the insurance premium that has already been paid to the investors from the annual interest rate;

4.3.2 the winning investors receive 33% (fifty percent) of all the funds in the “nominal escrow account” and 100% (one hundred percent) of the funds in the “premium escrow account”;

4.3.3 the investors that invested in the scenario that was 2^{nd} (second) closest to the actual outcome receives 17% (seventeen percent) of all the funds in the “nominal escrow account” (i.e. incurs a loss, but does not lose all of their investment and benefits from the infrastructure that is being built).

5. The City can immediately implement infrastructure upgrades at the conclusion of the investment period with the infrastructure bond. The City builds and operates the infrastructure asset, but the winning outcome shareholders own the asset until the bond is repaid. If the entire capital and interest are repaid at the end of the period, the City takes ownership of the asset.

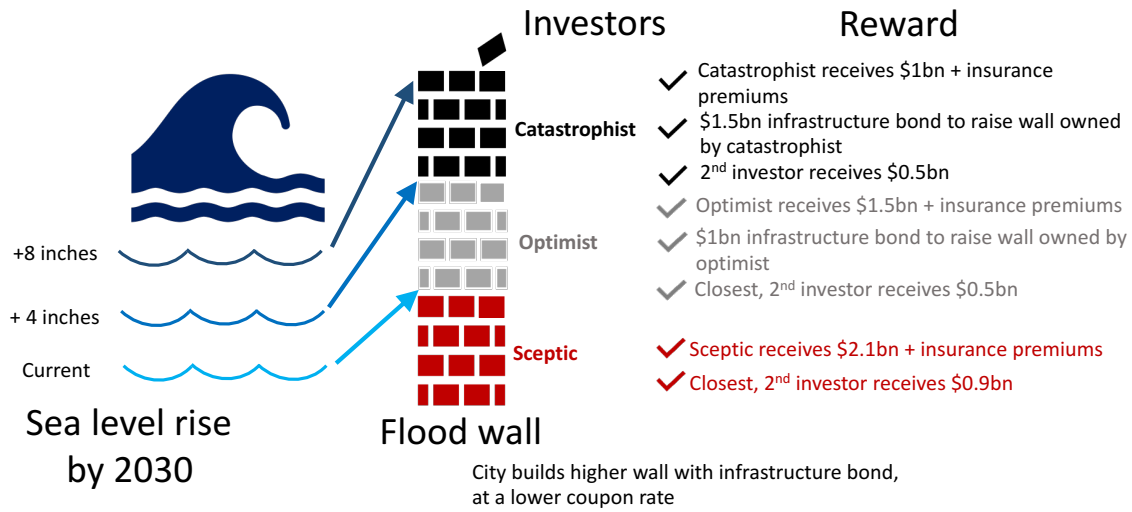

Figure 9: Example of the City using MECr market as an insurance instrument and the incentive/reward for investors to participate. Each investor type invests $1bn.

3.6 Price premiums

To overcome the shortcomings of conventional pari-mutuel markets (Pennock, 2004), a pricing mechanism is proposed to reward early investors that take the greater risk in the investment and capture the benefit of "infinite liquidity" that the mechanism allows. This is accomplished by newer investors paying a premium to existing shareholders on the issuance of new shares based on:

- The time passed when they enter the market; and
- Demand for a specific share type at a particular point in time.

3.6.1 Time premium

New shares are issued at a premium. This premium is paid to the existing shareholders of the same share type, equal to the rate of return of the anchor investors without any new shares being issued, adjusted for the period when they enter the market. Effectively existing shareholders will earn this time premium return risk-free (if they bought shares in the correct outcome). This is to compensate investors for the greater risk and uncertainty they face when making earlier investments.

The New Share Issue Price (NSIP) time premium increases the issued share price as follow:

$$NSIP_{time,d} = Price_{A,tO}(1+i)^{d}$$

where:

- $NSIP_{time,d}$ is the NSIP adjusted for the time premium on day d;

- $Price_{A,t0}$ is the nominal share price for share Class A at the issue date t0 (in this paper it defaults to $1000);
- *i* is the *locked-in daily return* of anchor investments at launch for the specific share type *X;*
- *d* is the number of days passed since the issue date.

The *locked-in daily return* for anchor investments at launch is calculated as follow:

$$\left(\frac{Sum\ of\ all\ Issued\ Share\ Prices\ at\ launch}{Sum\ of\ issued\ Share\ Prices\ of\ Share\ type\ X\ at\ launch}\right)^{\frac{1}{n}} - 1$$

Where:

- *n* is the number of days from issue until maturity;
- *type X* is the Share type.

The *Time Premium* paid for a specific share is calculated as follow:

$$Time\ Premium = NSIP_{time,d} - Nominal\ Share\ Price$$

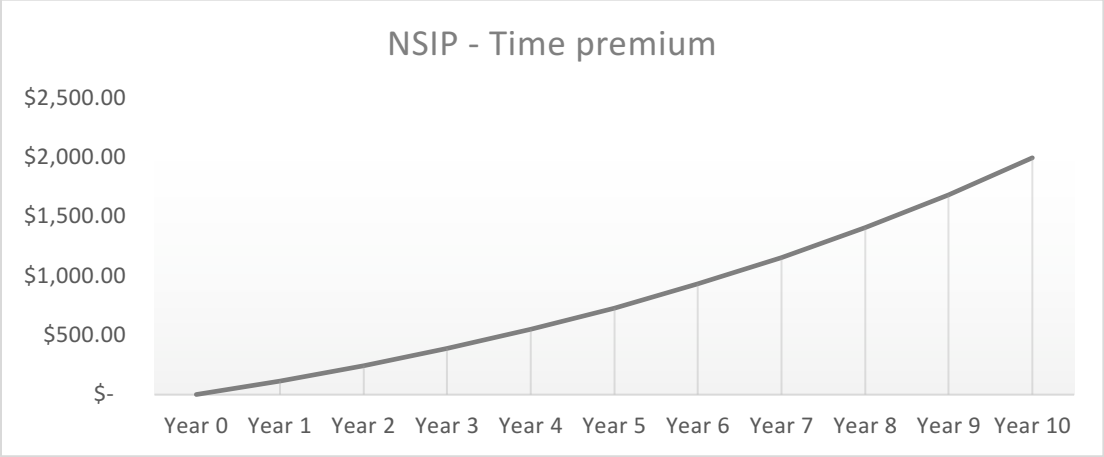

Figure 10: Time Premium added to a nominal share valued at $1,000

3.6.2 Demand premium

To mitigate against late-comers utilizing buying power to acquire material stakes in an investment, that can materially decrease the returns of earlier investors, a logarithmic S-curve demand premium is used to increase the price of new shares issued. This should incentivize new investors to purchase a minimum number of new shares, and larger stakes are pursued by trading existing shares. It also gives increased comfort to existing shareholders that their returns will not be materially altered from when they made their investments.

The NSIP demand premium on any given day is calculated as follow:

$$NSIP_{demand,d} = (\max - NSIP_{time,d}) * \left(\frac{1}{(1 + e^{-k(x-x_0)})}\right)^a$$

where:

- $NSIP_{demnd,d}$ is the NSIP adjusted for the Demand premium on day *d*;
- $NSIP_{time,d}$ is the NSIP adjusted for the Time Premium on day d;
- max is the maximum price of a share;
- *e* is the *exponent;*
- *k* is a parameter that controls the shape of the S-curve. The larger k>0, the later the growth starts into fast growth and the steeper growth;
- *x* is the number of new shares already purchased on that day, by the ten thousand (10^5);
- x_0 is the mean number of new shares to be purchased per day, defaulted to 50,000 per day;
- *a* is another parameter that controls the shape of the S-curve. The lower the value (a>0), the sooner the start to fast, less steep growth.

$$Demand\ premium = NSIP_{demand,d} - NSIP_{time,d}$$

The S-curve for the Demand premium based on different demand levels per day, is illustrated below for the following parameters:

- $NSIP_{time,d}$ *= $1,000*
- max *is* 2 *x* $NSIP_{time,d}$*, i.e. $2,000*
- *k = 2, x0 = 2, a = 1*

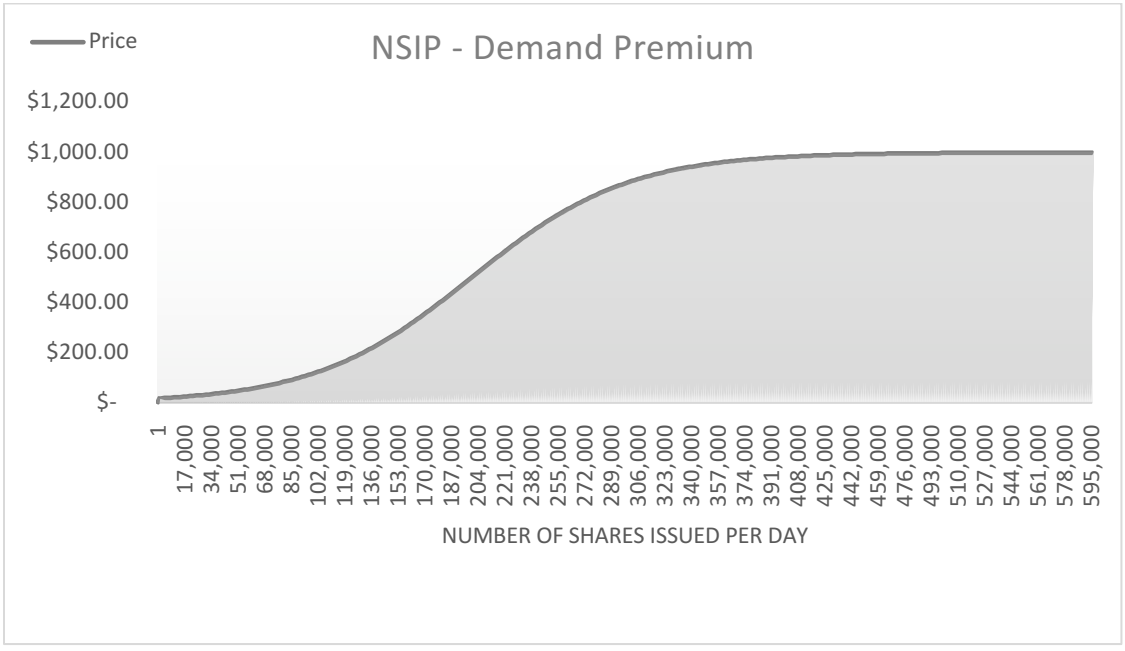

Figure 11: Demand premium based on number of new shares issued per day

3.6.3 Premium escrow account

The Time and Demand premiums are separated from the nominal share price and paid into a separate "premium escrow" account. The remaining nominal share price (fixed throughout the investment period) is paid into the "nominal escrow" account. These premiums are paid to all share owners that existed before issuing a new share, which is maintained in the "premium history log".

3.7 Price premium examples[5]

Three simple scenarios were modelled to highlight how the price premium impacts return to shareholders and incentivize behavior[6].

No interim trading during the period is considered (as per the CDA market). The CDA market is a mechanism to allow investors to change their exposure to different outcomes or exit an investment early. If demand for specific outcome shares increases as more information becomes available, the prices for those shares should increase accordingly and demand for unfavorable outcomes should decrease (as per the design of CDA markets). Note that the trading of shares between buyers and sellers' results in funds directly transferred between their personal accounts. The funds in the nominal or premium escrow accounts are not affected.

3.7.1 Only anchor investors

For the scenario where three (3) anchor investors buy one (1) million shares each at $1,000 (one thousand dollars) per share each on day 0 (the setup stage), the share purchase profile and investment returns for the different outcomes are shown in the following figures.

- Investor A buys shares in the "Low" outcome scenario;
- Investor B in the "Medium" (Med) outcome scenario;
- Investor C in the "High" outcome scenario.

[5] To illustrate how these price premiums incentivize investor behavior, the scenario is where no support is received from the City (i.e. no insurance premiums received or bonds issued) and the "winner takes all" (i.e. the 2nd closest investor receives no return).

[6] Results are based on an 11-year investment period.

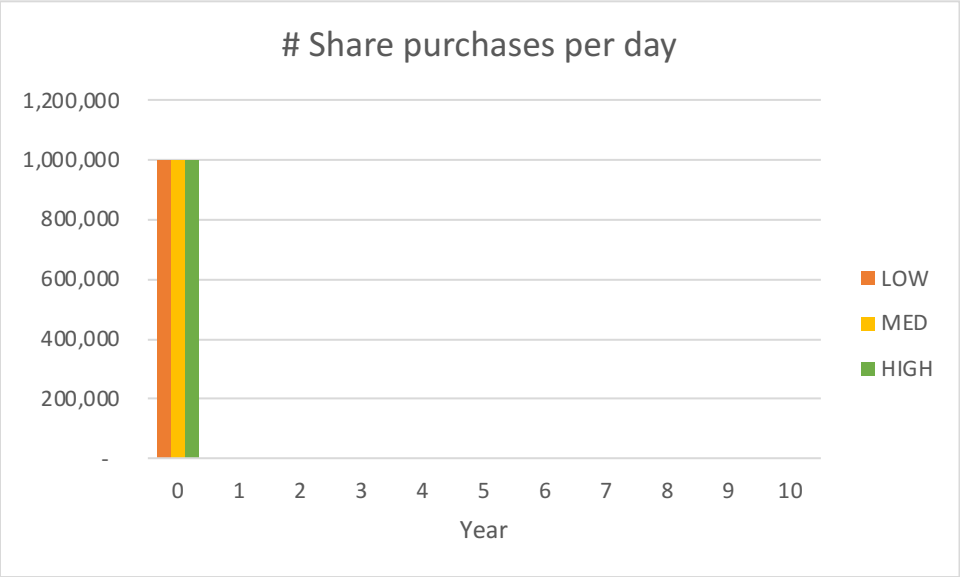

Figure 12: Scenario A - 1 million shares purchased for each outcome on Day 0

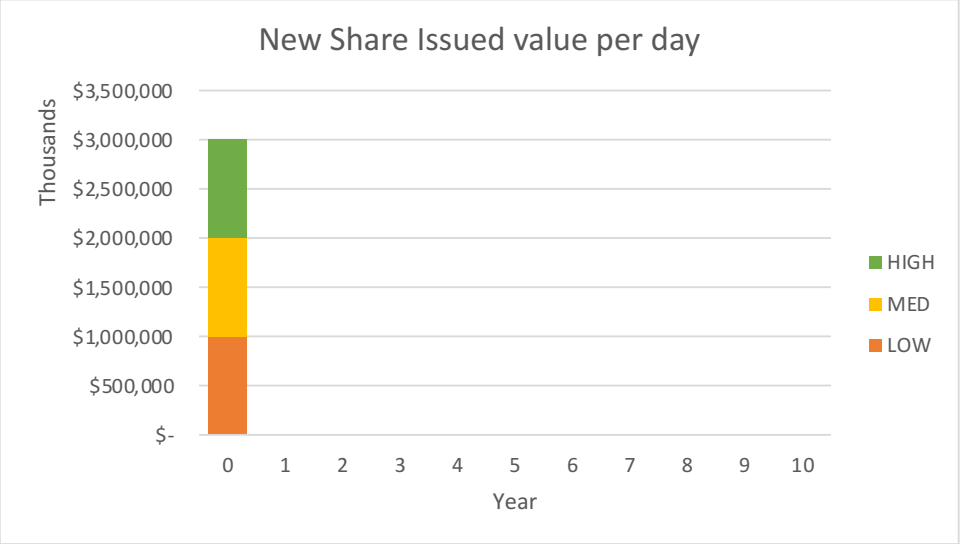

Figure 13: Scenario A - Total value of shares issued per year

	RETURN PER ANNUM FOR EACH OUTCOME		
	LOW	MEDIUM	HIGH
Investor A	11.61%	-7.18%	-7.18%
Investor B	-7.18%	11.61%	-7.18%
Investor C	-7.18%	-7.18%	11.61%

Figure 14: Scenario A - Return per annum for each outcome

The returns for the successful outcome outperform other financial classes (refer to Figure 7) while also being uncorrelated to conventional markets[7].

[7] These returns can be enhanced if the funds are invested into high quality, low risk instruments such as US Treasuries, similar to CAT bonds.

3.7.2 Changing climate views and small investors

For the scenario where:

- 3 anchor investors each buys 1 million shares at $1,000 per share on day 0;
  - Investor A buys shares in the "Low" outcome scenario;
  - Investor B in the "Medium" (Med) outcome scenario; and
  - Investor C in the "High" outcome scenario.
- A new investor, Investor D, buys 500,000 new "High" outcome shares in Year 1 at $2,229.49 per share;
  - The NSIP consist of a "Time premium" of $116.12 and a "Demand premium" of $1,113.36 above the nominal $1,000 per share
- Investor C changes their exposure by buying 50,000 new "Medium" outcome shares in Year 3 at $1,456.33 per share;
  - The NSIP consist of a "Time premium" of $390.39 and a "Demand premium" of $65.94 above the nominal $1,000 per share
- A new investor, Investor E, buys 1,000 new "Med" outcome shares in Year 7 at $2,229.49 per share;
  - The NSIP consist of a "Time premium" of $1,157.69 and a "Demand premium" of $39.58 above the nominal $1,000 per share

The share purchase profile and investment returns for the different outcomes are as follow:

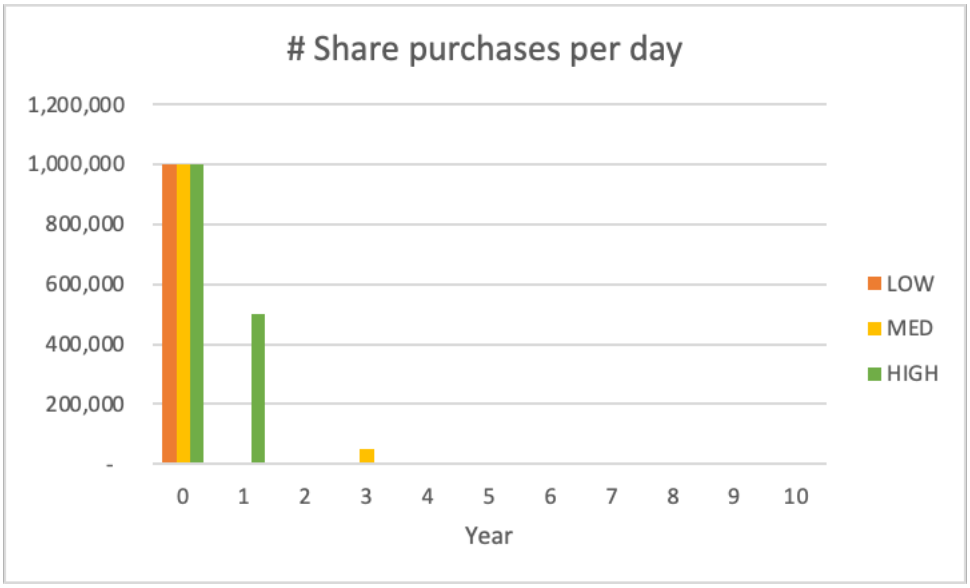

Figure 15: Scenario B - Changing of exposure and new, small investors buying shares

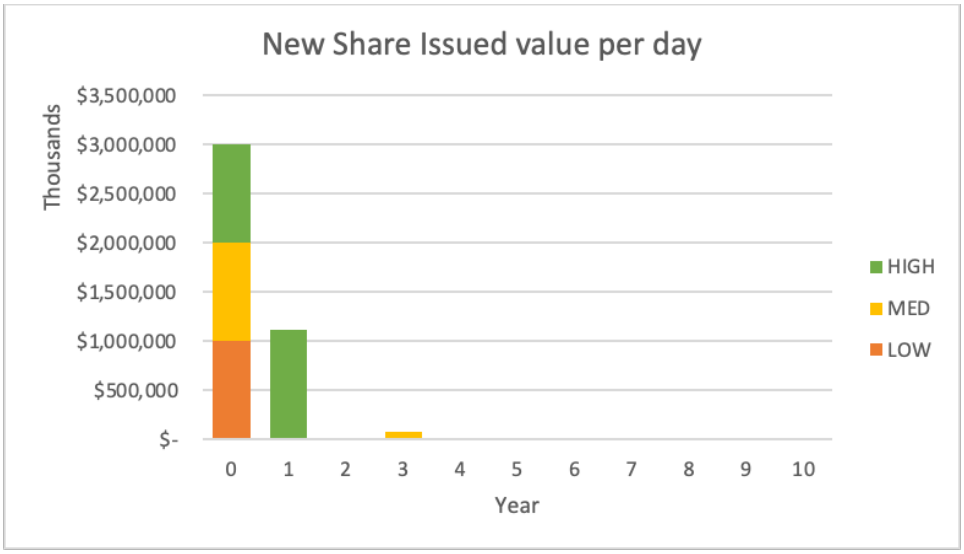

Figure 16: Scenario B - Value of new shares being issued

	RETURN PER ANNUM FOR EACH OUTCOME		
	LOW	MEDIUM	HIGH
Investor A	15.40%	-7.18%	-7.18%
Investor B	-7.18%	14.88%	-7.18%
Investor C	-7.18%	-6.22%	10.85%
Investor D	-7.18%	-7.18%	0.60%
Investor E	-7.18%	4.40%	-7.18%

Figure 17: Scenario B - Return per annum for each outcome

The following is noted:

- The "Demand premium" that Investor D pays for new "High" shares is high and results in a low return. Investor D can pursue buying shares from Investor C at a lower price than the NSIP, which can provide more favorable outcomes for both shareholders (Shareholder C can take some profit earlier). The returns due to Investor C in the "High" outcome scenario also decrease due to Investor D increasing the number of "High" shares in issuance by 50%, as well as Investor C losing with its Medium share purchase.

- The "time premium" that Investor C pays for "Medium" shares is significant and results in a negative return to the investor. Investor C can pursue buying shares from Investor B directly at a lower price than the NSIP, which can provide more favorable outcomes for both shareholders (Shareholder B can take some profit earlier). Investor B's return does decrease, but lesser because of the time premium it receives from Investor C.

- Investor E, which buys a small amount of new "Medium" shares fairly late in the investment period, can still generate a positive return due to a smaller market entry position. Investor E can now increase its exposure to this share type by buying shares from either Investor B or Investor C.

3.8.3 Large, later-stage investors with buying power

For the scenario where:

- 3 anchor investors each buys 1 million shares at $1,000 each on day 0;
    - Investor A buys shares in the "Low" outcome scenario;
    - Investor B in the "Medium" (Med) outcome scenario; and
    - Investor C in the "High" outcome scenario.
- A new investor, Investor D, buys 1,000,000 new "Low" outcome shares in Year 8 at $4,816.45 each;
    - The NSIP consist of a "Time premium" of $1,408.12 and "Demand premium" of $2,408.22 above the nominal $1,000 per share
- A new investor, Investor E, buys 1,000,000 new "Med" outcome shares in Year 10 at $6,000.00 each;
    - The NSIP consist of a "Time premium" of $2,000.00 and "Demand premium" of $3,000.00 above the nominal $1,000 per share

The share purchase profile and investment returns for the different outcomes are as follow:

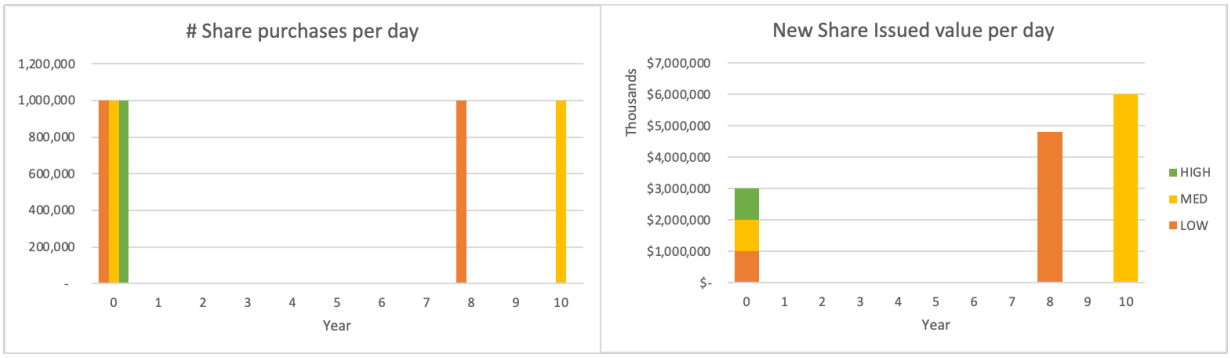

Figure 18: Scenario C - Share purchase profile where bidders try to benefit from late information

The returns for this scenario is as follow:

	RETURN PER ANNUM FOR EACH OUTCOME		
	LOW	MEDIUM	HIGH
Investor A	27.46%	-7.18%	-7.18%
Investor B	-7.18%	27.46%	-7.18%
Investor C	-7.18%	-7.18%	30.03%
Investor D	-4.00%	-7.18%	-7.18%
Investor E	-7.18%	-4.70%	-7.18%

Figure 19: Scenario C - Return per annum for each outcome

The following is noted:

- Large, late investors cannot "game" the returns of the initial investors through brute buying power of newly issued shares. They should focus on buying shares from other investors to be able to generate a positive return;

- Investors A and B generate the same return for the “Low” and “Medium” outcome scenarios. This is because each investor earns all the nominal returns and share premiums from the respective escrow accounts.

3.8 Benefits

The benefits that MECr can realize for investors include:

- Uncorrelated investment class with high returns;
- Infinite buy-in liquidity as anyone can take a position at any time;
- Zero risk to the market institution as money is only distributed amongst investors and cannot be greater than the amount invested;
- Investors can buy and sell their shares at any time enabling continuous incorporation of new information;
- Pricing of new shares positively correlated to time in the market and demand for a specific share at a particular point in time;
- Additional funding sources introduced that previously would not have been available;
- If supported by the City, climate risk mitigating infrastructure can be built or enhanced more timeously at a lower cost. In this instance, all investors receive some benefit, as the actual climate outcome is addressed which impacts them directly;
- Costs to manage climate change is aligned with the actual climate change;
- Such an instrument can be launched every 10 or 15 years, for the City to gain access to cost-effective capital to build the required infrastructure of the actual climate outcome (if required).

3.9 Market challenges

The following are challenges with this structure that may limit its feasibility:

- Risky investment class as majority of investors will receive a negative return;
- A fairly long lock-in period for the anchor investors, as climate risks are also long term in nature (for example the City of Boston catered scenarios until 2030, 2050, 2070 and 2100);
- No market maker is available to accept sell orders;
- End of term payouts can be change if the number of new shares issued is material;
- Funds are only available once the investment term is concluded.

3.10 Proposed enhancements

The following improvements could enhance the product:

- Additional returns are to be earned if escrow funds are invested in high quality, liquid investments such as US Treasuries. This can enhance annual returns by 1.3% (Difiore, Drui, & Ware, 2021);
- The City could use this structure as insurance and pay premiums to cater to the risk of prevailing Medium and High scenarios. The City could utilize funds from these investors to build risk mitigating infrastructure (e.g., higher sea walls);

- If the final outcome requires that mitigating climate infrastructure be built, enhanced or expanded upon, the respective winning shareholders could earn an additional return on these assets over their lifetime, e.g. via the issuance of a bond by the City that the winning shareholders own.

4 System design

This design focuses only on the RPM marketplace sub-system within MECr. It is responsible for the main functionality of the system.

4.1 Principles

In determining the requirements for the RPM marketplace, the following principles guide system development. The system must be:

- Fair: A system that does not discriminate against a correctly behaving player is said to be fair (Asokan, 1998);
- Trustless: Players must trust the system and not each other or third parties for the system to function;
- Consistent: Nodes within the system must have access to the same ledger at the same time (Kanga, Azzouazi, El Ghoumrari, & Daif, 2020)
- Simple: Simpler explanations of observations should be preferred over more complex ones (Bratspies, 2018)
- Auditable: An audit trail must be available for all transactions (COSO, 2020)

4.2 Options analysis

An options analysis is performed to evaluate different architectural decisions that lead to the most appropriate design to meet stakeholder needs. The respective options considered were:

	Option 1	Option 2	Option 3	Option 4
Governance	Centralized	Decentralized		
Market	Pari-mutuel	Continuous double auction	Bookmaker	Real-time Pari-mutuel
Maturity	5-years	10-years	15-years	20-years
Consensus mechanism	Proof of Work	Proof of Stake	Proof of Elapsed Time	Proof of Authority
Privacy	Permissioned	Permissionless		
Blockchain framework	Ethereum	R3 Conda	Hyperledger Fabric	
Trigger	Indemnity	Parametric	Industry loss	Modelled loss
Measurement	Difference in Final Year and Start year (inches)	Compounded annual growth rate (%)	Average monthly change (%)	

The preferred system concept is one with:

- Governance enforced through a **decentralized** structure can improve transparency, privacy and realize efficiencies while avoiding the participation of "trusted" third parties. It allows for increased automation, which should result in lower transaction and system costs (both administrative and operational). Decentralization, combined with

verified digital identities, can profoundly impact capital markets by enabling standardized yet customizable products to be built and used by approved stakeholders.

- A **Real-time Pari-Mutuel** (RPM) pricing mechanism is proposed to price new shares. No risk is taken by the market institution as all the winnings (after transaction fees) are distributed to the winners. Pari-mutuel pricing has infinite liquidity and the real-time adjustments of RPM allow participants to react to new information and cash out if wanted. RPM also mitigates the bias of standard pari-mutuel pricing to make purchases immediately before closing a pricing round (to incorporate all available into the purchasing decision).

- The City identified the first scenario for SLR due in 2030, which is closest to a **10-year maturity** when the investment will be realized and returns paid to respective shareholders/stakeholders[8]. The average green bond maturity in the US is 12 years (Baker, Bergstresser, Serafeim, & Wurgler, 2018), which is closest to 10 years.

- A **"Proof of Stake"** consensus mechanism will allow a small, core group of founding members to be responsible for the system's governance. This creates an additional incentive for participants to be founding/anchor investors. It also gives increased comfort to "sponsors" of specific products that the system can mitigate against "Sybil Attacks" occurring (Lipton & Treccani, 2022)". This mechanism requires that the majority of bidders, based on their shareholding at the launch, need to approve and agree on the truth of the ledger.

- **Permissioned** privacy enforces access controls that allow that participants be known and approved beforehand, to mitigate the ability of bad actors to influence outcomes. This means that the system can comply with regulations relevant to the financial services industry, such Know-Your-Customer (KYC) and Anti-Money Laundering (AML). It will also be allowed that participants remain private, to protect them from possible negative public rhetoric.

- **Hyperledger Fabric** is selected as the blockchain framework because it is open-source and hosted by the Linux Foundation that promotes trust, governance, and interoperability. Its modular architecture enables network designers to "plug-in" and update preferred implementations of components (Hyperledger, 2017).

- A **parametric trigger** is to be used as the trigger event. This requires a measurable characteristic of the covered risk (e.g. SLR levels) at a set of predetermined locations. A parametric trigger is the most transparent option and allows for a fast payout since the readings of the physical parameter values are immediately available. The New York City Metropolitan Transportation Authority (MTA) launched its first CAT bond as a parametric trigger. The trigger used was based on the water height at selected tidal gauges chosen (Braun & Kousky, 2021).

[8] There are bonds available with 30-year terms, and the US is testing the market for longer terms (Saeedy, 2019). For example, climate bonds can have terms of greater than 30-years (Siswantoro & Syakhroza, 2018).

- **Average monthly change (%)** is used to determine the outcome, as it helps to determine long term trends and is less dependent on the final year value than the other two metrics. This approach removes the effect of higher frequency phenomena to compute an accurate sea level trend, and is aligned with NOAA methodology (Center for Operational Oceanographic Products and Services, 2020).

4.3 System decomposition

A modular design is to be pursued for the RPM marketplace that consists of the following modules:

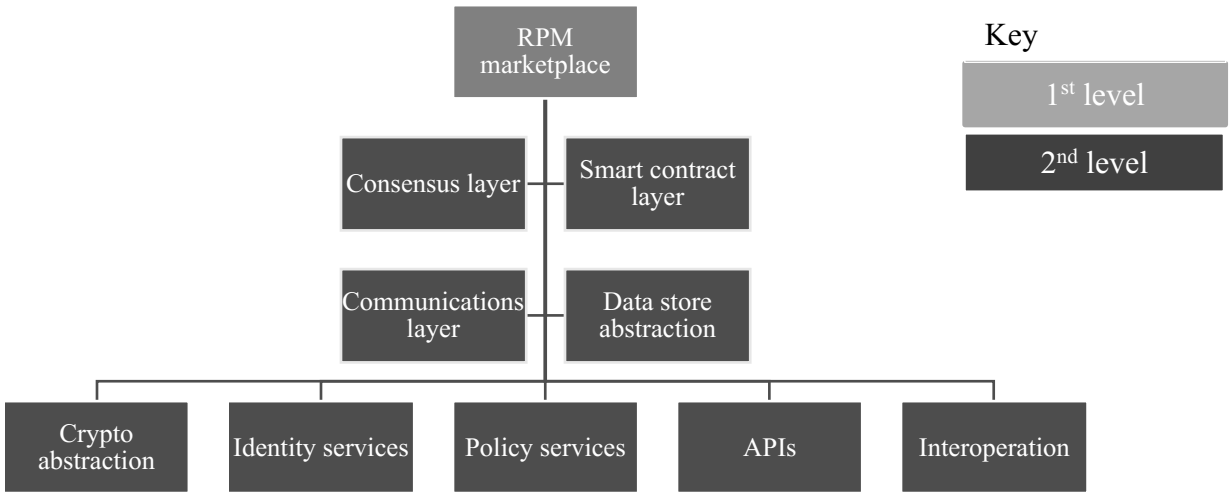

Figure 20: 2nd level decomposition of Hyperledger Fabric framework (Hyperledger, 2017)

Each module is responsible for the following (Hyperledger, 2017):

- Consensus layer: Must reach agreement on the order and confirm the correctness of the set of transactions that constitute a block;
- Smart contract layer: Ensures correct processing of transaction logic and determines whether transactions are valid by executing business logic;
- Communication layer: Enables peer-to-peer messaging;
- Data store abstraction: Allows different data stores to be used by other modules;
- Crypto abstraction: Allows different crypto algorithms (or modules) to be swapped out without affecting other modules.;
- Identity services: Enables the establishment of a root trust during the setup of a blockchain instance, the enrollment and registration of identities or system entities during network operation, and the management of changes like drops, adds, and revocations. Also provides authentication and authorization;

- Policy services: Responsible for managing various policies specified in the system, such as the endorsement policy, consensus policy or group management policy. It interfaces and depends on other modules to enforce the various policies;
- APIs: Enables clients and applications to interface to blockchains;
- Interoperation: Support the interoperation between different blockchain instances.

4.3.1 Interfaces

The RPM marketplace interfaces with two external sub-systems, the i-CAM and the respective investors. It will use oracles to communicate with them.

4.4 System model

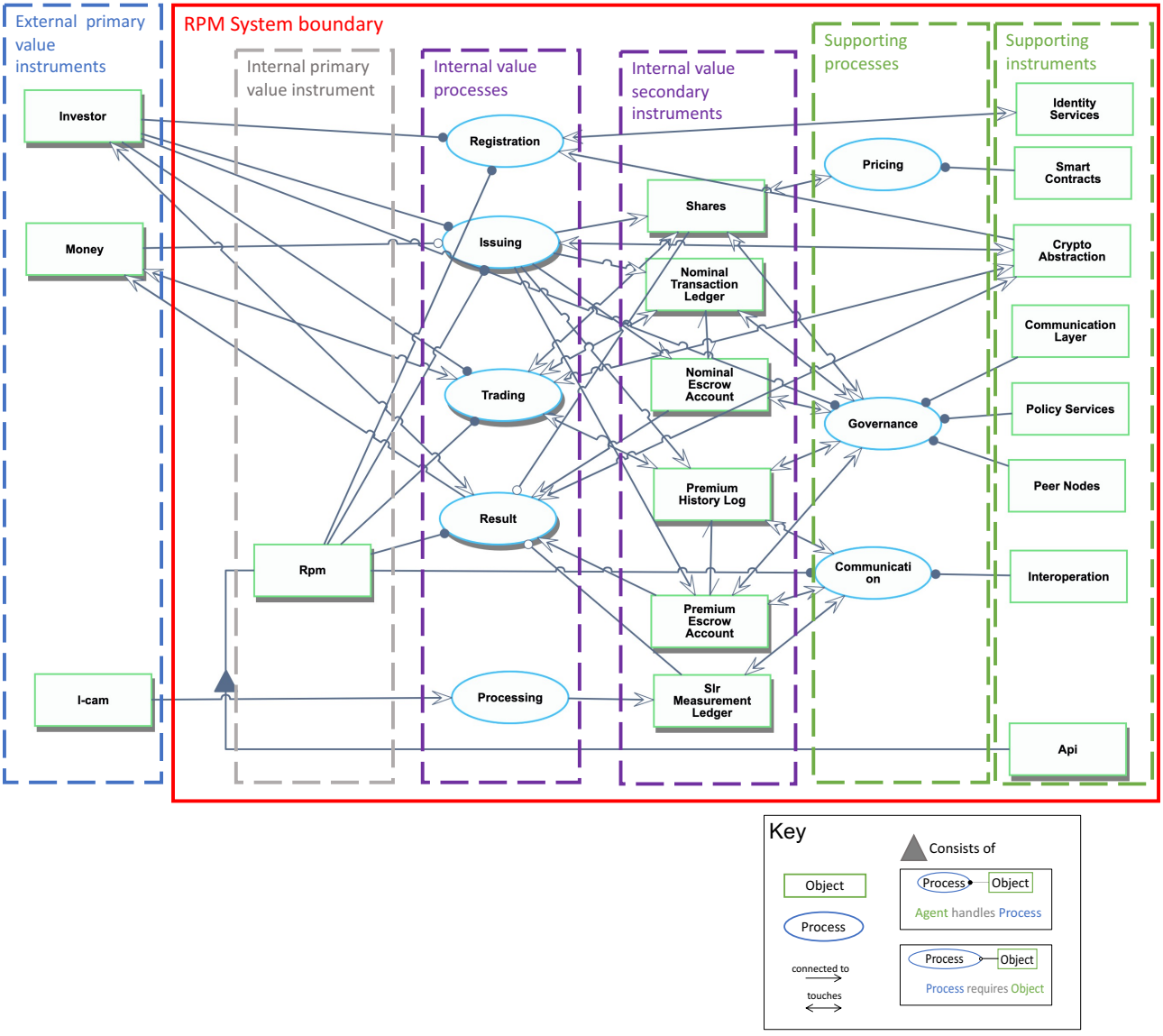

Figure 21: Object Process Methodology (OPM) model of the RPM marketplace

Investors are the main external entity in the model. They will invest, buy new shares and trade shares throughout the investment period.

4.4.1 Value-adding services

The main value-adding processes and instruments within the system are:

- Investors registering on the system;
- Shares are issued and traded in each of the different climate outcomes;
- The Nominal Transaction Ledger (also referred to as the "nominal transaction log") maintains the ownership of all the nominal shares;
- The Nominal Escrow Account stores all funds used to purchase new shares at nominal value;
- When a new share(s) is issued, the Premium History Log records and appends the share ownership history immediately prior to the issue of that new share(s);
- The Premium Escrow Account stores the difference in funds for newly issued shares between the NSIP price and the nominal share value (i.e. the time and demand premiums);
- The Sea Level Rise (SLR) Measurement Log records the sea level rise values received from the i-CAM;
- The final result announcement of disbursement of funds.

4.5 Governance

4.5.1 Smart contracts

The RPM marketplace consists of assets that enable the exchange of monetary value over a network, using smart contracts that enforce the business rules related to different transactions. Each smart contract has endorsers that check compliance with the business rules and endorse the transactions for that contract if its conditions are satisfied.

Some examples of smart contract business rules include:

- If a share is being sold, the person selling the share is also the owner of the share;
- If an entity is buying a new or existing share, they must have sufficient funds available to conclude the transaction;
- If a "new" share is issued and bought, the funds are transferred to the "normal" and "premium" escrow accounts of the investment;
- If an "existing" share is bought, the buyer transfers the funds directly to the seller's account.

4.5.2 Peer nodes and transaction processing

Peer nodes are a fundamental element of the network because they host ledgers and smart contracts. In the RPM marketplace, the investor submits a transaction request to the peer nodes. The request consists of the smart contract method and supporting data to execute. The transaction is validated and signed by the respective peer nodes. After the transaction is validated, the peer nodes submit the transaction to an order node(s) to chronologically

order the transactions. Then the peer nodes run the core consensus routine with all the received transactions and append the new records to the blockchain.

4.5.3 Endorsement policies

Endorsement policies define the smallest set of organizations required to endorse a transaction for it to be valid. To endorse, an organization's endorsing peer needs to run the smart contract associated with the transaction and sign its outcome. When the ordering service sends the transaction to the committing peers, they will each individually check whether the endorsements in the transaction fulfill the endorsement policy. If this is not the case, the transaction is invalidated and will not affect the world state.

The RPM marketplace requires that if most peer nodes, or the validators, agree on a proposed block, then this block is appended to the blockchain. This is a Proof of Stake or voting consensus mechanism, as each peer is allowed to vote with the shares they purchased when the network was initialized (i.e. their founding shares).

4.6 User stories

Critical but straightforward MECr user stories are provided below.

4.6.1 MECr initialization

As an anchor investor, we need to setup a reusable trading environment in a fast and efficient manner, to focus on the outcome of the climate risk and not the development of the technology.

Condition of satisfaction
All the system environments, including databases, must be automatically created when the anchor investors agree on the terms of the investment. The environment must allow for minimal customization to accommodate the specific terms of the investment and launch with only integration required with the i-CAM.

4.6.2 Investor registration

As an investor, I need to register on the system without the involvement of any third party. I need to participate anonymously if required, so I am not exposed to any unwanted attention.

Condition of satisfaction
I would like to register via a website on the system and provide all required documentation in a digital format without engaging with another person. If required, I am provided with a secret key during registration that only I know, which is how I will engage with the system in the future.

4.6.3 Liquidity

As an investor, I need to be able to protect against one or multiple climate outcomes at any time during the investment period so that I can actively manage the risk.

Condition of satisfaction
I can buy any number of shares in different climate outcomes at any time.

4.6.4 Price premiums

As an investor, I do not want later stage investors who have better information to be detrimental to my returns.

Condition of satisfaction
I receive compensation from investors who participate later to reward the greater risk my earlier investment was exposed to.

4.6.5 Trading

As an investor, I want to be able to change my view on the climate outcome or exit the investment before its maturity date.

Condition of satisfaction
I can buy and sell shares at prices at any time during the investment period before the maturity date.

4.6.6 Outcome

As an investor, I want an independent party that is not susceptible to influence or bias to determine the winning outcome.

Condition of satisfaction
An independent, trusted third party determines the outcome based on a single, authoritative, measured and agreed metric and respective data sources (e.g. a data exchange).

4.6.7 New share issuance, trading and announcing the result

The lifecycle for shares in the RMP marketplace is represented in the following state transition diagram:

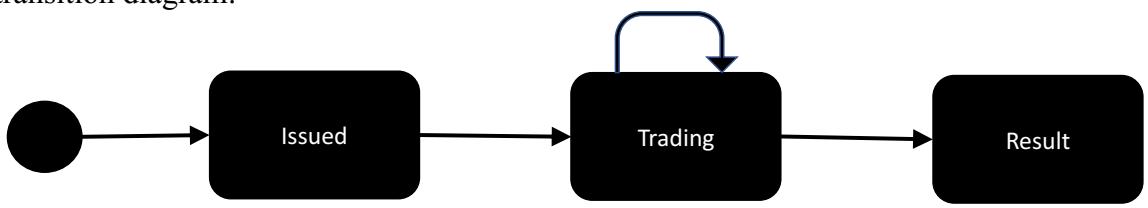

Figure 22: State transition diagram to issue and trade shares

4.7 Example[9]

As an example, the following transactions in chronological order should result in the updated "blocks" of the "nominal share" and "premium share" transaction logs and escrow accounts being created in the chain:

1. On 1 January 2022, 1,000,000 shares @ $1,000.00 per share are issued for each Low, Medium and High scenario for SLR risk in the City of Boston.

Nominal escrow account value:	$ -

Nominal transaction ledger										
ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	RPM	Hi_001_iss	1,000,000	High	$1,000.00	1/1/22	12/31/31			issued
2	RPM	Med_001_iss	1,000,000	Med	$1,000.00	1/1/22	12/31/31			issued
3	RPM	Low_001_iss	1,000,000	Low	$1,000.00	1/1/22	12/31/31			issued

Premium escrow account value:	$ -

Premium transaction ledger					
ID	Owner	Share_ID	Number of shares	Share Type	Issue Date

Figure 23: Nominal and premium escrow account and transaction ledger after Step1

2. Sarah Polin is the anchor investor for the Low scenario and buys the initial shares, but prefers to remain anonymous and uses the secret key of "Little Birdie" to trade on the platform. Paul Reveered is the anchor investor for the Medium shares and Greta Thunderberg for the High scenario shares. The shares are bought and transferred at the nominal value of each share is $1,000.

[9] Respective owner names are only used for illustrative purposes.

Nominal escrow account value:	$ 3,000,000,000.00

Nominal transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	Little Birdie	Hi_001_tra	1,000,000	High	$1,000.00	1/1/22	12/31/31	$1,000.00	12/31/31	trading
2	Paul Reveered	Med_002_tra	1,000,000	Med	$1,000.00	1/1/22	12/31/31	$1,000.00	12/31/31	trading
3	Greta Thunberg	Low_001_tra	1,000,000	Low	$1,000.00	1/1/22	12/31/31	$1,000.00	12/31/31	trading

Premium escrow account value:	$ -

Premium transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Date

Figure 24: Nominal and premium escrow account and transaction ledger after Step2

3. A new High scenario share is issued on 1 Jan 2023 which Paul Reveered buys. He pays $1,136.20 for the share, of which $1,000 is transferred to the nominal escrow account and $136.20 to the premium account. Because of the new share issuance, the history of the transactions prior to this issuance is recorded in the Premium history log.

Nominal escrow account value:	$ 3,000,001,000.00

Nominal transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	Greta Thunberg	Hi_001_tra	1,000,000	High	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
2	Paul Reveered	Med_002_tra	1,000,000	Med	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
3	Little Birdie	Low_001_tra	1,000,000	Low	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
4	Paul Reveered	Hi_002_tra	1	High	$1,136.20	1/1/23	12/31/31	$1,136.20	1/1/23	trading

Premium escrow account value:	$ 136.20

Premium history log

ID	Owner	Share_ID	Number of shares	Share Type	Issue Date
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
2	Paul Reveered	Med_002_tra	1,000,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22

Figure 25: Nominal and premium escrow account and transaction ledger after Step3

4. On 1 Mar 2023, Little Birdie buys 10,000 Medium shares from Paul Reveered. She pays $1,100 for each share, and Paul Reveered receives $11,000,000 in his own personal account[10]. The respective escrow accounts are unaffected.

[10] Note that ownership of the respective shares in the initial single batch is now broken into two share batches. Both the nominal transaction ledger and premium history log are updated to reflect this and the change in ownership.

Nominal escrow account value:	$ 3,000,001,000.00

Nominal transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	Greta Thunberg	Hi_001_tra	1,000,000	High	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
4	Paul Reveered	Med_003_tra	990,000	Med	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
3	Little Birdie	Low_001_tra	1,000,000	Low	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
5	Paul Reveered	Hi_002_tra	1	High	$1,136.20	1/1/23	12/31/31	$1,136.20	1/1/23	trading
6	Little Birdie	Med_004_tra	10,000	Med	$1,000.00	1/1/22	12/31/31	$1,100.00	1/3/23	trading

Premium escrow account value:	$ 136.20

Premium history log

ID	Owner	Share_ID	Number of shares	Share Type	Issue Date
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
4	Paul Reveered	Med_003_tra	990,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22
5	Little Birdie	Med_004_tra	10,000	Med	1/2/22

Figure 26: Nominal and premium escrow account and transaction ledger after Step4

5. Another 1,000 High scenario shares are issued on 1 Jan 2025 which new investor Warren Bugger buys. He pays $1,415.89 per share, of which $1,000 is the nominal value and $415.89 is the risk premium.

Nominal escrow account value:	$ 3,001,001,000.00

Nominal transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	Greta Thunberg	Hi_001_tra	1,000,000	High	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
4	Paul Reveered	Med_003_tra	990,000	Med	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
3	Little Birdie	Low_001_tra	1,000,000	Low	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
5	Paul Reveered	Hi_002_tra	1	High	$1,136.20	1/1/23	12/31/31	$1,136.20	1/1/23	trading
6	Little Birdie	Med_004_tra	10,000	Med	$1,000.00	1/1/22	12/31/31	$1,100.00	1/3/23	trading
7	Warren Bugger	Hi_003_tra	1,000	High	$1,415.89	1/1/25	12/31/31	$1,415.89	1/1/25	trading

Premium escrow account value:	$ 416,026.20

Premium history log

ID	Owner	Share_ID	Number of shares	Share Type	Issue Date
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
4	Paul Reveered	Med_003_tra	990,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22
5	Little Birdie	Med_004_tra	10,000	Med	1/2/22
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
4	Paul Reveered	Med_003_tra	990,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22
5	Paul Reveered	Hi_002_tra	1	High	1/1/23
6	Little Birdie	Med_004_tra	10,000	Med	1/1/22

Figure 27: Nominal and premium escrow account and transaction ledger after Step5

6. Results with City support

These results are calculated with City support, as per par 3.5 "Concept of Operations, [OPTIONAL] City support".

The following assumptions are made:

- The City requires additional insurance against the Medium and High outcome scenarios. For this coverage, the City pays an annual insurance premium of fifty basis points (0.5%) on $1.25bn (one billion, two hundred and fifty million dollars)[11]. This increases the escrow account by $6.25mm (six million, two hundred and fifty thousand dollars) per annum, increasing the nominal escrow account by $62.5mm (sixty two million, five hundred thousand dollars) over the ten (10) years;
- Currently the City pays on a 10-year (ten-year) bond an interest rate of 5% (five percent) per annum (City of Boston, Massachusetts, 2020). A portion of the insurance premiums paid to MECr before any bond issuance will be deductible from the respective bonds' interest rate.

Immediately prior to the conclusion of the investment, the respective ledgers and escrow account balances are as follow:

Nominal escrow account value:	$ 3,063,501,000.00

Nominal transaction ledger

ID	Owner	Share_ID	Number of shares	Share Type	Issue Price per share	Issue date	Maturity date	Purschase Price	Purchase date	Current state
1	Greta Thunberg	Hi_001_tra	1,000,000	High	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
4	Paul Reveered	Med_003_tra	990,000	Med	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
3	Little Birdie	Low_001_tra	1,000,000	Low	$1,000.00	1/1/22	12/31/31	$1,000.00	1/1/22	trading
5	Paul Reveered	Hi_002_tra	1	High	$1,136.20	1/1/23	12/31/31	$1,136.20	1/1/23	trading
6	Little Birdie	Med_004_tra	10,000	Med	$1,000.00	1/1/22	12/31/31	$1,100.00	1/3/23	trading
7	Warren Bugger	Hi_003_tra	1,000	High	$1,415.89	1/1/25	12/31/31	$1,415.89	1/1/25	trading

Premium escrow account value:	$ 416,026.20

Premium history log

ID	Owner	Share_ID	Number of shares	Share Type	Issue Date
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
4	Paul Reveered	Med_003_tra	990,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22
5	Little Birdie	Med_004_tra	10,000	Med	1/2/22
1	Greta Thunberg	Hi_001_tra	1,000,000	High	1/1/22
4	Paul Reveered	Med_003_tra	990,000	Med	1/1/22
3	Little Birdie	Low_001_tra	1,000,000	Low	1/1/22
5	Paul Reveered	Hi_002_tra	1	High	1/1/23
6	Little Birdie	Med_004_tra	10,000	Med	1/1/22

Figure 28: Nominal and premium escrow account and transaction ledger status immediately prior to the results announcement

[11] $1.25bn is the average between the two scenarios ($1bn and $1.5bn, respectively) of the infrastructure bond the City can raise.

At 24:00 on 31 December 2030, the RPM calculates that the AMSLC over the period was 0.008 inches and announces that the High scenario was the actual outcome and the second closest was the Medium scenario.

A summary of the share ownership and trades at maturity is provided in the table below:

		Nominal Shares		Residual Shares		Trading				Infastructure Bond		Total
Owner	Share Type	# of Shares	Value ($ '000)	# of Shares	Value ($ '000)	Shares bought	Value ($ '000)	Shares sold	Value ($ '000)	Ownership (%)	Value ($ '000)	Returns ($ '000)
Greta Thunberg	Low		$ -		$ -						$ -	$2,540,563
	Med		$ -		$ -						$ -	
	High	1,000,000	$ 1,009,944	2,000,000	$ 400					99.9000%	$ 1,530,219	
Paul Reveered	Low		$ -		$ -						$ -	$ 526,585
	Med	990,000	$ 515,582	1,980,000	$ -			10,000	$11,000		$ -	
	High	1	$ 1	1	$ 0					0.0001%	$ 2	
Little Birdie	Low	1,000,000	$ -	2,000,000	$ -						$ -	$ 5,208
	Med	10,000	$ 5,208	20,000	$ -	10,000	$11,000				$ -	
	High		$ -		$ -						$ -	
Warren Bugger	Low		$ -		$ -						$ -	$ 2,540
	Med		$ -		$ -						$ -	
	High	1,000	$ 1,010		$ -					0.0999%	$ 1,530	
Total		**3,001,001**	**$ 1,531,745**	**6,000,001**	**$ 400**	**10,000**	**$11,000**	**10,000**	**$11,000**		**$ 1,531,751**	**$ 3,074,896**

Figure 29: Example - Summarized ownership and trades of MECr at maturity

The returns[12] of each investor is as follow:

	Total investments	Total returns	Investment returns
Greta Thunberg	$ 1,000,000,000	$ 2,540,563,127	154%
Paul Reveered	$ 1,000,001,136	$ 526,584,840	-47%
Little Birdie	$ 1,011,000,000	$ 5,207,900	-99%
Warren Bugger	$ 1,415,890	$ 2,540,163	79%

Figure 30: Example - Total returns of each investor

The transactions relevant to each investor's returns are as follow:

- Nominal share returns[13]:
  - 1,001,001 "High" shares in issue in the nominal transaction log. The winning shares are entitled to 33% of the funds in the nominal escrow account; therefore each share receives $1,009.94[14] immediately:
    - Greta Thunberg owns 1,000,000 High shares;
    - Paul Reveered owns 1 High share;
    - Warren Bugger owns 1,000 High shares;
  - 1,000,000 Medium in issue in the nominal transaction log and is the second closest shares to the actual outcome. This share pool is entitled to 17% of the funds in the nominal escrow account, therefore each share receives $520.79 immediately.
    - Paul Reveered owns 990,000 Medium shares;
    - Little Birdie owns 10,000 Medium shares;

[12] Returns exclude the coupons to be earned by the infrastructure bond owners and any additional returns that may be realized if the funds were invested into low risk, highly liquid assets during the investment period.
[13] All the funds in the "nominal escrow" account are disbursed to the winning share owners directly proportional to the number of shares they own.
[14] All values are rounded down to hundredths.

- Residual share returns[15]:
  - 2,000,001 "High" shares reflected in Premium transaction log; therefore, each share receives $0.20 immediately;
  - Greta Thunberg is entitled to the returns of 2,000,000 of these shares, therefore $400,000;
  - Paul Reveered is entitled to the returns of 1 of these shares, therefore $0.20;
- Trading
  - Little Birdie bought 10,000 Med shares from Paul Reveered at a cost of $1,100 share. Paul Reveered earned a profit of $1,000,000 on his initial investment. Funds related to this transaction are paid directly from Little Birdie to Paul Reveered.
- Infrastructure bond issuance:
  - The City issues a bond with a face value of $1,531,750,500 and a coupon of 4.6%[16];
  - Greta Thunberg owns 99.9% of the infrastructure bond;
  - Paul Reveered owns 0.0001% of the infrastructure bond;
  - Warren Bugger owns 0.0999% of the infrastructure bond;
  - The City saves 0.6% per annum over the life of the bond, i.e. $6,172,002 per year or $61,720,020 over 10-years (depending on the term of the bond);
  - In this scenario, the City received insurance coverage for $250mm more than what it paid for.

[15] All the funds in the "premium escrow" account are disbursed according to their proportion of the history of the winning outcome shares reflected in the premium transaction ledger.

[16] The City paid an insurance premium of $6.25mm per annum. This equates to 0.4167% (rounded to 0.4%) of a principle with a value of $1.5bn. This amount has already been paid to the investor and is deducted from the coupon rate of the newly issued infrastructure bond.

5 Conclusions and recommendations

5.1 Conclusion

MECr is a novel concept to address different and opposing climate views, that can mitigate against a possible extreme eventuality. Parties that previously may not have participated in the same funding structure due to their different views and needs, can now form investment vehicles whereby “new” and “different” funding sources are introduced to address future climate outcomes. In an increasingly polarizing society, MECr may even serve a unifying purpose by getting people in the wrong to make financial contributions to those in the right.

Privacy protection mechanisms also allow investors to take contentious positions, possibly making new capital available.

The development of climate related data exchanges that monitors actual climate change can become the de-facto source of climate risk data. This should address a significant gap currently, where financial institutions and other entities are required to model physical climate risk with limited data sources being available.

A conventional pari-mutuel marketplace can become a dynamic exchange where people can trade different views against each other, to protect against possible extreme outcomes. It can also offer a sponsoring entity a more cost-effective mechanism to insure against unwanted outcomes.

By utilizing a decentralized and trustless governance structure, parametric trigger events and i-CAMs, funds can be made available quickly and transparently to address the eventual outcome, improving the agility and trust of conventional insurance instruments. The automated nature of such a system should also result in lower administrative and operational cost over the period of the investment.

Finally, a sponsoring entity such as the City may address climate change more appropriately and cost-effectively. By converting a fairly lost cost insurance premium into a low-cost infrastructure bond that builds physical climate risk-mitigating infrastructure, the significant damage and economic losses associated with even more extreme climate catastrophe events can be mitigated.

5.2 Recommendations for future work

The author would like to recommend the following for future work:

- testing MECr in the market as a climate insurance mechanism (and obtaining appropriate pricing);
- enhancing the demand price mechanism, so that poor demand results in price reductions;
- developing an outcome adjudication metric that incorporates advanced trend analysis; and

- the extensive development of climate data exchanges in different locations throughout the world.

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