Carbon Quantitative Easing: Scalable Climate Finance for Managing Systemic Risk

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ABSTRACT

The climate crisis brings complex challenges for economists, policy makers, and politicians. In recent years the mandates of central banks, which tend to promote 'sector neutrality', have been scrutinised for not supporting a low-carbon transition. Here we propose that the mandates of central banks can be expanded based on a revision to the 'standard model' for externalised costs. The expanded model is comprised of two kinds of cost: the first is the Social Cost of Carbon (SCC), and the second is the Risk Cost of Carbon (RCC). The RCC is a relatively new concept, and it may be described as the monetisation of climate-related systemic risk. The RCC is equivalent to the cost of 'preventative insurance' against unwanted climate change. For example, the RCC can be estimated for the objective of avoiding 2°C of global warming with a 67% chance of success.

The RCC links to a game-changing monetary policy that can provide scalable climate finance and manage systemic risk. The policy is called a Global Carbon Reward, and the financial mechanism involves a long-term program of 'carbon quantitative easing' (CQE) and currency trading. CQE requires a currency instrument—called a Central Bank Digital Currency (CBDC)—to act as an international unit of account for carbon (i.e. 100 kg of CO_2-e mitigated). A policy framework for internalising the SCC and the RCC into the economy is discussed in terms of barriers to change, social principles, market neutrality, and environmental and social governance (ESG). A recommendation is given for financial regulators to research the macroeconomics of CQE, and to consider a new macroprudential role for central banks in response to climate change.

Keywords
Climate change, central bank, systemic risk, social cost, quantitative easing, risk cost, externality, market failure, insurance, hypocognition

Carbon Quantitative Easing: Skalierbare Klimafinanzierung für systemische Risikosteuerung

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ABSTRACT

Die Klimakrise bringt komplexe Herausforderungen für Ökonomen, politische Entscheidungsträger und Politiker mit sich. Die Mandate der Zentralbanken, welche üblicherweise Sektorneutralität verfolgen, sind in den letzten Jahren zunehmend auf den Prüfstand gestellt worden, da sie den Übergang auf eine CO_2-arme Wirtschaft nicht unterstützen. Wir empfehlen hier, dass die Mandate der Zentralbanken erweitert werden können auf der Grundlage einer Überarbeitung des Standardmodells für ausgelagerte Kosten. Das erweiterte Modell besteht aus zwei Arten von Kosten: erstens die sozialen Kosten von Kohlenstoff (SCC) und zweitens das Kostenrisiko von Kohlenstoff (RCC). Das RCC ist ein relativ neues Konzept, welches als Monetarisierung des klimabezogenen systemischen Risikos bezeichnet werden könnte. Das RCC ist vergleichbar mit den Kosten einer Vorsorgeversicherung gegen unerwünschten Klimawandel. Zum Beispiel könnte das RCC zur Vermeidung der Erderwärmung von 2°C mit einer Erfolgsaussicht von 67% beziffert werden.

Das RCC stellt eine wegweisende Geldpolitik dar, die skalierbare Klimafinanzierung und Risikosteuerung liefern kann. Die Richtlinie heißt Global Carbon Reward und die finanzielle Strategie umfasst ein langfristiges Programm von strategisch-quantitativer Lockerung namens *carbon quantitative easing* (CQE) sowie einen Devisenhandel. CQE benötigt ein Währungsinstrument—die Central Bank Digital Currency (CBDC)—um als internationale Rechnungseinheit für Kohlenstoff (d. h. 100 kg CO_2-Äq. gemildert) zu dienen. Politische Rahmenbedingungen, welche die SCC und das RCC mit in die Wirtschaft aufnehmen, werden erörtert hinsichtlich von Barrieren im Zusammenhang mit Veränderung, sozialen Kriterien, Marktneutralität sowie Umweltmanagement und Sozialpolitik (ESG). Eine Empfehlung für Finanzaufsichtsbehörden besteht darin, die makroökonomischen Vorteile von CQE zu untersuchen und eine neue Rolle für Zentralbanken zu erwägen, um eine makroprudenzielle Regulierung der Wirtschaft zu gewährleisten.

Keywords

Klimawandel, Zentralbank, systemisches Risiko, soziale Kosten, quantitative easing, Kostenrisiko, Externalität, Marktversagen, Versicherung, Hypokognition

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1 INTRODUCTION

In this paper we define an ‘expanded model’ for understanding the costs and risks of climate change, and we recommend an ‘expanded policy framework’ for addressing these costs and risks. The entire discussion is qualitative, and references are cited for details on the economic theory.

We begin in Section 2 by presenting terminology for two major types of climate-related systemic risk, in relation to (1) the 2015 Paris Climate Agreement under the UNFCCC; and (2) findings of the Task Force on Climate-related Financial Disclosures (TCFD) and the Financial Stability Board.

In Section 3 we consider the shortcomings of the ‘standard model’ for the externalised cost of carbon emissions. The standard model is based on the *Social Cost of Carbon* (SCC). We describe a second cost for managing systemic risk: the *Risk Cost of Carbon* (RCC). The expanded model challenges long-held assumptions about the externalised cost of carbon and it offers a doorway to new policy options.

In Section 4 we describe a public policy that can internalise the RCC into the economy. The policy is called a *Global Carbon Reward*, and it involves an unconventional monetary policy called *Carbon Quantitative Easing* (CQE). We explain how central banks can use CQE and a Central Bank Digital Currency (CBDC) to mobilise scalable climate finance and regulate the climate-related systemic risk.

In Section 5 we discuss human cognition, sector neutrality, and environmental and social governance (ESG). We explain why the RCC shines a light on the notion of preventative insurance as a *public good*; and we describe the relevant social principles based on the term *Collective and Systemic Risk Insurability* (CASRI).

In Section 6 we offer our concluding remarks for governing institutions and stakeholders; and in Section 7 we provide our recommendations for policy reviews and assessments.

2 CLIMATE RELATED SYSTEMIC RISKS

A consensus has emerged in the science community that unmitigated greenhouse gas emissions will cause the climate to experience tipping points that herald irreversible damages and systemic changes to the planetary ecosystem (e.g. Lenton, 2012; Fischer et al., 2018; Steffen et al., 2018). This justifies the use of the term ‘climate systemic risk’, as recommended by Aglietta and Espagne (2016), however man-made climate change could produce a variety of systemic risks, including financial, social, political, biological, military, etc. We use the term ‘climate-related systemic risks’ to refer to the universal set of these systemic risks (see Figure 1)

There is a need to clarify the specific types of ‘systemic risk’ that are being discussed, because it is not always obvious that the risks are different for different stakeholders. Here we define two major types of systemic risk in relation to the (1) the 2015 Paris Climate Agreement (UNFCCC, 2015); and (2) public statements by the Financial Stability Board (TCFD, 2017). The two relevant types of systemic risk are defined here as: (1) physical systemic risk, and (2) financial systemic risk, respectively (see Figure 1). The terminology is explained below.

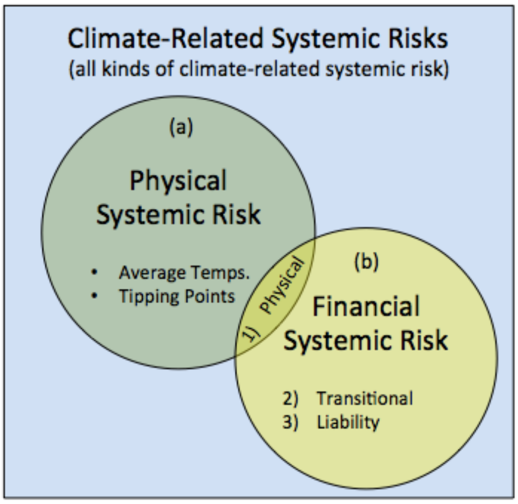

Figure 1. Venn diagram of climate-related systemic risks, including two overlapping sub-sets: (a) physical systemic risk and (b) financial systemic risk.

2.1 Physical Systemic Risk

Here we define the term 'physical systemic risk' to refer to the immediate physical risks associated with climate change (refer Figure 1). Awareness of the physical systemic risk is centred on the 2015 Paris Climate Agreement and the possibility of passing 1.5°C/2°C of global warming, which further risks catastrophic climate change and a 'Hothouse Earth' because of positive feedbacks in the climate system (Fischer et al., 2018; Steffen et al., 2018). The 1.5°C and 2°C warming limits are mentioned in Article 2 of the Paris Climate Agreement, as follows:

> "*Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;* " (UNFCCC, 2015; Article 2(a)).

For the Paris Agreement to be effective in managing physical systemic risk, the Agreement should define the 1.5°C and 2°C average temperature rises in terms of acceptable levels of uncertainty. This is necessary because risk is by definition "*the effect of uncertainty on objectives*" (ISO, 2018).

A hypothetical example of a magnitude of uncertainty for fulfilling the Paris Agreement is to petition a 67% chance of staying below 2°C (i.e. to accept a 33% chance of exceeding 2°C). Uncertainty limits—also called risk tolerances—are needed to define the risk management objective. To be effective in delivering the risk management objective, the Paris Agreement should also provide a legal framework and a financial mechanism. The Paris Agreement has shortcomings of a political nature, however as claimed in Section 3, the shortcomings of the Paris Agreement are also linked to the standard model for the Social Cost of Carbon (SCC).

2.2 Financial Systemic Risk

We define a second term—called 'financial systemic risk'—to specifically refer to the following three sources/types of climate-related financial risk that were previously identified by the Prudential Regulation Authority (2015) and the Financial Stability Board (TCFD, 2017):

(1) physical risk, arising directly from climate change and weather-related events;
(2) transitional risk, arising from the process of adjusting to a lower-carbon economy; and
(3) liability risk, arising from parties who have suffered loss or damage.

The term ‘financial systemic risk’ mentioned here is different to the ‘physical systemic risk’ mentioned to in Section 2.1 (and in reference to the 2015 Paris Agreement). The Paris Agreement is mainly concerned with 1.5/2°C of global warming as physical limits. The Financial Stability Board, on the other hand, is mainly concerned with the stability of the financial system. As shown in Figure 1, the (a) physical systemic risk and the (b) financial systemic risk overlap where there are immediate financial risks due to climate change impacts and extreme weather (refer (1) above).

To clarify the remainder of this discussion, a key assumption is that to manage the financial systemic risk it is necessary to also manage the physical systemic risk because climate change is the root cause of all climate-related systemic risks. The following revision to the model for externalised costs is directly relevant to the assessment and management of the physical systemic risk.

3 EXPANDED MODEL FOR EXTERNALITIES

It is an ‘open secret’ within the economics literature that the *ideal* carbon tax—a global carbon tax that perfectly matches official estimates of the Social Cost of Carbon (SCC)—will not be sufficient to meet the Paris ambition of avoiding 2°C of global warming. Boyce (2018) gives the following explanation for this anomaly:

> “*Conventional SCC measures, in turn, generally fall below the carbon prices that are likely to be required to meet the Paris goal. The divergence between the lower SCC and higher Paris-consistent prices reflects the difference between neoclassical efficiency and climate safety as normative criteria for policy making.”* (p.1).

Boyce’s (2018) comment suggests that a choice can be made between an efficiency-based approach and a risk-based approach for policy making. Aglietta and Espagne (2016) argue that improving market efficiency should not be relied upon as a governance framework, and that the SCC should be abandoned in favour of collective insurance for climate safety.

Limitations to the benefits of improving market efficiency have been discussed as early as the 19th century, when the economist William Jevons wrote a book titled the “The Coal Question” and presented the notion of demand rebound under increasing energy efficiency (Jevons, 1866). In the following sections we discuss a solution to the dual problems of (a) market efficiency, and (b) systemic risk, by expanding the standard model for the externalised costs of carbon emissions.

3.1 Social Cost of Carbon (SCC)

The Social Cost of Carbon (SCC) is the time-discounted economic welfare loss caused by an additional tonne of carbon dioxide (CO_2) emissions or its equivalent. The standard model for the externalised cost of carbon emissions is based on the SCC, as indicated in Equation 1. The standard policy response is to tax carbon emissions to internalise the SCC, as indicated in Figure 2. The standard approach is to select market-based climate policies based on cost-benefit analysis (CBA). CBA is efficiency orientated and supports the objective of achieving efficient markets.

As mentioned above, the standard model does not necessarily provide a roadmap for staying below 2°C of global warming. This is because the SCC is not a risk-based cost metric. Mark Carney (2015, 2016)—Chairman of the Financial Stability Board—explained to financial regulators that climate change results in a *Tragedy of the Horizon*, which is the market’s apparent inability to address the temporal problems of climate change. Some economists have attempted to adjust the various time discounting parameters as a method of hedging against the systemic risks of climate change (e.g. Weitzman, 2010; Dietz, Gollier and Kessler, 2018), but such approaches have not been met with broad acceptance. Adjusting the time discounting can even lead to paradoxical results in terms of future consumption and investment (e.g. Nordhaus, 2007b). In the following section we present an amendment to the standard model for addressing the physical systemic risks created by carbon emissions.

$$\mathit{Externalised\ Cost\ of\ Carbon} = \mathrm{SCC}(t)\,\hat{n}$$

where t is time; $\hat{n}$ is a unit vector denoting a negative externality; and SCC is the Social Cost of Carbon (US$ per 1000 kg of CO_2-e emissions[1]) which is internalised into the economy with taxes.

(**Equation 1**)

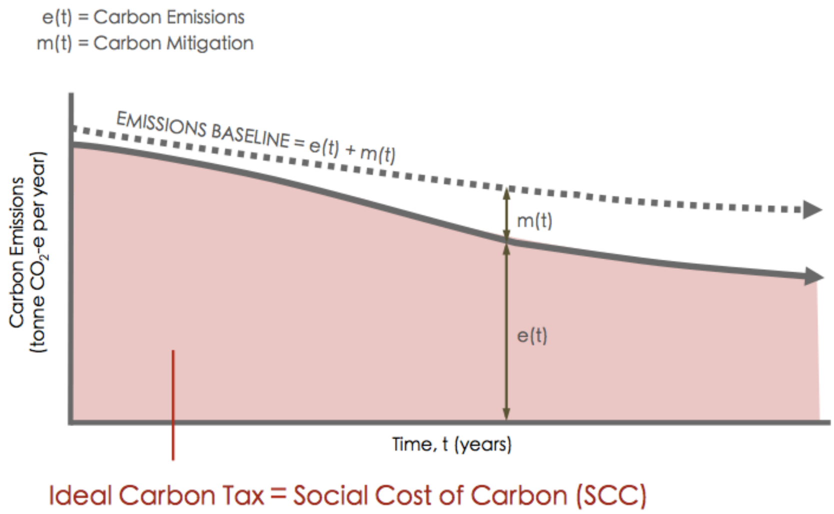

Figure 2. Hypothetical mitigation by a market actor based on the standard model for externalities and incentives. The pink shaded area represents the total carbon tax collected over time.

3.2 Risk Cost of Carbon (RCC)

Before introducing the Risk Cost of Carbon (RCC), let's first consider that insurance can be applied in two different ways: (1) to provide compensation for future unwanted events, and (2) to reduce the likelihood of future unwanted events. The second type of insurance is *preventative insurance*. An example is preventive health services under the U.S. Patient Protection and Affordable Care Act (2010): insurance coverage that aims to prevent the onset of disease. What is the cost of a collective and preventative insurance policy that can protect the world against 1.5°C/2°C of global warming, as recommended in the Paris Agreement? If we denote this cost as the Risk Cost of Carbon (RCC), then we may begin to appreciate that an expanded model for externalities is plausible based on the concept of preventative insurance.

[1] CO_2-e stands for carbon dioxide equivalent.

Official estimates of the SCC are generally too low to support the 1.5°C/2°C global warming limits as a risk management goal. The SCC could be revised higher by proposing different time discounting parameters and damage functions, but these solutions are *ad hoc* and do not explain why the SCC can fall short of the scientific consensus on climate-related systemic risk. Here we clarify the model of Chen, van der Beek and Cloud (2017; 2018) by emphasising that the inability to address risk is an inherent shortcoming of the standard model (refer Equation 1) because the SCC denotes a negative externality, whereas the RCC denotes a positive externality, as defined in Equation 2 and illustrated in Figure 3.

$$Externalised\ Cost\ of\ Carbon = \mathrm{SCC}(t)\ \hat{n} + \mathrm{RCC}(t)\ \hat{p}$$

where t is time; $\hat{n}$ is a unit vector denoting a negative externality; $\hat{p}$ is a unit vector denoting a positive externality; SCC is the Social Cost of Carbon (US$ per 1000 kg of CO_2-e emissions) which is internalised into the economy with taxes; and RCC is the Risk Cost of Carbon (US$ per 1000 kg of CO_2-e mitigated) which is internalised into the economy with rewards.

(Equation 2)

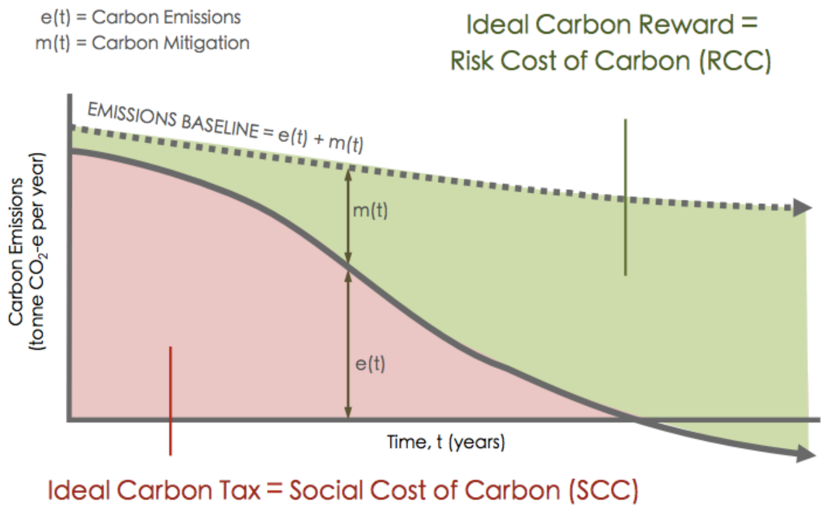

Figure 3. Hypothetical mitigation by a market actor based on the expanded model for externalities and incentives. The pink shaded area represents the total carbon tax collected over time, and the green shaded area represents the total carbon reward issued over time.

The RCC is a measure of the cost of implementing collective-preventative insurance against climate change. It may at first appear paradoxical that the RCC is called a 'cost' if it is a measure of a positive externality (refer Equation 2). This paradox is illusory, because the positive externality is the preventative insurance, which is a public good. This public good is not functionally important in the economic process because it is the reward price that actually incentivises markets and not the benefits of the reward price. It is more practical to express the positive externality as the RCC, which is the average cost of mitigating one metric tonne of carbon dioxide equivalent (US$ per 1000 kg of CO_2-e mitigated). The RCC is used to determine the average reward price for carbon.

The actual 'cost' of the positive externality is the cost of funding the collective-preventative insurance, but this cost is dispersed throughout the economy via monetary policy, and this cost does not appear in fiscal budgets (refer Sections 4 & 5).

The expanded model (Equation 2) presents the idea that the (a) carbon tax and the (b) carbon reward are 'natural' policy choices for addressing (a) market efficiency and (b) systemic risk, respectively. These policy choices are unusual, however, because no other pollutant has been managed with this expanded model for externalities. A deep theoretical justification for adding the RCC to the model for externalities is warranted, and to address this question Chen, van der Beek and Cloud (2018) present the *Holistic Market Hypothesis* (HMH) for verifying the RCC. The inspiration for developing the HMH is the strong coupling that exists between carbon and energy. This coupling is not a feature of other pollutants, and so the expanded model is considered a special case that might only apply to carbon emissions. The HMH is original because it takes into consideration the *entropy*[2] of carbon when comparing climate policies.

The HMH is not discussed here in detail for reasons of brevity, however it is worthwhile noting that the expanded model is consistent with the Tinbergen Rule (1952): a principle that there must be as many policy tools as policy objectives. The expanded model keeps to this rule by associating the SCC and RCC with independent policy tools (i.e. the SSC associates with carbon taxes, and the RCC associates with carbon rewards). The HMH was used to derive the entire policy framework for internalising the RCC. The generic name given to this policy is the 'Global Carbon Reward', which based on the work of Chen, van der Beek and Cloud (2107; 2018) and Chen (2018). The policy involves Carbon Quantitative Easing (CQE), which is mentioned in the title of this paper and is described below.

4 EXPANDED POLICY FRAMEWORK

Here we introduce the expanded policy framework for a Global Carbon Reward[3]. The Global Carbon Reward is a policy that functions as preventative insurance for avoiding unwanted climate change, and it is designed to internalise the Risk Cost of Carbon (RCC) into the economy using unconventional monetary policy and open market operations. Two points of clarification are necessary before considering this policy. Firstly, the Global Carbon Reward does not replace carbon taxes or cap-and-trade schemes etc., because it is complementary to fiscal policies that set a price on carbon. Secondly, although the Global Carbon Reward is an unorthodox policy, it is believed to be fundamentally important because it enables carrot-and-stick pricing when applied with carbon taxes or cap-and-trade.

4.1 Global Carbon Reward

The Global Carbon Reward is issued to market actors as an *ex post* reward for successful carbon mitigation—and with service conditions attached. The reward is delivered as a Central Bank Digital Currency (CBDC), which is available to trade in open markets, and central banks will buy/sell the CBDC under a coordinating monetary policy (Chen, 2018). The coordination of central banks is to ensure that the CBDC's exchange rate is pegged and is a reliable store of value. The operational

[2] The entropy of a system is an expression of the disorder of the system, and it is an emergent property with a statistical explanation. The entropy of the Universe increases until it reaches maximum entropy at thermal equilibrium.

[3] The specific policy version presented here is called the Global 4C Risk Mitigation Policy (Global 4C), after Chen, van der Beek, and Cloud (2017, 2018) and Chen (2018).

objective is to peg the CBDC's price to the Risk Cost of Carbon (RCC) over a rolling 100-year planning horizon, and the long-term policy objective is to achieve a climate mitigation target that can limit the physical systemic risk of climate change (refer Figure 1).

The CBDC is offered to market actors as a financial incentive for the abatement and sequestration of carbon. The financial reward for market actors is the *seigniorage* income after the CBDC is digitally created. The *seigniorage* income is the face value of the CBDC less fees and commissions. Administration of the policy is funded with fees and commissions that are subtracted from rewards to cover the cost of measurement, reporting and verification (MRV) of the carbon stocktake, long-term monitoring, policing, RCC assessments, and general administration. Chen (2018) provides a design brief for the CBDC administrative system based on Decentralised Ledger Technology (DLT).

In addition to increasing the rate of climate mitigation, the Global Carbon Reward will also have flow-on effects in the economy by boosting: (i) carbon prices in voluntary and compliance carbon markets, (ii) the yield on climate/green bonds, (iii) share prices for low-carbon firms, and (iv) investment in low-carbon R&D.

4.1.1 Carbon Quantitative Easing (CQE)

Carbon quantitative easing (CQE) is a monetary policy of the Global Carbon Reward that is used to underwrite the *carbon reward price*. CQE is similar to conventional quantitative easing—an expansion of the quantity of fiat—but CQE is only used for the purchase of the Central Bank Digital Currency (CBDC), which is denominated in carbon dioxide equivalent mitigated (100 kg of CO_2-e mitigated). An official authority—termed the *Carbon Exchange Standard* (CES)—gives instructions and guidance to central banks for CQE and CBDC trading in open markets.

4.1.2 Carbon Exchange Standard (CES)

The CES takes responsibility for assessing the Risk Cost of Carbon (RCC), managing the CBDC exchange rate to follow the RCC, conducting mitigation assessments, managing the carbon stocktake, and administrative duties.

The CES gives regular instructions and guidance to central banks in relation to CQE and CBDC trading, however the CES may also use other methods to influence market sentiment. For example, the CES can make public announcements concerning future CBDC prices, and can adjust the rules and guidelines regarding the carbon mitigation technologies and market sectors that are open to receiving rewards under the policy. The CES does not interfere with the central banks' other activities under their existing remits.

The CES may allow the CBDC to be traded instantaneously over a peer-to-peer exchange platform, but this option needs to be managed in terms of the economic and regulatory implications. Although the CBDC is tradable, the carbon mass is automatically 'retired' when the CBDC is first issued. The carbon mass associated with the CBDC is not transferable and is not available for carbon offsetting, and this is because the carbon is 'owned' by the CES (i.e. the carbon is non-transferable). Chen (2018) describes a mechanism for the CES to manage the carbon stocktake should actors default on their service agreements.

4.1.3 Central Bank Digital Currency (CBDC)

Barrdear and Kumhof (2016) define a CBDC as a "*universally accessible and interest-bearing central bank liability, implemented via distributed ledgers, that competes with bank deposits as medium of exchange*." The CBDC of this policy has a unit of account of '100 kg of CO_2-e mitigated', and so the CBDC's supply is coupled to a carbon stocktake. The CBDC circulates in the economy and is openly exchanged for hard currencies. From a monetary perspective, the CBDC may be defined as a representative currency because its supply is constrained by the carbon stocktake that is managed by the CES. From a financial perspective, the CBDC may be defined as a security because it has the attributes of a sovereign bond. From a legal perspective, the CBDC may be defined as an international unit of account, and it could be managed like a parallel currency. For tax purposes, the CBDC may be classified as a currency, a bond, or a commodity.

4.2 Internalising the RCC

The Global Carbon Reward is designed to 'internalise' the Risk Cost of Carbon (RCC) into the economy. The internalisation process for the RCC does not occur in the same way as with the SCC, and this is because the policy for carbon rewards does not seek a social welfare maximum. The target rate of mitigation corresponds to the level of physical systemic risk that is deemed acceptable under existing and new international agreements.

The internalisation of the RCC involves setting a carbon reward price in world markets—with CBDC *seigniorage* income being the incentive for mitigation—and then allowing market actors to trade the CBDC. The internalisation process occurs when market actors undertake long-term mitigation actions and increase the CBDC supply. The CBDC supply is an important macroeconomic index for mitigation success. The internalisation process also occurs when the CBDC has a rising/falling value—following the assessed RCC—resulting in more/less investment demand for the CBDC. The CBDC is attractive as a security because it has a risk-free rate of return (i.e. yield) because it is underwritten with CQE. The internalisation process also involves annual risk assessments (refer Section 4.3), and the entire financial mechanism is explained in Section 4.4.

4.3 RCC Assessments

The Risk Cost of Carbon (RCC) is formulated to quantify the cost of managing the physical systemic risk of climate change (refer Figure 1). The *Carbon Exchange Standard* (CES)—which is the peak body responsible for the policy—has the duty of assessing the RCC on an annual basis and coordinating central banks to underwrite the Global Carbon Reward.

Before the CES can undertake the RCC assessments, an international agreement is needed to define the risk objective. The risk objective will include a set of average global temperature rises, ΔT_j, and associated risk tolerances, R_j, in percentage probability of failure, where j denotes the j^{th} risk limit that is proposed concurrently. For example, three hypothetical values of (ΔTj, Rj) are (1.5°C, 50%), (2°C, 33%) and (3°C, 5%) over a rolling 100-year time horizon.

An important task in the assessment of the RCC is the evaluation of the *Systemic Risk of a Climate Mitigation Failure* (SRCMF), which is the probability (%) of failing to stay below each ΔT_j limit. After the SRCMF (%) is estimated for each ΔT_j, a target mitigation rate, $\Delta Q(t)$, is then estimated such that $\Delta Q(t)$ is sufficient to reduce SRCMF (%) to fall below the R_j (%) tolerance for each ΔT_j that is established as the policy objective.

The RCC(t) is estimated from the target mitigation rate, $\Delta Q(t)$, and a *Systemic Risk Abatement Cost Curve* (SRACC) for international carbon markets. The SRACC represents the estimated average international price of mitigating carbon at various rates, and is based on experience with existing abatement and sequestration technologies. The SRACC represents the average cost of mitigation after taking into account the administrative and hidden costs: as required to finance the target mitigation rate, ΔQ(t). The RCC(t) time-series for the rolling 100-year time horizon is assessed from the target mitigation rate, ΔQ(t), and the SRACC.

4.4 Financial Mechanism

The financial mechanism for the CBDC is explained below using the term *Complementary Currencies for Climate Change* (4C) as the CBDC trading name. The abbreviation '4C' denotes the 'base currency' when quoting exchange rates in relation to the USD, which is the 'quote currency'. Five currency-related terms are introduced here to help explain the financial mechanism:

- 4C is the currency;
- P4C is the currency exchange rate and the carbon reward price;
- Y4C is the currency yield;
- S4C is the currency supply; and
- SI is the seigniorage income for market actors.

4.4.1 Carbon Reward Price (P4C)

The carbon reward is one unit of 4C per 100 kg of CO_2-e mitigated because the unit of account of 4C is '100 kg of CO_2-e mitigated'. The carbon reward price, P4C, is expressed as an exchange rate, with 4C as the base currency and the USD as the quote currency (see Equation 3). The ideal P4C is proportional to the RCC over time. Given that the RCC has units of 'US$ per tonne (1000 kg) of CO_2-e mitigated', the ideal carbon reward price is 1/10th of the RCC over time, as follows:

$$\begin{aligned} \mathrm{P4C}_i(t) &= \mathrm{4C/USD} \\ &\cong 0.10\ \mathrm{RCC}_i(t) \end{aligned}$$

where *t* is time (years); P4C is the carbon reward price and 4C/USD is the exchange rate pair (US$ per 100 kg of CO_2-e mitigated); RCC is the Risk Cost of Carbon (US$ per 1000 kg of CO_2-e mitigated), and subscript *i* denotes the year of the relevant RCC assessment.

(Equation 3)

The carbon reward price over time—P4C(t)—follows the RCC(t) over the 100-year planning horizon, and is presented as the '100-Year Advance 4C Price Alert' (see Figure 4). The P4C price alert is to be presented in the international media and revised annually in response to the changing risk exposure. The 100-year duration for the planning horizon is believed reasonable because the atmospheric CO_2 concentration adjustment occurs about 100 years after CO_2 is emitted to the atmosphere (IPCC, 2013), and because the Global Warming Potential (GWP) of greenhouse gases is based on 100 years (IPCC, 2014).

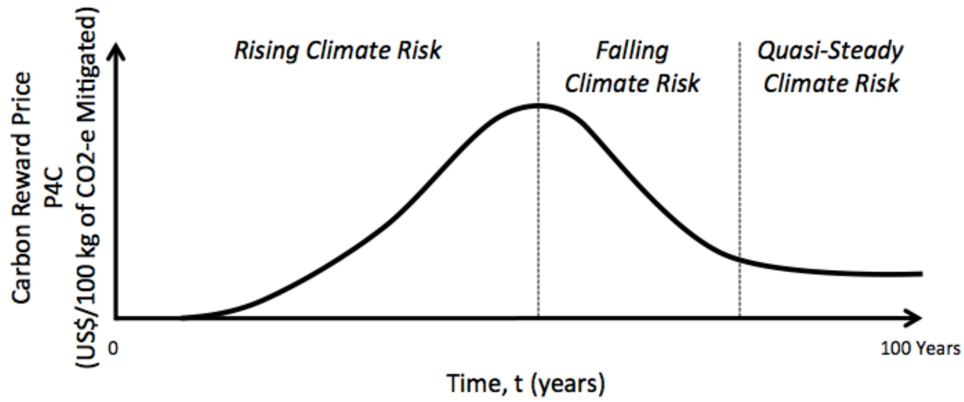

Figure 4. Hypothetical forecast of carbon reward prices over the coming 100 years. This is termed the '100-year Advance 4C Price Alert' and is proportional to the RCC (adapted from Chen, van der Beek and Cloud, 2018).

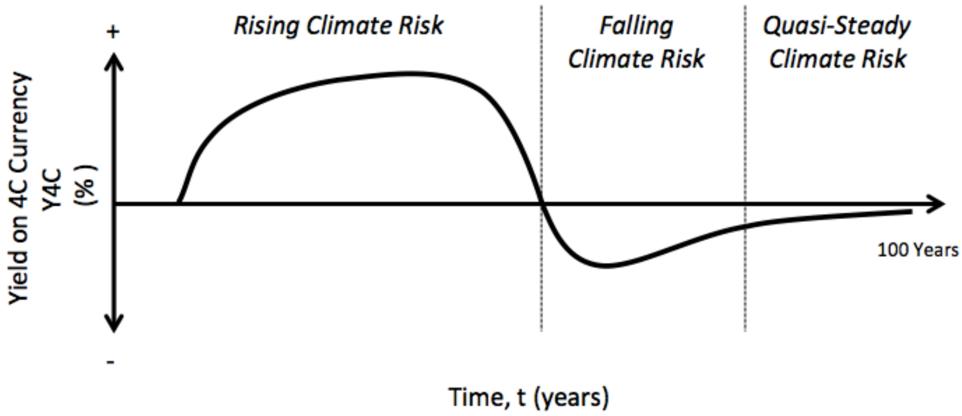

Figure 5. Hypothetical forecast of the 4C yield over the coming 100 years. A positive yield represents a risk-free return on 4C holdings (adapted from Chen, van der Beek and Cloud, 2018).

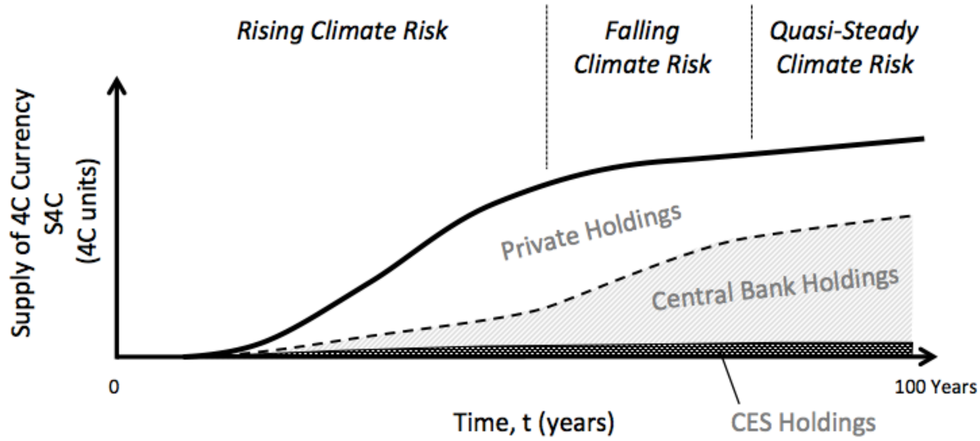

Figure 6. Hypothetical forecast of the 4C supply over the coming 100 years; and the partition of 4C holdings between private traders, central banks, and the CES.

4.4.2 Seigniorage Income (SI)

4C is awarded to market actors, but only after their climate mitigation actions are verified (refer Figure 3). These actions may involve a wide spectrum of technologies, and may occur in all sectors of the economy, such as in energy supply, transportation, construction, heating and cooling, agriculture, land and ocean management, manufacturing, family quality, etc. Each technology requires a rule for assessing its emissions baseline and mitigation rate, and also for defining suitable service agreements.

A formula for the financial incentive for market actors is shown in Equation 4. This incentive is the *seigniorage income*, SI(t), that is offered to market actors who undertake mitigation work. Seigniorage is traditionally afforded to central banks when they print money and earn the face value of that money less the cost of production. The mass of carbon mitigated, $m(t)$, is determined through a measurement, reporting and verification (MRV) process. Fees and commissions, $\mu(t)$, are subtracted by the CES, and the resulting seigniorage income, SI(t), is given to market actors. Market actors are required to enter into service contracts with the CES before receiving their seigniorage income.

$$\mathrm{SI}_i(t) = 10\, m(t) - {}^{\mu(t)}\!/_{\mathrm{P4C}_i(t)}$$

where t is time (years); SI is the seigniorage income for market actors (4C); m is the mass of carbon mitigated (tonne of CO_2-e mitigated); μ is the administrative cost as fees and commissions (US$); P4C is the exchange rate (US$ per 100 kg of CO_2-e mitigated); and subscript i denotes the year of the relevant RCC assessment (adapted from Zappalà, 2018).

(Equation 4)

4.4.3 Currency Demand and Yield (Y4C)

Central banks under the guidance of the CES will intervene in currency markets to ensure that demand for 4C is sufficient to achieve the carbon reward price over time—P4C(t)—as defined by the '100-Year Advance 4C Price Alert' (Figure 4). Demand for 4C is underwritten with carbon quantitative easing (CQE) to ensure that 4C is near risk-free for 4C holders. The price alerts will incentivize private purchases of 4C in foreign exchange markets based on the advertised 4C yield over time—Y4C(t)—which is the annual *ex ante* change in the 4C price, as follows:

$$\mathrm{Y4C}_i(t) \cong \frac{\mathrm{RCC}_i(t+1) - \mathrm{RCC}_i(t)}{\mathrm{RCC}_i(t)} \times 100\%$$

where t is time (years); Y4C is the annual yield on 4C (%); RCC is the Risk Cost of Carbon (US$ per 1000 kg of CO_2-e mitigated); and subscript i denotes the year of the relevant RCC assessment.

(Equation 5)

A key feature of the policy is that market sentiment for 4C is influenced by Y4C(t) forecasts that are presented by the CES to the marketplace and citizens. Markets will be aware that 4C securities have high credit-worthiness because the sovereign risk is spread amongst the world's major central banks and is underwritten by CQE (refer Figures 4 & 5). The yield on 4C is conceptually similar to the yield on sovereign bonds, but 4C has no maturity date because the holding period is flexible, and 4C transactions are managed similar to currency transactions.

The CES will implement rules and strategies to provide adequate 4C price stability. Based on the assumption that the CES will be effective in managing 4C, positive Y4C values will occur during periods of rising climate risk, and this will guide a managed secular bull market in 4C trade (refer Figure 5). On the other hand, negative Y4C values will occur during periods of falling climate risk, and this will guide a managed secular bear market in 4C trade. Bull and bear markets will continue until a quasi-steady risk condition is achieved (refer Figure 5).

The price and yield of 4C are managed by the CES to follow a path that ensures that the target mitigation rate, ΔQ(t), is achieved. These dynamic features of the financial mechanism are the primary channel for mobilising private wealth into climate mitigation actions, and they create a negative feedback on global warming. The rate of wealth mobilisation under the policy is always commensurate with the assessed physical systemic risk, as denoted by RCC(t).

4.4.4 Currency Supply (S4C)

The mitigation of one tonne of CO_2-e under the policy's reward rules corresponds to the issuance of 10 units of 4C and an expansion of the 4C currency supply by 10 units (refer Equations 3 and 4). A hypothetical scenario is shown in Figure 6 for the cumulative 4C supply (S4C). Figure 6 shows the hypothetical amounts of 4C held by private traders, central banks, and the CES. A small percentage of 4C is claimed by the CES to cover administrative costs.

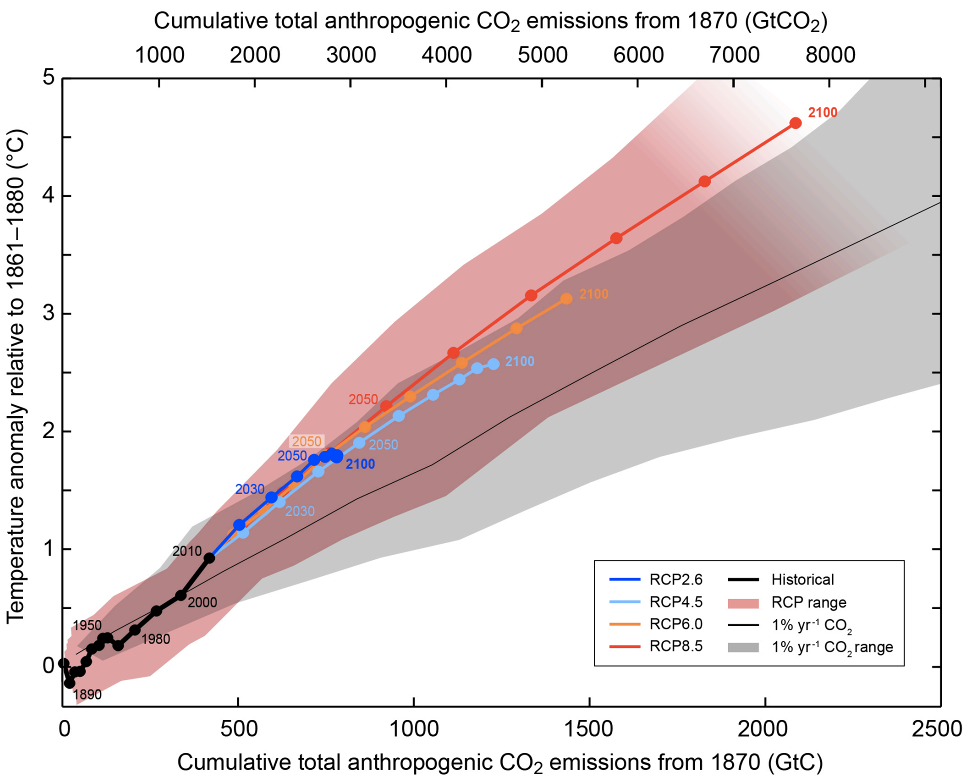

Figure 7. Simulated global mean surface temperature increase as a function of cumulative total global CO_2 emissions (reproduced from IPCC, 2103).

Raftery et al. (2017) estimate that 3.2°C (2.0-4.9°C) of global warming will occur by 2100 based on a probabilistic assessment of national trends. An order-of-magnitude estimate of S4C can be found by assuming that the policy will be implemented between 2020-2100 to reduce global warming from 3.2°C to 2°C. The IPCC's Fifth Assessment Report (IPCC, 2103) shows that cumulative total global emissions of CO_2 correlate with the mean surface temperatures as shown in Figure 7. Using the data presented in Figure 7, the carbon stocktake that corresponds to mitigating from 3.2°C to 2°C of global warming is the difference between about 5000 Gt CO_2 (3.2°C) and 3000 Gt CO_2 (2°C) of emissions, or about 2000 Gt of CO_2 mitigated. This scenario corresponds to about 20 trillion units of 4C issued between 2020-2100—or 250 billion units of 4C issued per year on average—as a rough guide.

5 DISCUSSION

The expanded model for the externalised costs of carbon—the SCC and RCC—invokes a review of the policy toolkit for responding to climate change. Before we discuss the policy implications, we will first consider whether human cognition could be playing a role in limiting our policy options. We then review the definition of a market failure, discuss environmental and social governance (ESG), and offer justifications for expanding the mandates of central banks to provide scalable climate finance and to manage climate-related systemic risk.

5.1 Hypocogition

Donald Rumsfeld, the former US Secretary of State for Defence, commented:

> *"'There are known knowns… There are known unknowns… But there are also unknown unknowns. There are things we do not know we don't know."* (Logan, 2009, p.712).

The things we do not know, or do not have words to express, can cause *hypocognition*. Hypocognition occurs when a specific concept is not represented in language resulting in some dysfunctional behaviour. Hypocognition was first recognised by Robert Levy (1973) after studying Tahitians and their emotional responses to situations that had no name in their native tongue. Could the market failure in carbon be a source of hypocognition? Here we make the claim that economists are missing concepts and words that are needed to describe the dynamic nature of the market failure, and with major implications for public policy.

Evidence of hypocognition is an absence of words that specifically describe the dynamic benefits of carrot-and-stick carbon pricing for climate mitigation. Evidence includes the experiment of Andreoni, Harbaugh and Vesterlund (2003) that tested human cooperation under carrot-and-stick incentives. They used a proposer-responder game to examine the dynamic benefits, and they discovered that combining incentives has a significant positive influence on cooperation:

> "*Thus, while adding rewards only had little effect, adding rewards to punishments has a profound effect. In other words, rewards and punishments seem to act as complements in encouraging proposers to increase their offers.*" (p.897).

Chen et al. (2014) undertook a study of carrot-and-stick incentives based on a public goods game. They found that "*...punishment acts as a 'booster stage' that capitalizes on and amplifies the pro-social effects of rewarding...*", and that carrot-and-stick incentives are *"...a surprisingly inexpensive and widely applicable method of promoting cooperation*" (p.1). These results support our claim that the standard model is causing hypocognition by ignoring carrot-and-stick carbon pricing.

Hypocognition over carrot-and-stick carbon pricing is unlikely to be rectified using conventional words and models. This is because the policy for the 'carrot' is unconventional according to the epistemological[4] analysis of Chen, van der Beek and Cloud (2018). They infer that a Global Carbon Reward is the 'carrot' (refer Section 4.1). They also infer that Complementary Currencies for Climate Change (4C) is the appropriate tool for delivering the 'carrot' (refer Section 4.4).

We claim that the notion of a 'dynamic market failure' shines a light on the following key terms that are otherwise overlooked because of hypocognition (refer Section 4):

(i) global carbon reward;
(ii) carbon quantitative easing (CQE);
(iii) carrot-and-stick carbon pricing; and
(iv) carbon exchange standard (CES).

5.2 Dynamic Market Failure

Lord Nicholas Stern, who wrote the 'Stern Review' for the UK government, commented that:

> "*Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.*" (Stern, 2007, p.vi).

In a classical interpretation of the market failure in carbon, the allocation of goods and services is considered inefficient when carbon emissions create negative externalities. In this classical interpretation, Pigovian taxes are the focus of policy makers because a tax is used to lower the rate of private production to achieve a socially 'optimal' quantity of production. While taxes may be effective in a classical situation, the missing concept is that carbon does not behave like a regular pollutant because carbon is strongly coupled to energy. The coupling of carbon with energy produces *dynamic barriers* to mitigation and *dynamic drivers* of pollution such that conventional policies are much less effective than would otherwise be the case if there were no such coupling.

Lord Nicholas Stern writes that the standard model for externalities is not necessarily sufficient:

> "*Standard externality and cost-benefit approaches have their usefulness for analysing climate change, but, as they are methods focused on evaluating marginal changes, and generally abstract from dynamics and risk, they can only be starting points for further work"*. (Stern, 2007, p.3)

Here we propose that the market failure be renamed a *dynamic market failure* because the classical definition of the market failure does not adequately describe dynamic processes that result from the coupling of carbon with energy.

The notion of a dynamic market failure invites us to take a fresh look at the drivers of pollution and the barriers to mitigation. We propose that carrot-and-stick carbon pricing is actually needed to overcome dynamic drivers and dynamic barriers. The dynamic market failure involves the

[4] An epistemology is a method of acquiring knowledge based on principles, rather than seeking ideas based on opinions. The Holistic Market Hypothesis (HMH) uses an epistemology of complementary-and-opposite relationships to derive the policy for the 'carrot' when the simple carbon tax is the 'stick'. The principle that underpins complementary-and-opposite pricing is termed Market Policy Dualism (MPD).

expanded model (refer Equation 2 and Figure 3) for (i) negative externalities associated with carbon emissions, and (ii) positive externalities associated with carbon mitigation.

5.2.1 Dynamic Barriers & Tipping Points

Chen, van der Beek and Cloud (2017, 2018) revised the standard model by developing Equation 2 for carrot-and-stick carbon pricing. Their expanded model begins with the classical interpretation of the SCC, as follows:

- The SCC is a measure of climate damages, and is defined as the time-discounted future loss in the utility of consumption (i.e. losses in economic welfare) per tonne of CO_2-e emitted.

The novelty of the expanded model is that it identifies the Risk Cost of Carbon (RCC), which is not accounted for with the SCC, as follows:

- The SCC does not readily account for endogenous drivers of carbon emissions that act as dynamic barriers to economic reform. These barriers include increasing energy demand with economic growth, vested financial interests, and non-cooperative political and social behaviour.

- The SCC does not readily account for exogenous drivers that result from positive climate feedbacks and *tipping points* that could lead to runaway climate change (e.g. Lenton, 2012; Fischer et al., 2018; Steffen et al. 2018).

The dynamic barriers and tipping points of the market failure create a need for risk management and preventative insurance. The cost of this insurance is the RCC, and the insurance policy is classified as a positive externality because it is a public good. The RCC is an 'off balance sheet' cost until the insurance policy is recognised and accepted. The RCC is defined as follows:

- The RCC is the cost of limiting the physical systemic risk of climate change when using a reward price for carbon in a calibrated response to endogenous and exogenous drivers of the systemic risk.

- The RCC is technically defined as the financial reward per tonne of CO_2-e mitigated that is needed to avoid specific levels of global warming with an agreed percentage probability of succeeding or failing.

5.2.2 Time Discounting

A feature of the dynamic market failure in climate change is that the SCC is discounted over time, whereas the RCC is not. This has deep theoretical and philosophical implications for addressing the 'precautionary principle' with market-based climate policies. Scholars have considered various methods for hedging against climate risk, such as adjusting the time discount rate for the SCC (e.g. van den Bergh and Botzen, 2014). A major challenge of hedging against risk with adjustments to the time discounting of the SCC, is that finding consensus on the risk premium is inherently difficult (e.g. Nordhaus, 2007a; Kousky, Kopp and Cooke, 2011). The solution presented with the expanded model is to recognise the existence of the second externalised cost—the RCC. The solution includes these statements as principles: (a) the RCC is a *probabilistic* metric and is not discountable with time, and (b) rewards are effective for communicating and managing risk.

5.2.3 Expanded Policy Framework

The dynamic market failure results in an expanded model for externalised costs (Equation 2) and an expanded policy framework that includes carbon taxes and carbon rewards (rewards should not be confused with subsidies). The internalisation of the RCC into the economy with carbon rewards is part of a *risk management plan*, and the policy for a Global Carbon Reward may be described as *preventative insurance*. Carbon taxes are still needed to internalise the SCC and to improve *market efficiency*. The expanded policy framework is summarised as follows:

- The SCC associates with negative externalities, taxes, market efficiency, fiscal policy, and government budgets.

- The RCC associates with positive externalities, rewards, physical systemic risk, monetary policy, and currency supply.

Chen, van der Beek and Cloud (2018) verified the expanded policy framework—for the SCC and RCC—by comparing the policy for a carbon reward with the policy for a carbon tax in terms of how these policies influence efficiency and risk in markets. They interpret that the two policies are *time-asymmetric* based on their complementary-and-opposite objectives and their effect on the *entropy*[5] of carbon in the environment. The name given to their interpretation is the *Holistic Market Hypothesis* (HMH).

Chen, van der Beek and Cloud (2018) also developed an analytical formula for a carbon reward price that can achieve net zero emissions. This formula for net zero emissions is based on the economy-energy model of Garrett (2012) combined with the financial mechanism that is described in Section 4. This financial mechanism acts as a negative feedback on carbon emissions that are generated with Gross World Product (GWP).

5.3 Environmental and Social Governance

Here we discuss the Global Carbon Reward in terms of environmental and social governance (ESG) and how it relates to (a) social principles, (b) market neutrality for central banks, and (c) the 2015 Paris Climate Agreement.

5.3.1 Social Principles

The *polluter pays principle* is popular because (i) it appeals to the notion of equity under the UNFCCC (Stern, 2007), and (ii) it appeals to economists because it is consistent with standard neoclassical model for externalities and market efficiency (Boyce, 2018). The social principles that support the Global Carbon Reward are complementary to the polluter pays principle, and include: (i) preventative climate insurance as a public good; (ii) mitigation services that are priced for effectiveness; and (iii) the precautionary principle. These principles are jointly termed *Collective and Systemic Risk Insurability* (CASRI) after Chen, van der Beek and Cloud (2017).

CASRI implies that the Global Carbon Reward is a positive externality and a *public good* because the physical benefits of the reward are non-excludable and non-rivalrous. CASRI ignores the issue of who should 'pay' since culpability and beneficiaries of carbon emissions are not assessed.

[5] Chen, van der Beek and Cloud (2018) claim that policies for the carbon tax and the carbon reward should express time-asymmetry under the Second Law of Thermodynamics (i.e. the entropy law).

CASRI takes a systems-based approach by recognising that dynamic barriers to mitigation and tipping points create systemic risks that need to be managed.

CASRI is different to the polluter pays principle for another reason: the carbon reward price is managed with cost-effectiveness analysis (CEA), whereas the ideal carbon tax is based on cost-benefit analysis (CBA). An example of CEA is when medical treatments are selected on the basis of saving human lives rather than achieving an efficiency outcome.

5.3.2 Market Neutrality

The Global Carbon Reward relies on Carbon Quantitative Easing (CQE) to underwrite the reward price. Given that central bank mandates are designed to avoid market distortions, there is a need for a concrete argument to support CQE because CQE is both unconventional and non-neutral. Here we provide our argument for CQE based on three key points: (Point I) CQE can improve long-term financial stability; (Point II) CQE and the Carbon Exchange Standard (CES) have similarity with the central bank practice of trading gold bullion; and point (Point III) market neutrality is not a rigid convention for central banks based on historical records.

I. The first point that supports CQE is the theory that the RCC (refer Equation 2 & Section 4) needs to be internalised into the economy to avoid dangerous-to-catastrophic global warming and a 'domino effect' on the financial system (refer Figure 1). The RCC is part of a cohesive policy framework for addressing the risks of climate change (refer Section 4). In this policy framework the responsibility of central banks is derived from principles and without relying on ideologies (refer Section 5.2).

II. The second point that supports CQE are the similarities between the Carbon Exchange Standard (CES) and central bank exchange standards for gold and silver backed currencies that were popular during the 19th and 20th centuries. Gold and silver standards are not market neutral because they influence the value of gold and silver commodities in relation to national currencies, and they also influence the mining of metals. Central banks may similarly view the CES as an exchange standard for a representative currency, but with a focus on carbon mitigation. Central banks and the International Monetary Fund (IMF) have traded gold[6] during the post-Bretton Woods era to hedge against financial risk. Economists and policy makers are invited to view future carbon stocktaking by central banks as a hedge against climate-related financial risk: analogous to gold reserves but functionally different.

III. The third point that supports CQE is a historical review of monetary policy. Barkawi (2016) and Zappalà (2018) comment that recently implemented monetary policies are not sector neutral, including, for example, the large-scale purchase of mortgage-backed securities by the US Federal Reserve in late 2008. Moreover, central bank mandates have evolved with time (Goodhart, 2011) and the adoption of climate-friendly remits for central banks is mainly a political issue (Volz , 2017, p. 20).

5.3.3 Paris Climate Agreement

The Global Carbon Reward is directly relevant to the Paris Climate Agreement (UNFCCC, 2015) because the reward can be used to set risk tolerances for the 1.5°C/2.0°C global warming limits under Article 2 (e.g. a 67% chance of not exceeding 2.0°C). The reward also relates to Article 8, by "*...reducing the risk of loss and damage...*" and by offering "*Comprehensive risk assessment and management...*".

[6] https://www.gold.org/research/latest-world-official-gold-reserves

Official SCC assessments and ideal carbon taxes are not calibrated to avoid the 1.5°C/2°C global warming limits of the Paris Agreement (e.g. Boyce, 2018). A market-based response to the Paris Agreement might involve a global increase in carbon taxes to levels that exceed official SCC estimates—as suggested by Joseph Stiglitz and Lord Nicholas Stern (CPLC, 2017)—and by tightening cap-and-trade schemes. Will raising carbon taxes to new highs be politically acceptable? If they are implemented, will they be effective? According to Nordhaus (2016), the 1.5°C/2°C limits agreed in Paris are already unattainable based on the results of his DICE model:

> *"A second result is that the international target for climate change with a limit of 2°C appears to be infeasible with reasonably accessible technologies – and this is the case even with very stringent and unrealistically ambitious abatement strategies. This is so because of the inertia of the climate system, of rapid projected economic growth in the near term, and of revisions in several elements of the model."* (p.3).

With respect to 2.5°C of global warming, Nordhaus (2016) concluded that:

> "*A target of 2½°C is technically feasible but would require extreme virtually universal global policy measures.*" (p.3)

The DICE assessment of Nordhaus (2016) and various other assessment methods (e.g. Raftery et al., 2017; Garrett, 2012) indicate that a significantly stronger policy toolkit is needed to achieve the ambition of the Paris Agreement. The expanded policy framework presented here is maximally supportive of the Paris Agreement because the Global Carbon Reward offers finance for negative emissions technologies (NETs) to pull carbon out of the atmosphere; and it also complements carbon taxes and cap-and-trade schemes for reducing carbon emissions (i.e. compare Figure 2 with Figure 3).

6 CONCLUDING REMARKS

International negotiations for climate mitigation began around 1995 with the first UNFCCC Conference of the Parties (COP1) held in Berlin. Since 1995, the collective effort to transition to a low-carbon economy has been too feeble to remain below 1.5°C/2°C of global warming. Based on national trends, it now appears that global warming will reach 3.2°C (2.0-4.9°C) by 2100 (Raftery et al., 2017) and with the added risk of passing a climate tipping point (Steffen et al., 2018). The 2018 summer heat wave in Europe, North America and North-East Asia, is an example of what to expect in a warmer world[7]. Järvensivu et al. (2018) recommend that a transition to a low-carbon economy should also address inequality, unemployment, rising debt, and resource constraints.

The need to quickly transition to a low-carbon economy is a political issue. In this paper we propose something remarkable. We argue that the standard policy toolkit for climate mitigation is a driver of political conflict because the 'standard model' does not fully address the externalised costs of carbon emissions. In this paper we coin the term 'dynamic market failure' to denote that this market failure is a special case because carbon is strongly coupled to energy. We claim that the concept of a 'dynamic market failure' brings to our attention two kinds of externalised cost: (1) the Social Cost of Carbon (SCC), which is a negative externality; and (2) the Risk Cost of Carbon (RCC), which is a positive externality. The implications are dramatic for public policy, because the expanded model shines a light on the expanded policy framework.

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1 [7] "Heatwave in northern Europe, summer 2018" https://www.worldweatherattribution.org/attribution-of-the-2018-heat-in-northern-europe/

The analysis of Chen, van der Beek, and Cloud (2017, 2018) and Chen (2018) indicate that the RCC is the monetisation of physical systemic risk, and that the RCC is internalised into the economy with rewards. The policy for a Global Carbon Reward is technically a 'risk management plan' and is analogous to 'preventative insurance' against unwanted climate change. We classify the benefits of the Global Carbon Reward as a positive externality and a 'public good'. The Global Carbon Reward is an umbrella policy, which—under ideal circumstances—offers carbon rewards in all national jurisdictions. The intention of the policy is to manage the transition to a low-carbon economy with scalable climate finance and 'carrot-and-stick carbon pricing' for maximum socio-economic cooperation.

The Global Carbon Reward has several novel features that require careful attention:

i. The carbon reward price is a second price that is complementary to the conventional 'carbon price' that is founded on taxes, cap-and-trade and carbon-offset markets. The two prices are jointly termed 'carrot-and-stick carbon pricing'.
ii. The instrument for the reward price—the 'carrot'—is a Central Bank Digital Currency (CBDC). The CBDC is an international *medium of exchange*, *store of value*, and a *unit of account* (100 kg of CO_2-e mitigated).
iii. The CBDC is financed independently of fiscal budgets, using a monetary policy—called Carbon Quantitative Easing (CQE)—and private currency trading in open markets.
iv. The CBDC has a yield that is underwritten by CQE, and this yield is conceptually similar to the yield on a sovereign bond.
v. The CBDC is not a carbon-offset and is not traded in carbon markets. The CDBC is traded like a hard currency, and its value is expressed in currency exchange rates.
vi. The carbon stocktake is transferred to a peak authority—called the Carbon Exchange Standard (CES)—and is analogous to gold held in reserve by central banks.

The social principles that underpin the policy are jointly termed Collective and Systemic Risk Insurability (CASRI) (refer Section 5.3). CASRI is complementary to the polluter pays principle, and CASRI provides a stronger basis for environmental and social governance (ESG). The polluter pays principle reinforces conventional thinking about applying carbon taxes and balancing fiscal budgets. This conventional thinking is a policy trap, because central banks can also generate revenue by expanding the currency supply and influencing market sentiment with monetary policy.

Monnin (2018), in his recent review of central bank policy, wrote:

> "*Climate change is a fundamental challenge for our societies. Containing it will require a profound and radical transformation of our economic system, including a substantial reorientation of investments toward low-carbon technologies.*" (p.1)

According to the reviews of Campiglio et al. (2018) and Zappalà (2018), it appears that conventional and progressive central bank policies do not attempt to resolve the climate crisis at its physical foundation: they do not attempt to manage the physical systemic risk. Carbon Quantitative Easing (CQE) is an unconventional monetary policy that may be described as 'profound' and 'radical', because it does address the physical systemic risk. The new approach is justified under the expanded model for externalities—the SCC and the RCC (refer Equation 2)—and the expanded policy framework (refer Section 4). This expanded model for externalised costs is relevant to financial regulators, because it offers a justification for expanding the mandates of central banks.

Important for central banks, is that the Carbon Exchange Standard (CES) has the hallmarks of a macroprudential regulator for the world economy. Most of the regulatory responsibility is attributed to the CES, thereby allowing central banks to focus on their core activities. Interesting for regulators, is that the CES is similar to a gold exchange standard. Gold is economically important because its price communicates financial systemic risk, and holding gold is an accepted strategy of central banks for hedging against this risk. In this paper we explain how a CBDC[8] can communicate climate-related systemic risk (refer Figures 4 & 5), and we explain why holding the CBDC can hedge against this risk (refer Figures 6 & 7).

7 RECOMMENDATIONS

Given that there are conceptual and political challenges over climate policy, it could take years, if not decades, for economists and policy makers to discuss and agree on the Global Carbon Reward—and by that time it could be too late. A more strategic approach may be taken by financial regulators to pre-empt the need for stronger action on climate change. Given that there is a lag time between policy theory and policy implementation, we recommend that financial regulators undertake a review of the Global Carbon Reward at the earliest opportunity.

A review could examine the macroprudential benefits of a Carbon Exchange Standard (CES) and Carbon Quantitative Easing (CQE) (refer Section 4). This review could assess the RCC and the macroeconomic effects of a Central Bank Digital Currency (CBDC) priced to the RCC (refer Figures 4 to 7 & Equations 3 to 5). A review could assess the feasibility of Collective and Systemic Risk Insurability (CASRI) under existing international laws and treaties. Pilot projects are also recommended to test the effect of carrot-and-stick carbon pricing on markets.

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