

Managing nature-related financial risks: a precautionary policy approach for central banks and financial supervisors

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Managing nature-related financial risks: a precautionary policy approach for central banks and financial supervisors

Katie Kedward^a Josh Ryan-Collins^b and Hugues Chenet^c

Abstract

This paper considers how financial authorities should react to environmental threats beyond climate change. These include biodiversity loss, water scarcity, ocean acidification, chemical pollution and — as starkly illustrated by the Covid-19 pandemic — zoonotic disease transmission, among others. We first provide an overview of these nature-related financial risks (NRFR) and then show how the financial sector is both exposed to them and contributes to their development via its lending, and via the propagation and amplification of financial shocks. We argue that NRFR — being systemic, endogenous and subject to ‘radical uncertainty’ — cannot be sufficiently managed through ‘market-fixing’ approaches based on information disclosure and quantitative risk estimates. Instead, we propose that financial authorities utilise a ‘precautionary policy approach’, making greater use of qualitative methods of managing risk, to support a controlled regime shift towards more sustainable capital allocation. A starting point would be the identification and exclusion of clearly unsustainable activities (e.g. deforestation), the financing of which should be discouraged via micro- and macro-prudential policy tools. Monetary policy tools, such as asset purchase programmes and collateral operations, as well as central banks’ own funds, should exclude assets linked to such activities.

Keywords: Financial stability, financial regulation, macroprudential policy, central banks, environmental risks, nature-related financial risks, environmental degradation, biodiversity loss, sustainable finance, systemic risk, low carbon transition, climate change, climate-related financial risks

JEL codes: Q54, Q57, E44, E58, G28, G14

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1. Introduction

The Covid-19 pandemic has starkly exposed the fragility of our economic and financial system to the threats posed by environmental breakdown. Described as the 'first economic crisis of the Anthropocene' (Tooze 2020), the global lock-down required to bring Covid-19 under control looks set to result in the worst economic downturn since World War II, resulting in record levels of unemployment and public debt. It also required central banks to act on an unprecedented scale to prevent financial crisis and prop-up multiple sectors of the economy (Cavallino and De Fiore 2020). The weight of evidence suggests the novel coronavirus emerged due to zoonotic (animal-to-human) transmission linked to wildlife trafficking and habitat loss (Xiao et al. 2020; Zhou et al. 2020; Lam et al. 2020; Johnson et al. 2020; Crow 2020). Indeed, almost half of new diseases since 1940, including previous coronaviruses such as SARS, can be traced to environmental degradation and it is estimated there are 10,000 other mammalian viruses that are potentially dangerous to humans (May et al. 2004; Keesing et al. 2010; Carlson et al. 2019).

Yet global pandemics are just one of a number of existential threats linked to environmental breakdown. As well as climate change, present and future generations face threats from biodiversity loss, water scarcity, ocean acidification and chemical pollution, among other challenges; and these risks interact and compound each other in a complex and unpredictable fashion (Rockström et al. 2009; Steffen et al. 2015). Environmental breakdown presents material risks to both the real economy and the financial sector. Businesses across sectors and regions are embedded within the environment via their impacts and dependencies upon the natural world. Through lending, advisory and investing activities, financial institutions are exposed to business dependencies and are also responsible for facilitating negative impacts. Environmental risks may be amplified by the financial system, presenting potentially systemic threats to financial and economic stability (Chenet 2019; Bolton et al. 2020).

This paper considers how financial authorities should react to environmental threats beyond climate change. The most prominent sustainable finance frameworks, such as the Taskforce for Climate-related Financial Disclosures (TCFD), are founded upon the concept of 'market failure', whereby a lack of information leads to the mispricing or non-pricing of environmental externalities in financial markets (Campiglio 2016; Christophers 2017; Thomä and Chenet 2017). Focusing primarily on climate change, these approaches have prioritised information disclosure and scenario analysis as a means of internalising risks and guiding markets towards a smooth transition (TCFD 2017; NGFS 2019a; Chenet 2020; NGFS 2020c). Yet there are limits to this 'market-fixing' perspective: climate-related financial risks are complex and subject to 'radical uncertainty', which may impede efficient price discovery and credit allocation (Chenet et al. 2019; Bolton et al. 2020).

We argue that market-fixing approaches, such as the recently announced Taskforce for Nature-related Financial Disclosures (TNFD),¹ are also unsuitable for managing the systemic risks posed by environmental breakdown. As a series of interconnected, non-linear threats involving the

¹ The TNFD is at present an informal working group comprised of private financial institutions, civil society groups, the UN Environmental Programme and the UN Development Programme. See <https://tnfd.info>.

interaction of multiple environmental and socioeconomic sub-systems, environmental breakdown is an even more complex set of phenomena than climate change and it poses extraordinary challenges for financial risk modelling. It is not clear that quantitative methodologies can be sufficiently advanced within the limited time window left for transformative action.

Moreover, the role of private finance in supporting nature protection is less clear than for climate mitigation. Unlike low-carbon investments, preservation, conservation and restoration projects may not yield returns that are monetisable in the conventional sense (Chenet 2019; Hache 2019). Yet private finance does have a crucial role to play in accelerating the transition to sustainable ways of doing business. To do so, financial actors must reduce their exposure to, and hence facilitation of, environmentally harmful corporate behaviours. Just as with climate change, the failure to achieve such capital reallocation threatens to 'lock in' future environmental impacts. Nature-related financial risks may arise endogenously from behaviours within the financial system itself.

Nevertheless, so far there is little evidence of central banks and supervisors taking steps to deal with these threats, despite the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) including broader environmental risks within its remit (NGFS 2019a). Instead, regulated financial institutions have been largely left to their own devices in developing policies to avoid the financing of environmentally damaging activities. Usually these sit within voluntarily developed Environmental, Social and Governance (ESG) or Corporate Social Responsibility (CSR) frameworks. While there are some good examples of exclusionary policies, in general this approach — which has been around for many years — has not been effective in materially reducing the flows of finance to unsustainable activities (Suttor-Sorel and Hercelin 2020).

We argue that a 'precautionary policy' approach (Chenet et al. 2019) to financial supervision is warranted, focusing on preventative action to build financial- and economy-wide system resilience. Given the structural inability of financial markets to manage the systemic risks associated with environmental breakdown, central banks should implement regulations at the micro- and macroprudential level to address drivers of environmental risk where they intersect with the financial system.² Such risk management should also be integrated into wider central bank policy instruments, including monetary policy.

The paper proceeds as follows: Section 2 expands upon the physical threats posed by environmental breakdown; Section 3 articulates how nature-related risks feed through to the real economy and the financial system; Section 4 lays out and critiques the market fixing approach to sustainable finance and considers supervisory responses to nature-related risk; Section 5 develops precautionary approaches to financial supervision and policy recommendations; and Section 6 concludes.

² We use the term 'environmental risk' to refer to the risks posed by both climate change and environmental breakdown, while the term 'nature-related risk' encompasses environmental risks beyond climate change.

2. The age of environmental breakdown

The Covid-19 pandemic can be viewed as a manifestation of a broader problem, where the increasing scale and intensity of human activity is pushing natural systems towards and beyond their functional limits. From pollination to flood defences to disease control, the benefits of nature upon which society depend are increasingly threatened by environmental degradation (IPBES 2019). The extent of the problem is not only evident at local and regional levels, but also at the global scale (Rockström et al. 2009).

The focus of attention for financial policymakers in recent years has been on climate-related financial risks (Carney 2015; TCFD 2017; NGFS 2019a). Less attention has been paid to the biosphere, defined as all of Earth's ecosystems and its living organisms. The biosphere balances material and energy flows, and its diversity increases the resilience of the Earth system to both abrupt and gradual change (Steffen et al. 2015). Climate and biosphere integrity³ should be understood as *core* planetary systems that regulate life support processes on Earth. They interact with each other: climate-induced flooding, wildfires and droughts accelerate habitat and biodiversity loss, while these in turn are key contributors to climate change. The degradation of critical carbon-sink ecosystems, such as forests, wetlands and peatlands, reduces the planet's carbon-absorbing capacity (IPBES 2019). Certain policy innovations that mitigate climate change may have damaging unintended effects on the biosphere; for example the electrification of transport networks may require the extraction of scarce minerals such as lithium for batteries (Hache 2018).⁴ The preservation, conservation and restoration of the biosphere is therefore not only critical in order to resolve biodiversity loss, but also to mitigate and adapt to the impacts of climate change and other environmental threats (Global Commission on Adaptation 2019).⁵

As the unforeseen economic fallout from Covid-19 has demonstrated, the interaction of environmental threats with the financial and economic spheres compounds existing socioeconomic challenges, such as inequality. Beyond the pandemic, the unprecedented speed and scale of natural system collapse is already threatening social stability through the increasing likelihood of conflict, hunger and involuntary mass migration (Rüttinger et al. 2015; Geisler and Currens 2017; WEF 2018). In contrast to climate change, where the worst physical impacts are expected to emerge over the coming decades, environmental breakdown is occurring in the short-term, and well within business and policy horizons. One salient example is the widespread decline

³ Biosphere integrity is comprised of two components. Genetic diversity represents the 'information bank' of genetically unique material that determines the capacity of life to continue to coevolve with the Earth system, persisting under and adapting to conditions of both abrupt and gradual change. Functional diversity captures the role played by the biosphere in maintaining stable Earth system conditions, as performed by the functional traits of the organisms in a given ecosystem (Steffen et al. 2015). For simplicity, this paper will refer to 'biodiversity' to reflect both of these characteristics of biosphere integrity.

⁴ A growing literature is emerging on the issue of raw material shortages. Since 2000, more than 2000 articles, conference papers or peer-reviewed resources have been published on the issue of material criticality, nearly 80% of them since 2010 (Diederer 2009).

⁵ The terms conservation and preservation are often used interchangeably, but represent distinct concepts. Conservation seeks to ensure the sustainable use of nature for human purposes and is associated with the management of natural resources. Preservation, by contrast, seeks to minimise human use of nature, and is associated with attempts to create and maintain pristine 'wilderness'. These terms, however, remain contested (Sarkar, 1999). Throughout this paper, we refer to environmental protection as an umbrella term for both concepts.

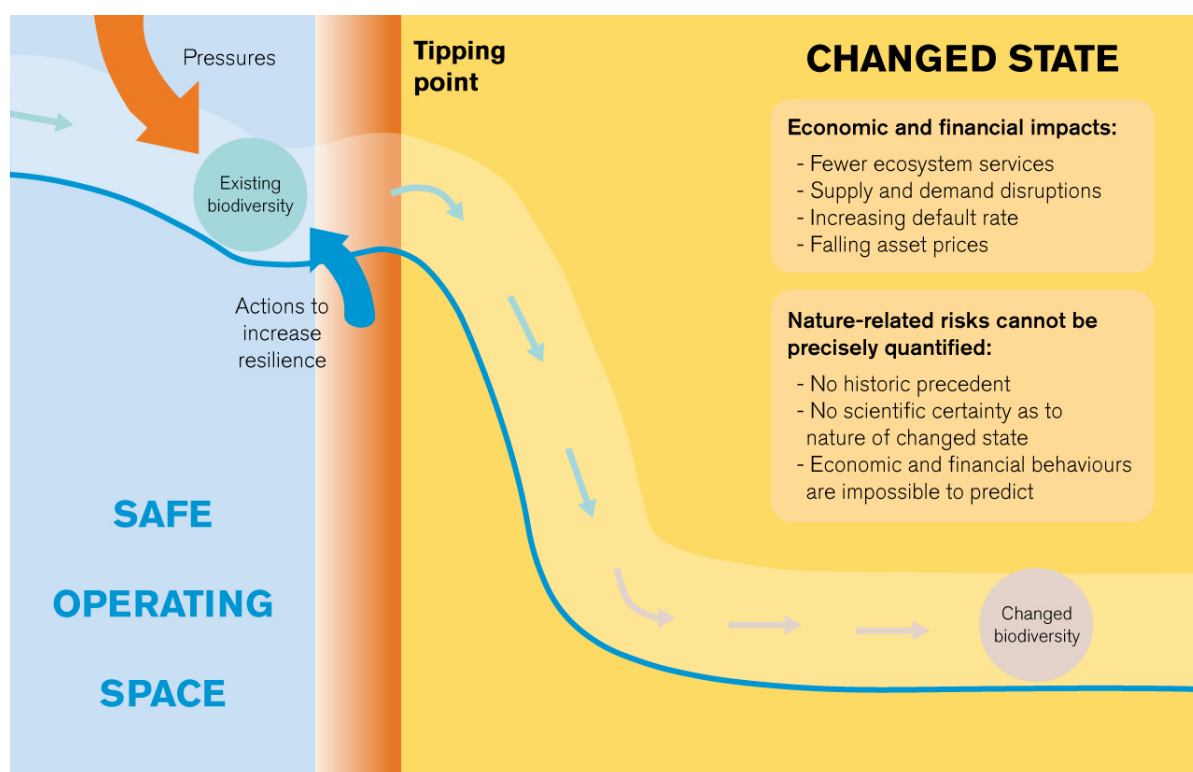
of pollinators (Biesmeijer et al. 2006; IPBES 2016). With 75% of food crops dependent to some extent upon animal pollination, reductions in global crop production as a result of biodiversity loss are already evident (Garibaldi et al. 2011; Reilly et al. 2020).

Environmental breakdown, and its interactions with the socioeconomic sphere, displays a high degree of complexity. Multiple interconnected threats are characterised by non-linearities and complex system dynamics, while the potential impacts upon the planet are likely to be both historically unprecedented and ultimately irreversible. Environmental breakdown cannot be conceptualised as an example of probabilistic risk, but rather as a situation of radical uncertainty (Chenet et al. 2019; Kay and King 2020; Bolton et al. 2020). This distinction, first articulated by Knight (1921) and later developed by Keynes (1936), highlights that the ability to assign a probability of occurrence to an event relies on either a robust theory that can establish a probability distribution function or past trends in order to estimate possible future outcomes. In situations where there is no scientific basis or historical trend to work with, the future remains inherently unknowable. This is especially true for complex adaptive systems, such as socioecological systems, where the unpredictable reactions and interactions of different market players, other living organisms and natural processes, mean it is not possible to ever know all the possible outcomes of an event. For environmental breakdown, the precise timing and magnitude of potential impacts are unpredictable, but the fact that they will occur at some point is increasingly likely. To distinguish them from exogenous tail risks, the Bank for International Settlements has designated such radically uncertain environmental threats as 'green swans' (Bolton et al. 2020).

There is consensus that the window of opportunity for transformative action relating to nature-related risks is narrow and closing (IPCC 2018; CBD 2018). Once critical thresholds (or 'tipping points') are breached, catastrophic outcomes will become unavoidable and irreversible (Rockström et al. 2009; Steffen et al. 2015) — illustrated in Figure 1. The UN global assessment report on biodiversity concluded that restoring natural systems requires the reduction of human claims upon nature, which itself implies a structural economic transformation focused on sustainability (IPBES 2019). The EU's recently published Biodiversity Strategy is one of the first major policy interventions that addresses biodiversity risk. The strategy aims to conserve 30% of land and sea in Europe, and restore degraded ecosystems through tree planting, pesticide control and river restoration. The ambition for the upcoming Conference of the Parties (COP 15) to the Convention on Biological Diversity, now postponed in the wake of Covid-19, is to agree an internationally binding target for biodiversity equivalent to the 2015 Paris Agreement.

The sustainability challenge ahead, therefore, encompasses not only the transition to a low-carbon economy, but also to one that can flourish while protecting and restoring natural systems. Such a herculean task requires a fundamental rethink of how the real economy, and by extension the financial system, interacts with the natural world.

Figure 1: Nature-related financial risks will increase as anthropogenic pressures push biodiversity loss towards and beyond an irreversible tipping point



Source: Adapted from the Secretariat of the Convention on Biological Diversity (2010)

3. The economy and financial system: impacts and dependencies

3.1 Nature-related financial risks and the real economy

The economy is not separate to the environment, but embedded within it and dependent upon it (Raworth 2012; Neumayer 2013). Business activities — and indeed all human activities — rely on the ‘free’ benefits of nature flowing from the stocks of renewable and non-renewable resources that maintain functioning life support systems on earth. For example, a healthy woodland provides clean air, flood defences, insects for pollination and carbon sequestration, among other services. Depleting, damaging or even failing to maintain the ecosystem threatens the future provision of these vital benefits, upon which societal welfare depends.

Accordingly, environmental breakdown threatens the real economy through three main channels:

1. **Supply shocks.** Firms and sectors heavily dependent upon ecosystem services (e.g. agriculture) will suffer both acute and chronic effects of environmental degradation, including increased vulnerabilities to climate change and natural disasters, leading to an increased likelihood of negative supply shocks.

2. **Demand shocks.** Firms and sectors which have large negative impacts upon natural systems (e.g. mining) will face possible demand shocks resulting from changing consumer preferences and shifts in policy, regulatory, technology or trade environments. Additionally, firms face increased litigation or liability risks if they are assigned responsibility for environmental degradation.
3. **Systemic effects.** Environmental breakdown will give rise to second- and third-order effects which may affect firms and sectors further down the supply chain. Disruption to production and supply chains from environmental threats has already increased by 29% since 2012 (WEF 2019). As shown by the Covid-19 pandemic, responding to nature-related shocks may have huge, complex and permanent socioeconomic costs that are impossible to predict.

A review of analyses undertaken by financial institutions found that food and beverages, metals and mining, oil and gas, utilities, forestry, construction and transportation are the sectors consistently identified as facing the most material environmental risks (McCraine et al. 2019). Meanwhile, many of these same sectors, in particular the primary production industries, are those responsible for the most severe impacts upon the natural world (Trucost 2013). For exposed firms, supply disruption and shifting demand will manifest in tangible financial impacts, including increased cost of capital and/or stricter borrowing requirements, write-downs or write-offs of asset value, increased risk of default and changes to firm market valuation (Pinzón and Robins 2020).

As significant contributors to natural system collapse, firms across all sectors need to structurally transform their interactions with the natural world. Reducing the throughput of materials and energy within the real economy is essential in order to not undermine urgent conservation and regeneration efforts (Ellen MacArthur Foundation 2015). Faced with significant environmental risks, firms also need to move beyond an efficiency-maximising mindset to build resilience and robustness into their business models (Pereira da Silva 2020; WEF 2020).

New perspectives are starting to influence such a transition. The *circular economy* concept strives to minimise the linear throughput of energy, material inputs and waste through cradle-to-cradle design principles, closed loop production processes, and technological innovation in the collection and processing of end-of-life products (Ghisellini et al. 2016; Bocken et al. 2016). Other perspectives are rethinking how businesses transact with consumers, such as *products-service systems*, where consumption shifts from ownership to pay-per-use models (Reim et al. 2015; Agrawal and Bellos 2016). Reforming the business-nature interface represents a significant transformation in the structure of modern economies. As with decarbonisation, its success will be determined to a great extent by the helping or hindering hand of the financial system.

3.2 Nature-related financial risks and the financial system

The financial system is exposed to the environmental dependencies and impacts of businesses through its lending, investing and advisory activities (NGFS 2019a). Nature-related financial risks, being highly complex and systemic, share many similarities with climate-related financial risks and consequently present similar threats to the financial system (Volz 2017; Bolton et al. 2020;

Koumbarakis et al. 2020). Accordingly, the movement to integrate broader environmental issues into green finance initiatives has gained momentum over recent years, encompassing private sector initiatives (e.g. NCFI and PWC 2018), as well as the EU's sustainable finance action plan (European Commission 2018).

Yet while it is increasingly recognised that nature degradation poses systemic risks for finance, it is less often acknowledged that the financial system also *facilitates* the business activities that cause such degradation. This concept of 'double materiality' has been recently used by the European Commission, in its Non-Binding Guidelines on Non-Financial Reporting for corporates, to encompass both financial materiality (impacts from the external world on the financial value of a company), and environmental and social materiality (impacts of the company's activities on the external world). Yet the most prominent green finance initiatives, such as the TCFD, concentrate only on the financial materiality aspect of climate risks (European Commission 2019). The recently announced Taskforce for Nature-related Financial Disclosures (TNFD) also looks set to focus on exposures, but not impacts.

The Dutch central bank (*De Nederlandsche Bank* — DNB) has been leading the way in exploring the interactions between the financial system and nature-related risks. Recent quantitative analysis found that 36% of Dutch financial institution portfolios were highly or very highly dependent upon at least one ecosystem service (DNB 2020).⁶ The DNB also estimated that the biodiversity footprint⁷ of Dutch financial institutions (i.e. its impact on biodiversity) represents the loss of over 58,000 km² of pristine nature, an area 1.7 times larger than the Netherlands (DNB 2020).

The facilitating, and potentially exacerbating, role of finance *via-à-vis* systemic risks is especially evident in the banking sector. As the only private sector agents able to endogenously create new spending power through granting loans, *where* banks decide to allocate credit has considerable implications on the direction of economic development and growth (Schumpeter 1934; Bezemer et al. 2016). The assumption that financial markets optimally allocate capital has been increasingly questioned since the Global Financial Crisis, heralding a new era of central bank intervention through macroprudential regulation. The global interconnectedness and dynamic complexity of the financial system as a whole may also amplify environmental risks and provoke 'Minsky moments' whereby sudden falls in key asset valuations trigger widespread systemic financial shocks (Carney 2015; Battiston et al. 2017; Bolton et al. 2020).

The capacity of the financial sector to endogenously generate and spread risks into the real economy even before environmental impacts crystallise was made clear at the onset of the Covid-19 crisis, where destabilising capital outflows caused serious economic dislocations in emerging economies before the disease had fully established itself in the Global South (Hofmann et al. 2020). Financial system-induced volatility has also been observed in global food markets, where the increased presence of speculative interest in commodity derivatives has been linked to greater

⁶ This analysis, which encompasses 86 business processes and 21 ecosystem services, only considers first-order dependencies (e.g. food processing as a secondary industry is not considered reliant upon animal pollination) and is therefore an under-estimation of true economic dependency.

⁷ A metric that estimates the pressure human activities put on biodiversity, expressed as the loss of ecosystem species and populations relative to its pristine condition.

food price volatility (Ghosh et al. 2012). Relatedly, export-oriented nations highly dependent on soft commodity agriculture — which is itself reliant on natural processes such as pollination, soil fertility, etc. — are likely to be vulnerable to future environmental threats feeding through to sovereign bond markets, with implications for both financial and economic stability (Pinzón and Robins 2020).

At the more granular level, certain financial instruments and practices are exacerbating the depletion of nature. Land, and in particular agricultural land, has become a prominent investment vehicle since the Global Financial Crisis,⁸ due to its prospects for capital appreciation, income generation, inflation hedging and uncorrelated returns with equity markets (OECD 2010; Deininger et al. 2011; Cotula 2012). It has been argued that the rise of agricultural land as an alternative investment class demonstrates the extension of financialisation to environmental domains (Williams 2014; Loftus and March 2015; Ouma 2020).⁹ Indeed, the rise of agricultural real estate investment trusts (REITs), which pool income streams from various farm properties, embodies such financialised logic, representing a step towards land securitization (Fairbairn 2014).

The evolution of agricultural land into an 'alternative asset' highlights the tension between private finance and sustainability. Capital markets are institutionally short-termist (Davies et al. 2014; Chenet 2020) and private investors, governed by the same myopia, favour short-term returns from assets, incentivising land to be put to its most immediate profitable use. At the agricultural frontier,¹⁰ this involves the so-called 'flex crops', such as soy and oil palm, which can be used for food, feed or biofuel, and which are also the most associated with deforestation (Henders et al. 2015). Empirical analysis has shown foreign direct investments into agriculture in Latin America and South East Asia to have driven cropland expansion (Ceddia 2020), which itself has been linked to accelerated deforestation (Davis et al. 2015; Steinweg et al. 2018). Meanwhile, complex financial structures, such as securitization, arguably further impede sustainability governance by lengthening and obscuring the chain of information disclosure and investor stewardship.

The need for assets to generate returns reveals an uncomfortable truth about the constraints on private finance in facilitating nature protection (Hache 2019). Unlike low-carbon investments, many conservation projects may not yield returns that are monetisable in the conventional sense. Additionally, environmental protection often requires minimising human claims upon nature, which implies a reduction of economic activity. Wetlands restoration, for example, delivers significant economic benefits — flood defences, carbon sequestration, pollinators — yet these are not easily translated into an income stream. On the other hand, monetisable activities, such as tourism, may undermine the effectiveness of restoration. Even where returns are tangible, environmental protection is a challenging sell for private investors. High transaction costs and returns that may take decades to materialise make for an unappealing risk-return profile. And the necessarily small

⁸ Between 2005 and Q3 2018, the number of investment funds specialising in food and agriculture grew from 45 to 531, with aggregated assets under management, excluding timber, reaching US\$83 billion (Valoral Advisors 2018).

⁹ Through macro-financial analysis and ethnographic fieldwork, Ouma (2020) provides a comprehensive 'bottom-up' exploration of this trend, showing how global agriculture has been reconfigured to function in an era of increasing financialisation.

¹⁰ Dynamic environments, usually located in tropical habitats, which represent the transition zone between human settlement and natural habitat, and are hence subject to significant land use change (Schiesari et al. 2013).

and localised nature of many projects renders them difficult and costly to incorporate into large-scale investment vehicles such as green bonds.

A recent review cited these factors in its findings that market-based tools (e.g. ESG/impact investing, natural capital accounting, mapping and footprint tools) are ineffective in channelling private finance towards conservation (Suttor-Sorel and Hercelin 2020). Yet while private finance may be unsuitable for accelerating environmental protection projects, it does have a key role to play in facilitating the transition to sustainable and resilient ways of doing business.¹¹ As discussed above, the move to non-extractive business processes will require finance for innovation and capital investment. But beyond that, such a transition also implies that financial actors must reduce their exposure to, and hence facilitation of, harmful corporate behaviours. The failure to materially shift capital in this way risks 'locking in' future environmental impacts, especially as natural processes approach critical tipping points.

Overall, the dynamics explored in this section reveal an important point about nature-related financial risks: they may emerge endogenously from within the financial system itself. To resolve these particular challenges, conventional financial and economic frameworks for dealing with environmental breakdown need rethinking.

4. Market-fixing approaches to environmental breakdown

4.1 Risk, uncertainty and market failure

Most sustainable finance initiatives are grounded in a market failure conceptualisation of environmental problems, where it is assumed that a lack of information about risk and exposures prevents efficient price discovery and resource allocation (Christophers 2017; Ryan-Collins 2019). It is argued that financial institutions act according to perceived risk/return ratios and so shifting financing to sustainable activities requires the internalisation of the hidden costs of harmful activities to returns, and of the broader risks associated with loss of natural system functioning (HLEG 2018; BEIS 2019).

The Taskforce for Climate-related Financial Disclosures (TCFD) has been the most prominent initiative promoting this 'market-fixing' approach in recent years, recommending the use of portfolio-level risk screening and forward-looking scenario analysis in order to price climate risks into strategic decision-making (TCFD 2017). Other finance sector-led initiatives have extended this approach to nature-related risks, including the Natural Capital Finance Alliance (NCFA), and,

¹¹ For an exploration of how finance affects the directionality of low-carbon innovation, see Mazzucato and Semieniuk (2017).

most recently, the Taskforce for Nature-Related Financial Disclosures (TNFD), which aims to establish a disclosure framework for nature-related risks similar to the TCFD recommendations.¹²

We argue that such market-fixing approaches are unsuitable for managing the systemic risks posed by environmental breakdown. Firstly, current policy action to compensate for the absence of 'natural' price signals is too weak to create the materiality required by financial actors in order to reallocate capital. Secondly, and more fundamentally, we contend that even in the presence of such signals financial markets are incapable of sufficiently internalising nature-related financial risks into prices, due to the multi-dimensional complexity and radical uncertainty that characterises environmental breakdown. We now discuss each of these points in turn.

There has been insufficient policy action at both national and international levels to define the pathway to resolving the global environmental breakdown, especially at financial system level. Implementation of the 'polluter pays principle' — through, for example, environmental taxes — does constitute an interesting example of isolated policy action, but there are a number of practical and political obstacles,¹³ as embodied by the slow progress in levying a meaningful carbon tax (OECD 2019). Moreover, there are no binding, internationally agreed targets for resolving other nature-related risks, unlike the 2015 Paris Climate Agreement. The various conventions that do exist (mostly focused on biodiversity) do not express the need for public and private finance flows to be aligned with environmental protection and restoration. Overall, as Table 1 summarises, the conceptual framework for measuring and understanding nature-related financial risks is far less advanced compared with progress in climate finance.

Table 1: Frameworks and indicators for understanding and measuring nature-related financial risks compared to climate-related financial risks

Frameworks and indicators	Climate-related risks	Nature-related risks
Clear, quantifiable goal	The 2015 Paris Agreement sets the ambition to limit global average temperature increases since the industrial revolution to below 2°C and ideally below 1.5°C.	There are no internationally agreed headline targets for resolving other environmental threats, with the exception of the Aichi Biodiversity Targets, which are non-binding and on track to be missed in 2020. To bring global biodiversity action in line with the Paris Agreement, a 2°C-like single target has recently been proposed to keep species extinctions to well below 20% over the next 100 years across all major groups (fungi, plants, invertebrates and vertebrates) and across all ecosystem types (Rounsevell et al. 2020).

¹²The NCFAs has developed a number of tools to 'price in' nature-related financial risks (NCFAs and PWC 2018). Financial institutions are also developing their own in-house pricing approaches, such as ASN Bank's Biodiversity Footprint for Financial Institutions (BFFI) (DNB and Sustainable Finance Platform 2020).

¹³ Challenges include, for example, how to identify and levy payment from polluters located across jurisdictional boundaries; how to measure environmental harms that may not materialise within the time frames required to internalise costs; and if the appropriate tax level to achieve the most efficient outcome can be determined ex ante (Ruhl and Craig 2011).

Frameworks and indicators	Climate-related risks	Nature-related risks
Established scientific metrics and indicators	The <i>tonnes of CO² equivalent</i> metric is well-established for measuring the drivers of climate change, while <i>global mean average temperature change</i> is the single indicator for measuring progress. There are established frameworks for reporting and recording CO ² emissions from human activities.	Multiple metrics are required to track multiple problems across different time and spatial scales, and types of local environment. Drivers are multi-dimensional, meaning there is no single indicator for tracking human impacts (like emissions). For threats such as biodiversity loss, there is no scientific consensus on the best way to measure trends or progress (Mace et al. 2018).
Acknowledgement of financial system within international agreement(s)	The Paris Agreement article 2.1(c) sets the expectation to align financial flows with the headline goal.	There are various conventions/agreements, mostly focused on biodiversity, ¹⁴ but none express the need for public or private finance flows to be aligned with environmental protection and the need to transition business models.
Materiality of financial risks	Climate risks are widely acknowledged to be material, including at the systemic level, and are well-established in the academic literature.	The concept is less established than climate risk. Awareness is growing, but there is very limited academic research empirically testing materiality of the financial risks associated with broader environmental threats. ¹⁵
Financial tools and metrics	Frameworks for disclosing financial risks are under development (e.g. TCFD). There are a variety of portfolio tools, e.g. Climate VaR, Carbon Earning at Risk, and Paris Agreement Capital Transition Assessment (PACTA).	There are no standardised or widely used tools for measuring financial impacts or risks, though multiple approaches are under development, such as the Global Biodiversity Score by CDC Biodiversité and the Biodiversity Footprint for Financial Institutions by ASN Bank. (Berger et al. 2018).
Central bank and supervisory initiatives	Central banks (especially NGFS members) are increasingly putting in place infrastructure for climate stress testing, e.g. The Bank of England's 2021 Biennial Exploratory Scenario.	The NGFS is beginning to explore nature-related risks from a supervisory perspective. The Dutch central bank, DNB, has undertaken a preliminary exercise to quantify financial exposures resulting from biodiversity loss (DNB 2020).
Financial opportunities	The opportunities posed by the transition (e.g. new sectors and technologies) as a solution to climate change are well understood by investors. There has been large growth in new financial instruments, such as green bonds, though concerns remain about the robustness of standards and greenwashing.	Critical questions remain as to how nature can become a new sector of opportunity. Many ecosystem services are public goods, which calls into question the feasibility and suitability of monetising such assets for financial instruments. Additionally, environmental protection often requires minimising human claims upon nature, which implies a reduction of economic activity.

¹⁴ For example, Convention on Biological Diversity (CBD), the Ramsar Convention, Convention on International Trade of Endangered Species, Convention on Migratory Species and International Treaty on Plant Genetic Resources for Food and Agriculture.

¹⁵ A systematic review by Bassen et al. (2019) found strong evidence linking flood and wildfire events to adverse impacts on real estate values. Serious holes in the literature were also identified, in particular a lack of empirical analysis into the financial impacts of biodiversity loss and deforestation.

However, even if progress were to be accelerated in the policy sphere, market-fixing approaches would remain fundamentally ill-suited to dealing with the radical uncertainty that characterises environmental risks. This point has been articulated in detail for climate change, with the market failure paradigm critiqued for assuming climate-related financial risks are measurable or at least can be assigned a probability (Chenet et al. 2019; Bolton et al. 2020). The probabilistic approaches typically employed by financial models rely on past trends and known distribution functions in order to estimate future outcomes (Thomä and Chenet 2017). Yet climate change has no historical basis upon which to form any calculable probability and unpredictable reactions between different market players means the future is inherently unknowable (Chenet et al. 2019). The same argument applies equally — if not even more so — to nature-related risks.

Environmental breakdown is an even more complex set of phenomena than climate change, as discussed in Section 2. It encompasses multiple interconnected threats (e.g. soil erosion, groundwater depletion, biodiversity loss), which are the result of multiple anthropogenic causes (e.g. intensive agriculture, soil sealing, chemical pollution, deforestation) acting upon various scales (from local ecosystems to planetary processes), and interacts with climate change. Such multiplicity presents challenges for measurement. Unlike climate change,¹⁶ environmental breakdown cannot be easily simplified into isolated metrics and parameters, as its impacts are the result of multiple interactions.

Biodiversity loss exemplifies many of these challenges: it threatens Earth system functioning at the planetary scale, yet it is driven (and must be resolved by) processes acting at the level of distinct local ecosystems. Measuring biodiversity therefore requires multiple metrics across different spatial scales and types of ecosystem, and there is no established consensus on the appropriate indicators (Mace et al. 2018). This makes biodiversity an inherently less manageable task for financial analysis. For example, unlike CO₂ emissions, which are fungible, biodiversity gains in one location cannot offset losses elsewhere (Chenet 2019).

The multi-dimensionality of environmental breakdown therefore poses extraordinary challenges for financial modelling. Impacts are most directly identifiable at the micro-level, where one firm will be both exposed to, and responsible for, multiple nature-related risks (e.g. within agriculture: pollination, water scarcity, land use and soil fertility, *inter alia*). Each of these risks will have differing effects within different local ecosystems and across different points in time. Replicating such granular analysis up to the financial portfolio level implies an unmanageable level of complexity unless very broad and aggregative abstractions are made.

Financial institutions noted precisely these challenges in a recent review of current approaches to managing biodiversity risk, highlighting that more and better-quality data was needed to improve measurement of risks at the portfolio level (DNB and Sustainable Finance Platform 2020). Yet while it may be possible to intricately model *individual* environmental threats, the insights are meaningless in isolation from the other environmental processes with which they interact.¹⁷ It is

¹⁶ While the climate itself is, of course, a multidimensional and complex system, established metrics do exist for measuring climate change — both its primary identifiable driver (GHG emissions) and its initial consequence (surface temperature increase).

¹⁷ This statement is, of course, also valid for the analysis of climate change, which has been artificially 'isolated' from other environmental issues.

not clear that a fully integrated, financial system-wide model of environmental breakdown is feasible within the limited time window left for transformative action.

Finally, as discussed in the previous section, there is the issue of endogeneity. Financial markets cannot generate a material shift in capital reallocation if financial institutions are not encouraged (due to lack of policy action) or are unable (due to methodological impossibility) to internalise environmental risks and this lack of capital shift itself risks crystallising future environmental threats by continuing to facilitate harmful corporate activities. Market-fixing approaches therefore have serious limitations in managing the systemic risks posed by environmental breakdown. Where financial institutions cannot individually take a holistic perspective, it falls, to some extent at least, to central banks and financial supervisors to deal with managing systemic threats. As the BIS recently noted, addressing environmental threats beyond climate change, ‘...could be critical for central banks, regulators and supervisors insofar as the stability of the Earth system is a prerequisite for financial and price stability’ (Bolton et al. 2020, p.66). In order to do so, financial authorities should embrace a more interventionist, precautionary approach to policymaking.

4.2 Supervisory responses to environmental breakdown

Central banks and supervisors appear to have recognised the limitations of using standard, backward looking quantitative risk modelling approaches to deal with climate change (Bolton et al 2020; NGFS 2019a). However, they still appear to believe such risks can be quantitatively modelled using more forward looking techniques, in particular stress testing and scenario analysis. The Network for Greening the Financial System (2020b) — the international grouping of central banks and supervisors researching and developing policy recommendations on environmental risks — proposes that supervisory interventions focus on:

- Identifying environmental exposures and estimating the magnitude of potential losses, using tools such as scenario analysis and stress testing;
- Setting supervisory expectations regarding the governance, strategic management and measurement of environmental risks, including, for example, expectations on disclosures; and
- Ensuring adequate management of environmental risks by financial institutions, taking mitigation action (such as board level engagement) where appropriate.

These forms of intervention largely sit within a market failure paradigm. Information and measurement are emphasised as a prerequisite for action, and the focus on disclosure, scenario analysis and stress testing assumes that these tools are able to produce reliable and meaningful quantitative estimates of the risks in question. Overall, the central bank’s role is conceptualised as an intellectual leader whose convening power will catalyse financial institutions to voluntarily improve their management of climate and environmental risks, shifting capital allocation towards sustainable business activities.

There are a number of problems with this approach. Firstly, although central banks have acknowledged the financial materiality of environmental breakdown, there remains insufficient analysis of the additional complexities these risks pose within current sustainable finance narratives — with the most prominent initiatives focusing primarily on climate risk (e.g. NGFS

2020a). While climate change in and of itself is a huge challenge for supervisors, this is a potentially dangerous oversight for the reasons discussed in section 2 — climate change interacts with other environmental threats, especially biodiversity loss, in a series of reinforcing feedback loops (IPCC 2018; IPBES 2019). All efforts to measure and manage climate-related financial risks are therefore likely to be *underestimating* true potential impacts unless nature-related risks are also taken into account.

Secondly, as discussed in the previous section, it is questionable whether meaningful quantitative estimates of nature-related risks can be feasibly developed within the time frame remaining for transformative action and it is not clear at what point such information-gathering exercises would trigger supervisory action. Progress with existing market-fixing initiatives has also been slow. Three years after the publication of the Taskforce on Climate-related Financial Disclosures' (TCFD) recommendations, voluntary disclosures of carbon-related asset exposure remain low among European banks, according to recent survey data (ShareAction 2020a). Moreover, even where climate disclosures have been implemented, evidence suggests that these practices alone are not stimulating effective management of climate risks (BCAM 2019; Christophers 2019; Ameli et al. 2019).

Furthermore, financial actors have made even less progress in understanding and managing nature-related risks. In the first supervisory survey of its kind, the DNB concluded that Dutch financial institutions have yet to fully operationalise broader environmental risk management, finding that whole portfolio analysis remained rare and that the ESG indicators used were not always appropriate measures of the environmental risks in question (DNB 2019).

Finally, stress testing and scenario analysis are likely to be insufficient tools for capturing the complex system dynamics associated with ecological thresholds. The NGFS recommends focusing on 'extreme but *plausible*' scenarios to predict likely impacts in order to inform policy (NGFS 2020a, p.25, our emphasis). This shows that trust in and 'realism' of scenarios is central to the market failure framework, which assumes that financial institutions will only act upon risks they deem material. Yet the complexity and multi-dimensionality of environmental breakdown means the number of 'plausible' outcomes is likely to be very large.¹⁸ Given limitations in data availability and modelling capacity, in practice central banks choose a narrow range of 'representative' scenarios to ensure the analysis exercise remains feasible (NGFS 2020c). In doing so, what is deemed plausible becomes a subjective exercise. Current initiatives, although increasingly transparent as to the assumptions underlying chosen scenarios, lack sufficient analysis into validity of chosen assumptions and, in particular, on what basis they are deemed plausible.¹⁹

¹⁸ Looking at greenhouse gas emission pathways alone, the IPCC considers 222 scenarios compatible with the below 2°C target, and a further 189 scenarios for various warmer futures (IPCC 2018).

¹⁹ To use the NGFS' recently published climate scenarios (NGFS 2020d) as a case in point, the representative 'Orderly' scenario assumes full availability of negative emissions technologies (NETs), despite good reasons to question the technological, economic and ethical viability of carbon dioxide removal (Anderson and Peters 2016; Lenzi et al. 2018; Bednar et al. 2019). The NGFS scenarios also assume that final energy use can be significantly decoupled from output — an assumption that has been contested by ecological economists (Sorrell and Ockwell 2010; Hickel and Kallis 2019).

Furthermore, plausibility is unlikely to remain fixed over time. A wide range of impacts may be explored under scenarios deemed plausible today, but bigger risks that may become more likely as time passes will not be visible. This insight is relevant to understanding ecological thresholds, given tail risks may increase rapidly in likelihood as natural systems approach their tipping points (Sharpe 2019). Overall, the complexity of the modelling exercise, coupled with radical uncertainty that spans both environmental and socioeconomic domains, calls into question whether scenario analysis and stress testing can sufficiently capture the financial risks stemming from complex, interconnected threats over long-time horizons (Chenet et al. 2019). While there may be a place for exploratory models²⁰ — investigating, for example, sector-specific transition shocks over short-time horizons — we contend that the current emphasis upon quantitative methodology development as the main form of supervisory action will fail to both assess and manage the worst possible impacts facing the financial system from environmental breakdown

5. Towards a precautionary policy approach

5.1 Managing tipping points

Building on Chenet et al. (2019), we propose that a ‘precautionary approach’ to financial supervision is a more appropriate means of managing nature-related financial risks given the severe and potentially irreversible consequences of inaction.

The precautionary principle recommends the use of preventative policies to protect human and environmental health under situations of scientific uncertainty. Instead of waiting for better information and probabilistic forecasting as a prerequisite for action, as per a market-fixing approach, the general magnitude, speed and direction of harmful trends are taken as sufficient incentive for policymakers to act, even if there are no models that can assign a probability to such harmful events occurring (Henry and Henry 2002). Precautionary policymaking is well-established in the environmental sphere, forming the cornerstone of the 2015 Paris Climate Agreement, which established a threshold of below 2°C as a target to avoid the worst effects of climate change, and also the EU’s Biodiversity Strategy, which aims to conserve 30% of European land and sea, and restore degraded ecosystems.

Instead of focusing on the identification of *plausible* scenarios, precautionary approaches focus on *worst-case* outcomes and construct policies in order to avoid them (Dupuy 2002). By recognising that ‘what appear to be small and reasonable risks accumulate inevitably to certain irreversible harm’ (Taleb et al. 2014), precautionary policymaking is better suited to managing the non-linear risks presented by ecological thresholds. Indeed, ecological tipping points are obvious *worst-case*

²⁰ In a comment piece for *Nature*, Saltelli et al. (2020) articulate key principles to ensure that models serve society, noting that ‘excessive regard for producing numbers can push a discipline away from being roughly right towards being precisely wrong’ and that ‘qualitative descriptions of multiple reasonable sets of assumptions can be as important in improving insight in decision makers as the delivery of quantitative results.’

outcomes around which to design preventative policies for environmental breakdown (Neumayer 2013).

A recent body of literature has also focused upon harnessing tipping point dynamics to achieve transformative change in socioecological systems (Milkoreit et al. 2018; Farmer et al. 2019; Otto et al. 2020). If a tipping point represents a system sitting at the boundary of two different states (see Figure 1), a small intervention could trigger non-linear dynamics (e.g. desirable feedback loops and positive spillover effects) that generate a controlled regime shift towards sustainability (Westley et al. 2011) — or the opposite. One prominent example is how carbon pricing and subsidy policy has tipped the costs of new coal power plants over the threshold of new renewable investments in all major markets (Gray and Sundaresan 2020).

These insights are highly relevant for the supervisory management of nature-related risks. Complex threshold behaviour exists in financial systems (Battiston et al. 2017) and it poses systemic risks, such as the 'climate Minsky moment' (Carney 2015), where a late energy transition leads to a disorderly and potentially catastrophic repricing of assets. To build directional certainty in the sustainability transition and minimise potential market dislocations, central banks and supervisors — in coordination with fiscal and industrial policy — should take precautionary action to proactively steer market actors towards a managed transition (Chenet et al. 2019). By focusing on discouraging the financing of clearly harmful business practices, supervisory tools can manage drivers of nature-related risk where they intersect with the financial system. Carefully targeted interventions may effectively act as 'social tipping points' (Farmer et al. 2019), enabling the financial system to shift to more sustainable patterns in capital allocation.

This precautionary approach requires a shift in the supervisory mindset. Rather than attempting to correct for market failures such as information asymmetries, central banks should embrace more of a 'market-shaping' role (Ryan-Collins 2019). This approach recognises that central banks are not exogenous to the financial system, as a weather forecaster is to the weather system. Rather, financial supervisors are active market participants whose decisions will feedback and influence market outcomes (Danielsson and Shin 2003). In other words, lack of active intervention is itself a policy choice that carries risks.²¹ In fact, central banks have played such an interventionist role in the past in both developed and developing economies, actively steering credit away from undesirable and towards more desirable sectors of the economy (Bezemer et al. 2018).

5.2 Qualitative risk management

Precautionary policies to address environmental financial risks should shift towards a more qualitative risk management approach, where discretion, experience, heuristics and general direction-setting replace complicated mathematical models in the face of radical uncertainty (Chenet et al. 2019). Where there is little doubt as to the potential magnitude of a threat, or the speed and direction of a harmful trend, fixating on precise quantitative results does not necessarily improve insights for decision makers and at worst can distract from the best course of

²¹ This is also due to the escalating costs and risks of delaying action. As the has IPCC noted, 'Every year's delay before initiating emission reductions decreases by approximately two years the remaining time available to reach zero emissions on a pathway still remaining below 1.5°C' (IPCC 2018).

action (Kay and King 2020; Saltelli et al. 2020). As former Bank of England governor Mervyn King has argued, in opposition to banks determining their own capital adequacy ratios using models, 'If the nature of the uncertainty is unknown... it is better to be roughly right than precisely wrong, and to use a simple but more robust measure of required capital.' (King 2016, chapter 4).

Indeed, the emergence of macroprudential policy in the aftermath of the 2008-09 financial crisis is a step in the direction of precautionary policymaking. Representing preventative action to reduce the likely emergence of instability within the financial system (De Nicoló et al. 2012; Favara and Ratnovski 2014), macroprudential policy aims to avoid large losses across scenarios, regardless of the likelihood of any scenario (Taleb et al. 2014; Bahaj and Foulis 2016). It is also deliberately not 'market neutral', using sector-specific tools to manage sectors that are more prone to systemic risks, such as real estate.

Policies deployed by central banks in response to recent crises, including the Covid-19 pandemic, arguably also fall into the category of qualitative risk management. The recent relaunch of asset purchase programmes, intra-central bank swap lines, corporate loan facilities and loosened capital buffers were not decisions taken as a result of sophisticated quantitative risk modelling, but rather due to financial authorities using their experience and discretion to act rapidly in a situation of considerable urgency (Cavallino and De Fiore 2020). The former governor of the European Central Bank, Jean-Claude Trichet, made a similar admission during the Great Financial Crisis:

'As a policymaker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools. In the absence of clear guidance from existing analytical frameworks, policymakers had to place particular reliance on our experience. Judgement and experience inevitably played a key role.'

Trichet (2010)

If precautionary, qualitative risk management policies can (and have) been used effectively to respond to systemic threats, there is a strong case for financial authorities to explore how such policies can also be deployed to prevent systemic risks, such as nature-related financial risks, arising in the first place. To do so, the logic of policy design must shift from optimisation (the best possible policy) to adaptation (the 'good enough' policy that may be continually adjusted) (Kay and King 2020). While this is a much-needed area for future research, Table 2 summarises the novel concepts that may underpin a precautionary policy approach to financial supervision.

Table 2: Qualitative risk management concepts

Concept	Example	Source
'Rules of thumb'	We know in general we need to stop financing unsustainable sectors, even though we don't know the exact effects this will have.	Heiner (1983)
'Bounded rationality'	We know and accept that our understanding of environmental financial risks is inherently limited, but we can still make decisions within these limits.	Simon (1997)
'Learning by doing'	Early policy action can bring useful additional information on the reaction properties of the system, allowing better future decisions.	Gollier (2001)
Exploiting 'animal spirits'	Investment behaviour could quickly shift away from undesirable activities if we can shift sentiment decisively.	Keynes (1936)

Source: Adapted from Chenet et al. (2019) and King (2016)

5.3 Exploring precautionary policy options

How can financial authorities implement precautionary approaches to managing nature-related financial risks? One option would be the development of a public taxonomy that includes nature-related risks in its designation of both appropriate and inappropriate activities. The EU Taxonomy for climate financial regulation already embeds a precautionary approach, establishing the requirement to 'do no significant harm' to any of its environmental objectives as one of its thresholds for 'green' eligibility. However, a taxonomy approach also presents a number of issues. Incorporating the sectors and practices associated with nature-related risks would be significantly more complex and contested for the reasons we have outlined in this paper. Taxonomies have also been criticised for focussing too much on designating what is 'green', rather than defining what constitutes an unsustainable asset (NGFS 2020a).

A more practical way forward would be for central banks and supervisors, in collaboration with ministries of industrial policy and wider government, to identify clearly harmful activities that must be reduced over time, such as deforestation (see Table 3). Such an exclusionary list can then determine eligibility criteria within the central banking toolkit. Monetary policy tools, such as asset purchase programmes and collateral operations, should exclude assets linked to such activities, while micro- and macroprudential regulation should be used to discourage future financing of excluded practices.

Table 3: Examples of selected exclusion criteria to manage biodiversity-related risks

Financed activities must not lead to:
Loss or degradation of high carbon stock forests, high conservation value forests, endangered forests or forests where restoration and wildlife re-introduction is taking place.
Loss or degradation of high carbon stock or high conservation value ecosystems, including peatlands and wetlands, or nationally or internationally protected areas.
Use of fire for the conversion of land, excepting cases where there is a scientific consensus that fire is a natural part of the dynamics of the ecosystem.
Harvest or trade in species protected under host country laws or regulations or listed on the IUCN red list for endangered species.

Source: Adapted from EPN (2016)

Table 3 gives a non-exhaustive list of activities that act as anthropogenic pressures tipping biodiversity towards critical thresholds. Preventing flows of finance from facilitating such activities is a critical (if not the only) intervention to address pressure points and increase the overall resilience of the system. Returning to Figure 1 (p. 5), financial authority intervention would contribute to the blue arrow, representing actions to prevent natural processes approaching tipping points.

Importantly, central banks and supervisors would not be starting from scratch. Many private financial institutions already define excluded practices within sector-specific lending criteria as part of voluntary CSR frameworks, although in practice exclusion policies are inconsistent across firms and often not ambitious enough to materially shift capital allocation (ShareAction 2020a; ShareAction 2020b; Kolle and McNevin 2020). Central banks also commonly apply socially responsible investment (SRI) criteria to their own investment practices, including exclusionary criteria (NGFS 2019b). The Banque de France, for example, excludes investments in companies ‘that derive more than 20% of their revenues from coal’ and also ‘investments that promote agricultural commodity speculation’ (BdF 2018, p. 3).²²

²² The exclusionary criteria currently apply to its own funds and pension funds, not policy portfolios.

In its latest guidance, the NGFS has opened the door to extending exclusionary criteria to financial supervision:

'If supervisors find that the level of risk driven by climate-related and environmental factors is excessively high, they could require institutions to reduce such risks by applying measures such as:

- risk mitigation tools (guarantees by third parties, reinsurance or other forms of protection);
- setting more stringent limits on risk concentration;
- *limiting or prohibiting them from carrying out certain categories of activities* (e.g. financing customers/subscribing securities from a specific territory or economic sector/or underwriting particular types of risks);
- prescribing the deleveraging of certain risks; and
- requiring business model adjustments within a longer-term perspective.'

(NGFS 2020a, p. 51, our emphasis)

This guidance encapsulates a precautionary approach, but is given from a microprudential perspective — i.e. applying risk-reduction measures on a case-by-case basis once shortcomings have been identified in individual institutions. We propose that this approach to be extended to rules applying to all financial institutions. Given the systemic and endogenous nature of nature-related financial risks, and given central banks have a duty to manage environmental risks where they intersect with the financial system, there is a strong argument for system-wide exclusion criteria to be set and overseen by supervisory authorities.

Such environmentally focused interventions are not without precedent. Central banks and supervisors in emerging economies have pioneered the use of sector-targeting approaches to environmental risk management, exploring in particular the use of macroprudential and credit allocation policies (Dikau and Ryan-Collins 2017; Dikau and Volz 2018; D'Orazio and Popoyan 2019). Green macroprudential tools, including sector-differentiated capital buffers, risk weights and exposure restrictions, aim to increase the systemic resilience of the financial sector to environmental shocks. Credit allocation policies aim to steer finance towards or away from certain sectors, activities or geographies, and can include, among other things, credit floors/ceilings and differentiated loan/rediscount rates. Macroprudential tools can also have allocative effects, while credit allocation can also be appreciated as a tool to reduce systemic risk exposures (Campiglio 2016; Schoenmaker and Van Tilburg 2016). As Table 4 shows, both sets of these tools have been deployed to target sectors in order to advance environmental goals in several countries.

Table 4. Environmental policies undertaken by selected emerging economy central banks

Country	Green credit guidance policies	Green prudential and macroprudential policies
Bangladesh	<ul style="list-style-type: none"> ▪ There is a requirement for commercial banks and non-bank financial institutions to allocate 5% of their total loan portfolio to green sectors. ▪ A number of targeted green refinancing lines subsidise green lending. 	<ul style="list-style-type: none"> ▪ Equity margin requirements are lower for environmental and socially favourable projects.
Brazil	<ul style="list-style-type: none"> ▪ Regulations explicitly prohibit lending to projects which violate laws on deforestation and the use of forced labour in the Amazon region. ▪ National Development Bank (BNDES) is a major investor in green sectors. 	<ul style="list-style-type: none"> ▪ Banks must engage in environmental and social stress testing, and incorporate such risks into capital requirements in line with Internal Capital Adequacy Assessment Process (ICAAP)/Basel 2 accords.
China	<ul style="list-style-type: none"> ▪ The Green Credit Policy restricts banks from lending to firms that violate environmental compliance rules. ▪ As part of this, the People's Bank of China (PBOC) and the Ministry of Environmental Protection created a national database disclosing credit, fines, and environmental compliance as a source of information on which to base credit restrictions. 	<ul style="list-style-type: none"> ▪ Green finance has been incorporated into macroprudential assessment since 2017. ▪ Green loans with AA rating are included as collateral in the medium-term loan facility. ▪ Green Credit Guidelines launched in 2012 to encourage banks to adopt environmental and social risk management and governance standards, as well as increase support for green projects.
India	<ul style="list-style-type: none"> ▪ Under the Priority Sector Loans scheme, 40% of net commercial bank credit must support priority sectors, including renewable energy. 	

Source: Adapted from Dikau and Ryan-Collins (2017)

While most of these policies aim to support green sectors, the Brazilian experience stands out as one example of restricting credit to undesirable business practices. In 2008 the Brazilian central bank (BCB) published Resolution 3545, which restricts rural credit in the Amazon to firms compliant with environmental regulations. Econometric estimations have shown that the BCB's policy resulted in a material reduction in deforestation over the period 2003 to 2011, especially in municipalities where cattle ranching is the main economic activity (Assunção et al. 2020). While the Brazilian example has been complicated in more recent years by renewed deforestation under the Bolsonaro regime, the initial success of using credit steering in this way demonstrates the effectiveness of applying precautionary policies to sensitive intervention points in a socioecological system (Nepstad et al. 2014). Without waiting to quantify potential exposures or losses, the BCB enacted a 'rule of thumb' policy to restrict financing to a harmful corporate behaviour. In doing so, deforestation risks were reduced and companies operating in the region were incentivised to accelerate the transition of their business models.

5.4 Rethinking institutional mandates

The precautionary approach to managing nature-related financial risks explored in this paper raises important questions as to the institutional role of central banks and supervisors. Current financial stability and monetary policy mandates are designed to maintain the continuity of the current system, not necessarily to change it. Yet we have argued that the financial system in its current form is facilitating and potentially exacerbating the emergence of nature-related financial risks. The effective management of environmental financial risks therefore requires financial authorities to influence the directionality of activities facilitated by the financial system, so as to enable — and not hinder — the transition to an economy that functions within planetary boundaries. This ‘market-shaping’ intervention is necessary because of the systemic and endogenous nature of the risks in question, which cannot be sufficiently captured or managed through conventional market-fixing approaches.

Importantly, central banks cannot act as ‘lone agents’ in the management of environmental risks, as they are often regarded as doing in other areas of monetary policy and financial supervision (Pereira da Silva 2020). Resolving the particular challenges posed by complex environmental threats requires not just prudential and monetary tools, but also wider regulatory and fiscal interventions. Central bank responses must therefore be *coordinated* with other departments within government — most obviously those concerned with finance and industrial policy — and other public institutions that may be better placed to provide patient, high risk finance for sustainable innovations, such as state investment banks (Mazzucato and Penna 2016).

Going forward, central banks and supervisors should also commit to ensuring their actions align with broader industrial strategy targeting the ecological transition. As governments designate new norms and technological pathways, central banks should use supervisory tools to ensure that financing practices do not undermine environmental policy. Such fiscal-monetary coordination has already been demonstrated during the response to the Covid-19 crisis, with the Federal Reserve and the Bank of England launching a range of new corporate financing facilities to support companies facing liquidity crises — an extension of monetary policy that sees the central banks acting effectively as a fiscal arm of the government.

Recognising the limits independent central banks and supervisors face amidst the societal challenges ahead, calls for green fiscal-monetary-prudential coordination have been made by the BIS (Pereira da Silva 2020), among others (Macquarie 2018; Stirling et al. 2019; Ryan-Collins 2019). Such calls foreground an alternative theory of central banking that recognises the ‘battery of instruments’ at central banks’ disposal that can and should be deployed in the pursuit of democratically determined social goals (Braun and Downey 2020). These are, of course, political economy questions, but we argue that serious consideration of the broader institutional role of central banks within society is justified given the severity and time urgency of the environmental threats we face.

6. Conclusion

Environmental breakdown poses a series of complex, multi-dimensional threats to society and the economy characterised by radical uncertainty. Businesses across sectors and regions are exposed to material financial risks due to their impacts and dependencies upon the natural world. Through its lending, investing and advisory activities, the financial system will also suffer adverse consequences from environmental breakdown. The transition to a non-extractive economy that flourishes while protecting nature requires the financial system to provide capital investment for innovation, but also reduce its exposure to, and hence facilitation of, environmentally harmful corporate practices. Yet in its present form, the financial system threatens to amplify environmental risks and, in some areas, exacerbate the depletion of nature. Both firms and financiers must transform their interactions with the natural world, not only in order to manage exposures to nature-related risks, but also because the viability of the future economy rests upon the integrity of the biosphere.

Market-fixing approaches to sustainable finance, such as the Taskforce for Nature-related Financial Disclosures (TNFD), will struggle to resolve the complex risks posed by environmental breakdown. The multi-dimensionality of environmental threats presents extraordinary challenges for financial modelling, far beyond those posed by climate change. The conceptual framework for measuring the associated financial risks lags far behind progress made so far in climate finance and it is not clear that these significant methodological challenges can be overcome within the limited time remaining for transformative action. Prominent central bank initiatives continue to operate within the market failure paradigm and have yet to develop a more sophisticated understanding on environmental risks beyond climate change. Given the interconnected nature of climate- and nature-related risks, current sustainable finance approaches are therefore likely to be *underestimating* the true potential impacts of climate change.

Given the structural inability of financial markets to manage systemic environmental risks, financial authorities need to move towards precautionary approaches to maintaining the safety and soundness of the financial system. Precautionary policy prioritises preventative action and a qualitative approach to managing risk above quantitative measurement and information disclosure. It aims to steer away from tipping points and build system resilience as a superior means of managing radical uncertainty.

To operationalise such an approach, we have suggested that central banks could discourage the financing of clearly harmful business practices in order to address drivers of environmental risk where they intersect with the financial system. Such an exclusion list of damaging environmental activities, identified in collaboration with relevant parts of government, could inform both regulatory and monetary policy toolkits. Going forward, the effective management of nature-related risks will inevitably require significant coordination with other actors as part of a broader sustainable industrial strategy.

References

- Agrawal, V.V. and Bellos, I. (2016). The Potential of Servicizing as a Green Business Model. *Management Science*, 63(5), pp. 1545–1562.
- Ameli, N., Drummond, P., Bisaro, A., Grubb, M. and Chenet, H. (2020). Climate finance and disclosure for institutional investors: why transparency is not enough. *Climatic Change*, 160, pp. 565–589.
- Anderson, K. and Peters, G. (2016). The trouble with negative emissions. *Science*, 354(6309), p. 182.
- Assunção, J., Gandour, C., Rocha, Romero and Rocha, Rudi. (2020). The Effect of Rural Credit on Deforestation: Evidence from the Brazilian Amazon. *The Economic Journal*, 130(626), pp. 290–330.
- Bahaj, S. and Foulis, A. (2016). *Macroprudential policy under uncertainty* [Online]. Bank of England. Available from: doi.org/10.2139/ssrn.2726526.
- Bassen, A., Busch, T., Lopatta, K., Evans, E. and Opoku, O. (2019). *Nature Risks Equal Financial Risks: A Systematic Literature Review* [Online]. University of Hamburg, Germany. Available from: https://d2ouvy59p0dg6k.cloudfront.net/downloads/nature_risks_equal_financial_risks_rg_sustainable_finance_hamburg_2019_final.pdf.
- Battiston, S., Mandel, A., Monasterolo, I., Schütze, F. and Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7, p. 283.
- BCAM. (2019). *Banking on a low-carbon Future: Finance in a time of climate crisis* [Online]. Boston Common Asset Management. Available from: <http://news.bostoncommonasset.com/banking-on-a-low-carbon-future-finance-in-a-time-of-climate-crisis/>.
- BdF. (2018). *Responsible Investment Charter of the Banque de France* [Online]. Banque de France. Available from: https://www.banque-france.fr/sites/default/files/media/2018/03/29/818080_-charte-invest_en_2018_03_28_12h12m41.pdf.
- Bednar, J., Obersteiner, M. and Wagner, F. (2019). On the financial viability of negative emissions. *Nature Communications*, 10(1), p. 1783.
- BEIS. (2019). *Green Finance Strategy: Transforming Finance for a Greener Future* [Online]. HM Government. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/813656/190701_BEIS_Green_Finance_Strategy_Accessible_PDF_FINAL.pdf.
- Berger, J., Goedkoop, M., J., Broer, W., Nozeman, R., Grosscurt, C., D., Bertram, M. and Cachia, F. (2018). *Common Ground in Biodiversity Footprint Methodologies for the Financial Sector* [Online]. Paris: Actiam, ASN Bank, CDC Biodiversité. Available from: <http://www.mission-economie-biodiversite.com/publication/1833>.
- Bezemer, D., Grydaki, M. and Zhang, L. (2016). More mortgages, lower growth? *Economic Inquiry*, 54(1), pp. 652–674.
- Bezemer, D., Ryan-Collins, J., van Lerven, F. and Zhang, L. (2018). *Credit where it's due: A historical, theoretical and empirical review of credit guidance policies in the 20th century* [Online]. UCL Institute for Innovation and Public Purpose. Available from: <https://www.ucl.ac.uk/bartlett/public-purpose/wp2018-11>.
- Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. and Kunin, W.E. (2006). Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. *Science*, 313(5785), p. 351.
- Bocken, N.M.P., de Pauw, I., Bakker, C. and van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), pp. 308–320.
- Bolton, P., Després, M., Pereira da Silva, L., Samama, F. and Svartzman, R. (2020). *The green swan: Central banking and financial stability in the age of climate change* [Online]. Bank for International Settlements. Available from: <https://www.bis.org/publ/othp31.pdf>.
- Braun, B. and Downey, L. (2020). *Against Amnesia: Re-Imagining Central Banking* [Online]. Council on Economic Policies. Available from: <https://www.cepweb.org/wp-content/uploads/2020/01/CEP-DN-Against-Amnesia-Re-Imagining-Central-Banking.pdf>.
- Campiglio, E. (2016). Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. *Ecological Economics*, 121, pp. 220–230.
- Carlson, C.J., Zipfel, C.M., Garnier, R. and Bansal, S. (2019). Global estimates of mammalian viral diversity accounting for host sharing. *Nature Ecology & Evolution*, 3(7), pp. 1070–1075.

- Carney, M. (2015). Breaking the Tragedy of the Horizon – climate change and financial stability. Available from: <https://www.bankofengland.co.uk/-/media/boe/files/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability.pdf?la=en&hash=7C67E785651862457D99511147C7424FF5EA0C1A>.
- Cavallino, P. and De Fiore, F. (2020). *Central banks' response to Covid-19 in advanced economies* [Online]. Bank for International Settlements. Available from: <https://www.bis.org/publ/bisbull21.pdf>.
- CBD. (2018). Statement of Ms. Cristiana Pasca Palmer, Executive Secretary of the Convention on Biological Diversity, at the opening of the high-level segment of the fourteenth meeting of the Conference of the Parties. Available from: <https://www.cbd.int/doc/speech/2018/sp-2018-11-17-cop14-en.pdf>.
- Ceddia, M.G. (2020). The super-rich and cropland expansion via direct investments in agriculture. *Nature Sustainability*, 3(4), pp. 312–318.
- Chenet, H. (2020). Financial risk management and climate change. In (forthcoming): R. Benkraiem, I. Kalaitzoglou and C. Zopounidis, eds., *Risk Management and Modelling* [Preprint]. Risk, Systems and Decisions. Springer. Available from: <https://doi.org/10.2139/ssrn.3407940>
- Chenet, H. (2019). *Planetary Health and the Global Financial System*. Rockefeller Foundation Economic Council on Planetary Health. Available from: <https://www.planetaryhealth.ox.ac.uk/wp-content/uploads/sites/7/2019/10/Planetary-Health-and-the-Financial-System-for-web.pdf>.
- Chenet, H., Ryan-Collins, J. and van Lerven, F. (2019). *Climate-related financial policy in a world of radical uncertainty: Towards a precautionary approach* [Online]. UCL Institute for Innovation and Public Purpose. Available from: <https://www.ucl.ac.uk/bartlett/public-purpose/wp2019-13>.
- Christophers, B. (2017). Climate change and financial instability: Risk disclosure and the problematics of neoliberal governance. *Annals of the American Association of Geographers*, 107(5), pp. 1108–1127.
- Christophers, B. (2019). Environmental Beta or How Institutional Investors Think about Climate Change and Fossil Fuel Risk. *Annals of the American Association of Geographers*, 109(3), pp. 754–774.
- Cotula, L. (2012). The international political economy of the global land rush: A critical appraisal of trends, scale, geography and drivers. *The Journal of Peasant Studies*, 39(3–4), pp. 649–680.
- Crow, D. (2020). The next virus pandemic is not far away. *Financial Times* [Online]. [Accessed 10 August 2020]. Available from: <https://www.ft.com/content/dc33f21b-740f-4be8-9947-b47439f557d2>.
- Danielsson, J. and Shin, H.S. (2003). Endogenous Risk. In: P. Field, ed., *Modern Risk Management: A History*. London: Risk Books.
- Davies, R., Haldane, A.G., Nielsen, M. and Pezzini, S. (2014). Measuring the costs of short-termism. *Journal of Financial Stability*, 12, pp. 16–25.
- Davis, K.F., Yu, K., Rulli, M.C., Pichdara, L. and D'Odorico, P. (2015). Accelerated deforestation driven by large-scale land acquisitions in Cambodia. *Nature Geoscience*, 8(10), pp. 772–775.
- De Nicoló, M., Favara, M.G. and Ratnovski, L. (2012). *Externalities and macroprudential policy*. IMF.
- Deininger, K., Byerlee, D. and Lindsay, J. (2011). *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* [Online]. Washington: World Bank. Available from: <http://documents.worldbank.org/curated/en/998581468184149953/pdf/594630PUB0ID1810Box358282B01PUBLIC1.pdf>.
- Diederer, A.M. (2009). Metal minerals scarcity: A call for managed austerity and the elements of hope. *TNO Defence, Security and Safety*.
- Dikau, S. and Ryan-Collins, J. (2017). *Green Central Banking in Emerging Market and Developing Country Economies* [Online]. New Economics Foundation. Available from: <https://eprints.soas.ac.uk/24876/1/Green-Central-Banking.pdf>.
- Dikau, S. and Volz, U. (2018). *Central Banking, Climate Change and Green Finance* [Online]. Tokyo: Asian Development Bank Institute. Available from: <https://core.ac.uk/download/pdf/161527987.pdf>.
- DNB. (2020). *Indebted to nature Exploring biodiversity risks for the Dutch financial sector* [Online]. De Nederlandsche Bank. Available from: https://www.dnb.nl/en/binaries/Indebted%20to%20nature%20_tcm47-389172.pdf.
- DNB. (2019). *Values at risk? Sustainability risks and goals in the Dutch financial sector* [Online]. De Nederlandsche Bank. Available from: https://www.dnb.nl/en/binaries/Values%20at%20Risk%20-%20Sustainability%20Risks%20and%20Goals%20in%20the%20Dutch_tcm47-381617.pdf.

- DNB and Sustainable Finance Platform. (2020). *Biodiversity opportunities and risks for the financial sector* [Online]. Working Group Biodiversity, De Nederlandsche Bank. Available from: <https://www.dnb.nl/en/news/news-and-archive/persberichten-2020/dnb389021.jsp#>.
- D'Orazio, P. and Popoyan, L. (2019) Fostering green investments and tackling climate-related financial risks: Which role for macroprudential policies? *Ecological Economics*, 160, pp. 25–37.
- Dupuy, J.-P. (2002). *Pour un catastrophisme éclairé: quand l'impossible est certain*. Paris: Seuil.
- Ellen MacArthur Foundation. (2015). *Towards a circular economy: business rationale for an accelerated transition* [Online]. Available from: https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf.
- EPN. (2016). *Green Paper, Red Lines: Requirements for pulp and paper industry finance* [Online]. Environmental Paper Network, BankTrack. Available from: <https://environmentalpaper.org/wp-content/uploads/2017/11/Green-Paper-Red-Lines.pdf>.
- European Commission. (2018). *Action Plan: Financing Sustainable Growth* [Online]. Brussels: European Commission. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0097&from=EN>.
- European Commission. (2019). *Guidelines on reporting climate-related information* [Online]. Brussels. Available from: https://ec.europa.eu/finance/docs/policy/190618-climate-related-information-reporting-guidelines_en.pdf.
- Fairbairn, M. (2014). 'Like gold with yield': evolving intersections between farmland and finance. *The Journal of Peasant Studies*, 41(5), pp. 777–795.
- Farmer, J.D., Hepburn, C., Ives, M.C., Hale, T., Wetzler, T., Mealy, P., Rafaty, R., Srivastav, S. and Way, R. (2019). Sensitive intervention points in the post-carbon transition. *Science*, 364(6436), p. 132.
- Favara, M.G. and Ratnovski, L. (2014). Externalities: An economic rationale for macroprudential policy. In: D. Schoenmaker, ed., *Macroprudentialism*. London: CEPR Press.
- Garibaldi, L.A., Aizen, M.A., Klein, A.M., Cunningham, S.A. and Harder, L.D. (2011). Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences*, 108(14), p. 5909.
- Geisler, C. and Currens, B. (2017). Impediments to inland resettlement under conditions of accelerated sea level rise. *Land Use Policy*, 66, pp. 322–330.
- Ghisellini, P., Cialani, C. and Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Towards Post Fossil Carbon Societies: Regenerative and Preventative Eco-Industrial Development*, 114, pp. 11–32.
- Ghosh, J., Heintz, J. and Pollin, R. (2012). Speculation on Commodities Futures Markets and Destabilization of Global Food Prices: Exploring the Connections. *International Journal of Health Services*, 42(3), pp. 465–483.
- Global Commission on Adaptation. (2019). *Adapt Now: A Global Call for Leadership on Climate Resilience* [Online]. World Resources Institute and Global Center on Adaptation. Available from: https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf.
- Gollier, C. (2001). Should we beware of the precautionary principle? *Economic Policy*, 16(3), pp. 302–327.
- Gray, M. and Sundaresan, S. (2020). *How to waste over half a trillion dollars: The economic implications of deflationary renewable energy for coal power investments* [Online]. Carbon Tracker. Available from: <https://carbontracker.org/reports/how-to-waste-over-half-a-trillion-dollars/>.
- Hache, E. (2018). Do renewable energies improve energy security in the long run? *International Economics*, 156, pp. 127–135.
- Hache, F. (2019). *50 Shades of Green: The Fallacy of Environmental Markets* [Online]. Green Finance Observatory. Available from: <https://greenfinanceobservatory.org/wp-content/uploads/2019/05/50-shades-biodiversity-final.pdf>.
- Heiner, R.A. (1983). The origin of predictable behaviour. *The American Economic Review*, 73(4), pp. 560–595.
- Henders, S., Persson, U.M. and Kastner, T. (2015). Trading forests: land-use change and carbon emissions embodied in production and exports of forest-risk commodities. *Environmental Research Letters*, 10(12), p. 125012.
- Henry, C. and Henry, M. (2002). *Formalization and applications of the precautionary principles* [Online]. SSRN Electronic Journal. Available from: <https://doi.org/10.2139/ssrn.1084972>.

- Hickel, J. and Kallis, G. (2019). Is Green Growth Possible? *New Political Economy*, 25:4, pp. 469–486.
- HLEG. (2018). *Financing a sustainable European economy* [Online]. EU High Level Expert Group on Sustainable Finance. Available from: https://ec.europa.eu/info/sites/info/files/180131-sustainable-finance-final-report_en.pdf.
- Hofmann, B., Shim, I. and Song Shin, H. (2020). *Emerging market economy exchange rates and local currency bond markets amid the Covid-19 pandemic* [Online]. Bank for International Settlements. Available from: <https://www.bis.org/publ/bisbull05.pdf>.
- IPBES. (2016). *Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production* [Online]. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Available from: <http://doi.org/10.5281/zenodo.2616458>.
- IPBES. (2019). *The global assessment report on Biodiversity and Ecosystem Services: Summary for Policymakers* [Online]. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Available from: https://ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf.
- IPCC. (2018). Summary for Policymakers. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Geneva: World Meteorological Organization, p. 32.
- Johnson, C.K., Hitchens, P.L., Pandit, P.S., Rushmore, J., Evans, T.S., Young, C.C.W. and Doyle, M.M. (2020). Global shifts in mammalian population trends reveal key predictors of virus spillover risk. *Proceedings of the Royal Society B: Biological Sciences*. 287(1924), p. 20192736.
- Kay, J. and King, M. (2020). *Radical Uncertainty: Decision-making for an unknowable future*. London: The Bridge Street Press.
- Keesing, F., Belden, L.K., Daszak, P., Dobson, A., Harvell, C.D., Holt, R.D., Hudson, P., Jolles, A., Jones, K.E., Mitchell, C.E., Myers, S.S., Bogich, T. and Ostfeld, R.S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, 468(7324), pp. 647–652.
- Keynes, J.M. (1936). *The General Theory of Employment, Interest, and Money*. Springer.
- King, M. (2016). *The End of Alchemy: Money, Banking and the Future of the Global Economy*. London: WW Norton and Company.
- Knight, F. (1921). *Risk, Uncertainty and Profit* [Online]. New York: Schaffner and Marx. Available from: <https://doi.org/10.1017/CBO9780511817410.005>.
- Kolle, K. and McNevin, G. (2020). *Fool's Gold: The financial institutions risking our renewable energy future with coal* [Online]. Europe Beyond Coal. Available from: https://www.banktrack.org/download/fools_gold_1/foolsgold2020_final_14_7_2020.pdf.
- Koumbarakis, A., Hirschi, S. and Meier, K. (2020). *Nature is too big to fail. Biodiversity: the next frontier in financial risk management* [Online]. PWC and WWF. Available from: <https://www.pwc.ch/en/publications/2020/nature-is-too-big-to-fail.pdf>.
- Lam, T.T.-Y., Shum, M.H.-H., Zhu, H.-C., Tong, Y.-G., Ni, X.-B., Liao, Y.-S., Wei, W., Cheung, W.Y.-M., Li, W.-J., Li, L.-F., Leung, G.M., Holmes, E.C., Hu, Y.-L. and Guan, Y. (2020). Identifying SARS-CoV-2 related coronaviruses in Malayan pangolins. *Nature*, 583, pp. 282–285.
- Lenzi, D., Lamb, W., Hilaire, J., Kowarsch, M. and Minx, J. (2018). Don't deploy negative emissions technologies without ethical analysis. *Nature*. 561, pp. 303–305.
- Loftus, A. and March, H. (2015). Financialising nature? *Geoforum*, 60, pp. 172–175.
- Mace, G.M., Barrett, M., Burgess, N.D., Cornell, S.E., Freeman, R., Grooten, M. and Purvis, A. (2018). Aiming higher to bend the curve of biodiversity loss. *Nature Sustainability*, 1(9), pp. 448–451.
- Macquarie, R. (2018). *A Green Bank of England. Central Banking for a Low-Carbon Economy* [Online]. Positive Money. Available from: http://positivemoney.org/wp-content/uploads/2018/05/PositiveMoney_AGreenBankofEngland_Web.pdf.

- May, R.M., McLean, A.R., Pattison, J., Weiss, R.A., Bell, D., Robertson, S. and Hunter, P.R. (2004). Animal origins of SARS coronavirus: possible links with the international trade in small carnivores. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 359(1447), pp. 1107–1114.
- Mazzucato, M. and Penna, C.C.R. (2016). Beyond market failures: the market creating and shaping roles of state investment banks. *Journal of Economic Policy Reform*, 19(4), pp. 305–326.
- Mazzucato, M. and Semieniuk, G. (2017). Financing renewable energy: who is financing what and why it matters. *Technological Forecasting and Social Change*, 127, pp8-22.
- McCraine, S., Anderson, C., Weber, C. and Shaw, M. (2019). *The Nature of Risk. A Framework for Understanding Nature-Related Risk to Business* [Online]. World Wildlife Fund. Available from: https://d3bzkjkd62gi12.cloudfront.net/downloads/wwf_nature_of_risk_final2.pdf.
- Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J.F., Mathias, J.-D., Rocha, J.C., Schoon, M. and Werners, S.E. (2018). Defining tipping points for social-ecological systems scholarship—an interdisciplinary literature review. *Environmental Research Letters*, 13(3), p. 033005.
- NCFA and PWC. (2018). *Integrating Natural Capital in Risk Assessments: A step-by-step guide for banks* [Online]. Geneva, Oxford and London: Natural Capital Finance Alliance and PricewaterhouseCoopers. Available from: <https://www.unepfi.org/wordpress/wp-content/uploads/2019/01/Integrating-Natural-Capital-Risk-Assessments.pdf>.
- Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Seroa da Motta, R., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O. and Hess, L. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science*, 344(6188), pp. 1118–1123.
- Neumayer, E. (2013). *Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Cheltenham: Edward Elgar Publishing.
- NGFS. (2019a). *A call for action: climate change as a source of financial risk* [Online]. Network for Greening the Financial System. Available from: https://www.banque-france.fr/sites/default/files/media/2019/04/17/ngfs_first_comprehensive_report_-_17042019_0.pdf.
- NGFS. (2019b). *A sustainable and responsible investment guide for central banks' portfolio management* [Online]. Network for Greening the Financial System. Available from: <https://www.ngfs.net/sites/default/files/medias/documents/ngfs-a-sustainable-and-responsible-investment-guide.pdf>.
- NGFS. (2020a). *A Status Report on Financial Institutions' Experiences from working with green, non green and brown financial assets and a potential risk differential* [Online]. Network for Greening the Financial System. Available from: https://www.ngfs.net/sites/default/files/medias/documents/ngfs_status_report.pdf.
- NGFS. (2020b). *Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision* [Online]. Network for Greening the Financial System. Available from: https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_for_supervisors.pdf.
- NGFS. (2020c). *Guide to climate scenario analysis for central banks and supervisors* [Online]. Network for Greening the Financial System. Available from: https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_scenario_analysis_final.pdf.
- NGFS. (2020d). *NGFS Climate Scenarios for central banks and supervisors* [Online]. Network for Greening the Financial System. Available from: https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_final.pdf.
- OECD. (2010). *Private Financial Sector Investment in Farmland and Agricultural Infrastructure* [Online]. Paris: OECD. Available from: <https://doi.org/10.1787/5km7nzpjr8v-en>.
- OECD. (2019). *Tax Policy Reforms 2019* [Online]. Available from: <https://www.oecd-ilibrary.org/content/publication/da56c295-en>.
- Otto, I.M., Donges, J.F., Cremades, R., Bhowmik, A., Hewitt, R.J., Lucht, W., Rockström, J., Allerberger, F., McCaffrey, M., Doe, S.S.P., Lenferna, A., Morán, N., van Vuuren, D.P. and Schellnhuber, H.J. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050. *Proceedings of the National Academy of Sciences*, 117(5), p. 2354.
- Ouma, S. (2020). *Farming as Financial Asset: Global Finance and the Making of Institutional Landscapes*. Newcastle: Agenda Publishing.

- Pereira da Silva, L. (2020). *Green Swan 2 – Climate change and Covid-19: reflections on efficiency versus resilience* [Online]. Bank for International Settlements. Available from: <https://www.bis.org/speeches/sp200514.pdf>.
- Pinzón, A. and Robins, N. (2020). *The sovereign transition to sustainability. Understanding the dependence of sovereign debt on nature* [Online]. LSE Grantham Research Institute on Climate Change and the Environment. Available from: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2020/02/The-sovereign-transition-to-sustainability_Understanding-the-dependence-of-sovereign-debt-on-nature.pdf.
- Raworth, K. (2012). *A Safe and Just Space for Humanity: Can we live within the doughnut?* [Online]. Oxfam. [Accessed 21 October 2018]. Available from: https://d1tn3vj7xz9fdh.cloudfront.net/s3fs-public/file_attachments/dp-a-safe-and-just-space-for-humanity-130212-en_5.pdf.
- Reilly, J.R., Artz, D.R., Biddinger, D., Bobiwash, K., Boyle, N.K., Brittain, C., Brokaw, J., Campbell, J.W., Daniels, J., Elle, E., Ellis, J.D., Fleischer, S.J., Gibbs, J., Gillespie, R.L., Gundersen, K.B., Gut, L., Hoffman, G., Joshi, N., Lundin, O., Mason, K., McGrady, C.M., Peterson, S.S., Pitts-Singer, T.L., Rao, S., Rothwell, N., Rowe, L., Ward, K.L., Williams, N.M., Wilson, J.K., Isaacs, R. and Winfree, R. (2020). Crop production in the USA is frequently limited by a lack of pollinators. *Proceedings of the Royal Society B: Biological Sciences*, 287(1931), p. 20200922.
- Reim, W., Parida, V. and Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics – a systematic literature review. *Special Volume: Why have ‘Sustainable Product-Service Systems’ not been widely implemented?* 97, pp. 61–75.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S.I., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society*, 14(2): 32.
- Rounsevell, M.D.A., Harfoot, M., Harrison, P.A., Newbold, T., Gregory, R.D. and Mace, G.M. (2020). A biodiversity target based on species extinctions. *Science*, 368(6496), p. 1193.
- Ruhl, J.B. and Craig, R.K. (2011). 12.12 - New Sustainable Governance Institutions for Estuaries and Coasts *In*: E. Wolanski and D. McLusky, eds. *Treatise on Estuarine and Coastal Science* [Online]. Waltham: Academic Press, pp. 239–270. Available from: <http://www.sciencedirect.com/science/article/pii/B9780123747112012146>.
- Rüttinger, L., Smith, D., Stang, G., Tänzler, D. and Vivekananda, J. (2015). *A New Climate for Peace. Taking Action on Climate and Fragility Risks* [Online]. Adelphi, International Alert, Woodrow Wilson International Center for Scholars, European Union Institute for Security Studies. Available from: <https://www.newclimateforpeace.org>.
- Ryan-Collins, J. (2019). *Beyond voluntary disclosure: why a ‘market-shaping’ approach to financial regulation is needed to meet the challenge of climate change* [Online]. SUERF: The European Money and Finance Forum. Available from: https://www.suerf.org/docx/f_a821a161aa4214f5ff5b8ca372960ebb_4805_suerf.pdf.
- Saltelli, A., Bammer, G., Bruno, I., Charters, E., Di Fiore, M., Didier, E., Nelson Espeland, W., Kay, J., Lo Piano, S., Mayo, D., Pielke Jr, R., Portaluri, T., Porter, T.M., Puy, A., Rafols, I., Ravetz, J.R., Reinert, E., Sarewitz, D., Stark, P.B., Stirling, A., van der Sluijs, J. and Vineis, P. (2020). Five ways to ensure that models serve society: a manifesto. *Nature*, 582, pp. 482–484.
- Sarkar, S. (1999). Wilderness preservation and biodiversity conservation – keeping divergent goals distinct. *BioScience*, 49(5), pp. 405–412.
- Schiesari, L., Waichman, A., Brock, T., Adams, C. and Grillitsch, B. (2013). Pesticide use and biodiversity conservation in the Amazonian agricultural frontier. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 368(1619), p. 20120378.
- Schoenmaker, D. and Van Tilburg, R. (2016). What Role for Financial Supervisors in Addressing Environmental Risks? *Comparative Economic Studies*, 58(3), pp. 317–334.
- Schumpeter, J.A. (1934). *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*. New Brunswick, N.J.: Transaction Books.
- Secretariat of the Convention on Biological Diversity. (2010). *Global Biodiversity Outlook 3* [Online]. Montreal. Available from: <https://www.cbd.int/doc/publications/gbo/gbo3-final-en.pdf>.
- ShareAction. (2020a). *Banking on a Low-Carbon Future II. A ranking of the 20 largest European banks’ responses to climate change* [Online]. Available from: <https://shareaction.org/wp-content/uploads/2020/04/ShareAction-Banking-Report-2020.pdf>.

- ShareAction. (2020b). *Point of No Returns – Biodiversity An assessment of asset managers' approaches to biodiversity* [Online]. Available from: <https://shareaction.org/research-resources/point-of-no-returns/point-of-no-returns-part-iv-biodiversity/>.
- Sharpe, S. (2019). Telling the boiling frog what he needs to know: why climate change risks should be plotted as probability over time. *Geoscience Communication*, 2(1), pp. 95–100.
- Simon, H.A. (1997). *Models of bounded rationality: Empirically grounded economic reason*. Cambridge, MA: MIT Press.
- Sorrell, S. and Ockwell, D. (2010). *Can we decouple energy consumption from economic growth?* [Online]. University of Sussex Energy Group. Available from: http://sro.sussex.ac.uk/id/eprint/58023/1/economic_growthweb%5B1%5D.pdf.
- Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B. and Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), pp. 1259855–1259855.
- Steinweg, T., Kuepper, B. and Piotrowski, M. (2018). *Foreign Farmland Investors in Brazil Linked to 423,000 Hectares of Deforestation* [Online]. Chain Reaction Research, Aidenvironment, Profundo. Available from: <https://chainreactionresearch.com/wp-content/uploads/2018/12/Foreign-Farmland-Investors-in-Brazil-Linked-to-423000-Hectares-of-Deforestation-2.pdf>.
- Stirling, A., Powell, D. and van Lerven, F. (2019). *Changing the fiscal rules: unlocking public investment for a Green New Deal* [Online]. New Economics Foundation. Available from: <https://neweconomics.org/uploads/files/changing-fiscal-rules.pdf>.
- Suttor-Sorel, L. and Hercelin, N. (2020). *Nature's Return Embedding environmental goals at the heart of economic and financial decision-making* [Online]. Finance Watch. Available from: https://www.finance-watch.org/wp-content/uploads/2020/05/Natures-Return_Finance-Watch-Report_May2020.pdf.
- Taleb, N., Read, R., Douady, R., Norman, J. and Bar-Yam, Y. (2014). *The precautionary principle (with application to the genetic modification of organisms)*. [Online]. New York University. Available from: <https://www.fooledbyrandomness.com/pp2.pdf>.
- TCFD. (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures* [Online]. Available from: <https://www.fsb-tcdf.org/wp-content/uploads/2017/06/FINAL-2017-TCFD-Report-11052018.pdf>.
- Thomä, J. and Chenet, H. (2017). Transition risks and market failure: a theoretical discourse on why financial models and economic agents may misprice risk related to the transition to a low-carbon economy. *Journal of Sustainable Finance & Investment*, 7(1), pp. 82–98.
- Tooze, A. (2020). 'We are living through the first economic crisis of the Anthropocene'. *The Guardian*. [Online]. Available from: <https://www.theguardian.com/books/2020/may/07/we-are-living-through-the-first-economic-crisis-of-the-anthropocene>.
- Trichet, J.-C. (2010). Reflections on the nature of monetary policy non-standard measures and finance theory. Available from: <https://www.ecb.europa.eu/press/key/date/2010/html/sp101118.en.html>.
- Trucost. (2013). *Natural Capital at Risk. The Top 100 Externalities of Business*. [Online]. Trucost and TEEB for Business Coalition. Available from: <https://www.naturalcapitalcoalition.org/wp-content/uploads/2016/07/Trucost-Nat-Cap-at-Risk-Final-Report-web.pdf>.
- Valoral Advisors. (2018). *Impact investing in the global food and agricultural investment space: Investing profitably while fostering a sustainable and thriving agriculture* [Online]. Available from: <https://www.valoral.com/wp-content/uploads/Valoral-Advisors-Impact-Investing-November-2018n.pdf>.
- Volz, U. (2017). *On the Role of Central Banks in Enhancing Green Finance* [Online]. United Nations Environment Programme. Available from: http://unepinquiry.org/wp-content/uploads/2017/02/On_the_Role_of_Central_Banks_in_Enhancing_Green_Finance.pdf.
- WEF. (2018). *Global Risks Report 2018*. Geneva: World Economic Forum.
- WEF. (2019). *Global Risks Report 2019* [Online]. Geneva: World Economic Forum. Available from: <https://www.weforum.org/reports/the-global-risks-report-2019>.
- WEF. (2020). *How to rebound stronger from COVID-19: Resilience in manufacturing and supply systems* [Online]. Geneva: World Economic Forum. Available from: http://www3.weforum.org/docs/WEF_GVC_the_impact_of_COVID_19_Report.pdf.

- Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D., Thompson, J., Nilsson, M., Lambin, E., Sendzimir, J., Banerjee, B., Galaz, V. and van der Leeuw, S. (2011). Tipping Toward Sustainability: Emerging Pathways of Transformation. *AMBIO*. 40(7), p. 762.
- Williams, J.W. (2014). Feeding finance: a critical account of the shifting relationships between finance, food and farming. *Economy and Society*. 43(3), pp. 401–431.
- Xiao, K., Zhai, J., Feng, Y., Zhou, N., Zhang, X., Zou, J.-J., Li, N., Guo, Y., Li, X., Shen, X., Zhang, Zhipeng, Shu, F., Huang, W., Li, Y., Zhang, Ziding, Chen, R.-A., Wu, Y.-J., Peng, S.-M., Huang, M., Xie, W.-J., Cai, Q.-H., Hou, F.-H., Liu, Y., Chen, W., Xiao, L. and Shen, Y. (2020). Isolation and Characterization of 2019-nCoV-like Coronavirus from Malayan Pangolins. *bioRxiv*, 2020.02.17.951335.
- Zhou, P., Yang, X.-L., Wang, X.-G., Hu, B., Zhang, L., Zhang, W., Si, H.-R., Zhu, Y., Li, B., Huang, C.-L., Chen, H.-D., Chen, J., Luo, Y., Guo, H., Jiang, R.-D., Liu, M.-Q., Chen, Y., Shen, X.-R., Wang, X., Zheng, X.-S., Zhao, K., Chen, Q.-J., Deng, F., Liu, L.-L., Yan, B., Zhan, F.-X., Wang, Y.-Y., Xiao, G.-F. and Shi, Z.-L. (2020). A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*, 579(7798), pp. 270–273.
- Yates, J. and Yanotti, M. 2016. Australia's 25 years with a deregulated housing finance system: looking back and looking forward, pp. 37–53, in Lunde, J. and Whitehead, C. (eds.), *Milestones in European Housing Finance*. London: John Wiley and Sons.

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