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The rapid development of the East Asian economies, the growth of intra-regional trade, financial and other economic interaction, and East Asia's new role in the global economy all underline the need for access to a vastly increased range of quality economic analysis on East Asia. Such analysis from both inside and outside government is essential to assist policymakers in responding to, and anticipating, issues confronting the East Asian economy.

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Natural Capital Markets: A Conceptual Framework

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Abstract

Natural capital and ecosystem services are fundamental inputs into the global economy, yet many ecosystem services are mispriced or excluded from market transactions. This mispricing creates a structural disconnect between private decision-making and socially optimal outcomes, driving overconsumption and under-provision of ecosystem services. This paper examines the economic foundations and rationale for natural capital markets and proposes a new policy framework to support more effective economic and environmental outcomes. The paper develops a three-part analytical framework based on excludability, rivalry and property rights to identify four archetypes of ecosystem services, each requiring different institutional responses. This framework identifies privately produced public services as the archetype most affected by market failure and least amenable to conventional policy responses. The paper then examines existing environmental markets and identifies individual, program and outcome-level barriers that contribute to markets underperforming. The paper adopts a real options analysis to formalise landholder participation decisions and identifies irreversibility and uncertainty as dominant barriers to market entry. Finally, the paper proposes a Natural Capital Market Framework that introduces a dual credit structure, flexible contract options, and a broader environmental remit supported by hedonic valuation. These innovations reduce the irreversibility and option value of waiting that discourage participation. The framework provides a conceptual foundation for market design that can be tested empirically and applied across developed and developing country contexts.

1. Introduction

The world's economy is highly reliant on natural capital. Estimates suggest that partial collapse of ecosystem services could decrease global GDP by US$2 trillion, presenting significant welfare challenges (Johnson et al. 2021). Economic activity can have direct and indirect negative impacts on the quantity, quality and health of local, regional and global environments. Many studies suggest the global economy demands more goods and services from the biosphere than it can sustainably generate (Dasgupta 2021). This presents a challenge where global economic activity may be degrading one of its essential inputs.

Overconsumption of the biosphere is the result of market failure within the global economy (Barbier 2022a). Externalities, missing markets, and public good characteristics result in many forms of natural capital and ecosystem services not being priced in traditional markets. This creates a gap between private decision-making and socially optimal outcomes leading to overconsumption and under-provision. Such overconsumption can lead to poor economic and environmental outcomes. These outcomes can include reduced ecosystem service provision, declining agricultural productivity, lower aesthetic amenity, increased vulnerability to and impact from natural disasters, and long-term declines in economic growth and welfare (Lampert 2019; Bradshaw et al. 2021; Barbier 2022a).

Taken to the extreme, an economy's misuse of environmental resources can lead to total social collapse (Tainter 2006). Such a relationship can be viewed in the archaeological record of Easter Island. Brander and Taylor (1998) apply a Ricardo-Malthus model of renewable resource use to Easter Island to show how fast population growth can overshoot the capacity and regeneration of a slow-growing resource base, ultimately leading to social collapse. This is described as "a pattern of economic and population growth, resource degradation, and subsequent economic decline" (Brander and Taylor 1998). This pattern is further observed in the archaeological record for the Mayan empire (Culbert 1988), ancient Mesopotamian states (Tainter 1988), and the Chaco Anasazi in what is now the southwestern United

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States (Tainter 1988; Brander and Taylor 1998; Tainter 2006). Archaeological examples highlight the need to balance economic activity and consumption and use of the environment with long-term regeneration and quality of the natural capital stock.

While the archaeological record shows examples of localised collapse, the world's interconnected economy is driving global-scale environmental destruction and degradation. Long-term changes to the global environment are now leading economists, environmental scientists and policy makers to suggest the world is on a trajectory of overconsumption of the global natural capital stock, often referred to as breaching 'planetary boundaries' (Rockström et al. 2009; Steffen et al. 2015; Dasgupta 2021; Barbier 2025). Adjusting economic activity to avoid negative environmental outcomes may require fundamental changes to practices, industrial structures, and incentives. Such changes may create an inherent tension between environmental conservation, sustainable use of the global resource base and the world's economic development imperative (Maron et al. 2019). For example, land use changes to protect biodiversity may prevent countries from reaching several UN sustainable development goals, such as zero hunger (Mehrabi et al. 2018; Simpson et al. 2021; Kok et al. 2023).

Globally, there is a general contrast between a country's development level and its level of ecosystem disruption. Many developing countries with the highest development need also have the richest natural capital stocks and lowest level of ecosystem disruption (Maron et al. 2019). Restricting development for environmental conservation may prevent several developing countries from achieving industrial development and realising economic potential. This suggests a need for economic tools that better reconcile economic growth and development with desired environmental conservation objectives and natural capital use. These tools should address externalities and natural capital mispricing to encourage economic development with lower environmental impacts.

Natural capital markets are one policy tool that may support better alignment between economic activity and environmental outcomes. Natural capital markets create an economic incentive to reward actions that conserve or enhance the environment and create a cost for environmental harm. Natural capital markets adopt a broader environmental remit than previous environmental market-mechanisms, including biodiversity and habitat markets.

Natural capital markets allow landholders to generate credits from actions that conserve or enhance natural capital. These credits can then be traded with buyers who seek to voluntarily invest in environmental enhancement or offset environmental harm due to mandatory regulations. Proponents of natural capital markets suggest several economic benefits, including overcoming mispricing of natural capital, mobilising private capital and investment and fostering innovation for environmental protection, shifting natural capital provision to the lowest-cost provider, and providing institutional flexibility to achieve environmental outcomes.

Different forms of environmental markets have existed for many decades (Maron et al. 2025; Zu Ermgassen et al. 2026). Developed across the 1990s, the United States Wetland Mitigation Banking Program (WMBP) is the oldest and most successful environmental market globally (Teytelboym 2019; Aronoff and Rafey 2026). However, several markets have struggled to keep pace with the increase in demands on the environment with consequential adverse economic and environmental outcomes (Bull et al. 2013; Zu Ermgassen et al. 2020; Maron et al. 2025; Zu Ermgassen et al. 2026). This includes the New South Wales Biodiversity Offset Scheme and the United Kingdom Biodiversity Net Gain Program (Zu Ermgassen et al. 2021; NSW Auditor General 2022; Zu Ermgassen et al. 2026). In many cases, success or failure of environmental markets stems from policy design, and a series of individual, program and outcome-level failures.

Environmental markets have gained pace in modern policy development since the 2022 Kunming-Montreal Biodiversity Protocol. This global agreement encourages countries to stimulate "innovative schemes such as payment for ecosystem services, green bonds, biodiversity offsets and credits" as tools to increase environmental protection (*United Nations Convention on Biological Diversity Kunming-Montreal Global Biodiversity Framework* 2022). Global interest in environmental markets offers an opportunity to leverage global political support for the implementation of new schemes to harness individual incentives for positive environmental outcomes. However, these schemes require robust policy design to ensure positive economic and environmental outcomes.

This paper examines the economic foundations and rationale for natural capital markets and proposes a new policy framework to support more effective economic and environmental outcomes. First, this paper assesses how rivalry, excludability and property rights shape ecosystem services in economic growth and traditional markets. This highlights four archetypes of ecosystem services, each with different policy and institutional interventions to overcome mispricing and inherent market failures. Second, existing environmental markets are examined for common factors that lead to underperformance due to individual, program and outcome-level failures. Third, the paper assesses the microeconomic foundations of natural capital market participation through the lens of a real options analysis. This highlights the role of irreversibility and uncertainty as key barrier that prevent individual participation decisions in environmental markets. Finally, a 'Natural Capital Market Framework' is proposed as a policy response to overcome irreversibility and uncertainty barriers.

The Natural Capital Market Framework addresses market design to support greater investment in environmental outcomes beyond single metrics such as biodiversity. The framework introduces three innovations in market design that overcome potential economic frictions and encourage greater individual participation. The first innovation is to adopt a two-credit structure of conservation and improvement credits, which respectively reward long-term environmental conservation and short-term actions that improve the quality of the underlying environmental assets. The second innovation is to allow bundling of conservation and improvement credits across five contract types including active conservation, passive conservation, progressive habitat creation, environmental management and practice change. The third is to broaden the market's environmental remit and value credits through hedonic valuation.

Combining new credit types with flexible contract options would provide new opportunities for individual landholders and custodians to participate in the natural capital market in line with their resource availability, legal standing, risk appetite, and social and cultural context. The framework addresses key economic factors that contribute to low participation in environmental markets. The framework reduces the market's barriers-to-entry and supports individuals to reduce the opportunity cost of conservation practices by reducing irreversibility and uncertainty without compromising robust environmental outcomes.

The remainder of this paper is set out as follows. Section 2 examines the theoretical foundations of how natural capital and ecosystem services contribute to economic activity. This section examines a three-part framework to identify inherent market failure and available prices for different archetypes of ecosystem services. Section 3 outlines policy options to address mispricing of privately produced public ecosystem services and discusses economic frameworks to generate and trade ecosystem service value. Section 4 reviews existing environmental market mechanisms, their success and barriers to effective market development. Section 5 assesses the microeconomic foundations of natural capital market participation through the lens of a real options analysis. Section 6 discusses a proposed 'Natural Capital Market Framework'. Section 7 concludes.

2. Natural capital, economic activity and market prices

The environment and economy interact over multiple channels. However, not all channels generate prices uniformly. An economic-environmental input-output framework demonstrates how the value of different environmental contributions is expressed based on the type of interaction (Table 1) (Gretton and Salma 1996). Direct production and consumption of environmental products are traditionally incorporated into economic models (Quadrant 1). The value of this direct use is expressed in monetary terms and traded in primary production markets.

Table 1. Economic-environmental input-output framework (Gretton and Salma 1996).

Quadrant 1 Production and consumption of goods and services	Quadrant 2 Waste and discharges to the environment from industry and households
Quadrant 3 Inputs of environmental resources to industry and consumption by households	Quadrant 4 Environmental flows from natural systems and outflows being absorbed by those systems

The environment can also have intra-system functions and inter-system dependencies (Gretton and Salma 1996). These functions and dependencies allow the environment to be used as a pollution sink (Quadrant 2) or used as inputs into economic activity, industry and household consumption (Quadrant 3). The value of these environmental uses is not easily expressed in monetary terms, though some resource flows are monetised where they overlap with direct economic activity.

Some environmental services also contribute to natural ecosystem functioning (Quadrant 4). These services can make important contributions to sustaining the environmental services underpinning Quadrants 1, 2 and 3. These services are integrated with other components of the input-output framework, despite no direct interaction with economic production, as economic demands can crowd out natural processes. Markets do not inherently form for these environmental services and their value is not easily expressed in monetary terms. The economic-environmental input-output framework shows that three of four channels through which the environment contributes to the economy lack reliable market prices. This mispricing means that production and consumption decisions systematically undervalue environmental inputs, risking long-term decline in the environmental assets that support economic activity.

Natural capital formalises the environment's contribution to economic activity. Natural capital frames the environment as a non-reproducible stock of goods that provide a flow of various services (Freeman et al. 1973; Pearce 1988). Natural capital stocks are described as environmental assets such as trees, animals, water, minerals, and ecosystems (Pearce 1988). Natural capital flows are ecosystem services, the conditions and processes through which environmental assets sustain and fulfil humanity (Daily 1997). The framing of environmental assets and ecosystem services allows natural capital's growth and depletion to be traced through economic activity. It also allows natural capital to be viewed alongside other capital forms within the economy, such as built capital and human capital.

Natural capital and ecosystem services can be incorporated into the classical growth theory model as an additional factor of production (Hallegatte et al. 2012). This extended model has output (Y) produced from a set of inputs: technology (A), physical capital (K), labour (L), and natural capital (N) so that:

$$Y = f(A, K, L, N) \text{ with } \frac{dY}{dA} > 0, \frac{dY}{dK} > 0, \frac{dY}{dL} > 0, \frac{dY}{dN} > 0$$

Changes to intertemporal size and quality of natural capital can be expressed as:

$$\dot{N} = g(N) - d(N) \text{ and } d = \omega(N) + \zeta(N) + \eta(N)$$

In this equation N is the existing stock of natural capital, g is the growth rate of the natural capital stock, and d is the decline rate of natural capital. Natural capital growth predominantly occurs through natural processes. However, there are also limited human activities that increase natural capital stocks. Natural capital decline can be decomposed into depletion (ω) (consumption of non-renewable natural capital), destruction (ζ) (permanent loss of renewable natural capital stocks) and degradation or overconsumption (η) (reversible impairment of ecosystem function).

Depletion, destruction and degradation all substitute natural capital for other capital types. The rate of this substitution determines the sustainability of economic activity. Economic sustainability requires non-declining utility or welfare over time, as initially described by Hicks (1939). There is ongoing debate about natural capital's role in non-declining utility. This debate views sustainability through four different categories, representing a spectrum of substitutability between natural capital and other capital forms. These categories are very weak (perfect substitutes), weak (imperfect substitutes), strong (imperfect complements) and very strong (perfect complements) (Turner 1993).

Weak sustainability suggests that welfare is not dependent on a specific capital form, but rather the total capital stock in an economy (Solow 1974; Hartwick 1977; Turner 1993; Ekins et al. 2003). Solow (1974) and Hartwick (1977) articulated a weak sustainability development pathway as one that draws down natural capital so long as the stock of reproducible capital grows at an equal or higher rate. This weak sustainability development path allows for other capital forms, including new technologies, to be substituted for natural capital so long as the total capital stock increases over time. This pathway ensures a constant capital stock within the economy so that no generation is better or worse off than another. Weak sustainability considers new technology and practices to be appropriate substitutes for the services that would be provided by natural capital.

Strong sustainability requires long-term capital accumulation with constant or increasing levels of natural capital. Strong sustainability views natural capital as a complement to rather than a substitute for other capital forms. Several natural capital characteristics can limit the level of substitution with other capital types. For example, irreversibility and uncertainty are more inherent for natural capital than built capital due to human knowledge limitations (Ekins et al. 2003). As such, natural capital substitution decisions cannot be made with perfect information.

Sustainability can apply differently at different levels of aggregation. Weak sustainability is appropriate for long-term economic growth when considered at the aggregate level. However, substitution may not be feasible for specific ecosystem services. For example, where an ecosystem service depends on non-reproducible assets and where loss is irreversible, no increase in built or human capital can restore the service once the underlying stock is depleted (Barbier 2019). In these circumstances strong sustainability is the appropriate standard at the individual product level. This therefore requires the natural capital stock to be maintained at or above a functional threshold. Such an approach aligns with the concept of 'critical natural capital' (Ekins et al. 2003). 'Critical natural capital' expects the natural capital stock to be maintained or grow at a regional and global level, while allowing for some substitution between natural and other capital where it does not reduce the overall quality or capacity of the natural capital stock to provide ecosystem services at or above a defined threshold (Ekins et al. 2003).

Achieving strong sustainability for specific types of ecosystem services depends on production and consumption decisions that affect g, ω, ζ and η, and those decisions are shaped by prices. Mispriced natural capital can lead to overconsumption and sub-optimal provision, potentially leading to long-term decline of the natural capital stock and inefficient resource allocation within an economy. Natural capital pricing depends on how the relevant ecosystem service enters the economy, with direct use priced and indirect use unpriced.

Environmental asset can generate both priced and unpriced ecosystem services. However, an owner can only capture the value of services with market prices. This creates a disconnect between the total value an asset generates and the value its owner can capture. A forest, for example, can provide multiple different ecosystem services. This includes timber, clean air and carbon sequestration, wildlife habitat, and recreation and spiritual use. However, the owner of the forest can only capture monetary value from services with market prices, which depend on the specific ecosystem service rather than the underlying capital asset. As such, the owner can capture only the value of timber and recreation.

The disconnect between value generation and value capture is determined by three factors: the public-private good characteristics of the service, the level at which property rights are assigned, and the presence or absence of markets to facilitate exchange. Understanding the relationship between these factors can inform a three-part framework for institutional and policy responses that price a broader range of natural capital and ecosystem services.

This framework considers three sequential questions:

1. Do an ecosystem service's excludability and rivalry characteristics suggest an inherent market failure?
2. Do stock-level property rights effectively capture the value of ecosystem services?
3. Can the ecosystem service be attributed to specific environmental assets?

Excludability and rivalry characteristics

Excludability and rivalry can determine how an individual captures costs and benefits of an ecosystem service. These characteristics can vary between ecosystem services from the same stock, with only the excludable services being appropriately priced. This is highlighted in Table 2 which shows how ecosystem services can differ in excludability and rivalry based on asset ownership, use and the distribution of benefits.

Private services are those with high rivalry and excludability. These services include private timber plantations, agricultural land, food and fibre products, and minerals and ores. Costs and benefits of these services can be internalised to the asset owner and are traditionally traded on markets.

Club services are those with high excludability but low rivalry. Common examples of club services include national parks and nature reserves, private gardens, and ecotourism on private land. Club services can be valued and regulated through entrance and use fees (Wunder et al. 2020). These fees can represent a form of market trade that internalises costs and benefits to the asset owner.

Open access services are characterised by low excludability and high rivalry. Open access services include open-ocean fisheries, public grazing lands, river systems, and groundwater aquifers. No price signals form for these services, leading to an inherent market failure. No excludability allows individuals to maximise private benefit relative to private cost which leads to overuse and degradation of the services as users fail to consider the collective resource costs. This is commonly referred to as 'The Tragedy of the Commons' (Hardin 1968).

Public services are those that are both non-rivalrous and non-excludable. Individuals do not bear the full costs of providing these services and cannot be excluded from receiving their benefits. Examples of public services include climate and weather regulation, carbon sequestration, biodiversity, clean air, ozone layer protection, erosion control, water filtration, decomposition and nutrient cycling, soil formation, and flood regulation. Non-excludable and non-rivalrous characteristics lead to inherent market failure, through divergence between private and social costs and benefits (Samuelson 1954). Decisions about the use of public services therefore do not properly account for the true social costs and benefits. Rather, decision makers rely on their individual costs and benefits which do not consider the public good services.

Table 2. Categorisation of selected ecosystem services based on rivalry and excludability characteristics.

	Rival	Non-rival
Excludable	Private service Fish - farmed stocks Timber - plantation Water – private dam Minerals and ores	Club service Environment-based recreation Pollination – managed Nature reserve – private Ecotourism – private property
Non-excludable	Open access service Open grazing land Seafood - wild stocks Water - river system Plants – timber from wild forest	Public service Air and water purification Erosion control Flood mitigation Biodiversity

Property rights

Low excludability can create an inherent market failure for open access and public services. Persistence of this market failure depends on the institutional structure that surrounds each service, specifically, the property rights that can be assigned to the underlying asset. Property rights are the authority to control a specific domain (Commons 1968). Property rights provide clarity and information on who can access and who bears the costs and benefits of use and misuse of environmental assets (Anderson and Libecap 2014). Defining and enforcing property rights can create incentives for individuals to manage an asset and internalise the costs and benefits of ecosystem services.

The property rights framework relies on the ability to define, monitor and enforce ownership and control over an asset (Anderson and Libecap 2014). As such, property rights generally attach to natural capital assets rather than ecosystem services as they are more stationary, observable and boundable. Asset-level property rights capture the benefits of excludable services but fail to capture the value of non-excludable services. This can result in different market outcomes for different ecosystem services produced from the same asset.

Environmental assets can be placed into three different categories according to their property rights. These categories are private property assets, collective stocks, and open access stocks (Table 3). Private property assets are those with high excludability and clearly defined boundaries that are easily monitored and enforced. Collective assets are those with low excludability but clearly defined, monitored and enforced boundaries. Collective assets are commonly associated with open access services for which the benefits from use of open access services can accrue to an individual. Open access assets are those where there is no excludability and no possibility of enforced boundaries. These assets include the atmosphere, international fishing stocks, and transboundary river systems. Table 3 provides examples of different assets and demonstrates how many public good ecosystem services are produced from private property assets. This includes erosion control, flood mitigation, air and water purification, and aesthetic environmental features.

Table 3. Ecosystem services categories by the property rights of the underlying environmental asset that produces the service.

Private property asset	Collective asset	Open access asset
Seafood - farmed stocks Plants - timber from private plantation Agricultural crops and livestock Minerals and fossil fuels Pollination – managed Erosion control Temperature and wind moderation Flood mitigation Air and water purification	Wildlife - products Seafood - wild stocks Water - river system Water - ground aquifer Plants – timber from wild forest Environmental aesthetic and cultural value	Wind systems and regional precipitation patterns UV protection by atmosphere Climate Atmosphere

Asset's contribution to ecosystem services

In addition to excludability, rivalry and property rights, it is helpful to differentiate how environmental assets or individual actions can contribute to specific ecosystem services. Some ecosystem services can be directly linked to specific environmental assets. For example, the quality or quantity of habitat, biodiversity and carbon sequestration can all be attributed to specific individual trees with changes to these ecosystem services monitored over time.

There are also ecosystem services that provide value through aggregate interactions. In these cases, the specific contribution of individual assets or actions can be difficult to attribute to the quality of aggregate ecosystem services. For example, the Amazon rainforest makes significant contributions to regional and global weather and climate patterns (Bowman et al. 2022). Some research indicates that deforestation in the Amazon could act as a driver of regional climate change and potentially disrupt weather patterns and precipitation in coastal northwest United States (Medvigy et al. 2013). However, it can be difficult to attribute how specific changes to individual environmental assets or actions impact on the size or quality of the aggregate ecosystem services.

This identifies two subsets of public ecosystem services: attributable and aggregate. Attributable ecosystem services are those that can be clearly linked to environmental assets and tracked over time. Aggregate ecosystem services are those where direct attribution to individual environmental assets is difficult or not possible. This paper focuses on attributable ecosystem services because their characteristics make them amenable to the policy interventions examined in subsequent sections.

Archetypes of ecosystem services

Examining excludability, rivalry and property rights identifies four different archetypes of ecosystem services. Characteristics of these archetypes influence appropriate policy and institutional responses to create pricing and efficient management within economic activity and individual decision-making. These archetypes are:

1. Privately produced private services
2. Privately produced public services
3. Publicly produced private services
4. Publicly produced public services

Privately produced private services

Privately produced private services are those with high excludability and high rivalry produced from assets with clear property rights. Market activity can occur through direct trade of the underlying asset (such as timber sales) or through access pricing (such as tickets and use fees), allowing the individual owner to fully internalise costs and benefits.

Privately produced public services

Privately produced public services are those with low excludability and low rivalry produced from assets with clear property rights. An individual owner can clearly identify and bound their asset but cannot internalise the costs and benefits of the services. Most privately produced public services cannot be traded on markets and in most cases, there is a disconnect between the private and social costs and benefits of these services. Individual use decisions, such as conservation, degradation or conversion, are made without considering the social costs and benefits of the ecosystem services. This lack of consideration stems from the inherent mispricing and drives misallocation of the capital stock, representing a broad structural failure.

Publicly produced private services

Publicly produced private services are those with low excludability and high rivalry that are produced from assets without clear property rights. These services are generally provided by open access resources and the value of services flows to individuals. Publicly produced private services can be managed through the implementation of institutional or collective use rights, such as access and usage fees, licences and quota. These interventions introduce a level of excludability and property rights embodied by the government or through social governance and institutions.

Publicly produced public services

Publicly produced public services have low excludability and low rivalry, produced from assets without clear property rights. Costs and benefits of use and provision of these services are diffuse and difficult to attribute to individuals. These diffuse costs and benefits and open access characteristics can mean they are appropriately provided by government as a single provider. These services may also be managed through cooperation between countries where there is overlap in the assets and services, which can be achieved through international agreements and treaties.

Ecosystem services policy and institutional intervention focus

Excludability, rivalry, property rights and missing markets can influence how ecosystem services are valued and that value captured by individual landholders. This discussion shows that privately produced public services do not have clear or simple policy interventions to overcome inherent market failures. As such it is currently complex and difficult to provide appropriate price signals for privately produced public services.

The lack of price signals creates a disconnect between the private and social costs and benefits of privately produced public service use and provision. Individual landholders can only capture the value of their private services and cannot capture any value from their public services. This creates a situation where the private marginal cost and marginal benefit are lower than the social levels. Viewed through the natural capital stock equation, the individual's destruction and restoration activities will occur at a point where:

$$\mathrm{MC}_{\mathrm{Private}}(\omega(N),\zeta(N),\eta(N)) < \mathrm{MC}_{\mathrm{Social}}(\omega(N),\zeta(N),\eta(N)) \text{ and } \mathrm{MB}_{\mathrm{Private}}(g(\mathrm{N})) < \mathrm{MB}_{\mathrm{Social}}(g(\mathrm{N})).$$

Without appropriate price signals, a rational individual is likely to maximise the returns from private services separate from impact on public services. Only considering a subset of ecosystem services may lead the individual to overexploit or degrade their private asset. Overcoming this disconnect is important to encourage individuals to align their private costs with social costs and deliver a more socially optimal level of natural capital and ecosystem services.

Policy and institutional interventions will be important to overcome the challenges of mispricing these services and supporting individuals to better capture the value of their public services. This will require policies to influence production and consumption decisions that affect the rate of natural capital growth (g), depletion (ω), destruction (ζ) and degradation (η). Policy tools appropriate for other archetypes (direct market trade, access fees, government provision) cannot effectively manage the provision of these public services. Rather, these services require policy tools to construct markets and incentives that otherwise would not occur. Without these interventions individual landholders may not consider the full range of costs and benefits associated with natural capital use and management. Section 3 examines the range of policy options to better manage privately produced public services and discusses different mechanisms to create individual incentives for landholders.

3. Policies to overcome mispricing of privately produced public services

Natural capital mispricing can create a gap between private and social costs and benefits of privately produced public services. Landholders do not currently fully consider how their natural capital management decisions spill over to third parties, representing externalities (Marshall 1890; Pigou 1920). Several interventions can manage externalities including voluntary actions, information provision and suasion, price instruments, and command-and-control rules (Table 4) (Hepburn 2010). This discussion focuses on how natural capital policies are viewed through an economic lens, while acknowledging the debates about moral and ethical considerations for the environment (Ferreira and Ferreira 2019; Neuteleers 2022; Luxton et al. 2024).

Table 4. Overview of different policy options to manage economic impacts on the environment (adapted from Hepburn 2010).

Intervention type	Description
Information provision	Interest groups (government or third-party) aggregate and disseminate information about externalities and their shadow prices to influence firm behaviour.
Moral suasion	Interest groups (government or third-party) seek to persuade people and firms to change their preferences and objectives through targeted information provision.
Information obligation	Government requires private sector actors to disclose their impact on the environment
Voluntary industry regulation	Private sector actors voluntarily regulate their activity in line with industry codes of conduct or best-practice guidance.
Economy-wide relative prices	Government determines an appropriate price or quantity of a social good or externality and implements policies to correct relative prices.

Output-based intervention	Government specifies output standards for specific sectors or firms but does not require the use of any particular method to deliver those standards.
Input- or technology-based intervention	Government specifies, encourages, or requires firms to employ particular technologies or inputs, either through explicit regulation or through taxes or subsidies.
Project-level intervention	Government specifies or encourages particular projects to occur, through subsidy or other financial support.
Nationalised delivery	Government finances and delivers environmental activities directly
Regulation and legislation	Government manages and controls natural capital management through regulation and legislation. This includes environmental protection legislation and building and development approval requirements.

Policy interventions in Table 4 can improve natural capital management. Economy-wide natural capital management will likely require a bundle of policies that address different circumstances, ecological requirements and ecosystem service archetypes. Privately produced public services require a unique set of policy interventions that drive individual decision-making. Individual decision-making rests on direct incentives to balance costs and benefits. Many of the policies in Table 4 do not construct the missing price signals identified in Section 2.

Low levels of government intervention, through information provision or moral suasion, can inform landholders about the value of public services from their natural capital assets. However, within a rational economic framework, the individual will maximise their profit without changing their decision-making calculus. This is because the landholder cannot capture the value of non-excludable services so new information does not change the individual's behaviour. At the same time, high levels of government intervention can set predetermined floors on natural capital use. For example, command and control regulation can prevent land clearing to protect species habitat and maintain a stock of environment. However, command and control does not encourage individuals to add to or improve the natural capital stock. Price-based policies, however, can create a cost for natural capital decline, incentivise the provision of ecosystem services, or a combination of both.

Policies that generate price signals can facilitate individual behaviour change that induces a virtuous cycle for natural capital management (Barbier 2022b). In a virtuous cycle, the individual can capture more value from public services and seek to maximise their income from these services. New practices and technology can support the individual to capture more value and income from services, encouraging increased investment. Ongoing investment supports innovation to lower the cost of practices that protect the environment and reduce environmental harm (Barbier 2022b). This cycle can drive behaviour that, when aggregated across individuals, delivers economic efficiency gains alongside improved natural capital management.

An economic framework for pricing and exchange

Prices can create incentives that facilitate more appropriate consideration of natural capital and privately produced public services. However, the existence of prices alone does not result in behaviour change. Natural capital prices alone can inform a landholder about the potential values, costs and benefits of their assets, but cannot be readily converted to income. Rather, individuals require mechanisms and frameworks that allow them to capture and trade the value of their priced natural capital. These mechanisms can provide infrastructure to exchange between parties and realise the value of different assets. Arthur Pigou and Ronald Coase provide complementary economic frameworks that use pricing mechanisms to manage externalities.

Pigouvian taxes and subsidies

Pigou proposed compensation as a mechanism to close any gap between private and social costs and benefits (Pigou 1920). Compensation, through a tax or subsidy, can remove divergence between private and social costs, incentivising individuals to adopt a socially optimal output level. Pigouvian compensation could be levied at an individual level or at a social or community level where individual actions deliver social costs and benefits. Pigouvian compensation is delivered by government '"extraordinary encouragements" or "extraordinary restraints"' in the form of 'bounties and taxes' (Pigou 1920).

A Pigouvian framework has been successfully applied to environmental and pollution issues with clearly defined and measured pollutants (Baumol and Oates 1971; Baumol 1972; Barnett 1980; Banzhaf 2020). However, the Pigouvian framework is difficult for ecosystem services due to heterogeneity and measurement difficulty. Ecosystem service provision and costs vary across landscapes, meaning a Pigouvian uniform price may result in varying levels of participation (Hanley 2026). The Pigouvian tax or subsidy can overcome the lack of pricing discussed in Section 2, however, it may not appropriately align private and social costs and benefits. Rather, a more appropriate approach may be to adopt differentiated prices that align with individual marginal costs, a policy approach not easily addressed through Pigouvian taxes or subsidies (Hanley 2026).

Coasian bargaining

Coase theorem evolved as an alternative framework to Pigou, offering a method to address externalities between individuals (Coase 1960). Coase recognises economic activity can positively and negatively impact on other individuals. However, Coase disagrees with an asymmetric treatment of the externality. Instead, Coase views externalities and property right infringements as bi-directional (Deryugina et al. 2021). Coase theorem proposes bargaining to manage externalities between individuals. Such bargaining can determine an equilibrium point through a combination of adjusted economic activity and direct compensation (Coase 1960; Deryugina et al. 2021). This is formalised as: 'in the presence of externalities and clearly defined property rights, agents can bargain their way to a Pareto optimum, and that Pareto optimum is the same regardless of who imposes an externality on whom' (Coase 1960; Deryugina et al. 2021).

Bargaining between individuals supports price discovery and compensation in line with individual marginal costs of ecosystem service provision. This approach overcomes the price and asymmetric information issues that constrain Pigouvian pricing. However, Coase theorem relies on several assumptions that hamper its effective implementation. Coasian bargaining requires clearly defined property rights, no or minimal bargaining costs, well-informed actors, and that compensation does not affect supply or demand curves (Coase 1960). However, many of these conditions do not exist for public ecosystem services, as discussed in Section 2. As such, a reliance on Coasian bargaining may not deliver ecosystem service outcomes due to barriers to bargaining.

Pigouvian and Coasian policy implementation

Differentiation between the Pigouvian and Coasian frameworks depends on specific policy design and implementation. This can be observed in different payments for ecosystem services (PES) schemes. PES are voluntary transactions between two parties that involve provision of a defined environmental service in exchange for a payment (Ferraro and Simpson 2002; Wunder 2005; Engel et al. 2008; Jayachandran 2013; Wunder 2015; Teytelboym 2019; Wunder et al. 2020). PES provide a direct payment to landholders, providing economic incentives for environmental conservation, land practice change, or actions that improve defined indicators (Salzman et al. 2018; Hanley 2026). PES and their economic incentives attempt to overcome mispricing by creating an alternative income stream for landholders through environmental conservation. One recent review suggests there are more than 550 active PES programs globally with around US$42 billion in annual transactions (Salzman et al. 2018). These PES schemes cover diverse environmental characteristics, including rivers and waterways, biodiversity and habitat, and forest and land-use carbon (Salzman et al. 2018). PES schemes can also be grouped by the funding organisation, including user financed, government financed, and compliance financed schemes.

Different characteristics can result in different Pigouvian or Coasian implementation. Government financed schemes can be observed as Pigouvian subsidies that encourage greater provision of public good environmental services. One example of a Pigouvian PES scheme include the US Conservation Reserve Program which offers long-term contracts to retire agricultural land and establish environmental cover in return for annual payments (Claassen et al. 2008). Other examples include the Pago por Servicios

Ambientales in Costa Rica (Pagiola 2008), the Payment for Hydrological Environmental Services in Mexico (Muñoz-Piña et al. 2008) and the Sloping Land Conversion Program in China (Bennett 2008).

Compliance and user financed PES schemes can also reflect a Coasian framework, through individual level bargaining and exchange. One example of this Coasian approach is the Pimampiro municipal watershed-protection scheme which compensates individual families for reforestation activities within the Pimampiro water catchment (Wunder and Albán 2008). This compensation comes from a water consumption surcharge on households with water meters in the same catchment (Wunder and Albán 2008). The New York City Government watershed management plan is a similar scheme that compensates landholders in specific watersheds for activities that deliver hydrological benefits for the water supply (Isakson 2001; City of New York 2025).

A Pigouvian-Coasian hybrid market

Pigou and Coase offer potential frameworks to manage externalities and ecosystem service mispricing, but face inherent constraints. A hybrid Pigouvian-Coasian approach could use government intervention to create a market under which decentralised bargaining and trade can operate. Such a market would create property rights over certain public ecosystem services and then provide opportunities for voluntary trade between parties and the distribution of regulated pricing and subsidies to address negative externalities (Diswandi 2017; Banzhaf 2020). These voluntary trades on a market could further support price discovery between heterogeneous production costs and reach Pareto optimum outcomes. A hybrid policy could also support a market to adopt a broader environmental remit. For example, Pigouvian taxes and subsidies may support market activities for ecosystem services where property rights are hard to define or enforce (such as atmospheric pollutants) while the market facilitates Coasian bargaining for ecosystem services that can account for localised costs and benefits (Wunder et al. 2020).

Implementing a hybrid market offers an opportunity to internalise the costs and benefits of public services, shift ecosystem service provision and environmental conservation to the lowest-cost provider, mobilise private capital and investment, foster innovation, and provide institutional flexibility. Such an environmental market relies on three factors: heterogeneity, property rights, and transaction costs.

Environmental markets require heterogeneity across land value, environmental characteristics, and abatement costs (Anderson and Libecap 2014; Needham et al. 2019). Land and environmental asset values are characterised by inherent heterogeneity. Different land assets can provide economic use and ecosystem services of differing costs, qualities and characteristics. This heterogeneity means that efficient use and decision-making depends on specific, individual information that cannot be possessed by a central authority. Efficient allocation therefore requires decentralised agents to use independent, local knowledge to trade to reveal the efficient price and allocation (Hayek 1945). Market mechanisms are uniquely placed to trade assets and services, through which prices emerge to aggregate dispersed knowledge (Hayek 1945). Leveraging these differences can provide the opportunity for the market to facilitate gains from trade. Gains from trade occur where one area has higher value from development and can compensate the lost environment through a trade for conservation on land with lower cost or development opportunity (Simpson et al. 2021; Zu Ermgassen et al. 2026).

Defining and enforcing property rights is necessary to facilitate trade within the market. Property rights restrict entry to the resource and encourage the individual to maximise their economic rents from that resource. Maximising rents creates incentives for individuals to consider the current and future uses of the resource across a variety of applications (Anderson and Libecap 2014). Maximising rents can also encourage innovation to lower the cost of providing a good or service and to identify new rent opportunities. Property rights accrue to environmental assets rather than services, as discussed in Section 2. Environmental markets will need to develop appropriate methods to extend property rights to the ecosystem service to allow individuals to extract rents from these services.

Transaction costs must be low to encourage participation. Even where property rights can be defined, high transaction costs and methodological complexity can prevent trade of environmental credits. Transaction costs and quality data can also be imperfect and asymmetric, making it difficult to interpret price signals. New markets will need to encourage ongoing declines in transactions costs to encourage greater participation and value maximisation.

Market-based mechanisms have a long history in managing environmental resources and environmental issues despite these challenges. There is a deep academic literature about the use of markets and pricing to manage negative externalities and overconsumption of the environment. These tools have been successfully implemented to manage greenhouse gas emissions, surface and groundwater water extraction, sustainable fisheries, and air pollution (Schmalensee and Stavins 2017; Teytelboym 2019; Rafey 2023).

However, markets have not naturally formed for public ecosystem services, in part due to missing markets. Missing markets occur where a Pareto-efficient exchange could occur but no market exists to facilitate the trade. Individuals who would potentially want to participate in environmental markets do not have an avenue to trade value between parties, potentially exacerbating the misallocation and mismanagement of ecosystem services. Correcting missing markets and implementing a Pigouvian-Coasian hybrid market will require actions to overcome issues previously discussed in Section 2, including poorly defined property rights, high transaction costs, coordination failure, and asymmetric information. The following section provides an overview of existing markets for public ecosystem services. This includes design, development and implementation and their effect on market success.

4. Natural capital markets for privately produced public services

Environmental markets are market-mechanisms that provide the structure and system to trade the provision of environmental assets and ecosystem services. These markets focus on providing individuals with economic incentives to increase investment in ecosystem service provision and environmental conservation and discourage actions that destroy or degrade the environment. Most environmental markets create incentives by providing credits, certificates, loans, bonds, investment, or payments for specific actions (Manez and Clifton 2025). However, the implementation of these markets has experienced mixed success.

Environmental markets for ecosystem services have operated in various forms for several decades, traditionally focusing on habitat or biodiversity (Maron et al. 2025; Zu Ermgassen et al. 2026). Examples of these markets include the US Wetland Mitigation Banking Program (developed in the 1990s), the NSW Biodiversity Offsets Scheme (established 2008), the UK Biodiversity Net Gain (established 2018), and the Australian Nature Repair Market (established 2023) (Zu Ermgassen et al. 2021; NSW Auditor General 2022; Aronoff and Rafey 2026; Department of Climate Change, Energy, the Environment and Water 2026). Each market operates by providing a credit for habitat creation, conservation or other outcomes on private land. In many cases, these credits are provided for the long-term conservation of new or existing habitat areas.

Environmental markets are broadly characterised by the source of demand. This distinguishes between compulsory regulatory markets and voluntary markets. Compulsory regulatory markets compel developers to compensate for environmental impacts that result from new development, such as housing or infrastructure construction (Hanley and Simpson 2025). Compulsory markets require the environmental impact of development to be offset in other locations to secure long-term environmental conservation. These markets are commonly referred to as ‘offset markets’. Voluntary markets allow individuals to compensate landholders for conservation or environmental outcomes. Voluntary markets operate to channel investment to environmental conservation, either for intrinsic factors or to voluntarily compensate for business impacts on the environment.

Most environmental markets have been developed around compulsory offsets. This includes the US Wetland Mitigation Banking Program, the NSW Biodiversity Offsets Scheme, and the UK Biodiversity Net Gain. Environmental offset markets provide a pricing mechanism approach to directly compensate for the destruction or degradation of the environment. Offsets are specifically defined as measurable conservation gains that deliberately balance environmental loss that compensates for unavoidable impacts from project development such as infrastructure, housing, or agricultural expansion (Bull et al. 2013; BBOP 2009; Hanley and Simpson 2025; Croci et al. 2025). Environmental offsets are generally viewed as one-for-one replacements of habitat and environment that has been destroyed as part of development (Bull et al. 2013). Offsets are intended to be applied as the final part of the mitigation hierarchy where developers have already avoided, minimised and restored their environmental impact (Arlidge et al. 2018).

There has been recent growth in voluntary markets for environmental improvement, including the Nature Repair Market and companies that provide voluntary environmental conservation activities, such as private conservation credit providers. Environmental improvement seeks to improve the quality and quantity of the environment to promote long-term environmental conservation separate from other losses (Croci et al. 2025). In this case, environmental improvement markets do not act as compensation for project developments. Environmental improvement markets intend to finance net gains in environmental quantity and quality (Croci et al. 2025; Manez and Clifton 2025). Environmental improvement schemes seek to provide alternative income sources for land to encourage private conservation and rehabilitation of the natural environment (Croci et al. 2025).

Existing environmental markets share similarities in their intention, design, and implementation. However, these markets have experienced different levels of success across implementation, trade volume and efficacy. The US Wetland Mitigation Banking Program and the NSW Biodiversity Offsets Scheme provide valuable contrasts in their long-term success as effective and efficient environmental markets.

The US Wetland Mitigation Banking Program is commonly viewed as one of the most successful environmental markets (Teytelboym 2019). Section 404 of the US Clean Water Act 1972 mandates a no net loss of wetland ecological and hydrological functions (United States Congress 1972; Aronoff and Rafey 2026). This requires developers to purchase credits if they fill or dredge a wetland. These credits are purchased from individuals who construct new or restore degraded wetlands (Teytelboym 2019; Aronoff and Rafey 2026). This mitigation requirement facilitated the development of for-profit mitigation banks which mediate financing and offsets between developers and mitigators (Teytelboym 2019).

The US Wetland Mitigation Banking Program is now the largest ecosystem services market globally with approximately $3.5 billion in annual revenue as of 2019 (Teytelboym 2019; BenDor et al. 2023). Economic analysis of this market also suggests that market trades create substantial value for participants by leveraging heterogeneous land values and mitigation costs (Aronoff and Rafey 2026).

The NSW Biodiversity Offsets Scheme by contrast demonstrates how an environmental market can underperform expectations. The Biodiversity Offsets Scheme has operated since 25 August 2017 and superseded BioBanking. BioBanking was a voluntary offsets scheme that ran between July 2008 and the introduction of the Biodiversity Offsets Scheme in 2017 (Environment and Heritage 2024a). The Biodiversity Offsets Scheme provides a market-mechanism for developers and landholders to avoid, minimise and offset environmental and biodiversity impacts in NSW (Environment and Heritage 2024b). The scheme applies to a range of land clearing activities that meet or exceed certain biodiversity thresholds (Environment and Heritage 2025).

The Biodiversity Offsets Scheme operates two types of credits: ecosystem credits and species credits. Ecosystem credits are for threatened ecological communities, species habitat and other plant community types (NSW Auditor General 2022). Species credits are targeted at threatened species that cannot be predicted to occur on or use a site based on the landscape and vegetation (NSW Auditor General 2022). Credits are traded between two parties who directly negotiate a credit sale price with no external facilitation by a regulator (NSW Auditor General 2022). Credits can be purchased by any individual regardless of intention to offset environmental harm. Once traded credits can be on-sold or retired, however, once retired they cannot be sold again (NSW Auditor General 2022).

However, the scheme has not supported clear economic efficiency since its implementation. A mismatch between market supply and demand is a clear example of this inefficiency. Legislative changes in 2017 have increased market demand as a result of new obligations on developers to offset environmental harm (NSW Auditor General 2022). However, this growing demand has not been met with increased supply, with approximately 96% of developer demand for credits not met by current supply (NSW Auditor General 2022). There is also a small number of credit types traded within the market. As of 2022, there were 1394 different types of ecosystem credits and 867 different types of species credits of which 86% and 97% respectively had never been traded (NSW Auditor General 2022).

The contrasting performance of the US Wetland Mitigation Banking Program and NSW Biodiversity Offsets Scheme reflects broader patterns across environmental markets. There is broad agreement within the academic literature that environmental markets must be carefully designed to address key factors including additionality, metrics and measurement, permanence and longevity of environmental improvements, tradability, equivalence, time lag and development timeframes, and uncertainty (Bull et al. 2013; Swinfield et al. 2024; Wunder et al. 2025; Zu Ermgassen et al. 2026). This section discusses barriers at three levels that explain why environmental markets have traditionally underperformed: individual-level, program-level, and outcome-level.

Individual-level barriers

Environmental markets rely on active individual participation for credit supply. Individual-level barriers can prevent potential suppliers from entering the market or reduce its relative appeal compared to other land use options. Individual barriers include high land tenure requirements, long-term security, participation costs, and price uncertainty.

Sale of long-term conservation contracts requires secure tenure and ownership. Individuals must own land that can be conserved or converted to habitat and sold on the market. This makes environmental markets capital intensive. Smallholders and individuals without clear ownership or strong land tenure therefore may not be able to participate as they cannot provide long-term certainty of their conservation activities. Capital intensity is especially problematic in developing countries where land tenure can be unclear and poorly documented (Löfqvist et al. 2023; Wunder et al. 2025).

Secure land tenure requirements are compounded by high start-up and transaction costs to participate in an environmental market (Alvarado-Quesada et al. 2014). Landholders must demonstrate their land's underlying ecological value to determine appropriate credit prices. This can include ecological surveys that demonstrate the presence of endangered species and provide a baseline to compare quality changes over time. This barrier is present in many markets which require upfront fees for certification and evaluation by a regulator (Alvarado-Quesada et al. 2014). These transactions costs present an immediate fixed cost before economic benefits can be received, reducing the return and attractiveness of participating in environmental markets (Alvarado-Quesada et al. 2014).

Individuals are also required to provide long-term security for the environmental asset they have traded. Project proponents are generally required to guarantee that areas used for environmental offsets retain their high ecological value so that the offset does not result in a long-term decline in environmental areas. This creates a long-term burden that may disincentivise environmental market participation in favour of other land use with minimal or short-term security obligations.

Price uncertainty may also reduce the expected returns from environmental markets. The development of environmental credits must be directly compared against the opportunity cost of alternative land use, such as agriculture. The relative immaturity of markets and long-term price uncertainty can disincentivise participation from landholders who believe they may face higher future compliance costs or forgo higher future profits from waiting to participate (Teytelboym 2019).

Program-level barriers

Market design can create barriers to participation at the program-level. These barriers may introduce factors that would prevent a willing participant from trading environmental credits distinct from their individual-level considerations. Program-level barriers include credit issuance, environmental metric and definition, and disincentives to trade.

The timing of credit provision can create economic and environmental uncertainty. Most environmental markets operate prospectively, providing credits at the start of an environmental restoration (Bull et al. 2013; Swinfield et al. 2024; Hanley and Simpson 2025). This assumes that restoration activities will deliver positive environmental gains (Swinfield et al. 2024). Prospective crediting provides economic certainty for suppliers but creates environmental uncertainty. Achieving environmental outcomes is not guaranteed and projects may not deliver their intended outcomes. This issue is especially prominent with activities that have long lead times such as habitat development. However, a shift to ex post crediting can create economic uncertainty where a provider may not be able to accurately plan business activities. How a program balances this credit provision can create uncertainty for suppliers through unrealised income under ex post crediting, or uncertainty for the community through unrealised environmental outcomes under prospective crediting.

Defining environmental features and benefits can shape how a program delivers positive outcomes. Existing environmental markets generally focus on a defined set of environmental benefits. This includes specific habitat such as wetlands or a characteristic such as biodiversity. This approach can lead to two negative outcomes. First, a narrow focus can result in a small, thin market that leads to inefficient outcomes. A narrow focus may mean that only some landholders can provide credits that suit market needs, resulting in low supply. The narrow focus prevents opportunities where similar but slightly different credits could be traded to meet some of the market demand. Second, a narrow focus on single environmental outcomes may lead to perverse outcomes. This has been observed in the carbon market where project proponents prioritised fast-growing tree species to maximise carbon credits rather than a naturally diverse species mix that can also provide positive biodiversity outcomes.

Beyond the scope of a market's coverage, measuring environmental features has also presented a barrier to environmental market operation. Market mechanisms for habitat and biodiversity have struggled in implementation due to the lack of quantifiable and measurable metrics that allow simple comparison between sites. This is especially important for offset markets that require like-for-like environmental conditions to compensate for environmental destruction.

Program design can also undermine or disincentivise trade, resulting in economic inefficiency. Program design can distort market operations through different compliance burden on different offset suppliers. For example, the UK Biodiversity Net Gain market and historically the US wetland banking scheme, applies more rigorous standards to third-party mitigation compared to developer-led on-site mitigations (Teytelboym 2019; Zu Ermgassen et al. 2020; Aronoff and Rafey 2026; Zu Ermgassen et al. 2026). These different standards encourage developers to implement less robust on-site mitigation rather than purchase higher cost credits, reducing the value of the market mechanism.

Outcome-level barriers

Market outcomes can also create barriers to long-term market operations. Even where individual and program barriers are overcome, observed market outcomes may undermine the market's long-term viability. These feedback effects may reduce public trust and social licence for environmental markets. Outcome-level barriers can include long-term management incentives and environmental integrity.

Long-term area-based environmental credits may not provide incentives for active management. This means a landholder may not conduct additional activities that can promote improvements in the environmental habitat, such as pest and weed management and habitat provision (Dayer et al. 2018). A lack of long-term management can have a significant impact on the social licence of conservation activities where local communities believe conservation removes long-term employment opportunities that would be present from other land use as well as the perception that conservation areas create negative externalities for other land use such as agriculture.

Robust ecological and scientific outcomes are essential for the long-term operation of any environmental market. However, several existing environmental markets have been criticised for not delivering sufficient environmental outcomes (Zu Ermgassen et al. 2021, 2020, 2026; Maron et al. 2025). Poor environmental outcomes can stem from failure of environmental restoration, lack of compliance, poor monitoring and evaluation of outcomes, inadequate comparison metrics and insufficient offset area to compensate for environmental destruction (Bull et al. 2013). Poor or uncertain ecological outcomes can reduce trust in the outcomes associated with tradeable credits, deter investment and create reputational and social licence risk for offset providers, purchasers and regulating governments. Ecological outcomes are especially important under imperfect information and adverse selection conditions as individual purchasers and regulators may not be able to differentiate between high and low quality environmental activities (Swinfield et al. 2024). Such a situation can create a ‘market for lemons’ where the market becomes dominated by low-quality credits reducing trust and participation (Akerlof 1970). Unaddressed poor ecological outcomes could create a death spiral within the market where higher quality suppliers and purchasers leave the market, accelerating negative perceptions of market quality and eventually leading to market collapse (Zu Ermgassen et al. 2026).

Economic dynamics of environmental markets

Clear, well-designed rules and market design can support environmental markets to overcome barriers this paper has discussed. Many studies have historically focused on regulatory development, ecological efficiency and the value of restoration from environmental markets (Simpson et al. 2021). However, few studies examine how policy design influences economic behaviour within environmental markets. Existing studies examine market-level dynamics and do not consider how market design influences individual participation decisions.

Doyle and Yates (2010) compare how a market’s environmental intention, no net loss of size versus no net loss of function, shapes compensation requirements. Kangas and Ollikainen (2019) extend this to examine trading ratios, intermediaries and uncertainty. Simpson et al. (2021) assess how biodiversity net gain requirements influence market dynamics. However, each study operates at the market level and does not consider how design features influence an individual landholder’s decision to enter the market. Understanding how market design influences individual participation requires a framework that accounts for the irreversibility, uncertainty and timing that shape a landholder's choice to enter an environmental market. Section 5 applies a real options framework to formalise these individual-level considerations and identify which design features can reduce barriers to participation.

5. Microeconomic foundations of a natural capital market

A landholder's decision to allocate land between agriculture and conservation is an intertemporal investment problem. The landholder must choose how to deploy their fixed asset across competing uses over time. The landholder will choose a consumption-investment path to maximise discounted welfare subject to a capital accumulation constraint (Ramsey 1928). However, the standard framework assumes investment is reversible and future returns are known. These assumptions do not hold for land use decisions involving conservation, which involve sunk costs, uncertain ecological and economic returns, and long-term contractual obligations. Real options analysis provides a framework to analyse participation decisions under these conditions.

A real options framework quantifies the value of flexibility of investment decisions (Arrow and Fisher 1974; Henry 1974; Dixit and Pindyck 1994). Land uses that are irreversible, have uncertain costs and benefits, and can be delayed will require higher future returns to justify immediate actions (Mezey and Conrad 2010; Wesseler and Zhao 2019). Three conditions are necessary for a real options framework: (i) irreversibility or adjustment costs, (ii) uncertainty and the ability to obtain more information in the future and (iii) the ability to delay the decision (Dixit and Pindyck 1994; Conrad 1997; Wesseler and Zhao 2019). These three conditions influence an individual’s decision to participate in a natural capital market. This section examines a landholder's participation decision through this real options framework. This examination identifies the economic frictions and market imperfections that discourage participation.

Understanding these frictions and imperfections can inform market design reforms intended to increase efficiency and encourage greater entry.

A rational land manager will manage their land to maximise profit from some combination of activities across a fixed land area (Plantinga 1996). Choice allocation between land use is influenced by site suitability, input costs, market output prices, and individual factors such as risk appetite, preferences, and legal standing. Total profit is the sum of profit from the bundle of land use activities and decisions:

$$\pi_{Land} = \sum \pi_{\mathrm{i}} = \pi_{Conservation} + \pi_{Agriculture} + \pi_{Development} + \pi_{Services}$$

The land use decision can be viewed as a binary participation decision. This simplifies the multi-activity problem to a comparison of conservation against a next best alternative. Land use decisions are prospective and require landholders to consider the expected value of land use. Prospective decisions consider both the expected profit in future periods and the associated opportunity cost of each land use (Stavins 1999). This consideration views potential profit alongside irreversibility, variance of potential returns from land use, and the landholder's individual risk preference (Markowitz 1952).

The expected value of a land use includes a risk adjustment following Pratt (1964) and an irreversibility term that captures the deterministic sunk costs of land use conversion (Dixit and Pindyck 1994):

$$Expected\ Value\ (Activity_i) = \pi_i - \Phi_i - \frac{1}{2}\sigma_i^2 r$$

where:

activity *i* is the land use choice
π_i is the expected profit from land use *i*
Φ_i is the level of irreversibility of land use *i*
σ_i^2 is the variance of potential returns from land use *i*
r is the landholder's risk aversion, where higher r denotes greater risk aversion

A rational landholder will choose a land use to maximise the expected value of a discounted stream of benefits. This stream may be annual profits (e.g. annual agricultural activities) or long-term use (e.g. profits from a housing development in annual tranches). A landholder can be assumed to participate in a conservation market when:

$$EV(Conservation) > EV(Alternate\ land\ use)$$

or

$$EV(\pi_{Cons}) - \Phi_{Cons} - \frac{1}{2}\sigma_{Cons}^2 r > EV(\pi_i) - \Phi_i - \frac{1}{2}\sigma_i^2 r$$

Irreversibility is one factor that influences land use decisions (Dixit and Pindyck 1994). The difficulty of land use change can increase the future opportunity cost of that land. Higher opportunity cost would require higher expected profit. Irreversibility (Φ_i) can be defined as:

$$\Phi_i = F + \rho\kappa$$

where:

F = Fixed costs of activity *i*
ρ = probability of exit from participation in land use *i*
κ = penalty of exit from participation in land use *i*

A secondary market could reduce the expected cost of irreversibility (Teytelboym 2019). A landholder's expected obligation can be lower when there is an ex ante possibility of a trade rather than bearing the full exit penalty. This can expand Φ_i to be:

$$\Phi_i = F + \rho[(1-\theta)\kappa + \theta(\kappa - T)]$$

where:

θ = the likelihood of transfer in a secondary market
T = the value of transfer in a secondary market.

Φ_i can be simplified and expressed as:

$$\Phi_i = F + \rho(\kappa \; - \; \theta T)$$

Decomposition shows how irreversibility can vary across a range of possible secondary market conditions. Irreversibility is higher with lower θ as the landholder bears a higher penalty of exit. Increasing θ lowers the penalty of exit, lowering irreversibility consideration. This indicates that a deep, liquid secondary market can reduce irreversibility.

Initial land use will influence a landholder's perception of their participation decision. Existing land use will shape existing sunk costs and available land use transitions. For example, existing agricultural land may be framed as a decision to maintain agricultural production, convert to conservation or convert to urban housing or industrial use. Similarly, existing environmental habitat may be framed as a decision to maintain the habitat, convert to agricultural production or convert to housing. This analysis focuses on a landholder's decision for land currently used for agriculture facing a decision to convert to conservation and participate in a conservation market. Most land that could enter a new conservation market is currently in agricultural use, making this the margin where market design has the greatest influence on participation (Simpson et al. 2021).

Continuing agricultural production does not require land conversion. Agriculture also has annual production cycles and a liquid secondary market for capital. This supports Φ_{Ag} to be treated as zero. Direct comparison between agriculture and conservation therefore presents the following decision condition for participation in the conservation market:

$$EV(\pi_{Cons}) \; - \; \Phi_{Enviro} \; - \; \frac{1}{2}\sigma^2_{Enviro}.r \; > \; EV(\pi_{Ag}) - \; \frac{1}{2}\sigma^2_{Ag}.r$$

Given prospective decision-making, the landholder may consider market participation intertemporally. Intertemporal decisions allow the landholder to enter the market in period t or to defer participation to period t+1. An intertemporal decision to convert from agriculture to conservation can therefore be viewed as the expected value of conservation compared to the expected value of agriculture plus an option value (Ω) of waiting to participate in the conservation market (Dixit and Pindyck 1994; Conrad 1997). The option value reorganises irreversibility and uncertainty into a decision about investment timing. This relationship can be expressed as:

$$EV(\pi_{Cons}) \; > \; EV(\pi_{Ag}) \; + \; \Omega$$

An option value provides scope to participate in the market in period t + 1 based on changes following period t. These changes can be mapped across participation costs, a factor of irreversibility, relative price variance, and risk appetite expressed as:

$$\Omega_{Enviro} \; = \mathrm{s}(\omega + g(\Phi_{Enviro})) + \frac{\sigma^2{}_{Enviro}}{\sigma^2{}_{Ag}} r$$

where:

s = site-specific characteristics
ω = participation costs

$g(\Phi_i)$ = reflects changing level of reversibility of practice. $g(\Phi_i)$ is increasing in (Φ_i) reflecting increasing irreversibility increases the option value of waiting.
σ^2 = price variance
r = the landholder's risk aversion, where higher r denotes greater risk aversion

This expression synthesises factors identified in both the general investment literature (Dixit and Pindyck 1994) and environmental real options applications (Conrad 1997; Leroux et al. 2009; Wesseler and Zhao 2019). The expression shows that in conservation markets participation costs, irreversibility, price uncertainty and individual risk preferences can all influence decisions to delay market participation. The expected value of conservation markets can be expressed as:

$$EV(Environmental\ Market) = \pi_{Enviro} - F - \rho(\kappa - \theta.T) - \mathrm{s}(\omega + g(\Phi_{Enviro})) - \frac{\sigma^2{}_{Enviro}}{\sigma^2{}_{Ag}} r$$

Given this structure, Φ_i and Ω show related contributing factors in market participation decisions. Here Φ_i influences the decision to enter conservation land use and Ω influences the timing of participation.

Comparative statics provide insights into how changes to specific factors could influence a landholder's expected value of conservation activities and their subsequent decision to participate in a market. Some factors will shape the level of expected value from conservation activities. Increasing fixed costs ($\frac{\partial EV(Cons)}{\partial F} < 0$), likelihood of reverse ($\frac{\partial EV(Cons)}{\partial \rho} < 0$), and reversal penalties ($\frac{\partial EV(Cons)}{\partial \kappa} < 0$) are all associated with lower expected value. However, these may be offset by increases in conservation prices ($\frac{\partial EV(Cons)}{\partial \pi} > 0$), opportunities to trade conservation obligations ($\frac{\partial EV(Cons)}{\partial \theta} > 0$) and value of secondary trades ($\frac{\partial EV(Cons)}{\partial T} > 0$). Other factors can also reduce the option value associated with conservation, leading to a higher expected value. Reducing participation costs ($\frac{\partial EV(Cons)}{\partial \omega} < 0$), volatility ($\frac{\partial EV(Cons)}{\partial \sigma^2} < 0$), risk aversion ($\frac{\partial EV(Cons)}{\partial r} < 0$), and irreversibility ($\frac{\partial EV(Cons)}{\partial \Phi_i} < 0$) will reduce the option value of conservation market participation.

From these foundations, irreversibility and option value will have a large influence on decisions to enter a conservation market. This includes the likelihood and timing of entry. Reducing irreversibility simultaneously improves the entry decision and reduces the incentive to wait. Because Φ_{Cons} appears both in the level equation (directly reducing EV) and inside Ω_{Cons} through $g(\Phi_{Cons})$ (increasing the option value of waiting), a reduction in irreversibility works on both margins simultaneously.

At the same time, reducing uncertainty associated with long-term conservation activities can offset challenges associated with irreversibility. Irreversibility is present in multiple land use activities (e.g. construction), however these industries have lower uncertainty relative to conservation. Policies that reduce uncertainty can overcome issues of irreversibility and reduce the option value.

Uncertainty could be reduced through thicker markets, higher ease of trading, established market information, scientific inquiry and cataloguing and other factors. Conservation markets could therefore be supported by policy and market design that reduces irreversibility, increases market thickness and offers diverse opportunities to participate. This includes policies that reduce the upfront fixed costs and reduce barriers to entry, reduce probability of need to exit, increase the likelihood of a secondary trade and increase the value of that secondary trade. While reducing the penalty of exit could encourage more conservation participants, it is likely to reduce confidence in long-term environmental outcomes, making it an improper policy consideration (Bull et al. 2013; Zu Ermgassen et al. 2026).

The real options analysis shows that irreversibility and price uncertainty are the dominant barriers to conservation market participation. Because irreversibility enters both the expected value of conservation and the option value of waiting, reducing it simultaneously improves the attractiveness and timing of entry. Deepening secondary markets, lowering fixed entry costs, and reducing price variance each act on distinct terms in the participation equation. The Natural Capital Market Framework proposed in Section 6 targets these channels directly.

6. The Natural Capital Market Framework

Policy design can materially influence environmental market performance. Environmental markets have underperformed due to individual, program and outcome-level barriers that discourage participation. When viewed through a real options framework, irreversibility (Φ) and the option value of waiting (Ω) emerge as dominant channels through which market design discourages entry. Fixed costs of entry, rigid long-term obligations and thin secondary markets all increase the cost of participation and the incentive to delay. The Natural Capital Market Framework responds to these findings.

The Natural Capital Market Framework is a policy and market structure that facilitates the trade of natural capital credits to support environmental protection and improvement. It introduces three innovations to overcome barriers to participation such as irreversibility, uncertainty and the option value of waiting. These innovations are: (i) a dual credit structure, (ii) flexible contract options and (iii) a broader environmental remit.

Dual credit structure

Traditionally, environmental markets trade specific credits that represent the conservation of environmental stocks, such as biodiversity credits and wetland credits. These credits focus on area-based parcels of land to reflect the stock of available habitat for nature. These credits are generally capital intensive, require strong land tenure, have high barriers-to-entry and often require long-term conservation. These factors can make it difficult for landholders to participate in the market.

The framework introduces a dual credit structure, conservation credits and improvement credits, to reflect a broader range of positive environmental actions and provide a greater range of participation opportunities for landholders. Conservation and improvement credits combine to provide a bundle of goods and practices that can be traded to encourage new investment in environmental outcomes. Conservation and improvement credits can be substituted for each other within the market, acknowledging different preferences and outcomes associated with the size, area and quality of environmental assets.

Conservation Credits

Conservation credits reflect traditional area-based parcels of environmental assets. A conservation credit would be awarded for the protection of existing habitat. These credits reflect the important value of existing environmental areas and provide an incentive to maintain the habitat rather than convert it to other land uses, such as agriculture. Conservation credits provide an individual landholder with economic value for environmental areas on their property.

Conservation credits would be awarded for conservation over multi-year or multi-decade timeframes, ranging from single year to infinite protection. The landholder would be obligated to conserve the land for this period. However, the landholder can re-sell a new conservation credit at the end of the obligation period. The accounting value of a conservation credit would depreciate over the credit's defined lifespan.

Resale and depreciation provide two benefits to the market. First, re-crediting and resale following set periods creates a long-term incentive for compliance, maintaining the quality of the asset and adding to the stock of environmental assets to be credited. These actions should increase the resale value of the new conservation credits. Second, accounting depreciation allows landholders and investors to track the declining obligation over time, which can provide information on a secondary market.

Conservation credits are the market instrument for environmental land use in the Section 5 model. The introduction of resale lowers the time obligation of environmental market practices, allowing the landholder to participate in the market for a shorter time. This can reduce both Φ_{Enviro} and σ^2_{Enviro} as the landholder retains the ability to change land use after the defined period. This operates by reducing

ρ and κ because the landholder knows the obligation has a fixed endpoint. Fixed time periods also allow the landholder to reassess the relative value of environmental land use which can reduce their perception of price volatility and uncertainty.
Depreciating credit value can support greater information and understanding of the ongoing obligation associated with a conservation credit. This information can overcome issues associated with asymmetric information, increasing θ and T by facilitating more informed trades on a secondary market.

The value of conservation credits would be determined by individual credit characteristics. Credit valuation is discussed in more detail below. The length of conservation credit would be a significant factor in their value. Longer conservation periods would attract higher value due to increased security, while shorter credit periods would have lower value. This allows landholders to make active decisions about how they participate in the market based on their risk appetite, resource availability, and legal standing.

An example of a conservation credit is as follows. A landholder owns 100 hectares of land, divided between agriculture (80%) and environmental habitat (20%). The landholder chooses to sell a conservation credit equivalent to the environmental habitat (20 hectares) for a period of 20 years. These credits are purchased by a philanthropic charity seeking to encourage environmental protection. On sale the credit becomes a liability for the landholder and an asset for the charity. The size and value of the respective asset and liability reduces on a straight line basis by 5% each year until year 20 when the conservation credit expires. The landholder can then sell a new conservation credit in year 21.

Improvement Credits

Improvement credits seek to enhance environmental quality separate from long-term conservation. Improvement credits could be awarded for activities that promote environmental quality or remove negative aspects within the environment. The trade of these credits could therefore support ongoing efforts to increase the underlying quality and value of the environment.

Improvement credits fall into three broad categories:

i. Actions that convert land use to create new environmental areas. This includes vegetation planting, managing growth and ensuring survival, replanting dead trees, and active vegetation selection. These credits provide a pathway for the creation of new environmental areas that once established can be certified and sold as conservation credits.
ii. Actions that maintain or improve quality of existing environmental areas. This includes rubbish collection, pest and weed management, targeted vegetation management, controlled fire management, active habitat management.
iii. Actions on non-environmental areas that have positive environmental outcomes that form part of existing land and do not seek to convert the area into environmental land. This includes pesticide reduction and short-term changes to agricultural management practices.

Improvement credits are a new market instrument that complement environmental land use in the Section 5 model. These credits can reduce Φ_{Enviro} and σ^2_{Enviro} and subsequently lower barriers to participation. Like conservation credits, the short lifespans reduce both Φ_{Enviro} and σ^2_{Enviro} as the landholder can make short-term decisions with less price uncertainty and lower commitment costs. Improvement credits can provide additional reduction of Φ_{Enviro} as they have fewer fixed costs for implementation. Improvement credits allow landholders to participate in environmental markets alongside existing land uses without long-term land conversion. This may encourage landholders to participate more readily, increase the number of credits and thicken the market.

Improvement credit value would be determined by the ecological significance of activities, the quality of environmental assets they occur on and the longevity of improvement impacts. Credit value is discussed below.

Credit Substitution

Conservation and improvement credits can be substituted for each other within the market. Substitution allows for dynamic market trades that could increase the market's economic efficiency. This efficiency stems from: (i) providing greater options for individuals with diverse preferences, (ii) changing the cost of an environmental protection bundle, and (iii) thickening the market through greater credit volume.

The framework facilitates substitution between credits through a constant elasticity of substitution (CES) relationship. A CES relationship is chosen for two reasons. First, the CES facilitates policy adjustable substitution between credit types, allowing government to embed their policy preferences within the model. Second, a CES relationship allows a bundle of environmental goods to contain a zero quantity of either credit type. This nests single-credit environmental markets as a special case. When improvement credits are zero, the framework collapses to a traditional conservation-only market, allowing governments to adopt the framework incrementally. The CES relationship between conservation and improvement credits can be expressed as:

$$Q_N = [\alpha {Q_C}^{\rho} + (1-\alpha){Q_I}^{\rho}]^{\frac{1}{\rho}}$$

where:

$Q_N = Total\ quantity\ of\ natural\ capital\ credits$
$Q_C = Quantity\ of\ conservation\ credits$
$Q_I = Quantity\ of\ improvement\ credits$
$\alpha = Share\ parameter$
$\rho = Substitution\ parameter$

Shifts to α and ρ would implement different policy preferences. Shifting α changes the relative weight of each credit type while shifting ρ changes the level of substitution. These settings allow government to shift the balance between conservation and improvement credits to meet intended environmental outcomes within the existing market framework.

Cost of delivering environmental outcomes through conservation and improvement credit substitution

Conservation and improvement credits may reduce the cost of delivering outcomes through a natural capital market. As previously discussed, environmental markets traditionally trade a single credit that represents environmental protection. These credits reflect conservation credits within the Natural Capital Market Framework. In these markets the quantity of conservation credits determines the environmental outcome.

This can be written as:

$$Z = Q_E = Q_C$$

where:

$Z = Environmental\ outcome$
$Q_E = Total\ quantity\ of\ Environmental\ Credits$
$Q_C = Total\ quantity\ of\ Conservation\ Credits$

The total cost of achieving the environmental outcome is therefore:

$$C_Z = Q_C \,.P_C$$

where:

$C_Z = Total\ cost\ of\ achieving\ Z\ outcome$
$P_C = Price\ of\ Conservation\ Credits$

The Natural Capital Market Framework introduces improvement credits so that Q_E is a constant elasticity of substitution (CES) relationship between conservation and improvement credits. The environmental outcome is therefore:

$$Z = Q_E = [\alpha {Q_C}^{\rho} + (1-\alpha){Q_I}^{\rho}]^{\frac{1}{\rho}}$$

where:

$Q_C = Quantity\ of\ conservation\ credits$
$Q_I = Quantity\ of\ improvement\ credits$
$\alpha = Share\ parameter$
$\rho = Substitution\ parameter$

The total cost of achieving the environmental outcome therefore becomes:

$$C_Z = Q_C \,.P_C + Q_I \,.P_I$$

This relationship can then be optimised to identify the cost minimising combination of conservation and improvement credits:

$$min\ Q_C \,.P_C + Q_I \,.P_I \text{ subject to } [\alpha {Q_C}^{\rho} + (1-\alpha){Q_I}^{\rho}]^{\frac{1}{\rho}} = 1$$

This can be conducted through a Lagrangian optimisation approach:

$$\mathcal{L} = Q_C \,.P_C + Q_I \,.P_I + \lambda[1 - \alpha {Q_C}^{\rho} - (1-\alpha){Q_I}^{\rho}]$$

Solving this equation gives the following relationships for Q_C and Q_I:

$$Q_C = Q_I . \left[\frac{(1-\alpha)}{\alpha}\frac{P_I}{P_C}\right]^{\frac{1}{\rho-1}} \text{ and } Q_I = Q_C . \left[\frac{(1-\alpha)}{\alpha}\frac{P_C}{P_I}\right]^{\frac{1}{\rho-1}}.$$

The quantity of conservation and improvement credits is influenced by the substitutability between credit type (ρ) and the share parameter magnitude (α). Both share parameter and substitutability are important factors of environmental policy design and determine the market's cost structure. These factors will determine if conservation and improvement credits are substitutes, complements or independent. This influences how the new framework changes total costs. An example of this is shown in Figure 1, demonstrating the change in total cost of environmental protection with conservation and improvement credits as substitutes, independent and complements. This is compared to the cost of conservation-only environmental protection.

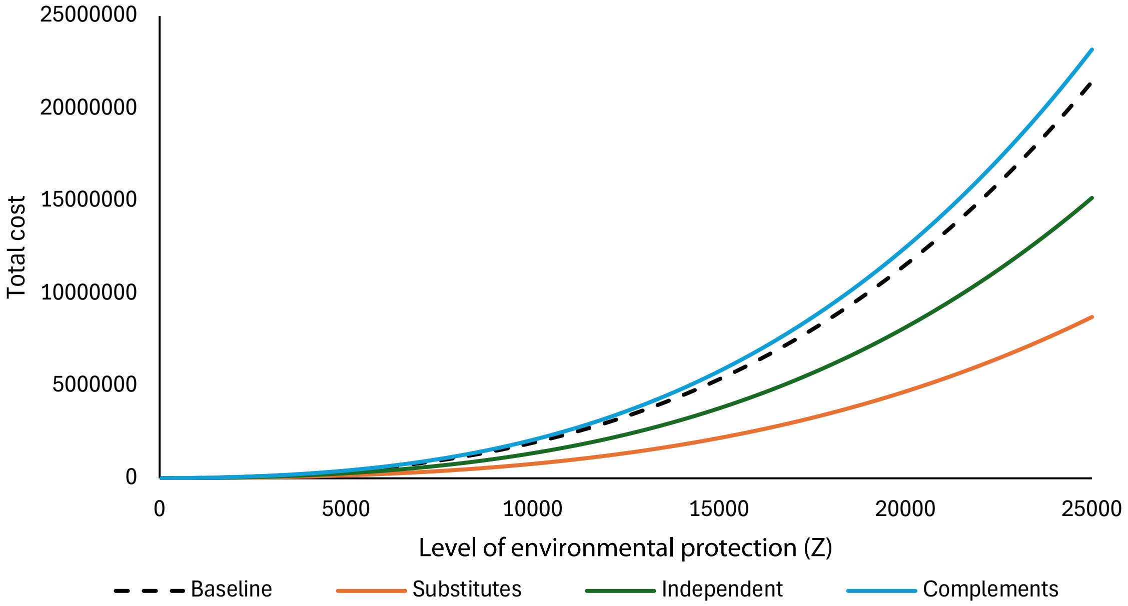

Figure 1 Theoretical impact of total cost for a given level of environmental protection with conservation and improvement credits as substitutes, complements or independent goods.

Figure 1 indicates that if conservation and improvement credits are substitutes or independent the introduction of improvement credits should deliver lower cost of environmental protection for a fixed environmental outcome Z. At the same time, a fixed investment would deliver a higher Z.

An important consideration of total environmental protection costs is the price ratio for any CES bundle. The cost minimising price to deliver Z with given input quantities is determined by the unit cost of the CES bundle:

$$c(P_C, P_I) = [\alpha^{\sigma} P_C^{1-\sigma} + (1-\alpha)^{\sigma} P_I^{1-\sigma}]^{\frac{1}{1-\sigma}}$$

The Natural Capital Market Framework is only cheaper if the unit cost of the CES bundle is less than P_C. This gives a breakeven ratio for conservation and improvement credit prices:

$$r_b = \left(\frac{1 - \alpha^{\sigma}}{(1 - \alpha)^{\sigma}}\right)^{\frac{1}{1-\sigma}}$$

From the breakeven ratio, the cost saving condition for the CES bundle is:

$$\frac{P_I}{P_C} < r_b$$

This price relationship provides a theoretical design expectation that the Natural Capital Market Framework can deliver lower cost environmental outcomes than traditional environmental markets. Improvement credits are expected to be lower cost than conservation credits. This lower cost stems from improvement credits' inherent characteristics of lower capital intensity, shorter timeframes and lower fixed costs of entry. As such, the combination of credits can be expected to meet the cost saving condition in practice.

Flexible contract options

The framework introduces new contracting categories that provide flexibility for landholders to participate in the market without compromising environmental outcomes. There are five contract categories within the framework that reflect different bundles of conservation and improvement credits:

1. Passive conservation – land management only for the generation and trade of conservation credits. Passive conservation can be characterised as leaving the environment to manage itself without human intervention.

2. Active conservation – land management that generates conservation and improvement credits. Active conservation uses human activities to improve environmental quality over time distinct from natural processes.

3. Progressive habitat creation – management practices that generate improvement credits by converting land to new habitat. Progressive habitat creation recognises management that is improving environmental areas but has not yet achieved outcomes consistent with complete functioning habitat.

4. Habitat improvement – ongoing activities that generate improvement credits through active management of existing environmental areas that are not protected for long-term conservation.

5. Time-limited environmental improvement – one-off activity that improves environmental outcomes to generate improvement credits but does not have ongoing environmental benefits.

Flexible contract options provide a broader range of opportunities for individuals and landholders to participate in the natural capital market. These options can be viewed as a hierarchy of participation. Differentiating credits across time and responsibility provides different opportunities that reduce Φ_{Enviro} and σ^2_{Enviro} to the point where they align with individual risk appetite, legal standing, and resource availability. These options also allow individuals to progressively move up the hierarchy over time, creating a mechanism that reduces Φ_{Enviro} and Ω_{Enviro} at the individual level.

Contract options also provide a pathway for new habitat creation that reduces economic and ecological uncertainty. A landholder earns improvement credits for progressive habitat creation, creating an income stream contingent on supporting positive ecological outcomes. Once this habitat has reached maturity, it can then be traded as conservation credits with defined and verified environmental values. This can balance the uncertainty challenges that have undermined existing environmental markets, as discussed in Section 4.

Environmental remit and credit value

The Natural Capital Market Framework adopts a broader environmental remit than previous environmental markets. A broader remit allows the market to better reflect a range of natural capital features and ecosystem services as well as providing a clear approach to credit valuation.

Environmental markets have historically focused on single environmental characteristics, such as biodiversity. However, a narrow focus on single characteristics can create issues of thin markets and difficulty determining appropriate metrics, as discussed in Section 4. This can mean that some environmental conservation or improvement is not properly captured within the market. For example, habitat can provide public good services like erosion control and water quality improvements from selective vegetation planting and agricultural management. However, these services may not be captured by a traditional, single focus environmental market.

The Natural Capital Market Framework overcomes this challenge by expanding the environmental remit of the market. The framework seeks to bring multiple environmental services into a single framework. This is achieved by focusing on environmental protection and enhancement through conservation and improvement credits. These credits allow different areas and actions to be traded in a single market and can increase the number and diversity of tradeable credits, thickening the market. A thicker market can increase liquidity (θ) and reduce price variance and volatility (σ^2).

While a single market can increase economic efficiency, it may face restrictions related to ecological heterogeneity. Ecological heterogeneity makes it difficult to accurately compare two environmental locations or actions. The Natural Capital Market Framework seeks to overcome this through hedonic valuation. Hedonic valuation would determine economic and ecological value through the combination of different characteristics. An example of a hedonic valuation structure could be:

$$\begin{aligned} Value_i = \alpha + \beta_1 Size + \beta_2 Location + \beta_3 Connectivity + \beta_4 Habitat\ Quality + \beta_5 Known\ Population \\ + \beta_6 Species\ Diversity + \beta_7 Environmental\ Outcome + \beta_8 Outcome\ Longevity \\ + \beta_9 Level\ of\ Environmental\ Compensation + \varepsilon \end{aligned}$$

Hedonic valuation aligns the Natural Capital Market Framework with existing markets that manage heterogeneity, such as property and labour markets. Both property and labour markets successfully adopt hedonic valuation to value different products through specific characteristics and how those characteristics align with the buyer's preferences.

Hedonic valuation would experience measurement and valuation difficulties, like those discussed in Section 4. However, hedonic valuation can facilitate two improvements in the framework's long-term pricing. First, new capacity, technology improvements and information can be actively incorporated into the valuation structure as they become available. This can provide a level of certainty for how the environment is valued with innovation improving the accuracy of measurement rather than changes to the underlying measures. Second, hedonic valuation supports governments to adjust weights to reflect data availability and policy preferences. This may include probability-weighted values to manage uncertainty or to encourage certain environmental features to align with policy preferences.

This section has outlined a new Natural Capital Market Framework as the basis for greater economic efficiency and ecological certainty within environmental markets. Considered alongside the individual's participation decision from Section 5, the framework can directly adjust several factors and encourage increased participation.

$$EV(Environmental\ Market) = \pi_{Enviro} - F - \rho(\kappa - \theta.T) - \mathrm{s}(\omega + g(\Phi_{Enviro})) - \frac{\sigma^2{}_{Enviro}}{\sigma^2{}_{Ag}} r$$

This framework introduces three innovations for environmental markets that reduce irreversibility and the option value of waiting. A dual credit structure reduces Φ by lowering exit penalties (κ) through defined commitment periods and increases secondary market information, raising θ and T. Flexible contract options reduce F by providing a hierarchy of entry points with different cost and commitment profiles, lowering both Φ and Ω. A broader environmental remit increases the volume and diversity of tradeable credits, raising θ and reducing σ^2.

7. Conclusion

Natural capital and ecosystem services are fundamental inputs into the economy. However, economic activity can have direct and indirect negative impacts on natural capital. This presents a challenge where global economic activity may be degrading one of its essential inputs. This paper has examined the characteristics that drive a disconnect between the value natural capital provides to the economy and how the economy misprices and misuses natural capital. Ecosystem services with low excludability and low rivalry produced from private assets are regularly mispriced and not properly incorporated into individual decisions.

Environmental markets are an opportunity to better price these ecosystem services and allow individuals to capture the full range of the benefits their assets produce. However, many existing environmental markets have faced individual, program and outcome-level barriers to effective operation. Economically, these barriers are exacerbated by the irreversibility of market participation and the presence of an option value where it is rational for landholders to delay participation.

This paper introduces the Natural Capital Market Framework to overcome several challenges identified in existing environmental markets. This framework introduces three innovations for environmental markets to reduce irreversibility and the option value of waiting: a dual credit structure, flexible contract options, and a broader environmental remit. However, this proposed framework exists as a conceptual framework. Empirical analysis can inform how the proposed framework delivers successful, economically efficient and ecologically robust environmental markets.

Future research can examine how the Natural Capital Market Framework can be implemented, the potential size of a market and how that market shapes economic conditions. This research should focus on institutional capacity and capability to implement a natural capital market in developing countries and the role of policy reform to facilitate a new market. Beyond market implementation, empirical analysis should estimate the potential size of a market to quantify the scale of opportunity available, especially in environment-rich developing countries. Finally, economic modelling should examine how implementation of a new market can shape domestic and international outcomes.

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