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The economics of natural capital

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Abstract

We develop a framework underscoring the importance of incorporating natural capital into growth models and policy discussions, recognizing its role as a productive input and as a source of enjoyment. Both firms and the government face the trade-off between exploitation and conservation and can (but do not have to) engage in costly conservation. Firms optimally conserve natural capital to support future production but underinvest compared to the social optimum. Public conservation complements private action, shifting focus from current consumption to future growth. Unique region-level data on the biodiversity of the forest in 582 regions across 44 countries confirm the main empirical predictions of the model.

JEL classification: N5, O4, Q5.

Keywords: Natural capital, biodiversity, endogenous growth

Non-technical summary

A plethora of recent evidence points to a steep anthropogenic decline in biodiversity in the past several centuries. This raises a number of questions that are not only interesting to academics and to policy makers alike, but also existentially important. Is our current economic model, where natural capital is employed by private firms in the production of the goods and services that humankind demands, sustainable, or is it a path to self-destruction? Are alternative economic arrangements available whereby similar levels of prosperity can be maintained with a lower degree of nature exploitation and degradation? Or is de-growth the only path to preserving ecological diversity?

We tackle these questions through the lens of economic theory and by providing empirical evidence. We first develop a theoretical framework in which the aggregate output function involves three separate inputs: labour ('human capital'), manufactured inputs ('produced capital'), and ecosystem inputs ('natural capital'). In the model, economic activity depletes natural capital, but natural capital can regenerate. Moreover, the rate of natural capital regeneration can be made higher via investment in costly conservation which can be carried out both by firms and by a public authority. The model delivers a natural tension between exploitation and conservation: a reduction in exploitation today removes resources from current consumption, but it increases natural capital and therefore boosts future productive capacity. Finally, in addition to an economic value, nature also has an enjoyment component to households, something that firms do not take into account but public authorities do.

Solving this model yields two useful insights about the long-term relationship between nature and economic activity. First, when natural capital is owned by firms and used as an input in the production process, it is never fully depleted, but it rather ends up being maintained at levels necessary to ensure uture production capacity. Second, firms' conservation efforts are low from a social point of view, because firms put more emphasis on current output and do not take into account the enjoyment component of natural capital. As a result, public conservation – which is higher than private conservation – is needed, shifting focus from current consumption to future growth.

We then take the model to the real world by using unique region-level data on the biodiversity of the forest in 582 regions across 44 countries. We show that publicly owned forests exhibit higher biodiversity than privately owned ones, confirming the "overuse" – from a social point of view – of natural capital in economic activity. At the same time, even within the same country the index of biodiversity in fully publicly owned forests is only 9% higher than in fully privately owned ones, pointing to the existence of economic incentives for private entities to maintain a sufficiently high level of natural capital.

Our analysis speaks directly to several pressing questions currently confronting policymakers. Should the forecasting models employed by central banks in the formulation of monetary policy incorporate measures of natural-capital degradation? Should estimates of potential output explicitly account for the stock of natural capital? And what constitutes the optimal balance between public ownership of natural capital and the regulation of natural-capital assets held in private hands? Ultimately, although an arrangement in which natural capital used for the production of goods and services is privately owned – combined with public ownership of non-trivial natural areas –yields lower long-run biodiversity than an Arcadian, non-industrial economy, it nonetheless represents the configuration of nature–economy interaction that provides the most favourable balance between economic prosperity and ecological diversity.

1 Introduction

The issue of environmental degradation and the role of human activity in driving it has recently moved to the forefront of public and policy discourse. Researchers in both the natural and the social sciences have documented the steep decline in biodiversity since the 1970s (e.g. Dasgupta, 2024; Ceglar et al., 2023; Flammer et al., 2025). Figure 1 documents the stark differences in soil biodiversity across regions of the world at present, making apparent the relatively low levels of biodiversity in much of the industrialized world. Moreover, the breadth of available data has allowed scientists to trace this process back to times predating the Anthropocene, with 85% of the wetlands having disappeared between 1700 and 2000 (Ceglar et al., 2023).

At the same time, humans have been interacting with, altering, and diminishing nature for tens of thousands of years. For example, approximately 80% of the mega fauna perished following the spread of Homo Sapiens across the Americas more than 10,000 years ago, and the primaeval forests of Europe had been cut down and used in the building of houses and ships and as a source of energy long before the Industrial Revolution (Harari, 2015). In fact, one fifth of forest cover loss in temperate parts of Europe occurred before the late Bronze Age (Roberts et al., 2018).

This discussion illustrates two interesting facts. Firstly, much of the decline in biodiversity we observe today occurred already before the modern (industrial) era. Secondly, even though the global economy has never been larger, nature is still all around us. In fact, there is evidence that several regions (e.g. parts of Europe, North America, and East Asia) have recently shown net gains in forest areas as the rate of regrowth has surpassed the rate of deforestation (Wilson et al., 2017). This raises the question whether the documented decline in overall biodiversity since 1970 is a path to self-destruction for the human race, or whether in contrast we have managed to establish an economic equilibrium whereby we exploit and degrade nature without ever pushing it to the brink.

In this paper, we attempt to address the question of how natural capital and economic activity interact and affect each other in the long run. We do so both through the lens of economic theory and by providing empirical evidence.

In the first step, we develop a nature-incorporating endogenous growth model. The model has four building components which are novel compared with traditional growth models. First, the aggregate output function involves three separate inputs: labour ('human capital'); manufactured inputs ('produced capital'); and ecosystem inputs ('natural capital'). Our modeling of natural capital is flexible and can capture both its quantitative aspects (e.g., the volume of lumber needed to manufacture a piece of furniture) and its qualitative aspects (e.g., the variety of species in a forest). Second, economic activity depletes natural capital through exploitation, but natural capital can regenerate. Third, the rate of natural capital regeneration can be made higher via investment in conservation. Such conservation can be carried out both by firms and by a public authority. At the same time, conservation is costly, and the cost of conservation increases as natural capital is depleted.[1] Fourth, in addition to an economic value, nature also has an enjoyment component to households who derive utility from, e.g., a walk in the forest or a visit to a wild reserve.

The model underlies a tension between nature exploitation and conservation: investment in conservation (or, alternatively, a reduction in exploitation) today removes resources from current consumption, but it increases natural capital and therefore boosts future productive capacity. Solving this model yields two useful insights about the relationship between nature and economic activity. First, we show that when natural capital is owned by firms and used as an input in the production process, it is never fully depleted. On the contrary, it ends up maintained at levels necessary to ensure future production capacity. Long-standing agricultural practices consistent with this idea include – but are not limited to – fallowing, agroforestry, and managed grazing. Second, firms' conservation efforts are too low from a social point of view. This is because firms put more emphasis on current output than future growth, and because they do not take into account the enjoyment component of natural capital. As a result, public conservation is needed to top up private conservation, shifting focus from current consumption to future growth. Examples of such public conservation efforts include, for example, urban parks, natural reserves and wildlife sanctuaries, and green corridors. Naturally, public investment in conservation increases with the enjoyment benefit of nature.

We then take the model to the real world by using unique region-level data on the biodiversity of the forest in 582 regions across 44 countries. We show that publicly owned forests exhibit higher

[1] This assumption captures the idea that it is cheaper to maintain nature at higher levels of natural capital, similar to Giglio et al. (2024).

biodiversity than privately owned ones, confirming the ”overuse” – from a social point of view – of natural capital in economic activity. At the same time, even within the same country the index of biodiversity in fully publicly owned forests is only 9% higher than in fully privately owned ones, pointing to the existence of long-term economic incentives for private entities to maintain a sufficiently high level of natural capital.

The paper proceeds as follows. In Section 2, we conceptualize the interaction between nature and economic activity and we discuss the relevant literature. In Section 3, we develop and solve an endogenous growth model with natural capital. In Section 4, we present empirical evidence consistent with the main predictions of the model. Section 5 concludes with a discussion of the policy implications of our work.

2 Nature and the economy

Nature underpins human wellbeing and survival. The living and non-living elements of our planet – plant and animal species, rivers, lakes, oceans, mountains, etc. – collectively form ecosystems. The quantity and quality of these ecosystems, together with other environmental resources and endowments, can be described as natural capital (Barbier, 2011, 2019), which provides a range of vital services to humankind. Such ecosystem services include the provision of tangible goods (such as food, medicine, timber, and freshwater) as well as regulating air quality, offering protection against floods and droughts, controlling the climate, and providing recreation and tourism benefits.

The value of these ecosystem services is substantial. The Joint Research Council (2021) estimate that in 2019, ecosystem services provided more than €234 billion of economic and social value in the European Union alone. Of those ecosystem services studied, nature recreation had the highest value, with water purification, flood control, and crop provision also making sizeable economic contributions. These benefits are greatly at risk from the current unprecedented rate of nature degradation and biodiversity loss (European Environment Agency, 2021).

The value of ecosystem services are not fully reflected in standard economic measures of output, such as gross domestic product (GDP). Even where they are indirectly included, the lack of precise measurement leads to the misattribution of their value (Martins Cardoso and Parker, 2024). For example, the value of natural pollination is included in the value of crops measured at the farm gate, but it is attributed to agricultural gross value added, rather than to ecosystem services. This has important implications for assessing returns to investing in agricultural intensification rather than rehabilitating ecosystems. Moreover, focus on gross value added rather than net value added means that the impact of degradation of natural capital is not factored into assessments of productivity (Cardenas Rodriguez et al., 2023). Indeed, when taking into account the relatively steeper reduction in carbon emissions and other pollutants in Europe over recent decades, the productivity gap relative to other advanced economies is narrower than indicated by standard measures.

The World Bank (2021) finds that global renewable natural capital increased in value between 1995 and 2018, although that aggregate figure masks diverging outcomes by type. For example, the value of global fisheries declined by 83% over the same period. While the surface area of mangroves declined, the value of the land they protect has increased sharply, resulting in an overall increase in the estimated value of natural capital. As the authors note, this highlights the economic benefits available from investing in natural capital: expanding areas covered by mangroves would boost the economic value of the flood protection they provide.

Maes et al. (2023) study the evolution of forest condition in Europe between 2000 and 2018. Using an index of various indicators of health, they find the average forest condition increased from 0.566 to 0.585 over that period (where 0 is completely degraded, and 1 represents the condition of pristine forests). Condition improved in around two-thirds of forests, but declined in around a third. (Döhring et al., 2025) incorporate ecosystem services into a standard aggregate production function, calibrating for the estimated role of forest ecosystem assets in the economy. They calculate that even under ambitious climate change mitigation pathways, nature degradation would result in losses of up to 2 percent of EU GDP by 2085. For scenarios where climate change is more pronounced and substitution between natural capital and other factors of production is low, losses could reach 15 percent of GDP.

The impact of nature degradation on economic activity is non-linear and can be difficult to monitor, particularly without timely metrics. Biodiversity loss can initially appear to have little impact, as other species carrying out similar ecosystem functions can replace lost species. However, at some point species loss becomes critical and certain ecosystem functions can collapse, resulting in a sharp decline of ecosystem services (Dasgupta, 2024).

Indeed, historical episodes demonstrate that the economic impacts of a sudden loss of ecosystem services can be swift, substantial, and sustained. Hornbeck (2012) studies the impact of the American Dust Bowl of the 1930s, where a combination of drought and destruction of native vegetation resulted in substantial soil erosion. Between 1930 and 1940, agricultural revenues declined by 27% in high-erosion counties and by 16% in medium-erosion counties, relative to low-erosion counties. These relative declines in agricultural revenues persisted for several decades.

Panagos et al. (2018) identify 12 million hectares of agricultural land in Europe that suffers from severe erosion. They estimate that the erosion reduces agricultural productivity by 0.43% per year, resulting in an overall estimated cost per year of €1.25 billion. Kopittke et al. (2019) point to further channels of soil degradation, including overuse of fertilisers, contamination, acidification, salinisation, and loss of genetic diversity. Degradation increasingly threatens the long-term viability of soil to provide sufficient food production in the future. Sartori et al. (2024) estimate that continuing climate change will accelerate soil erosion rate by between 30-66% between 2015 and 2070. They estimate that the higher rates of soil erosion will result in an economic loss of US$ 625 billion by 2070, as well as acute challenges to food security in a number of regions, such as Africa and the tropics.

Nature degradation, both domestic and overseas, therefore poses economic and financial risks for the European economy (Ceglar et al., 2024). These risks arise both through the potential of catastrophic loss of ecosystem services (see, for example, Ranger et al., 2023), as well as from the impacts of stricter environmental policies put in place to curb further degradation (NGFS, 2024). Three-quarters of global food crops, including fruit, vegetables, and important food commodities such as cocoa and coffee, rely on animal pollination IPBES (2019). European countries are therefore exposed to the loss of pollinators overseas, notably for crops that cannot be grown in Europe (see, for example, Murphy et al., 2022). Pollinators also play a key role beyond food production, including for some medicines and biofuels such as oilseed rape (Potts et al., 2016). Ceglar et al. (2025) find that 72% of euro area non-financial firms exhibit a high dependency on at least one ecosystem service, to the extent that production would be severely impaired should that service be curtailed. 60% of loans to non-financial companies in the euro area are to firms with unmet flood protection needs.

As Giglio et al. (2025) note, climate change and nature loss are interrelated, with both negative trends amplifying each other. The quality of ecosystems (in terms of biodiversity) affects both their ability to sequester carbon, and their resilience to extreme events. Nature loss therefore reduces carbon sinks and increases the rate of climate change for a given rate of carbon emissions. At the same time, climate change causes ecosystem stress, as conditions become unfavourable and excess heat and dryness cause species loss (e.g. Weiskopf et al., 2024; Mori et al., 2021). Ke et al. (2024) find a large decline in land carbon sink during 2023, with the decline more prominent in areas exposed to extreme heat and extreme dryness. This interrelationship has important implications for estimating the future impact of climate change and therefore the social cost of carbon (Bastien-Olvera and Moore, 2021). Benmir et al. (2025) incorporate natural capital dynamics into a dynamic stochastic general equilibrium model. The model incorporates a channel for climate change to exacerbate the degradation of natural capital. This channel amplifies the social cost of carbon by 12% relative to a standard integrated assessment model that considers just the direct economic impacts of climate change on economic activity.

As Döhring et al. (2023) note, assumptions about the degree of substitutability between natural and produced capital are key for determining the long-term sustainability of economic growth. While nature is capable (to an extent) of self-replenishing, there are a range of non-renewable resources, such as fossil fuels, that have contributed to measured economic growth over past centuries. Growth based on the exploitation of these non-renewable resources cannot continue indefinitely. Similarly, growth based on over-exploitation of renewable natural resources, to the extent that it depletes the stock of natural capital, cannot continue indefinitely. Yet these problems may be overcome if it is possible to invest in nature and deliver productivity growth arising from natural sources, or substitute natural capital for produced capital.

Riekhof et al. (2019) examine how international trade and economic growth affect renewable resource use under open access versus property rights. Their work shows that resource depletion slows consumption growth, while trade can shift countries from conservation to depletion when property rights exist. Crucially, institutional changes in one country spill over to trading partners. Also focusing on the link between trade and growth, Batini and Durand (Batini and Durand) show that trade in ecosystem-based inputs can slow growth in resource-rich countries during transition—-yet, recognizing the presence of ecological tipping points alters incentives, encouraging conservation and innovation to avoid nature collapse.

Potts et al. (2016) document a substantial decline in pollinators over the past century (notably in number and species of bees), although also note some slowing in the rate of decline in recent years. This has affected agricultural productivity, where yields have grown more slowly worldwide for pollinator-dependent crops than pollinator-independent crops. The authors note that there are a range of practices that can be implemented to bolster pollination, including reduced use of pesticides, increasing areas devoted to natural habitats and addressing parasites. By investing in nature conservation it is possible to slow and to reverse the decline in pollinators and consequently underpin agricultural productivity.

Flammer et al. (2025) study the use of private finance to support biodiversity conservation and restoration. They note that there may be some private returns that accrue from investing in nature that provide justification for private finance. For example, investing in wetlands and mangroves could improve fishery returns and increase the valuation of land now protected. Similarly, protecting pollinators could bolster the productivity of agricultural land. Studying 33 existing biodiversity finance deals, they find that 60% are financed with private capital alone. However, such projects are generally small, with equivalently small benefits to biodiversity. By contrast, the 40% of deals that also involve public or philanthropic money alongside private finance are generally larger, but have a smaller expected rate of return. Nonetheless, they conclude that private finance is unlikely to be able to fully underpin nature restoration, and that public policy intervention through regulation is likely necessary.

In contrast, Garel et al. (2024) find evidence of increasing attention paid by financial markets to biodiversity. They calculate the impact of 2100+ listed companies on biodiversity and find little impact on average monthly stock returns over the period 2019-2022. However, following the signing of the Kunming Declaration in 2021 at the UN Biodiversity Conference (COP15), they find evidence of a significant divergence, depending on firm-specific biodiversity impact. Firms with a high biodiversity impact witnessed an average total stock price decline of 1.14 percent in the three days following the signing, with divergent pricing also evident over the following year. Further divergence occurred following the inauguration of the Taskforce on Nature-Related Financial Disclosures. Giglio et al. (2024) similarly find increasing evidence of market pricing of biodiversity loss. Furthermore, they also estimate that CDS prices on government debt increase following a negative biodiversity news shock, with the increase larger in countries where nature is already relatively more degraded.

3 An endogenous model of growth with natural capital

3.1 Model description

Time is continuous, and the horizon is infinite. We consider an economy that admits a representative agent with logarithmic preferences and discount rate ρ:

$$\int_0^\infty e^{-\rho t} \ln \mathcal{C}_t dt \tag{1}$$

where $\mathcal{C}_t$ denotes consumption at time t. The representative agent is endowed with one unit of labour, which is supplied inelastically and yields a competitive wage denoted by W_t. Population size is constant at L, which we normalize to one for simplicity.

There is a unique consumption (or final) good serving as the numeraire of the economy, whose output is denoted by Y_t. The consumption good is produced competitively by the final good sector using labour and a continuum of intermediate inputs $j \in [0, 1]$ according to the following technology:[2]

$$Y_t = \frac{L^\beta}{1-\beta} \int_0^1 X_{jt}^{1-\beta} B_{jt}^\beta dj, \quad \beta \in (0, 1). \tag{2}$$

Each intermediate input j is owned by a firm, which acts as a monopolist in the production of j.[3] In the following, we refer to these firms as intermediate goods (or inputs) producers. For simplicity, we normalize the marginal cost of production to one. Both the inputs X_{jt} as well as the variety/quality

[2]In a previous version of the model, we adopted a different (linear) formulation of the production function. The main model implications continue to hold in that alternative version. Also, because L is normalized to one, we omit to report L when it causes no confusion.

[3]This assumption is standard in this class of models of endogenous growth.

of the natural capital B_{jt} supporting (or serving to produce) each of these inputs matters in the production of the final good. This modeling is consistent with the World Bank's framework (see World Bank, 2021), which estimates national wealth as stemming from produced capital (our X_{jt}), human capital (our L) and natural capital (our B_{jt})—which are the inputs we consider in Equation (2).[4]

The natural capital supporting each input j deteriorates with the associated output X_j by a factor δ. Thus, a greater output implies a greater exploitation of natural capital. Nonetheless, we allow natural capital to be improved by investment in preservation. Investment in preservation can be undertaken by the producer of input j—in which case we denote it by I_{jt}—or by a central authority—in which case we denote it by S_{jt}. For each j, the dynamics of dB_{jt} then satisfy:

$$dB_{jt} = (I_{jt} + S_{jt} - \delta X_{jt} + \gamma B_{jt})\, dt.$$

The first two terms on the right-hand side represent private and public investment in preservation, respectively. The third term represents the exploitation rate of natural capital due to production—notably, the idea that production leads to a deterioration of natural capital is consistent, for instance, with Martins Cardoso and Parker (2024) and the OECD framework to assess environmentally-adjusted productivity (Cardenas Rodriguez et al., 2023). The last term in this equation indicates the regeneration rate of natural capital. In general, Equation (3.1) implies that an intermediate producer can alternatively preserve natural capital by reducing its output (then slowing down exploitation) or by investing in preservation.

Because the natural capital associated with intermediate inputs enters the production of the final consumption good—and, thus, the demand from the final good sector—input producers may have incentives to invest in preservation, as we will show. Preservation is costly, however, and we assume that the investment cost is $\frac{\theta}{2}\frac{I^2}{B}$. This formulation implies that: (1) the cost is convex in I; (2) preservation is less costly when B is larger. To ease comparability, we also assume that investment in preservation pursued by the central authority has a similar functional form but a different cost coefficient, i.e., $\frac{\zeta}{2}\frac{S^2}{B}$.

At any time, the consumption flow of the representative agent is given by the competitive labour

[4]The World Bank framework also considers net foreign assets, which is beyond the scope of our model.

wage, the net dividends from the input producers and transfers to the central authority (e.g., public investment in preservation, entering negatively if non-zero). In addition, we assume that the representative agent derives a consumption flow from natural capital, which can be interpreted as the public good due to amusement, enjoyment or health associated with the quality/variety of natural capital. We denote this benefit as $A_t = \Psi \int_0^1 B_{jt} dj$, which is larger the greater B_{jt} across product lines.

We focus on a balanced growth path equilibrium, in which aggregate quantities grow at the constant endogenous rate g. An equilibrium is an allocation such that: (1) input producers maximize their value through production and investment in preservation; (2) the final good sector maximizes profits; (3) the representative agent maximizes utility from consumption; (4) the central authority sets investment in preservation to maximize welfare; (5) all markets clear.

3.2 Model solution

To isolate the economic strengths at play, we solve the model in steps. First, we consider a simpler setting in which there is no public investment to preserve natural capital. Second, we solve the more general case featuring the central authority setting the public investment in preservation so to maximize welfare.

3.2.1 Case with no public investment in preservation

The maximization of the consumption good sector delivers the demand curve for each intermediate input j:

$$X_{jt} = \left(B_{jt}^{\beta}/p_{jt}\right)^{\frac{1}{\beta}} = B_{jt} p_{jt}^{-\frac{1}{\beta}} \;\Rightarrow\; p_{jt} = X_{jt}^{-\beta} B_{jt}^{\beta} \tag{3}$$

where the price p is determined by the profit maximization of the j-th input producer. The higher B_t, the greater the quantity demanded for a given price level (or, equivalently, a greater price for a given quantity). This then generates incentives for private firms to investment in preservation (as we discuss in more detail later).

Given the demand schedule of the final good sector, natural capital matters in the maximization of the input producer. Following standard arguments, the maximization problem of an input producer—

whose value is denoted by $V_j(B)$—satisfies (suppressing the subscript j when it causes no confusion):

$$rV(B) = \max_{X,I} \left(I - \delta X + \gamma B\right) V_B + X(p-1) - \frac{\theta}{2B} I^2. \tag{4}$$

This equation admits the following interpretation. The left-hand side is the return required to invest in the firm, whereas the right-hand side represents the expected change in firm value on each time interval. Specifically, the first term on the right-hand side is the expected change in firm value due to a change in natural capital (due to investment in preservation I, production-driven exploitation δX and natural regeneration γB), the second term represents the revenues net of the cost of production and the third term represents the cost associated with investing in preservation. To solve the model, we conjecture that the value of an input producer can be expressed as $V(B) = vB$, where v can be interpreted as the marginal value of natural capital from the perspective of the intermediate producer. Using this scaling property, we also define scaled production $x = X/B$ and scaled investment in preservation $i = I/B$ (or investment rate). Maximizing Equation (4) then gives the optimal scale of production x:

$$x = \left(\frac{1-\beta}{1+\delta v}\right)^{\frac{1}{\beta}}. \tag{5}$$

This expression suggests that if production leads to a greater deterioration in natural capital (as captured by the parameter δ), then the optimal scale of production is lower and more so the higher the marginal value of natural capital v. Next, the maximization of (4) with respect to the firm's investment in preservation gives:

$$i = \frac{v}{\theta}. \tag{6}$$

This equation illustrates that the higher the marginal value of natural capital from the firm perspective, the higher its investment in preservation. However, the higher the associated cost, the lower the optimal engagement in preservation.

Along the balanced growth path, aggregate quantities grow at the equilibrium rate $g = i - \delta x + \gamma$.[5] The relation between x and g captures the idea that increased production leads to a greater exploitation—and, thus, deterioration—of natural capital, which then leads to a decline in long-term growth. Yet, firms can support long-term growth by investing in preservation, as captured by the term i entering positively in the expression of g. Along the balanced growth path, the consumption of the

[5]Following standard arguments, the Euler equation of the representative agent is then $r = \rho + g$.

representative agent as well as its components also grow at g.[6] When there is no public investment in preservation, the consumption of the representative agent is given by:

$$\mathcal{C}_t = W_t + D_t + A_t = (W_0 + D_0 + \Psi)e^{gt} \tag{7}$$

being the sum of the competitive equilibrium wage (the first term), the dividend coming from the intermediate good sector (the second term) and the flow coming from the enjoyment of natural capital (the last term). Notably, the dividend from the intermediate good sector decreases with their engagement in preservation. However, investment in preservation supports natural capital, then potentially its associated enjoyment.

Lastly, welfare is given by the intertemporal utility of the representative agent:

$$\text{Welfare} = \int_0^\infty e^{-\rho t} \ln \mathcal{C}_t dt = \frac{1}{\rho}\left[\log \mathcal{C}_0 + \frac{g}{\rho}\right]. \tag{8}$$

This expression suggests that both initial consumption as well as its growth rate matter in determining welfare. We will discuss in more details how preservation affects both quantities in our discussion in Section 3.2.3.

3.2.2 Case with public investment in preservation

Consider now the case in which a central authority invests in preservation so to maximize welfare. In this case too, the demand curve for each input continues being as in the case with no public investment (Equation (3)). Following standard arguments and similar to the previous case, the maximization problem of an input producer—whose value is denoted by $V(B)$—satisfies:[7]

$$rV(B) = \max_{X,I} \left(I + S - \delta X + \gamma B\right) V_B + X(p-1) - \frac{\theta}{2B} I^2. \tag{9}$$

The interpretation of this equation is similar to Equation (4) (i.e., its counterpart in the case with only private investment in preservation), with the main difference being that the first term on the right-hand side reminds that natural capital might also grow thanks to public investment in preservation S.[8] To solve the problem of the input producer, we again conjecture the same scaling property as

[6] As a result, we can express all of these quantities as their $t = 0$ value and their path going at rate g.

[7] As in the previous case, we omit the subscript j when it causes no confusion.

[8] This will be reflected in endogenous aggregate quantities as well as in the equilibrium interest rate.

in the previous case, $V(B) = vB$, where v continues to denote the marginal value of natural capital from the perspective of the intermediate producer. The optimal choices of the intermediate good producer—production and investment in preservation—satisfy the same functional form as before, see Equations (5) and (6). Namely, the firm's production decreases with δ (i.e., the rate at which production deteriorates natural capital) as well as with the marginal value of natural capital v. In turn, investment in preservation increases with the marginal value of natural capital.

In this case too, we focus on a balanced growth path equilibrium, in which all aggregate quantities grow at the equilibrium rate g. Differently, in this case, the equilibrium growth rate is positively affected by the public investment in preservation of the central authority: $g = i + s + \gamma - \delta x$. As in the previous case with no public investment, production leads to a deterioration in natural capital, which in turn has a negative effect on long-run growth. At the same time, the intermediate input producers can counteract the impact of such deterioration by investing in preservation, which has a positive effect on long-term growth. In addition, public investment in preservation further sustains long-run growth in this case.[9]

As in the previous case, aggregate quantities all grow at g along the balanced growth path, and so we can characterize them by their value at $t = 0$ as well as by their balanced growth going forward. When the public authority invests in preservation, the initial consumption of the representative agent (growing at rate g as $\mathcal{C}_t = \mathcal{C}_0 e^{gt}$) is given by

$$\mathcal{C}_0 = \left(D_0 + W_0 - \frac{\zeta}{2} s^2 + \Psi \right)$$

where the third term captures the cost associated with public investment in preservation. While a greater public engagement in preservation sustains growth (as shown in the expression for g), the above expression illustrates that it nonetheless reduces the initial consumption of the representative agent.

Welfare is given by the intertemporal utility of the representative agent, which again satisfies Equation (8). In this case, however, the central authority chooses the optimal public investment in preservation to maximize welfare with respect to s. This maximization then gives:

[9] The standard Euler equation continues to deliver the expression for the equilibrium interest rate $r = \rho + g$, which feeds back into the optimal choices of the input producer.

$$s = -\rho + \sqrt{\rho^2 + \frac{2(D_0 + W_0 + \Psi)}{\zeta}}$$

where D_0 and W_0 denote the dividend from the intermediate good sector to the representative agent and the equilibrium wage, respectively.

Intuitively, the larger the benefit from natural capital to the representative agent (Ψ), the greater the public investment in preservation.

Thus, public investment in preservation is set to maximize welfare of the representative agent—it therefore takes into account the consumption flow to the representative agent stemming from natural capital.

3.2.3 Discussion

Consistent with the World Bank's framework (World Bank, 2021)—which estimates national wealth as stemming from produced capital (our X_{jt}), human capital (our L) and natural capital (our B_{jt})—our model precisely considers these as inputs in the production of the final consumption good.[10] Thus, natural capital needs to be preserved to support long-term growth. Below we discuss in more detail the tension between exploitation versus preservation as well as the drivers of private versus public investment in preservation.

Exploitation versus preservation The model allows for natural capital to expand because: (1) firms exploit less (i.e., reduce their output), (2) firms invest in preservation, (3) a central authority invests in preservation. That is, a firm can positively impact natural capital both by exploiting less (then reducing their output, however) or by investing in preservation (which, nonetheless, is costly).

Resonating the OECD view, overexploitation of natural resources may jeopardize the future—in our model, it leads to lower growth.[11] More specifically, in our model, the extent to which output translates into deterioration of natural capital (i.e., how an unit of output translate into destruction of natural capital) is captured by the parameter δ. The choice of preservation/exploitation then trades

[10]Their setting also considers net foreign assets, although this is beyond the scope of our model.

[11]See. e.g., the OECD Green Growth paper by Cardenas Rodriguez et al. (2023).

off current consumption and future growth. Namely, decreasing exploitation leads to a decrease in output and then in current consumption but, by reducing the pace of deterioration of natural capital, it can sustain long-term growth. Similarly, investment in preservation reduces current consumption but, on the other hand, sustains growth.

Drivers of investment in preservation. Our model illustrates that the two types of investment in preservation—private by the intermediate firms and public by the central authority—are spurred by different motivations.

Realistically, our model takes into account that natural capital can serve productive as well as a non-productive purposes. The first is amenable to be monetised by value-maximizing firms. Namely, because natural capital enters the production of the final consumption good, it affects the demand for intermediate inputs. Our setting (endogenously) delivers that private investment in preservation is driven by the incentive to sustain the demand for intermediate goods—that is, it stems from profit-maximization of the intermediate good producers. This driver is consistent with the idea in Flammer et al. (2025), reporting that firms have incentives to invest in preservation if they realize that they can monetise such investment.

Additionally, our setting acknowledges that natural capital is associated with non-productive functions too, such as enjoyment. This aspect is only taken into account by public investment in preservation—that is, it falls beyond the scope of the value-maximization of intermediate firms. The larger the benefit to the representative agent from natural capital, the greater the public investment in preservation should be. A key prediction of our model is that, as long as private firms manage to monetise their investment in preservation, the public investment in preservation does not crowd out the private one. Yet, in the case without public investment, there is *underinvestment* in preservation, as the non-productive function of natural capital (i.e., enjoyment) is not taken into account, and private firms give more emphasis to current output than to future growth.

It is worth noting that the model implies positive public investment in preservation even when $\Psi = 0$ (i.e., when there is no consumption flow coming from the enjoyment of natural capital)—in fact, the central authority maximizes welfare by investing in preservation.[12] The maximization of welfare of the central authority reduces consumption today but attains a higher growth rate. This implies that the case with solely private investment downplays future growth while allowing for more consumption in the present—thus, it is relatively more short-termistic.

Overall, public and private investment in preservation address different purposes. Private investment is driven by firm profit maximization—and, thus, by the perspective to monetise such investment. While useful, this may not be enough. Indeed, with public investment, the balance is moved towards supporting long-term growth to a larger extent although at the cost of reducing consumption in the present. This is even more so when there are enjoyment benefits associated with natural capital, which are not accounted for by private investment.

4 Empirical evidence

In this section, we take the predictions of the model to the data. Recall that according to the model, there are two salient features of long-term growth when natural capital is used both as an input in production and as a source of enjoyment. First, there is an optimal level of physical and natural capital used in production, meaning that firms have an economic incentive to maintain the natural capital they are endowed with through a non-zero conservation effort. Second, a public authority always conserves natural capital at a higher rate than private firms. The empirical implication of these two predictions of the model is that private interests will maintain natural capital at non-trivial levels which are, however, strictly lower than when natural capital is in the hands of a public entity.

To test these predictions, we turn to data on the forest ecosystems condition in 582 regions across 44 countries from European Forest Institute (Pulla et al. (2013)) and the PBL Netherlands Environmental Assessment Agency.

We take advantage of two pieces of information. First, for each region, data are available on the proportion of forest under private versus state ownership. Across Europe, around 16 million entities,

[12] This is instead not maximized when there is no central authority. Obviously, however, public investment in preservation is even higher when $\Psi > 0$.

both private and public, own forest land. Public forests are managed by municipal, regional, or national authorities, while private forests encompass a wide range of ownership types. These include traditional, non-industrial holdings such as those owned by families, farms, rural commons, churches, and aristocratic estates. Industrial private owners, on the other hand, are typically forest industry companies involved in activities such as pulp and paper production. There are also intermediate forms of ownership, neither fully private nor fully public, such as community-owned forests managed by local citizens or farm cooperatives. Many of these ownership models trace their origins to historical land tenure systems or recent social movements promoting collective forest management.

Private ownership of forest area ranges from 0% (in one region each in Belarus, Germany, and Montenegro, two regions in Serbia, and every region in Russia) to 100% (in one region in Serbia). The average extent of private ownership of forest area in the sample is 46.2%. Across EU member states, approximately 60% of forests are privately owned and 40% are publicly owned. See Figure 2 for more details.

Secondly, we utilize the location-specific biodiversity indicator, Mean Species Abundance (MSA), which is calculated using the GLOBIO model developed by the PBL Netherlands Environmental Assessment Agency (www.globio.info). The MSA quantifies biodiversity intactness by assessing its response to various human-induced pressures, including land use, road disturbance, habitat fragmentation, hunting, atmospheric nitrogen deposition, and climate change (Schipper et al. (2019)). The MSA index ranges from 0 to 1, where 1 indicates a fully intact species assemblage and 0 means all original species are locally extinct. It compares the abundance of native species under human pressures to their abundance in undisturbed conditions, excluding opportunistic species whose increase under disturbance could otherwise inflate the indicator. For this study, the MSA index was derived from data for 2020.

As Figure 3 indicates, the average region has an index of biodiversity of 0.38. There is large heterogeneity in the data across countries, with Scandinavian countries exhibiting the highest and central European countries the lowest, levels of average biodiversity. However, there is also significant within-country cross-region variation.

With these data in hand, we run the following regression:

$$BiodiversityIndex_{r,c} = \alpha + \beta ShareStateOwned_{r,c} + \gamma_c + \varepsilon_{r,c} \tag{10}$$

where $BiodiversityIndex_{r,c}$ is the value of the MSA Biodiversity Index in region r in country c, and $ShareStateOwned_{r,c}$ is the share of the forest area in region r in country c that is onwed by public entities. We include country fixed effects γ_c in order to net out background factors that are common to all regions in a country, and we cluster the standard errors by country.

The estimates from this regression equation are reported in Table 1. We document a significant increase in biodiversity in state ownership, with a 0.88 higher biodiversity when regional state ownership increases by 10%. Put differently, 50% state/private ownership is associated with 13% higher values of the Biodiversity Index than 100% private ownership.

At the same time, the intercept points to high levels of biodiversity in the absence of public ownership: even with fully private ownership of forest areas, the biodiversity index is at 0.34, which corresponds to one-third of the absolute maximum and to one-half of the inter-quartile range.

Naturally, given the empirical set-up we employ, the data point to no more than a strong statistical correlation between state ownership and biodiversity. At the same time, through the lens of the model, we interpret the evidence as causal. With this caveat in mind, the data confirm two of the main implications of our model. Firstly, public ownership of natural capital increases biodiversity because of the higher public investment in conservation. Secondly, even with very high levels of private ownership, the quality of natural capital does not decline to very low levels. This is due to the endogenously arising incentive of firms that monetise natural capital have to invest in regeneration.

We conclude that consistent with the model, private conservation in the data is non-trivial but lower than optimal from a social point of view. This is because a public conservation top-up is needed to recalibrate current consumption versus future growth.

5 Conclusion

In this paper, we take a step towards advancing our understanding of how nature and the economy interact. We develop a growth model where natural capital is an input in the production function, together with physical capital and labor. The model yields a balanced growth path with both private and public conservation effort in equilibrium. There are two main empirical implications. Firstly, the model predicts that firms that monetise natural capital have an incentive to invest in regeneration. In this way, a natural non-zero private preservation effort emerges in equilibrium, making sure that natural capital is maintained at a level necessary to support economic production. Secondly, while non-trivial, private conservation is too low from a social point of view, and so a public conservation top-up is required to shift the balance away from current consumption towards future growth.

While not formally capturing all of these, our model allows us to think about four distinct modes of humanity's economic approach to nature. The first case is when the fruits of nature are collected for food by a limited number of people. This mode describes a classic hunter-gatherer society, and it exhibits high variety and healthy levels of natural capital. Such societies, however, are characterized by low and uncertain levels of consumption and low rates of growth. The second case is when natural capital is exploited by a large enough number of people with common access. This situation is typically known as "tragedy of the commons", and it results in a scramble for limited resources. Here, current consumption is high, but natural capital is depleted quickly and as a result, long-term growth is low (e.g., overfishing). The third case is biocapitalism where nature is exploited at a high rate for the benefit of production by a large, technologically advanced group of people, and property rights are assigned to private interests. Here, current consumption is as high as in the "tragedy of the commons" case, but because there are incentives to conserve natural capital, nature is not depleted as much as in the case of the "tragedy of the commons", and future growth is higher. The last case is what we describe in the model: natural capital is subject to both private access with delineated property rights and to public intervention. In this case, current consumption is somewhat lower than in biocapitalism because the public authority sets some of natural capital aside, but the equilibrium levels of both natural capital and of long-term growth are higher.

Our framework leaves open a number of important questions. For example, should forecasting models used by central bankers when taking decisions about monetary policy making include a measure of nature degradation? Relatedly, should estimates of potential output consider the stock of natural capital? Another set of questions is related to the optimal trade-off between public ownership of natural capital and the regulation of the use of natural capital that is in private hands. At present, the European Commission appears to favour the former, with large natural areas under public management subjected to protection and restoration, including projects such as urban greening and reforestation. Our analysis suggests that, when coupled with a clear assignment of property rights and a targeted regulatory effort, private management of natural capital is a vital tool for maintaining natural diversity while ensuring a healthy rate of economic growth. Finally, our model does not incorporate nature-preserving innovation, which in principle can serve as an alternative to conservation by allowing for a more efficient use of natural capital via substituting produced capital for natural capital. We leave these and other exciting questions for future research.

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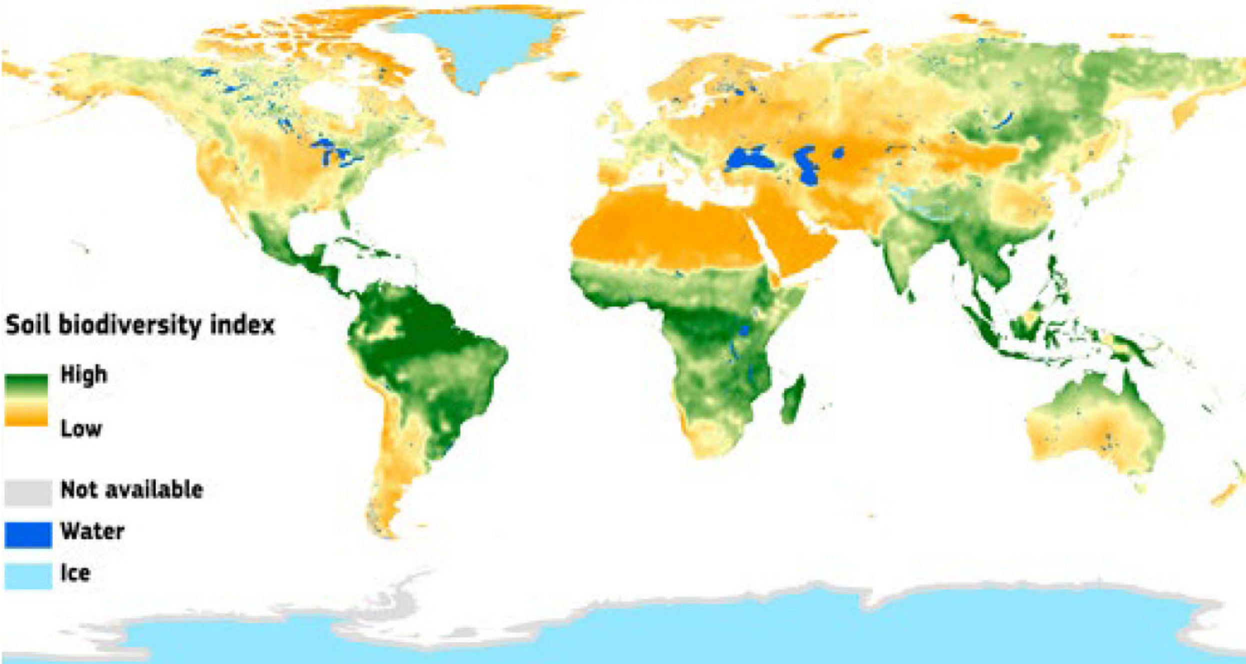
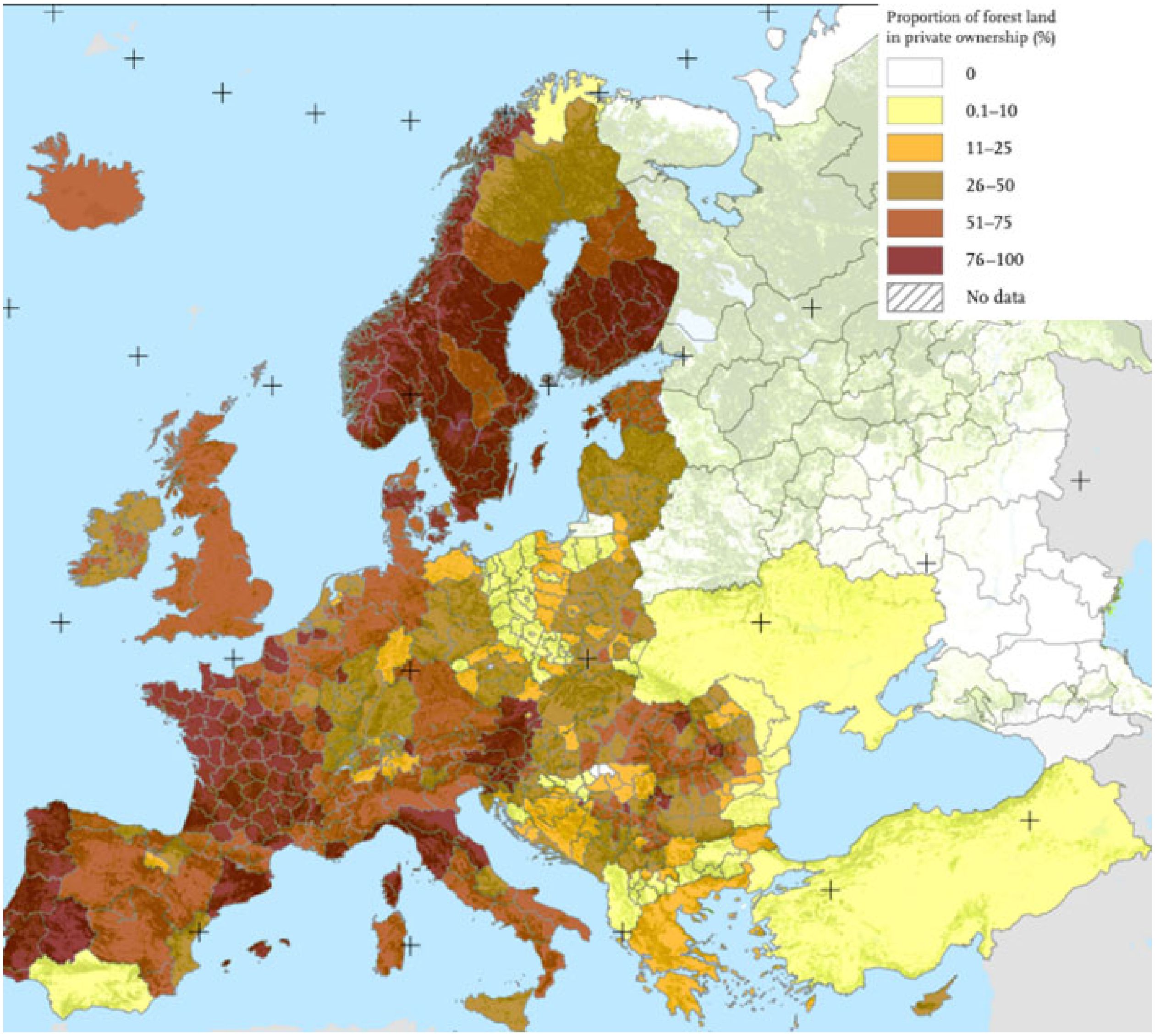
Figure 1. Soil biodiversity index



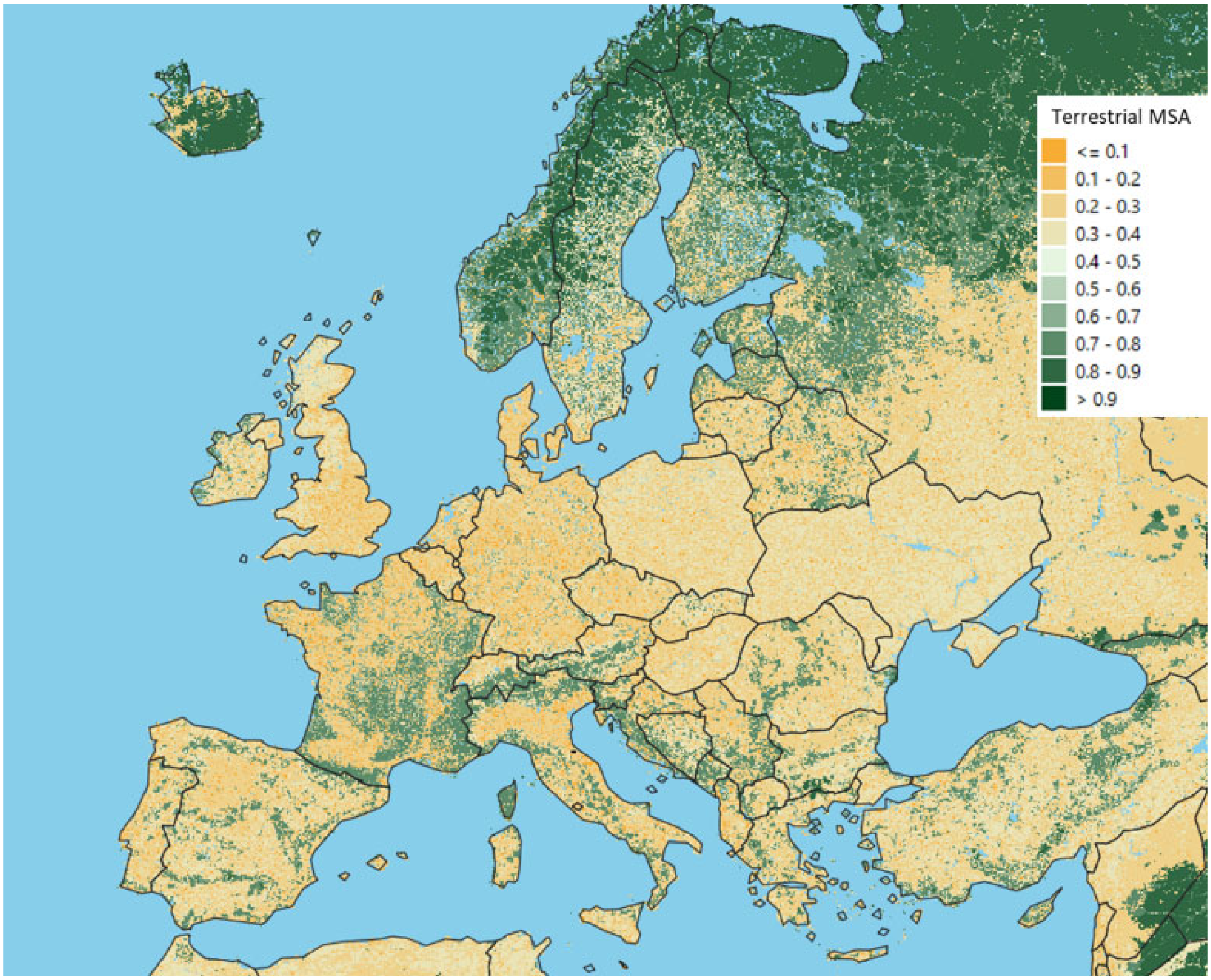
Notes: Soil biodiversity levels are measured from 0 to 1, where 1 indicates a fully intact species assemblage and 0 means all original species are locally extinct. Source: Orgiazzi et al. (2016).

Figure 2. Forest ownership



Note: The map displays the extent of private versus public ownership for 582 regions in 44 countries. Public forests are managed by municipal, regional, or national authorities. Private forests encompass a wide range of ownership types: traditional, non-industrial holdings such as those owned by families, farms, rural commons, churches, and aristocratic estates, and industrial private owners such as forest industry companies involved in activities such as pulp and paper production. Data come from the European Forest Institute.

Figure 3. Terrestrial biodiversity index



Notes: The Mean Species Abundance (MSA) biodiversity index quantifies biodiversity intactness by assessing its response to various human-induced pressures, including land use, road disturbance, habitat fragmentation, hunting, atmospheric nitrogen deposition, and climate change. Data are for 2020 and come from the PBL Netherlands Environmental Assessment Agency.

Table 1. Public ownership and biodiversity

Variable	MSA Biodiversity Index
Share state owned	0.0883**
	(0.0376)
Constant	0.3371***
	(0.0198)
Country fixed effects	Yes
Clustering	Country
# Observations	582
R-squared	0.47

Notes: The table presents estimates from Equation (10) where the dependent variable is the Mean Species Abundance (MSA) biodiversity index. ‚Share state owned' denotes the share, from 0 to 1, of the percentage of forest areas that is managed by municipal, regional, or national authorities. Data come from the European Forest Institute and from the PBL Netherlands Environmental Assessment Agency.

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