FROM LOCAL RELUCTANCE TO GLOBAL VALUATION: ECONOMIC PERSPECTIVES ON AFFORESTATION AND BIODIVERSITY

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Declaration

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Abstract

Afforestation is central to global strategies for mitigating climate change and restoring biodiversity, yet participation by private landowners remains persistently low despite decades of generous public incentives. This thesis investigates the economic, behavioural, and institutional foundations of this paradox through the case of Ireland—a country combining favourable biophysical conditions, sustained policy support, and chronically low planting rates. It asks: *How can economic theory and valuation methods inform the design of effective policies to incentivise long-term afforestation and biodiversity provision under conditions of landowner reluctance?*

The research adopts a sequential mixed-methods design integrating three analytical components.

First, a Discrete Choice Experiment (n = 150) quantifies Irish farmers' willingness to accept compensation for alternative afforestation contract attributes. Results reveal that preferences are driven less by payment levels than by contractual flexibility, security, and duration. Farmers strongly oppose mandatory replanting obligations, value longer-term or permanent payments, and favour native woodlands over spruce plantations, reflecting both economic consideration and environmental awareness.

Second, a Real Options Theory-informed qualitative analysis of 24 farmer interviews interprets reluctance as a rational response to irreversibility, uncertainty, and the appeal of more flexible land uses rather than as attitudinal resistance. Farmers assign high "option value" to waiting until policy, market, and ecological uncertainties are reduced, underscoring the need for more flexible, credible, and risk-sharing policy instruments.

Third, a Systematic Literature Review and Meta-Analysis of 93 studies complements Chapters 2–3 by shifting from the question of whether current payments are attractive to farmers to the question of what those payments should include. Focusing on biodiversity—the key public good differentiating native woodlands from monoculture plantations—the review synthesises how biodiversity is defined and monetised, highlights the trade-off between scientific rigor and public comprehensibility, and identifies standards needed to price biodiversity credibly in policy and markets. This links the Irish case to payment design: biodiversity values belong inside the payment envelope, particularly for longer-rotation native forests.

Together, the studies demonstrate that the persistent failure to meet afforestation targets — despite seemingly generous financial incentives — stems not from inadequate compensation but from deeper systemic gaps in valuation and decision-making. The thesis advances both theory and practice by integrating behavioural realism into economic analysis, extending Real Options Theory into socio-institutional contexts, and providing empirically grounded guidance for designing flexible, credible, and performance-based afforestation policies.

Keywords: Afforestation; Real Options Theory; Choice Experiment; Biodiversity Valuation; Environmental Economics; Ireland; Nature Finance; Policy Design

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Acronyms

AES	Agri-Environmental Schemes
AIC	Akaike Information Criterion
AC	Avoided Cost
BIC	Bayesian Information Criterion
BT	Benefit Transfer
CAP	Common Agricultural Policy
CE	Choice Experiments
CICES	Common International Classification Of Ecosystem Services
Coef.	Coefficients
CRCF	Carbon Removals And Carbon Farming Regulation
CSRD	Corporate Sustainability Reporting Directive
CV	Contingent Valuation
DAFM	Department Of Agriculture, Food And The Marine
DCE	Discrete Choice Experiments
Df	Degrees Of Freedom
DCF	Discounted Cash Flow
ES	Ecosystem Services
ESG	Environmental, Social And Governance
ESVD	Ecosystem Services Valuation Database
EUDR	European Union Deforestation Regulation
EVRI	Environmental Valuation Reference Inventory
FT	Forest Type
GBF	Kunming–Montreal Global Biodiversity Framework
GDP	Gross Domestic Product
ICC	Intraclass Correlation Coefficient
IIA	Independence From Irrelevant Alternatives
IID	Independently And Identically Distributed
IFA	Irish Farmers' Association
IHS	Inverse Hyperbolic Sine
Log	Logarithmic
IPCC	Intergovernmental Panel On Climate Change

IMF	International Monetary Fund
Int$	International Dollars
IPBES	Intergovernmental Science-Policy Platform On Biodiversity And Ecosystem Services
LC	Latent Class
LEA	Less Favoured Areas
MEA	Millennium Ecosystem Assessment
MNL	Multinomial Logit
MP	Market Price
MRV	Measurement, Reporting, And Verification
NDCs	Nationally Determined Contributions
NPV	Net Present Value
NTFP	Non-Timber Forest Product
PES	Payments For Ecosystem Services
PPP	Purchasing Power Parity
GVIF	Generalized Variance Inflation Factor
REM	Random Effects Models
RMSE	Root Mean Square Error
rSEEA	Refined Monetary System Of Environmental Economic Accounting
ROT	Real Option Theory
RPL	Random Parameter Logit
SBTN	Science Based Targets Network
SE	Standard Errors
SLR	Systematic Literature Review
TEEB	The Economics Of Ecosystems And Biodiversity
TEV	Total Economic Value
TNFD	Taskforce On Nature-Related Financial Disclosures
TPB	Theory Of Planned Behaviour
UEBT	Union For Ethical Biotrade
WoS	Web Of Science
WTA	Willingness To Accept
WTI	Willingness To Invest
WTP	Willingness To Pay

Chapter 1 Introduction

1.1.Background and Motivation

Forests play a crucial role in addressing the twin crises of climate change and biodiversity loss. Scientific assessments warn that human activity is pushing the Earth system beyond planetary boundaries, with profound consequences for ecological stability and human well-being (Rockström et al., 2009). The Intergovernmental Panel on Climate Change (IPCC), in its Sixth Assessment Report underscores the urgency of reducing greenhouse gas emissions to limit global warming to 1.5–2°C, beyond which catastrophic risks to ecosystems, economies, and societies are expected (IPCC, 2022). At the same time, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports that biodiversity is declining at rates unprecedented in human history, with one million species at risk of extinction within decades (IPBES, 2019). These crises are mutually reinforcing: climate change exacerbates habitat loss, species decline, and ecological disruption, while biodiversity loss undermines the resilience of ecosystems to sequester carbon and buffer against climate shocks (Díaz et al., 2019; Rockström et al., 2009).

Forests occupy a central position at the nexus of these crises. They are one of the largest terrestrial carbon sinks, absorbing roughly 7.6 gigatonnes of CO_2 annually—about 1.5 times the annual emissions of the United States (Harris et al., 2021). In addition to carbon sequestration, forests regulate hydrological cycles, stabilise soils, and provide flood protection, making them essential to climate adaptation strategies (Locatelli et al., 2010). Equally critical is their role in sustaining biodiversity: forests harbour more than 80 percent of terrestrial species of plants, animals, and fungi (FAO & UNEP, 2020). They also underpin cultural and spiritual values, particularly for Indigenous peoples and local communities whose identities and livelihoods are deeply tied to forest ecosystems (Trosper & Parrotta, 2012). In short, forests provide irreplaceable ecosystem services (ES) that lie at the heart of both climate stability and ecological integrity.

Recognising these multiple functions, forests have become a focal point of global environmental policy. The European Union's Biodiversity Strategy for 2030, launched as part of the European Green Deal, commits to planting at least three billion additional trees by 2030, with an emphasis on enhancing resilience and ecological quality rather than merely increasing forest area (European Commission, 2020). Similarly, the Kunming–Montreal Global Biodiversity Framework aims to ensure that 30 percent of global land and sea areas are effectively conserved and managed by 2030, alongside commitments to restore degraded ecosystems, including forests (CBD, 2022). Forests are also integral to the Paris Agreement, with many nationally determined contributions (NDCs) incorporating afforestation and reforestation as cost-effective pathways for climate mitigation (Austin et al., 2025).

These policy ambitions reflect a global consensus: protecting existing forests and expanding forest cover through sustainable afforestation and reforestation are not peripheral environmental measures but foundational strategies for climate stability and biodiversity recovery. Yet the success of these efforts is far from guaranteed. Global forest loss continues, and afforestation rates fall well below the levels needed to achieve international climate and biodiversity goals (FAO, 2022). Within the European Union, progress under the Three Billion Trees initiative remains modest—only about 36 million trees had been planted by September 2025, far below the trajectory required to meet the 2030 target (European Environment Agency, 2025).

Effective forest policy implementation is now widely recognised as a precondition for global sustainable development. Failure to mobilise large-scale and socially acceptable afforestation would represent not merely an environmental shortfall but a systemic failure with far-reaching implications for climate, biodiversity, and human welfare. This thesis is situated within this urgent global context, examining why implementation lags persist and how economic and institutional mechanisms can be redesigned to overcome them.

1.2. Ireland: A Critical and Instructive Case Study

Ireland provides a uniquely revealing context for examining the barriers to forest expansion. With its combination of favourable biophysical conditions, long-standing policy support, and persistently low planting rates, Ireland exemplifies the global implementation gap in microcosm.

Despite decades of sustained policy effort and substantial public investment, Ireland remains one of the least forested countries in Europe. Forest cover stands at just 11.6 percent, compared to an EU average of 38.6 percent (Eurostat, 2024). The government's Climate Action Plan and Forest Strategy 2023–2050 set an ambitious target of raising forest cover to

18 percent by 2050, requiring approximately 8,000 hectares of new planting each year (DAFM, 2023a). Yet actual planting has averaged little more than 2,000 hectares annually—barely a quarter of this target (DAFM, 2024a).

This underperformance is not uniquely Irish. Similar implementation gaps have been documented across Europe and other OECD countries, where afforestation uptake has fallen short of policy ambition despite sustained financial incentives (Van Gossum et al., 2008; Selby & Petäjistö, 1995). The Irish case therefore reflects a broader structural tension between policy design and private land-use decision-making.

Policy Evolution: Expansion, Competition, and Regulation

Ireland's current afforestation shortfall cannot be understood without situating it within the longer trajectory of forestry policy development. While contemporary debate focuses on persistent underperformance relative to national targets, Ireland experienced a period of rapid private afforestation expansion from the late 1980s to the mid-1990s (Figure 1.1).

Although state-supported forestry dates back to the 1920s, private planting remained limited until the introduction of enhanced financial incentives under the Western Package Scheme (1981) and the Operational Programme for Forestry (1989). These schemes introduced establishment grants and, critically, annual forest premium payments designed to compensate farmers for agricultural income foregone. The introduction of a 20-year tax-free premium under Council Regulation 2080/92 marked a turning point, contributing to a dramatic increase in annual private afforestation, which peaked at over 17,000 hectares in 1995 (Forest Service, 2013; Ryan et al., 2014).

However, this expansion coincided with significant structural changes in agricultural policy. The 1992 MacSharry reform of the Common Agricultural Policy (CAP) shifted support from price guarantees to direct headage payments and extensification schemes. For many livestock farmers—particularly in Less Favoured Areas (LFAs)—these reforms substantially increased agricultural subsidy income (Ryan et al., 2014). As subsequent decoupling reforms introduced the Single Farm Payment (2005) and area-based entitlements, agricultural payments became increasingly stable and predictable.

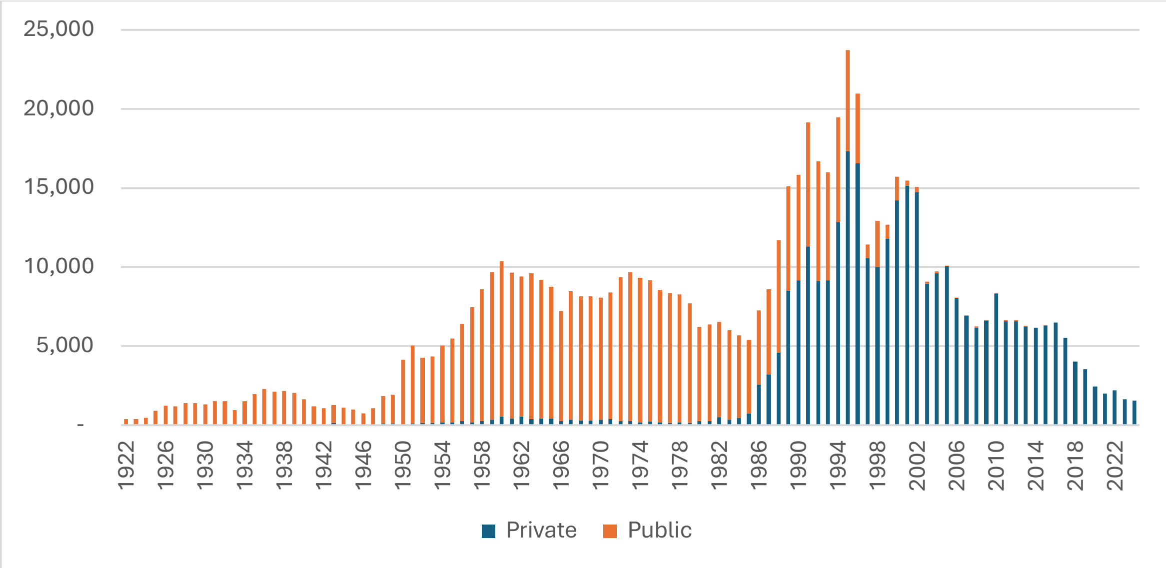
The interaction between forestry and agricultural subsidies proved critical. While forestry premiums increased over time, they often rose in parallel with agricultural payments, dampening their relative attractiveness. Detailed modelling of typical cattle farms demonstrates that, for much of the period from the mid-1990s onward, agricultural subsidies exceeded forestry premiums at medium to high stocking densities, particularly when agri-environment schemes such as REPS were included (Ryan et al., 2014). In effect, the opportunity cost of afforestation increased as agricultural support intensified.

In parallel, environmental regulation became progressively more complex. The EU Nitrates Directive (Council Directive 91/676/EEC) and associated stocking-rate limits altered production decisions and land eligibility conditions (European Commission, 1991). At the same time, forestry itself became subject to increasing environmental scrutiny, including restrictions on planting locations, habitat protection requirements, and licensing procedures (European Commission, 1992; DAFM, 2014). These developments strengthened environmental safeguards but also contributed to administrative delays, perceived policy instability, and increased uncertainty surrounding long-term forestry commitments.

More recently, the emergence of carbon markets, biodiversity finance mechanisms, and potential EU compliance penalties for failing to meet climate and restoration targets further complicates the policy landscape. Afforestation decisions therefore occur within a layered governance environment where agricultural support, environmental regulation, and emerging nature markets interact.

As a result, afforestation uptake cannot be understood solely in terms of payment levels. It reflects the interaction of relative opportunity costs, regulatory predictability, institutional credibility, and perceived long-term risk.

Figure 1.1 Annual State and Private Afforestation, 1922–2024



Note: the figure illustrates the historical shift from state-dominated afforestation in the mid-twentieth century to a peak in private planting during the mid-1990s, followed by a prolonged period of decline in overall planting rates.

Source: Department of Agriculture, Food and the Marine (DAFM). (2024a). Forest Statistics Ireland 2024.

Land Ownership and the Central Role of Farmers

The effectiveness of the national afforestation strategy depends almost entirely on the voluntary participation of private landowners. Since 2000, more than 90 percent of new planting has occurred on farmland (DAFM, 2024a), meaning that Ireland's forest transition ultimately rests on the decisions of thousands of individual family farmers. This ownership structure has two key implications. First, afforestation decisions are inherently heterogeneous, shaped by local land quality, family succession, and individual risk preferences. Second, each farmer's decision contributes directly to aggregate national outcomes. Understanding Ireland's afforestation shortfall therefore requires understanding how farmers interpret, evaluate, and respond to policy incentives under conditions of uncertainty.

Structural, Economic, and Socio-Cultural Barriers

While financial incentives have long been the centrepiece of Irish afforestation policy, a range of structural, economic, institutional, and socio-cultural factors continue to constrain forest expansion. One of the most significant structural barriers is the permanent change in land use that afforestation entails. Under Irish law—as in several other European jurisdictions—land that has been converted to forestry is subject to a perpetual replanting obligation, preventing its reversion to agricultural use (DAFM, 2023b; McDonagh et al., 2010; Ryan et al., 2022). However, Ireland's system is unusually rigid: once afforested, land is permanently reclassified as forest and cannot revert to agriculture. In contrast, some European countries, such as Finland, allow conversion to other land uses through defined administrative procedures (Bauer & Matleena Kniivilä, 2004). This legal permanence restricts land-use flexibility and can reduce the capital value of farmland, as it effectively removes the option to reallocate land to higher-value uses in the future. Many studies have identified this rule as a central deterrent to planting, particularly among farmers seeking to maintain flexibility for future generations (Wiemers & Behan, 2004; Ryan & O'Donoghue, 2016; Breen et al., 2010). Rising agricultural land prices have further amplified this concern, increasing the opportunity cost of long-term conversion to forestry (Breen et al., 2008; CSO, 2023).

The temporal profile of forestry income adds another dimension to this challenge. Whereas agriculture provides relatively stable and recurrent cash flows, forestry revenues are highly delayed and uneven. Most income derives from establishment grants and annual premiums over the first 15–20 years, with limited returns thereafter until final harvest—typically around 35–40 years for conifers and considerably longer for broadleaf species (Ryan & O'Donoghue, 2016; Donnellan & Hennessy, 2008; Phillips, 2006). After the premium period ends, landowners must bear all management and maintenance costs, and future timber prices remain uncertain. This long investment horizon contrasts sharply with the continuous income and ongoing public supports available to agriculture, thereby heightening perceptions of risk and discouraging participation (Ryan & O'Donoghue, 2016).

Institutional and regulatory factors have also undermined landowner confidence. The forestry licensing system, particularly the requirement to obtain a felling licence prior to harvesting, has been criticised for administrative complexity and long processing times (DAFM, 2014, 2022). Farmers often perceive the licensing process as unpredictable, exposing them to regulatory risk and threatening the reliability of future returns. Such procedural delays, coupled with recurring changes to programme design and grant conditions, reinforce perceptions of policy instability (Ryan & O'Donoghue, 2016; Irwin et al., 2022).

Economic and institutional barriers are reinforced by deep-seated cultural perceptions of forestry within Irish farming communities. Forestry has historically been weakly integrated into Irish farming culture (Irwin, 2023). Many farmers continue to associate tree planting with marginal or abandoned land (Ní Dhubháin & Gardiner, 1994; Duesberg et al., 2013), reinforcing the view that it represents a retreat from "productive farming." The traditional association of good farming with visible productivity—ploughed fields, livestock, and active land management—renders forestry, especially conifer plantations, symbolically incompatible with farming identity (O'Leary et al., 2000; McDonagh et al., 2010; Howley et al., 2012). Negative perceptions of monoculture plantations and clear-felling practices further compound this resistance by linking forestry with environmental degradation and aesthetic loss (O'Leary et al., 2000).

Ireland as Paradox and Prototype

Economic assessments have consistently shown that forestry can be financially competitive with, or even superior to, livestock production—particularly on marginal land (Behan, 2002; Collier et al., 2002; Breen et al., 2010; O'Donoghue, 2022). The persistence of low uptake despite these findings underscores that the barriers to afforestation are not primarily financial but institutional and behavioural. Ireland thus represents both a paradox and a prototype: a country with strong policy ambition, favourable biophysical conditions, and substantial financial support, yet chronically low farmer participation.

It is a paradox because extensive public subsidies have failed to generate expected afforestation outcomes. It is a prototype because its barriers—farmer resistance, policy volatility, institutional distrust, and identity conflicts—mirror those observed across Europe and beyond. Consequently, Ireland offers not merely a national case but a globally relevant lens through which to analyse the economic, institutional, and cultural determinants of afforestation decisions.

This paradox also exposes a deeper conceptual failure in prevailing economic models of afforestation policy—one with two dimensions. First, a valuation failure: conventional analyses focus narrowly on market outputs such as timber, undervaluing the non-market benefits of forests (e.g., biodiversity conservation, ecosystem resilience, cultural services) and the non-market costs perceived by landowners (e.g., loss of flexibility, regulatory burdens, identity tensions). Second, a behavioural failure: existing models misrepresent land-use change as a static, purely financial comparison, rather than a dynamic, uncertain, and socially embedded process. These intertwined failures of valuation and behaviour help explain why generous incentives have not translated into widespread planting.

The next section develops these conceptual issues in detail, outlining the theoretical and methodological frameworks—particularly Discrete Choice Experiments (DCE) and Real Options Theory (ROT)—through which this thesis addresses the valuation and behavioural failures underpinning Ireland's afforestation gap. By grounding the analysis in this empirically rich context, the Irish experience demonstrates how financial, institutional, and socio-cultural dimensions intersect to shape land-use change—and, by extension, how policy frameworks must evolve to enable the forest transition required to meet global sustainability goals.

1.3. The Persistent Implementation Gap: A Problem of Economic Valuation and Decision-Making

For decades, the principal analytical framework guiding afforestation policy has been the Net Present Value (NPV) model, which discounts future revenues and costs to a single present value and recommends investment whenever NPV > 0 (Graham & Harvey, 2001).

Within this neoclassical framework, financial incentives—such as grants and premiums—are assumed to correct market failure by raising the private profitability of forestry to a level competitive with agriculture. Yet despite these incentives, farmer participation has remained persistently low in Ireland.

Limitations of the Net Present Value Paradigm

The persistent gap between modelled profitability and real-world behaviour highlights three major shortcomings of NPV analysis. First, NPV is static. It treats investment as a one-off, irreversible decision made under conditions of certainty, ignoring the value of deferring action until more information becomes available (Dixit & Pindyck, 1994). In reality, farmers face uncertainty about future timber prices, policy stability, and ecological outcomes—all of which make waiting a rational strategy. Second, forestry's temporal scale magnifies uncertainty. Rotation lengths of 35–45 years for spruces and up to a century for broadleaves create exposure to policy, market, and climate risks far beyond the planning horizons of typical farm enterprises (Phillips, 2006; Donnellan & Hennessy, 2008). Even small variations in discount rates can transform a seemingly profitable forestry investment into a loss (Ross, 1995; Pindyck, 2007). Third, irreversibility is profound. Establishing a forest entails high sunk costs, and Ireland's statutory replanting obligation makes conversion back to agriculture practically impossible (Pindyck, 1991; Howley et al., 2012). Attempts to account for uncertainty by applying higher, risk-adjusted discount rates are conceptually weak: they distort valuation without capturing the strategic value of flexibility (Dixit, 1992; Baker & English, 2011).

Consequently, the NPV framework misrepresents afforestation as a simple financial calculation, overlooking both the dynamic nature of decision-making and the embedded social and institutional contexts in which farmers operate.

Behavioural and Socio-Cultural Perspectives

To address these shortcomings, research has increasingly drawn on behavioural and sociological frameworks. The Theory of Planned Behaviour (TPB) (Ajzen, 1991) posits that behavioural intentions are shaped by attitudes, subjective norms, and perceived behavioural control. Studies applying TPB to afforestation have shown that social norms, peer influence, and perceptions of self-efficacy play decisive roles in shaping willingness to plant trees (Rafiee et al., 2025; Irwin, 2023). Complementary work emphasises the role of farming identity and cultural capital in structuring land-use decisions: afforestation can conflict with the moral ideal of the “good farmer,” whose identity is tied to active agricultural production (Burton, 2004; Silvasti, 2003; Duesberg et al., 2014). In Ireland, these social dimensions are especially salient as discussed above.

While these perspectives have deepened understanding, they also have limitations. They tend to portray reluctance as cultural inertia or attitudinal resistance, implicitly contrasting farmer behaviour with an idealised model of economic rationality. They seldom explain how identity, trust, and uncertainty translate into the concrete logic of postponement observed in practice. What remains missing is an integrative framework that can reconcile the economic rationality of waiting with the social meaning of reluctance.

Methodological Response: Integrating Valuation and Decision Theory

To address this gap, the thesis adopts a sequential mixed-methods design that combines stated-preference modelling, qualitative inquiry, and ROT.

The DCE method was selected for Chapter 2 for several reasons. First, DCE is uniquely suited to ex-ante policy evaluation, allowing researchers to estimate preferences for attributes of hypothetical contracts that do not yet exist in reality (Louviere et al., 2000). This is critical for afforestation policy, where the goal is to design future schemes that better align with farmer preferences. Second, DCE enables the estimation of trade-offs between attributes—revealing, for example, how much additional compensation farmers require to accept a replanting obligation, or how much they are willing to forego in annual payment to secure a longer contract duration. These trade-offs cannot be observed in revealed preference data, where only existing contract configurations are available. Third, the method is well-established in the agri-environmental literature, with a substantial evidence base on farmers' preferences for contract design (Schulze et al., 2024).

While the DCE quantifies what farmers value, it cannot fully explain why they value it that way. Chapter 3 addresses this gap through in-depth qualitative interviews, which was chosen to capture the richness and complexity of farmers' reasoning in their own terms. This allows themes to emerge inductively while also enabling deductive coding against ROT concepts. The hybrid thematic analysis (Fereday & Muir-Cochrane, 2006) ensures that findings are grounded in farmers' lived experience while also contributing to theoretical development.

These empirical components are interpreted through the lens of ROT. ROT offers a dynamic lens for understanding behaviour under uncertainty. ROT conceptualises investment decisions as the exercise of options: when outcomes are uncertain and investments irreversible, the option to wait possesses real economic value (Dixit & Pindyck, 1994; McDonald & Siegel, 1986). Applied to afforestation, ROT predicts that landowners will defer planting until expected returns exceed both the cost of investment and the value of waiting. Policy volatility, ecological risks, and permanent reclassification of land thus elevate the option value of delay, explaining why farmers hesitate even when subsidies appear generous.

By combining DCE and Semi-structured qualitative interviews, this thesis unites quantitative and theoretical insights. DCE quantifies what farmers value; ROT explains why they value it that way. Together, they bridge the divide between valuation and behaviour, reframing reluctance not as a deviation from rationality but as a rational strategy of risk management under irreversibility and uncertainty.

1.4. From Local Problem to Global Solution: The Role of Innovative Financing

The integrated analysis of Ireland's afforestation paradox demonstrates that the prevailing policy model of direct subsidies is structurally inadequate to overcome the barriers to forest expansion. More broadly, it reveals a deeper limitation in current environmental policy frameworks: the failure to value ecological benefits adequately and to design institutions capable of mobilising long-term investment in natural capital.

Biodiversity loss represents one of the most urgent manifestations of this systemic weakness. Accelerating species extinctions and ecosystem degradation now threaten the stability of global life-support systems (Dirzo & Raven, 2003; Barnosky et al., 2011; Ceballos et al., 2015). Forests lie at the centre of this crisis. Covering roughly 31 percent of the Earth's land area, they support the majority of terrestrial biodiversity and perform essential ecological functions such as nutrient cycling, water regulation, and carbon sequestration (FAO, 2022; Hilton-Taylor et al., 2009). Protecting and restoring forest ecosystems is therefore pivotal not only for climate mitigation but also for halting biodiversity decline.

Economic valuation offers a bridge between ecological importance and policy relevance by expressing biodiversity benefits in terms that inform investment and regulation. Valuation evidence supports the creation of innovative financing mechanisms—such as payments for ecosystem services, biodiversity credits, and blended conservation finance—that can internalise ecological value within economic systems (TEEB, 2010; OECD, 2021; WEF, 2022). However, the existing valuation literature is fragmented and inconsistent. Studies differ widely in how biodiversity is defined (genetic, species, or ecosystem levels), which indicators are used, and which valuation methods are applied. This heterogeneity produces highly variable estimates and limits the comparability required for credible market instruments (Christie et al., 2006; Nunes & van den Bergh, 2001a). Moreover, many studies simplify biodiversity into abstract or single-attribute proxies to ensure respondent comprehension, thereby losing ecological specificity (Bartkowski et al., 2015; Farnsworth et al., 2015).

To address these limitations, Chapter 4 of this thesis undertakes a Systematic Literature Review (SLR) and Meta-Analysis of 93 forest-biodiversity valuation studies comprising 265 value observations. The SLR was undertaken to identify and synthesise forest biodiversity valuation studies using transparent, pre-defined eligibility criteria, in line with established standards for systematic evidence appraisal (Higgins et al., 2019). This is complemented by a meta-analysis, a quantitative synthesis method that statistically integrates findings across heterogeneous studies, allowing for the identification of methodological, ecological, and socio-economic drivers of variation in both market-based and non-market valuation outcomes (Nelson & Kennedy, 2009; Chiabai et al., 2011; Ratisurakarn, 2019; Taye et al., 2021; Pisani et al., 2022; Hassin et al., 2024).

The analysis examines how biodiversity has been conceptualised and monetised, assesses the ecological validity of the indicators employed, and identifies methodological and contextual factors driving variation in reported values. The findings reveal the need for greater methodological consistency, ecological grounding, and geographic diversity in valuation research to strengthen its policy applicability and support the emerging field of biodiversity finance.

Linking these global insights back to the Irish case clarifies a common lesson: policies that rely solely on direct subsidies or short-term incentives are insufficient to achieve large-scale forest transitions. What is required is a financial architecture that recognises biodiversity as a measurable, investable asset and rewards long-term stewardship. This is particularly relevant in Ireland, where current afforestation subsidies were historically designed around short-rotation conifer systems—assuming timber harvesting after roughly two decades as the main revenue stream—while native mixed forests, which mature over much longer periods, remain underrepresented and financially disadvantaged. Developing mechanisms such as biodiversity credits and ecosystem-service markets can help address this imbalance by assigning explicit value to the ecological and public-good benefits of long-rotation native woodlands. If grounded in robust and transparent valuation science, such instruments offer a means to realign private incentives with public environmental goals, while also providing a transferable framework for other countries seeking to finance forest restoration and biodiversity enhancement.

Taken together, the three analytical components of this thesis—DCE (Chapter 2), Real Options analysis of farmer decision-making (Chapter 3), and Meta-Analysis of global biodiversity valuation (Chapter 4)—form an integrated framework for rethinking afforestation policy. The sequence progresses from quantification (what farmers value), to explanation (why they value it that way), to generalisation (how these insights inform global valuation and financing).

1.5. Research Objectives and Contribution

The preceding sections have shown that the afforestation paradox is not merely a policy failure but a conceptual and behavioural one. Traditional financial incentive models assume that increasing profitability will automatically induce planting, yet the Irish case demonstrates that land-use decisions are shaped by deeper dynamics of uncertainty, irreversibility, institutional trust, and cultural identity. Overcoming these barriers requires economic frameworks that capture the full complexity of human decision-making and valuation under risk.

This thesis is guided by the overarching research question:

> *How can economic theory and valuation methods inform the design of effective policies to incentivise long-term afforestation and biodiversity provision under conditions of landowner reluctance?*

To address this question, the research pursues three interrelated objectives, each operationalised through an empirical study that builds conceptually and methodologically on the previous one.

Objective 1 – Quantifying Preferences and Compensation Requirements (Chapter 2)

The first objective is to identify and quantify the specific attributes of afforestation contracts that influence farmers' willingness to plant trees. Despite their central role in national forest strategies, relatively little is known about how farmers evaluate non-financial contract characteristics such as replanting obligations, forest type, and payment duration. Chapter 2 addresses this gap using a DCE with 150 Irish farmers, estimating their WTA compensation for different contract features. The results provide quantitative evidence of the scale of reluctance and the heterogeneity of preferences across farm types and socio-economic groups. In doing so, this chapter contributes to understanding the valuation failure by revealing the non-market trade-offs that shape adoption decisions.

Objective 2 – Explaining Decision-Making under Uncertainty (Chapter 3)

While the choice experiment quantifies preferences, it cannot fully explain the reasoning processes underlying them. The second objective therefore seeks to interpret the behavioural logic of reluctance through the lens of ROT. Drawing on 24 in-depth interviews with Irish farmers, Chapter 3 analyses how they perceive irreversibility, uncertainty, and flexibility when evaluating afforestation. By reframing hesitation as a rational response to risk rather than as irrational inertia, this chapter extends ROT beyond its conventional focus on market volatility to incorporate institutional credibility, policy stability, and socio-cultural identity as sources of option value. This theoretical innovation bridges behavioural economics and rural sociology, providing a richer explanation of land-use decision-making in contexts of long-term environmental policy.

Objective 3 – Linking Local Insights to Global Valuation Evidence (Chapter 4)

The third objective is to situate the Irish case within the global literature on forest biodiversity valuation, evaluating the methodological robustness and policy relevance of existing valuation evidence. While Chapters 2 and 3 identify the limits of conventional subsidy-based incentives, Chapter 4 extends the analysis by examining how biodiversity—the key non-market benefit of forests—is defined, measured, and monetised across studies. This is achieved through a SLR and Meta-Analysis of 93 studies and 265 value observations on forest biodiversity. The analysis investigates how methodological, socio-economic, and ecological factors influence reported values, revealing significant heterogeneity and bias. By synthesising this fragmented evidence base, Chapter 4 assesses whether current valuation practice is robust enough to support emerging biodiversity-credit markets and scalable ecosystem-service finance.

Together, these three objectives form a coherent research strategy that moves from quantification to explanation to generalisation. The sequence allows the thesis to trace the afforestation challenge from the level of individual decision-making to the global architecture of biodiversity finance.

The contributions are threefold:

Theoretical Contribution. The thesis advances ROT by integrating institutional and socio-cultural dimensions into models of investment under uncertainty. It reconceptualises farmer reluctance as an expression of rational flexibility rather than resistance, thereby bridging economic and behavioural understandings of land-use change.

Methodological Contribution. It demonstrates the value of combining stated-preference modelling, qualitative inquiry, and meta-analysis in a sequential mixed-methods design. This triangulation captures both the measurable and interpretive dimensions of decision-making, enhancing the explanatory and comparative power of environmental-economics research.

Empirical Contribution. It provides a comprehensive analyses of afforestation barriers in Ireland, revealing the complex interplay between financial incentives, institutional trust, and cultural identity. Under the European Green Deal and the EU Biodiversity Strategy for 2030, Member States have committed to planting at least three billion additional trees by 2030 (European Commission, 2020). Achieving this target depends heavily on the voluntary participation of private landowners across diverse agricultural landscapes. Ireland's persistent implementation gap, despite generous financial incentives and favourable biophysical conditions, offers important lessons for other Member States facing similar behavioural and institutional constraints. Understanding why afforestation uptake lags in Ireland therefore has direct implications for the feasibility of wider European forest expansion goals. At the global scale, it contributes to biodiversity-valuation research by bridging the gap between scientific definitions of biodiversity and public understanding, clarifying how methodological choices influence reported values, and informing the design of credible biodiversity-credit and ecosystem-service finance mechanisms.

In sum, the thesis links the micro-level rationality of farmers with the macro-level challenge of financing ecosystem restoration. It demonstrates that achieving large-scale afforestation requires policies that not only compensate landowners but also recognise the economic value of waiting, the social meaning of land, and the financial potential of biodiversity itself.

The following section outlines the overall structure of the thesis and how the subsequent chapters build on these objectives to develop a coherent and cumulative argument.

1.6. Structure of the Thesis

The remainder of the thesis is organised into six chapters. Chapter 2 presents the choice experiment study of Irish farmers' WTA afforestation contracts, quantifying how preferences for attributes such as forest type, payment duration, and replanting obligations shape uptake. Chapter 3 explores farmers' perceptions of afforestation through the interpretive lens of ROT, demonstrating how irreversibility, uncertainty, and the option to wait rationalise inaction. Chapter 4 reports a systematic review and meta-analysis of forest biodiversity valuation studies, identifying methodological patterns and biases with implications for biodiversity credit markets. Chapter 5 synthesises insights from all three studies, integrating their theoretical, empirical, and methodological contributions; it discusses cross-cutting policy implications, acknowledges the study's limitations, and outlines directions for future research and practice.

In summary, the thesis follows a sequential logic: it moves from quantifying farmer preferences for afforestation contracts (Chapter 2), to explaining the underlying decision-making processes through the lens of ROT (Chapter 3), to examining how the complex ecological benefits of forests—particularly biodiversity—can and have been measured and economically valued (Chapter 4). Finally, Chapter 5 integrates these findings, drawing theoretical, methodological, and policy conclusions. This structure allows the research to address both the micro-level rationality of landowners and the macro-level design of ecosystem financing systems, offering a coherent framework for understanding and overcoming the persistent barriers to forest expansion.

Chapter 2 Investigating Barriers to Afforestation in Ireland: Insights from a Choice Experiment Survey

Abstract

Afforestation is a key strategy for climate and biodiversity goals, yet uptake in Ireland remains low. This study uses a Choice Experiment to quantify Irish farmers' willingness to accept afforestation incentives under varying contract conditions. Employing Random Parameter Logit and Latent Class models, I find strong resistance to afforestation, primarily driven by two factors: legal irreversibility, captured by mandatory replanting obligations, and financial insecurity, linked to the short duration of support payments. Farmers demand significantly higher compensation for contracts with replanting requirements and for shorter payment terms compared to longer, more secure alternatives. Farmers prefer native over spruce-dominated forests, though preferences vary across segments. Our results reveal substantial preference heterogeneity, indicating farmers differ markedly in their motivations and sensitivities to contract attributes. These findings suggest that improving afforestation uptake will require moving beyond uniform incentives toward tailored contract structures that enhance land-use flexibility, extend support over longer timeframes, and accommodate diverse farmer profiles.

2.1. Introduction

Afforestation—the conversion of non-forest land to forest—is a key strategy for delivering climate mitigation, biodiversity enhancement, and ES provision (IPCC, 2022; FAO, 2022; Pan, et al., 2011; Naughton-Treves et al., 2005). In line with the European Green Deal and Biodiversity Strategy, EU member states are committing to ambitious afforestation targets. Ireland, for instance, has set a national goal of increasing forest cover to 18% by 2050, with at least half of new planting allocated to native or broadleaf species (DAFM, 2023a). Yet despite some of the most generous afforestation incentives in Europe, actual planting rates have declined in recent years, averaging less than 3,000 hectares annually—well below the 8,000-hectare target (DAFM, 2024). This pattern is mirrored in other jurisdictions (C. Edwards & Guyer, 1992; Ilbery & Kidd, 1992; Selby & Petäjistö, 1995; Van Gossum et al., 2008), raising a fundamental question for land-use economists and policymakers: Why do private landowners, particularly farmers, hesitate to afforest even when it appears financially attractive?

Standard economic models typically assess afforestation as a land-use choice based on expected net returns. In Ireland, several studies using NPV comparisons suggest that forestry—particularly spruce-dominated plantations—can outperform low-margin agricultural enterprises such as beef and sheep farming (Behan, 2002; Collier et al., 2002; Breen et al., 2010; O'Donoghue, 2022; Ryan et al., 2018; Ryan & O'Donoghue, 2016). However, uptake remains low, suggesting that financial returns alone are not the dominant constraint. The permanence of land-use change, lack of flexibility, delayed and uncertain timber revenues, and regulatory obligations such as mandatory replanting may generate behavioural and institutional frictions not well captured by conventional models.

This "uptake puzzle" mirrors patterns observed in agri-environmental schemes (AES), where participation remains below expectations despite payments that often exceed agricultural margins. A substantial AES choice-experiment literature has demonstrated that contract design elements such as permanency, duration, exit options, and payment timing strongly influence uptake (Greiner, 2015; Broch & Vedel, 2012; Schulze et al., 2024). However, these insights have rarely been extended to afforestation, where the time horizons are considerably longer and the land-use change is effectively permanent (Schulze et al., 2024).

This paper seeks to better understand these frictions by investigating how afforestation contract features influence Irish farmers' WTA compensation for converting agricultural land to forestry. The analysis adopts a DCE embedded in a national farmer survey to estimate preferences across four policy-relevant contract attributes: forest type, replanting obligations, payment duration, and annual compensation. By applying Random Parameter Logit (RPL) and Latent Class (LC) models, this study uncovers both average and segmented heterogeneity in preferences.

Our results indicate that Irish farmers' willingness to adopt afforestation is highly sensitive to contract design. The most salient barrier is the perceived irreversibility of afforestation, operationalized through the replanting obligation —a legal requirement for afforested land in Ireland (DAFM, 2023b). This was followed by concerns about long time horizons and limited flexibility in land use. Farmers showed a clear preference for native forests over spruce-dominated plantations, yet this environmental inclination did not necessarily translate into higher willingness to participate. Notably, farmers would require an additional €1,131 per hectare annually in compensation to accept mandatory replanting requirements, compared to a contract without such obligations. Longer payment durations are highly valued, with farmers requiring €865 and €1,120 in additional annual compensation to accept a 20-year contract over 50-year and 100-year alternatives, respectively. LC analysis revealed distinct subgroups—ranging from financially motivated, pro-spruce farmers to environmentally aware but risk-averse farmers—highlighting the inadequacy of one-size-fits-all policy approaches.

This study contributes to the literature in three ways. First, it quantifies farmers' willingness to accept compensation for afforestation under varying contract conditions, providing an empirical framework that can be applied to other regions where private landowners face long-term, uncertain land-use decisions. Second, it distinguishes between native forests and spruce-dominated plantations—an important differentiation often overlooked in prior studies, yet highly relevant across temperate regions where policy is shifting from production forestry toward biodiversity-oriented planting. Third, the findings offer actionable insights for designing more flexible and targeted afforestation policies that reflect heterogeneous landowner preferences—insights that extend beyond Ireland to other countries seeking to reconcile economic incentives with ecological and climate goals.

The remainder of the paper is structured as follows: Section 2.2 provides a review of the extant literature in this area and presents hypotheses development; Section 2.3 outlines the methodology, detailing the DCE design, econometric modelling approach, and data collection process; Section 2.4 presents the empirical results, including descriptive statistics and WTA estimates; and Section 2.5 discusses broader implications, acknowledges study limitations, and suggests directions for future research.

2.2. Literature Review and Hypothesis Development

2.2.1. Context of Afforestation in Ireland

Irish forestry policy has evolved significantly over recent decades, reflecting shifting economic, environmental, and social priorities. Prior to the 1960s, the primary objective of

Irish forestry policy was to increase domestic timber supply to reduce import dependency, whilst simultaneously avoiding competition with agricultural land use (DAFM, 2014). To achieve these goals, non-native conifer species such as Sitka spruce were widely introduced, chosen primarily for their rapid growth, resilience on marginal land, and economic viability (Ryan et al., 2016). Consequently, much of Ireland's 20th-century afforestation involved state-led monoculture plantations, leading to negative public perceptions and community opposition due to concerns about landscape impacts, biodiversity loss, and the perceived threat to agricultural development and rural vitality, including fears of depopulation and isolation(O'Leary et al., 2000; Carroll et al., 2011; Kearney & O'Connor, 1993).

A significant policy shift occurred with the Western Package Scheme in 1981, marking the transition from predominantly state-led afforestation to a private-driven approach. This scheme offered financial incentives to farmers to plant trees, particularly targeting Less Favoured Areas (Ryan et al., 2014). By 2005, state-led plantations had become negligible, with private landowners, primarily farmers, becoming the key drivers of afforestation activities through continued grant-based support mechanisms (DAFM, 2024a).

Parallel with this shift towards private plantation, policy emphasis gradually moved away from spruce-dominated plantations towards promoting afforestation using broadleaf and native species. Initiated in the late 1980s, policy measures such as the 20-year premium payment specifically for broadleaf plantations encouraged this transition (DAFM, 2014). The recently enacted 2023-2027 Forest Strategy and Afforestation Scheme further reinforces this direction, specifying the aim that at least 50% of new afforestation projects consist of native or broadleaf species and requiring spruce plantations to incorporate at least 20% broadleaf species (DAFM, 2023a; DAFM, 2024b). This aligns with evidence from international research underscoring the ecological advantages of mixed and native species forests in terms of biodiversity enhancement and ecosystem resilience compared to monoculture plantations (IPCC, 2022; FAO, 2022), as well as broader European policy trend prioritizing biodiversity and ecological integrity over purely commercial forestry. Comparable subsidy regimes exist in the United Kingdom, where the England Woodland Creation Offer rewards woodland creation that delivers public goods (Department for Environment, Food & Rural Affairs, 2021), and in Germany, where federal and state programs promote conversion of conifer monocultures into mixed, climate-resilient forests (Federal Ministry of Food and Agriculture, 2025). These approaches align with the EU

Forest Strategy for 2030, which emphasizes re- and afforestation of biodiverse forests to meet Union-wide climate and biodiversity goals (European Commission, 2021). Nonetheless, spruce-dominated plantation forests still dominate Ireland's landscape, constituting 69.4% of total stocked forest cover, with Sitka spruce alone accounting for 50.6% of the total (DAFM, 2024a).

Despite policy advancements and significant financial incentives, Ireland's afforestation rates remain stubbornly low, averaging just over 2,000 hectares per year—far below the target of 8,000 hectares annually (DAFM, 2024a). Consequently, forest cover remains at only 11.6%, substantially below the EU average of 38.6% (Eurostat, 2024).

2.2.2. Economic and Structural Barriers to Afforestation

A number of studies have assessed the financial competitiveness of forestry relative to traditional agricultural practices, typically using NPV analyses (Breen et al., 2010; O'Donoghue, 2022). These studies generally applied discount rates ranging from 4% to 5% and assumed a relatively low level of risk aversion. While such models often conclude that forestry, particularly conifer plantations, generates higher annualized returns per hectare compared to conventional agricultural enterprises, notably beef and sheep farming, their conclusions are constrained by simplified assumptions and limited time horizons— typically covering only a single 40-year rotation for conifers. Critically, these analyses rarely account for the option value of maintaining land-use flexibility—the economic value farmers place on the ability to delay or reverse land-use decisions in response to future market, policy, or personal circumstances (Wiemers & Behan, 2004). By committing land to forestry, a farmer relinquishes this flexibility, incurring a real but often unquantified cost that is absent from conventional NPV comparisons.

The gap between apparent financial attractiveness and actual uptake is a phenomenon well-documented in the wider AES literature. Schulze et al. (2024), in a systematic review of 127 DCE, find that contract design elements—particularly reversibility, flexibility, and duration—often have a stronger influence on participation than payment level alone. While standard AES contracts are typically temporary (e.g., 5–10 years), afforestation in Ireland carries a unique legal weight: a permanent replanting obligation that prevents reversion to agriculture.

Under Irish law—as well as in several other European countries—, once land is converted to forestry, it carries a perpetual replanting obligation, preventing reversion to agricultural use (DAFM, 2023b; McDonagh et al., 2010; Ryan et al., 2022; Bauer & Matleena Kniivilä, 2004). However, Ireland's system is unusually rigid: once afforested, land is permanently reclassified as forest and cannot revert to agriculture. In contrast, some European countries, such as Finland, allow conversion to other land uses through defined administrative procedures (Bauer & Matleena Kniivilä, 2004). This rigidity is compounded by Ireland's limited forestry tradition—forest cover was only 1.4% in 1921—so each new plantation is perceived as a permanent loss of productive farmland (DAFM, 2024a; McDonagh et al., 2010). The replanting requirement thus significantly diminishes land-use flexibility, directly reducing asset liquidity and subsequently resulting in permanent asset devaluation—a considerable sunk cost for farmers (Wiemers & Behan, 2004; Ryan & O'Donoghue, 2016; Breen et al., 2010). This loss of flexibility carries a quantifiable real option value—the right, but not the obligation, to change land use in the future. When this option value is omitted from financial assessments, the full economic cost of afforestation is underestimated, helping to explain the persistent gap between modelled financial attractiveness and actual uptake. Evidence from Schulze et al. (2024) further supports this, finding that across diverse agricultural contexts, farmers exhibit a strong preference for "termination options" that allow them to withdraw from contracts if circumstances change, viewing flexibility as a valuable asset. This issue has become even more pronounced in recent years, with significant increases in agricultural land prices (CSO, 2023).

Furthermore, forestry generates delayed and return. For the initial 15–20 years, forestry income is predominantly limited to annual premium payments. From approximately year 20 onwards, forests enter a cycle of thinning activities conducted every four to five years, generating periodic market income. However, significant market revenues only materialize at the time of final harvest, which occurs at around year 40 for conifers and considerably later for broadleaf species (Donnellan & Hennessy, 2008; Philips, 2006). Unlike in the United Kingdom, where verified carbon credits can supplement afforestation income through the Woodland Carbon Code, Ireland currently lacks an operational national carbon-crediting framework for forestry, limiting potential diversification of income streams. In contrast, agricultural enterprises typically provide more consistent annual returns, enhanced by greater flexibility in land management and continuous public subsidy support beyond any predefined term. Farmers therefore face a pronounced temporal mismatch between costs and returns in forestry, contributing to reluctance to commit to long-term contracts (Schulze et al., 2024).

Additionally, forestry investment carries substantial financial uncertainties, notably regarding future timber prices at final harvest, administrative risks associated with obtaining necessary felling licenses, and vulnerabilities to pests, diseases, and climate-related events (Phillips, 1999; Ryan & O'Donoghue, 2016). Wiemers and Behan (2004) explicitly addressed these concerns through a real options model, illustrating that economic factors alone can explain why many farmers choose not to invest in forestry. In particular, farmers require compensation for the irreversibility of forestry investment, especially when returns are uncertain.

However, existing economic evaluations, including Wiemers and Behan (2004), have predominantly focus on commercially oriented conifer-dominant plantations, especially Sitka spruce, with limited consideration given to other forest types (Ryan et al., 2018; Ryan & O'Donoghue, 2016; Wiemers & Behan, 2004). Breen et al. (2010) and O'Donoghue (2022) included some analyses of fast-growing broadleaf species, such as ash and sycamore; however, due to dieback outbreak, ash is no longer viable in Ireland. Consequently, existing economic assessments inadequately capture the financial realities of native and broadleaf species afforestation, characterized by significantly longer rotation cycles—up to 140 years—and delayed or potentially negligible timber revenues (Phillips, 2006). This narrow analytical scope fails to reflect the contemporary policy emphasis on native broadleaf afforestation, which prioritizes ecological outcomes alongside or above purely commercial returns.

Based on these economic and structural considerations, I propose the following hypotheses:

Hypothesis 1: Farmers will exhibit significant aversion towards afforestation contracts with mandatory replanting obligations.

Hypothesis 2: Farmers will prefer longer durations of financial support due to the long-term nature and associated uncertainties of forestry investment.

2.2.3. Socio-Cultural and Environmental Preferences

Beyond economic considerations, a substantial body of literature underscores the importance of social norms, identity, environmental values and farm characteristics. Previous research highlights various socio-demographic factors and farm characteristics that influence farmer attitudes towards afforestation, including prior experience with tree planting, local forest coverage, farm size and enterprise type, age, education level, household composition (e.g., presence of children), off-farm employment, and the distinction between full-time and part-time farming status (Ní Dhubháín & Gardiner, 1994; Duesberg et al., 2014; Howley et al., 2012; Ryan & O'Donoghue, 2018; Vidyaratne et al., 2020).

Farmer identity offers a valuable lens for understanding afforestation preferences, particularly in contexts where land-use decisions are shaped by more than financial considerations. Schulze et al. (2024), building on identity theory from Burke and Stets (2009), highlight that identities—such as "productivist," "conservationist," or "civic-minded"—can influence not only farmers' stated preferences but also how they derive utility from contract attributes, even beyond the choice tasks themselves. This framing is especially relevant to the Irish context, where prior research documents divergent attitudes toward forest types (O'Leary et al., 2000; Carroll et al., 2011). Native broadleaf forests, historically part of Irish farmland through hedgerows and small woodlots, typically align with stewardship identities and are favoured for their ecological and aesthetic benefits. In contrast, large-scale spruce plantations—introduced through state-led programmes since the 1950s—often provoke opposition due to visual impacts, incompatibility with farming traditions, and environmental concerns, potentially conflicting with productivist identities (Burton, 2004; Silvasti, 2003; Duesberg et al., 2014).

Social learning and normative influences further shape afforestation decisions. The AES literature shows that peer behaviour serves as a social signal that influences uptake by shaping perceptions of feasibility and legitimacy (Schulze et al., 2024), a pattern echoed in afforestation contexts where local forest cover and knowledge of other tree-planting farmers positively influence participation (Duesberg et al., 2014; Irwin et al., 2023). In Ireland's predominantly agricultural landscape, the absence of a critical mass of afforesting neighbours may reinforce cultural resistance to forestry adoption.

Acknowledging these nuanced preferences for different forest types is critical for understanding farmer attitudes and effectively addressing barriers to afforestation. Based on these considerations, I propose the following hypotheses:

Hypothesis 3: Farmers will show a distinct preference for native forests compared to spruce-dominated plantations.

Hypothesis 4: Socio-demographic characteristics, including age, farm size, and prior afforestation experience, will significantly influence preferences toward afforestation.

2.3. Method

2.3.1. Choice Experiment Design

A DCE is a survey-based method used to elicit stated preferences by presenting respondents with a series of hypothetical alternatives, each varying according to specific attributes and levels. Respondents are asked to select their preferred option in each scenario, allowing researchers to estimate the marginal utility of different policy characteristics (Louviere et al., 2000; Ferraro, 2008). This method is particularly valuable in ex-ante evaluations of policy design, as it provides insights into how individuals make trade-offs between competing factors (Louviere et al., 2000). The use of DCE techniques has already informed numerous policy recommendations in the context of afforestation contract design, particularly regarding farmers' preferences for payment levels, contract duration, flexibility, and afforestation objectives (Broch et al., 2013; Broch & Vedel, 2012; Brouwer et al., 2015; Vedel et al., 2015).

Building on these insights and drawing on the subsidy payment levels outlined in the Ireland Forestry Programme 2023–2027, this study employs a DCE to estimate Irish farmers' WTA compensation for afforestation under varying contractual conditions. The selection of attributes and levels is detailed below, focusing on aligning scenarios closely with current policy to ensure relevance, familiarity, and realism for respondents.

The experiment includes four key attributes: forest type, replanting requirements, premium payment duration, and annual premium amount. The forest types reflect the two most common afforestation choices in Ireland since 2018, namely native forests (Forest Type 1, FT 1), comprising 100% native tree species across six scenario-based combinations tailored to local soil types, and spruce-dominated forests (FT 12), comprising 80% spruce and 20% broadleaves (DAFM, 2024a; DAFM, 2024b). These two options represent distinct afforestation objectives—native forests primarily support biodiversity conservation and ecological benefits, while spruce forests are primarily associated with commercial timber production. In the survey, these options were introduced in plain language as “native forest (Forest Type 1 under the Forestry Programme)” and “mainly spruce forest (Forest Type 12, mixed high forest with 80% spruce and 20% broadleaves)” to ensure clarity for participants unfamiliar with technical forestry terminology. (See Appendix A1 for the full list of native species classified under FT 1 in the Forestry Programme 2023–2027.)

Given that replanting obligations have been identified as a major barrier to afforestation (DAFM, 2023b; McDonagh et al., 2010; Ryan et al., 2022), this study incorporates an alternative scenario in which the replanting requirement is removed, allowing for an assessment of its potential influence on afforestation uptake.

Another crucial factor is the duration of subsidy payments, as financial support currently ceases after 20 years, leaving farmers responsible for all subsequent management costs. To examine whether longer-term payments could incentivize afforestation, the study introduces two extended durations of 50 and 100 years. Financial compensation is also a critical determinant of afforestation decisions. This study tests five payment levels, beginning with the current annual premium rates of €746 per ha for spruce (FT 12) and €1103 for native forests (FT 1). Additionally, three higher levels are included: €1600 as an intermediate value, €2293 as the average annual dairy family farm income in 2022—the most profitable type of agricultural enterprise in Ireland (Teagasc, 2023a), and €2600 to test the upper bounds of financial incentives. The rationale for these values is to examine whether higher financial compensation relative to agricultural earnings could significantly increase participation. Table 2.1 summarizes the key attributes and levels used in the choice experiment, representing the financial and contractual conditions under which farmers evaluate afforestation options.

This combination of attributes and levels generates 60 possible alternatives, which would be impractical to present in full to each respondent. To ensure statistical efficiency while maintaining the robustness of the experiment, a D-efficient experimental design (Bliemer et al., 2009; Brouwer et al., 2015; Sandor & Wedel, 2001) was applied to reduce the number of choice sets to 24. Following this reduction, dominant alternatives —defined as profiles offering both a longer payment duration and a higher annual premium while holding the replanting requirement constant—were identified and removed to ensure that respondents were not presented with options that were clearly superior in all respects. The final 24-choice design (validated in R: D-efficiency = 0.544; A = 3.788; Ge = 0.654; Dea = 0.589) were then blocked into three versions, with each respondent randomly assigned one version containing four choice tasks.

Each choice task presented two afforestation contracts, each varying across the four attributes, alongside a "Neither" option, allowing respondents to opt out of afforestation entirely. The inclusion of this opt-out alternative is essential, ensuring that the WTA estimates reflect farmers' voluntary participation and capture their preferences. An example of a choice set is illustrated in Figure 2.1.

Table 2.1 Attributes and Levels in the Choice Experiment

Attributes	Levels
Forest type	• Native forest (FT 1) • Mainly spruce forest (FT 12)
Replanting requirement	• Require replanting • No replanting requirement
Premium payment duration (year)	• 20 years (current level) • 50 years • 100 years
Annual premium amount (€/ha/year)	• €746 (current FT 12 level) • €1103 (current FT 1 level) • €1600 • €2293 • €2600

Note: this table presents the attributes, and their corresponding levels used in the choice experiment.

Figure2 .1 Example of a Choice Set Used in the DCE

	Option A	Option B	Neither
Forest Type	Native	Mainly spruce	
Replanting requirement	Require replanting	Require replanting	
Premium payment duration	20 years	100 years	
Annual premium amount	€2600/ha	€746/ha	

Which would you enrol if it was available to you?

Option A ○ Option B ○ Neither ○

Note: this figure illustrates a sample choice task presented to respondents, where they are asked to choose between two afforestation contract options (Option A and B) or to opt out of afforestation altogether (Neither).

2.3.2. Survey Design and Data Collection

The DCE was embedded within a broader survey targeting farmers in Ireland. Hosted on the online survey platform Qualtrics, survey responses were gathered between June 2024 to January 2025. To maximize participation, a multi-channel distribution strategy was employed. The Irish Farmers' Association (IFA) featured the survey in its biweekly newsletters, while the Irish Farmers Journal promoted it through its forestry section. Further dissemination was facilitated by the Irish Forest Owners, Irish Agroforestry Forum and the Carbery Group, which shared the survey with their respective networks. In addition, a QR code linking to the survey was distributed at two of Ireland's largest agricultural events: the Tullamore Show in August and the National Ploughing Championships in September. Qualtrics automatically restricted responses to one submission per device and monitored IP addresses for repetition.

Ethical approval for this study was granted by the affiliated university's Research Ethics Committee (Ref. 3237, 24 April 2024). Participants received an information sheet outlining the study's purpose and data confidentiality and provided informed consent electronically before starting the survey. No personal identifiers were collected, and all data were handled in accordance with GDPR.

The questionnaire was structured into five main sections, with a total of 26 questions designed to gather information about farmers' demographics, knowledge, attitudes, and preferences regarding afforestation. The first section focused on demographic and farm characteristics, including age, gender, farm size, farm type, and location. These characteristics were selected based on existing studies examining factors that influence afforestation decisions, including research by Howley et al. (2012), McDonagh et al., (2010), Collier et al. (2002), Farrelly (2006), Frawley & Leavy, (2001), and Ní Dhubháin and Gardiner (1994). In line with evidence that social norms and peer networks influence adoption decisions (Irwin et al., 2023; Schulze et al., 2024), and that local forest cover positively correlates with planting intentions (Duesberg et al., 2014), the survey included a question on social exposure to forestry: "How many farmers do you know who have planted trees?" While not spatially explicit, this variable serves as a proxy for local descriptive norms—capturing both landscape visibility and social network effects. Since Irish farmers' peer networks are typically localized, knowing few or no tree-planting farmers suggests limited exposure to afforestation within their community and weaker social normalization of forestry.

The second section examined farmers' awareness of existing afforestation schemes and identified the primary sources from which they acquired information about these programs. The third section explored the barriers and enablers to forestry scheme uptake, using a Likert scale to assess farmers' perceptions of various incentives and obstacles. Additionally, respondents were asked about their post-planting experience, preferred sources of income, providing insight into financial motivations and constraints. The fourth section introduced participants to the DCE, beginning with an explanatory overview. Each participant was then presented with a randomly assigned block of choice cards to assess their preferences for different afforestation contract attributes. Finally, the last section of the survey explored farmers' attitudes toward biodiversity. Prior research has demonstrated that landowners' perspectives on climate change and biodiversity significantly influence their afforestation and forest conservation decisions (Broch & Vedel, 2012; Graves et al., 2022; Mäntymaa et al., 2009; Siebert et al., 2010), highlighting the relevance of this aspect in understanding afforestation choices.

The survey design was developed over a five-month period, beginning with a literature review of existing afforestation policies in Ireland. To refine its content, eight semi-structured key informant interviews were conducted with government officials, researchers, and forestry experts. The questionnaire underwent a two-stage pre-testing process with 24 farmers and forest stakeholders. In Round 1, participants completed the full Qualtrics survey and provided feedback on wording, layout, and the choice tasks. After revisions, the updated version was return to the same group for Round 2 to verify clarity and usability. No further issues were identified, and the final version of the survey was implemented.

This study received 265 responses, of which 150 were fully completed, yielding a completion rate of 56.6%. The achieved sample aligns with established DCE heuristics for minimum sample requirements (Johnson & Orme, 2003; Pearmain et al., 1991) and closely matches the power-based benchmark proposed by Assele et al. (2023).

2.3.3. Econometric Model

Farmer choices in the DCE were analysed using models grounded in random utility theory (Lancaster, 1966; McFadden, 1972). Rather than relying on the restrictive assumptions of the multinomial logit model, I employed two models that explicitly account for preference heterogeneity: a Random Parameter Logit (RPL) model and a Latent Class (LC) model (Train, 2009; Brouwer et al., 2015; Jaeck & Lifran, 2014; Mariel et al., 2013; Marsh, 2012).

Random Parameter Logit (RPL) Model

The RPL model accounts for continuous preference heterogeneity by allowing attribute coefficients to vary randomly across respondents according to specified probability distributions (Train, 2009). This specification is particularly appropriate for our study, as farmers likely exhibit diverse preferences for afforestation contracts based on their individual characteristics, experiences, and risk perceptions (Ryan et al., 2018; Ryan et al., 2022).

All non-monetary attributes—forest type, replanting requirements, payment duration, and the opt-out alternative—were specified as random parameters following normal distributions, allowing for testing Hypotheses 1, 2, and 3. I tested whether the payment parameter (annual premium amount) should also be random. A likelihood ratio test showed significant heterogeneity in payment sensitivity ($\chi^2 = 6.65$, $p = 0.0099$), and the random-payment model provided marginally improved fit.

However, because the random-payment model produces unstable WTA estimates and much wider confidence intervals, I retain the fixed-payment specification as our main model for policy interpretation. The random-payment results are reported as a robustness check in Section 4.2.1 and Appendix Table A2. All RPL models were estimated by maximum simulated likelihood using 1,000 Halton draws in the gmnl package in R (Sarrias & Daziano, 2017).

WTA compensation for each attribute was calculated as the negative ratio of each attribute's estimated coefficient to the monetary attribute's coefficient (Mariel et al., 2021). WTA estimates were calculated using Krinsky-Robb simulation methods with 10,000 draws from the multivariate normal distribution of parameter estimates. For the random payment specification, WTA distributions were derived using simulation methods with median values and 95% confidence intervals reported in Appendix Table A2.

Latent Class (LC) Model

The LC model captures preference heterogeneity by identifying discrete segments (classes) of farmers with similar preference structures (Scarpa et al., 2005; Nylund et al., 2007). This approach is well-suited for testing Hypothesis 4, which posits that socio-demographic characteristics significantly influence afforestation preferences. The optimal number of classes is determined by evaluating quantitative criteria, including the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), alongside interpretability of the resulting classes (Magidson & Vermunt, 2004; Greiner, 2015; Nylund et al., 2007).

Class membership probabilities were modelled as functions of socio-demographic covariates including age, farm size, farm type, household size, prior afforestation experience, social networks, and biodiversity attitudes.

The LC model produces posterior membership probabilities for each respondent in each class. Importantly, class membership is probabilistic rather than deterministic: the model estimates the likelihood that an individual belongs to each latent class. For descriptive profiling, I follow standard practice (Nylund et al., 2007; Greene & Hensher, 2013) by assigning respondents to the class for which they have the highest posterior probability (modal assignment). Demographic percentages reported for each class are based on these modal assignments; however, all parameter estimation relies on the full probability distribution, not on these classifications.

This modelling strategy enables identification of distinct types of farmers and allows us to examine how individual characteristics influence preference patterns, providing complementary insights to the RPL model's continuous treatment of heterogeneity.

Model Comparison and Robustness

We conducted model comparisons including preference-space RPL, and WTA-space models estimated using the logitr package (Helveston, 2021). The RPL specification demonstrated superior performance to WTA-space models, which exhibited convergence challenges and counterintuitive parameter signs despite multiple optimization attempts. Detailed model comparison results are presented in Appendix Table A3.

By employing both RPL and LC approaches, I provide complementary insights into farmer preferences: the RPL model captures continuous preference variations across the population, while the LC model identifies distinct farmer segments for targeted policy interventions.

2.4. Results

2.4.1. Sample Characteristics

This study garnered responses from 265 individuals, with 150 completing the survey fully, achieving a completion rate of 56.6%. Table 2.2 contrasts these respondents' characteristics against the national averages from the 2023 Irish Farm Structure Survey (CSO, 2024) and Teagasc's 2024 Outlook (Teagasc, 2023).

The sample predominantly consists of male respondents at 78.7%, with females making up 18.7% and 2.7% preferring not to disclose their gender. This slightly exceeds the national average of 13.2% for females. Age-wise, 54.0% of respondents are 55 years and older, aligning closely with the national figure of 64.2%. However, younger farmers aged 18-34 are overrepresented in the sample (12.7% compared to 4.3% nationally), while those 65 and over are underrepresented (28.0% compared to 37.8% nationally). With 61.3% living in households of 2-4 persons and 28.7% in households of 5-10 members.

Farm type distribution reveals notable deviations from national statistics, primarily due to the inclusion of 'Forest' as a distinct category, comprising 14.7% of the sample. While cattle farming is the most prevalent type at 31.3%, it falls below the national average of 56.1%. Conversely, mixed farming is significantly higher in the sample at 22% compared to just 7.0% nationally. The sample mirrors national trends closely in dairy farming and tillage but has fewer sheep farms and a higher diversity in the 'Other' category, which includes equestrian and hobby farms, among others. The sample also features a higher proportion of larger farms (over 50 ha) at 47.4%, compared to 19.8% nationally. Conversely, small farms (2-20 ha) are underrepresented at 18.0% versus 47.6% nationally. Geographically, the distribution of respondents varies from the national data, with farmers in the Mid-West (21.3%) and South-East (20.7%) being overrepresented, while those from the West (11.3%) are underrepresented. Notably, 62.7% of respondents either have already engaged in or are currently enrolling in government afforestation programs, significantly higher than the national average of 10% for farms with forests. This discrepancy suggests a selection bias towards those more actively involved or interested in forestry.

Table 2.2 Population (Census) and Sample Characteristics (N = 150)

Characteristic	Sample (%)	National (%)
Gender share		
Male	78.7%	86.8%
Female	18.7%	13.2%
Prefer not to say	2.7%	
Age share		
18-34	12.7%	4.3%
35-44	10.7%	11.2%
45-54	22.7%	20.2%
55-64	26.0%	26.4%
65 or over	28.0%	37.8%
Farm Type share		
Cattle	31.3%	56.1%
Dairy	14.0%	11.4%
Mixed farming*	22%	7.0%
Sheep	8%	13.1%
Tillage	4.7%	3.7%
Other, please specify:	5.3%	1.4%
Forest	14.7%	
Farm size share		
2-20 ha	18.0%	47.6%
20-30 ha	9.3%	15.0%
30-50 ha	23.3%	17.6%
50-100 ha	30.7%	14.2%
>100ha	16.7%	5.6%
Prefer not to say	2.0%	
Location share		
Border	17.3%	20%
Mid-East	11.3%	9%
Midlands	8.0%	9%
Mid-West	21.3%	14%
South-East	20.7%	9%
South-West	10.0%	16%
West	11.3%	23%
Household size share		
1	8.00%	
2-4	61.3%	
5-10	28.7%	
Prefer not to say	2.00%	
Have you planted trees supported by government subsidies (e.g. Forestry Programme) on your farm?		
1: Yes, or in the process of enrolling	62.7%	10%
2: No	37.3%	
As far as you are aware, how many farmers you know have planted trees supported by government subsidy schemes		
1: None	10.7%	
2: Very few, less than 5 farmers	34.0%	
3: Some, 5 to 15 farmers	31.3%	

4: Many, 16 to 30 farmers	10.0%
5: More than 30 farmers	14.0%
Do you think biodiversity benefits your farm?	
1: strongly disagree	6.0%
2: Somewhat disagree	5.3%
3: Neither agree nor disagree	11.3%
4: Somewhat agree	22.7%
5: Strongly agree	54.7%
For future financial earnings from your forest, which would be your most preferred source of income?	
1: Government subsidies	22.7%
2: Earnings from selling carbon and Biodiversity credit	39.3%
3: Harvest earning	30.7%
4: Others	7.3%

*Mixed farming: including Mixed livestock and Mixed Crops and Livestock.

Note: this table presents the share of various characteristics within the sample compared to national averages. Data sourced from the CSO 2024 Farm Structure Survey and Teagasc's 2024 Outlook.

The survey responses indicated that 34.0% of participants knew fewer than five farmers who had engaged in government-subsidized tree planting. Another 31.3% were aware of between five and fifteen such farmers, while 14.0% knew more than thirty. Regarding biodiversity, a substantial majority (77.4%) recognize its positive impact on their farms. Additionally, when considering future income sources from forestry activities, a total of 39.3% of respondents preferred carbon and biodiversity credits, highlighting strong interest in these alternatives over traditional market-based returns for timber harvesting and government subsidies.

In conclusion, while the sample broadly aligns with national demographics in some respects, the variations in farm type, size, and proactive engagement in forestry initiatives suggest that the respondents are potentially more innovative and engaged in sustainable land-use practices than the broader farming population.

2.4.2. Model Estimation and WTA Calculation

2.4.2.1. The RPL Model

Table 2.3 presents results from the RPL models: (i) the fixed-payment specification, which serves as the primary model for WTA interpretation, and (ii) the random-payment specification, included as a robustness check. The fixed-payment model achieves a McFadden pseudo-R^2 of 0.152[1], while the random-payment version shows a slightly higher pseudo-R^2 of 0.157, indicating a modest improvement in fit. Mean coefficients are statistically significant with expected signs in both specifications, demonstrating consistent preference patterns.

The alternative-specific constant (ASC) for the "Neither" option is positive and marginally significant, indicating that farmers prefer the opt-out relative to the baseline contract combining the least favourable levels (spruce-dominated forest, mandatory replanting, 20-year payment, and lowest compensation). This reflects that farmers find the baseline package unattractive, with some alternative attribute combinations generating higher utility than opting out.

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[1] McFadden's Pseudo R^2, commonly used for logistic regression models and discrete choice models, differs from the traditional R^2 in linear regression. It is calculated as one minus the ratio of the log likelihood with baseline model, and the log likelihood with all predictors. According to McFadden (1977), Pseudo R^2 values between 0.2 and 0.4 indicate excellent model fit.

Farmers highly value the absence of a replanting requirement, indicating a strong preference for land-use flexibility, allowing farmers to revert land to previous uses or alternative uses after the contract period. These provide evidence supporting Hypothesis 1, which postulates farmers' aversion to irreversible afforestation contracts involving mandatory replanting obligations.

A significant preference for native forests over spruce-dominated plantations, supporting Hypothesis 3 that farmers have a distinct preference for forest type. Longer payment durations are also preferred, with positive coefficients for both 50-year and 100-year subsidies, supporting Hypothesis 2 regarding the value farmers place on long-term financial security[2]. This reflects both the additional security of extended annual payments and the higher total contract value associated with longer-duration schemes—an important consideration given the long rotation periods of forestry investments.

The annual premium amount significantly affects choices (coefficient = 0.001, $p<0.01$), and when multiplied by realistic payment levels (€746–€2,600/ha/year), contributes greatly to utility as a key decision-making driver.

Substantial unobserved heterogeneity is evident through significant standard deviations for the ASC, native forest, and no-replanting attributes, indicating farmers differ widely in environmental preferences and land-use flexibility valuation. Duration attributes show relatively more consistent preferences. These findings validate using RPL and confirm preference heterogeneity as a defining feature of Irish farmers' afforestation decisions.

The random payment specification shows similar coefficient patterns with slightly improved model fit (AIC = 1082.63 vs 1083.96), consistent with the significant payment parameter heterogeneity (LR test: $\chi^2 = 6.65$, $p = 0.0099$). However, for policy interpretation clarity, I maintain the fixed payment model as the primary specification, with random payment results serving as robustness checks.

[2] To assess whether the preference for longer payment durations reflects a trade-off between extended financial support and longer mandatory land-use commitments, we estimated interaction terms between payment duration (50-year and 100-year contracts) and the no-replanting attribute. Both interaction effects were small and statistically insignificant (50-year × no-replanting: –0.082, p = 0.848; 100-year × no-replanting: 0.050, p = 0.925), indicating that farmers' valuation of longer payment horizons is not significantly moderated by their preference for land-use flexibility.

Table 2.3 RPL Model Results

Attribute	**Coef. (SE)**	
Mean	Fixed Payment Model	Random Payment Model
Neither	0.922*(0.490)	1.030*(0.527)
Native forest	0.598**(0.263)	0.644**(0.288)
No replanting requirement	1.012***(0.257)	1.130***(0.285)
50 yrs Payment	0.794***(0.235)	0.870***(0.262)
100 yrs Payment	1.030***(0.341)	1.117***(0.365)
Annual premium amount	0.001***(0.000)	0.001***(0.000)
Standard Deviations		
Neither	2.632***(0.460)	2.804***(0.563)
Native forest	1.837***(0.353)	2.070***(0.433)
No replanting requirement	1.269***(0.362)	1.417***(0.400)
50 yrs Payment	0.632 (0.393)	0.743*(0.404)
100 yrs Payment	0.483 (0.5564)	0.206 (0.917)
Annual premium amount		0.001***(0.000)
Number of obs.	600	600
Pseudo R2	0.1517	0.1570
L-pseudolikelihood	-532.64	-529.31
AIC	1083.963	1082.63
BIC	1149.909	1135.39

*Note: RPL model coefficients with standard errors in parentheses. Significance: * p<0.1, ** p<0.05, *** p<0.01. Estimated with 1,000 Halton draws. Sample: 600 choice sets (150 respondents × 4 choice sets; 1,800 total alternatives).*

Table 2.4 reports WTA values from the fixed-payment model. These values quantify the compensation farmers require to accept changes to contract attributes relative to the baseline. Negative WTA values indicate that respondents would require lower compensation relative to the baseline contract to accept the more desirable attribute level (Ben-Othmen & Ostapchuk, 2023; Greiner, 2015; Le Gloux et al., 2025).

Farmers would require €1,131 per hectare annually to accept mandatory replanting obligations—the highest mWTA among all attributes. This underscores the profound aversion to irreversible land-use changes and represents the economic value farmers place on maintaining future flexibility. The preference for native forests carries an economic value of €696 per hectare annually, indicating farmers' significant non-market valuation of environmental benefits. Longer payment durations are highly valued, with farmers requiring €865 and €1,120 additional compensation to accept 20-year contracts over 50-year and 100-year alternatives, respectively. This reflects both the long-term nature of forestry investments and farmers' preference for financial security, particularly given the mismatch between current 20-year support periods and 40+ year investment horizons. Notably, the opt-out alternative requires €955 per hectare annually in compensation, representing the opportunity cost of diverting land from current agricultural uses.

Confidence intervals indicate substantial heterogeneity in mWTA values across farmers, particularly for native forests (95% CI: €78-€1,550) and replanting flexibility (95% CI: €561-€1,903), indicating diverse preferences across the farming population. This heterogeneity validates the RPL approach and underscores the limitations of uniform policy instruments. Robustness checks using the random-payment model yield comparable WTA patterns (Appendix Table A2), reinforcing the stability of results across model specifications.

Table 2.4 WTA Estimates from Fixed Payment Model (€/Ha/Year)

Attribute	mWTA	CI_lower	CI_upper
ASC	-955.37	-1801.97	201.23
Native forest	-696.42	-1549.87	-78.33
No replanting	-1131.40	-1902.59	-560.58
50-year payment	-865.43	-1321.23	-420.50
100-year payment	-1120.81	-1620.96	-511.99

Note: WTA estimates calculated using Krinsky-Robb simulation with 10,000 draws and random seed 123 for reproducibility. mWTA represents mean willingness-to-accept values. CI_lower and CI_upper correspond to the 2.5th and 97.5th percentiles of the simulated WTA distribution, representing the 95% confidence interval.

2.4.2.2.The Latent Class Model

The LC model was used to identify discrete segments within the farmer population based on their choices and socio-demographic characteristics, enabling targeted policy recommendations and explicitly testing Hypothesis 4.

To determine the optimal number of classes, models with two to five classes were tested. The five-class model failed to converge, making it unsuitable for interpretation. Although the four-class model had the lowest AIC and highest pseudo-R^2, its BIC was notably higher than the three-class model. After considering both statistical fit and narrative clarity, the three-class model was selected as the most appropriate representation of farmers' preferences (Greiner, 2015; Le Gloux et al., 2025).

Table 2.5 summarizes the LC model results, clearly defining the preference structures within each class. The model yields a McFadden Pseudo R^2 value of 0.192, suggesting a better fit than RPL model. Overall, the LC model confirms substantial heterogeneity among farmers and supports all four hypotheses. Due to non-significance of the monetary attribute in Classes 1 and 3, WTA estimates are not computed for the LC model.

Table 2.5 LC Model Results

	Class 1	**Class 2**	**Class 3**
Class membership probabilities (%)	42%	44%	14%
Attributes		Coef. (SE)	
Neither	-1.453** (0.567)	4.449*** (0.985)	3.245** (1.331)
Native forest	-0.611** (0.268)	2.632*** (0.617)	0.664 (0.622)
No replanting	0.617** (0.239)	1.196** (0.481)	1.045*(0.611)
50 yrs Payment	0.693** (0.286)	0.358 (0.540)	1.558 (1.129)
100 yrs Payment	0.553 (0.420)	0.667 (0.736)	1.161 (1.093)
Annual premium	0.0003 (0.0002)	0.002*** (0.0004)	-0.0005 (0.0006)
Covariates			
Age	-0.107 (0.254)	-0.609** (0.286)	Reference level
Household size	0.263 (0.215)	-0.151 (0.236)	
Farm size	0.117 (0.179)	0.403** (0.198)	
Farm type	-0.027 (0.241)	0.726** (0.293)	
Perceived biodiversity benefits	-0.032 (0.211)	0.148 (0.233)	
Knowledge of other tree planter	-0.194 (0.535)	0.639 (0.587)	
Prior afforestation experience	0.158 (0.677)	-1.277* (0.726)	
cons	0.688 (2.329)	0.114 (2.647)	
Number of obs.	600		
Pseudo R2:	0.192		
Log likelihood:	-481.682		
AIC:	1031.364		
BIC:	1218.213		

*Note: this table shows coefficients and standard errors for each attribute across three latent classes. Asterisks denote levels of statistical significance (*for p<0.1, ** for p<0.05, *** for p<0.01). Standard errors (model-based) are shown in parentheses. Covariates are defined as: Perceived biodiversity benefits (5-point scale from strongly disagree to strongly agree that biodiversity benefits the farm), Knowledge of other tree planters (number of farmers known to have planted trees with government subsidies), and Prior afforestation experience (binary indicator for having planted trees with government subsidies). The term "Class" refers to discrete groups of respondents characterized by similar choice patterns and underlying preference structures identified through Latent Class modelling. Class membership is probabilistic, with percentages representing the proportion of respondents assigned to each class based on maximum posterior probability.*

Class 1: Pro-Afforestation with a Preference for Spruce (42%)

This class accounts for 42% of respondents and represents farmers who exhibit a strong preference for afforestation, as evidenced by the significant negative coefficient for the "Neither" option. However, they prefer spruce plantations over native forests, as indicated by the significantly negative coefficient for native trees. Additionally, they favour afforestation contracts without a replanting requirement and show a preference for longer-term financial commitments, particularly the 50-year payment scheme.

Demographically, Class 1 primarily consists of older farmers, with 41.3% aged 65 or above. These individuals typically manage large-scale operations, as 60.3% own farms larger than 50 ha. The household size within this group tends to be smaller, with 69.8% having between 2 and 4 members. A significant proportion, nearly 80%, already engage in forestry on their lands, indicating a substantial level of familiarity and commitment to forestry practices.

Socially, these farmers are well-connected within the forestry community, with 36.5% knowing more than 15 farmers who are actively engaged in forestry—the highest proportion among the identified classes. Despite their active engagement in and familiarity with forestry practices, only 38.1% of them strongly affirm that biodiversity contributes positively to their farms, which is relatively lower compared to other classes.

Class 2: Anti-Afforestation with a Preference for Native Forests (44%)

This class represents the largest share of respondents (44%) and consists of farmers who strongly oppose afforestation, as reflected in the large positive coefficient for the "Neither" option. However, if required to plant trees, they express a clear preference for native forests over spruce plantations and strongly favour contracts without replanting requirements. Unlike Class 1, their willingness to plant is influenced by annual premium payments, with a significant positive coefficient for this attribute.

Demographically, Class 2 is comprised largely of younger farmers, with 34.9% under the age of 44, which is a higher proportion compared to the other classes. This demographic tends to manage smaller-scale operations, as evidenced by 25.8% of them owning farms ranging from 2 to 20 ha. Additionally, a notable 42.4% of this class live in larger households consisting of 5 to 10 members, and they are more likely to be involved in mixed farming practices.

Interesting, a significant portion of this group (57.6%) reports having no existing forests on their land, which may correlate with their limited social networks within the forestry sector—40.9% know fewer than five farmers engaged in forestry, and 12.1% know none. This limited engagement with the forestry community could influence their perceptions and attitudes towards afforestation practices. Despite their general opposition to afforestation, Class 2 farmers demonstrate the most robust pro-biodiversity sentiment among all groups, with 74.2% strongly affirming the positive impact of biodiversity on their agricultural practices.

Class 3: Anti-Afforestation even with Post-Planting Experiences (14%)

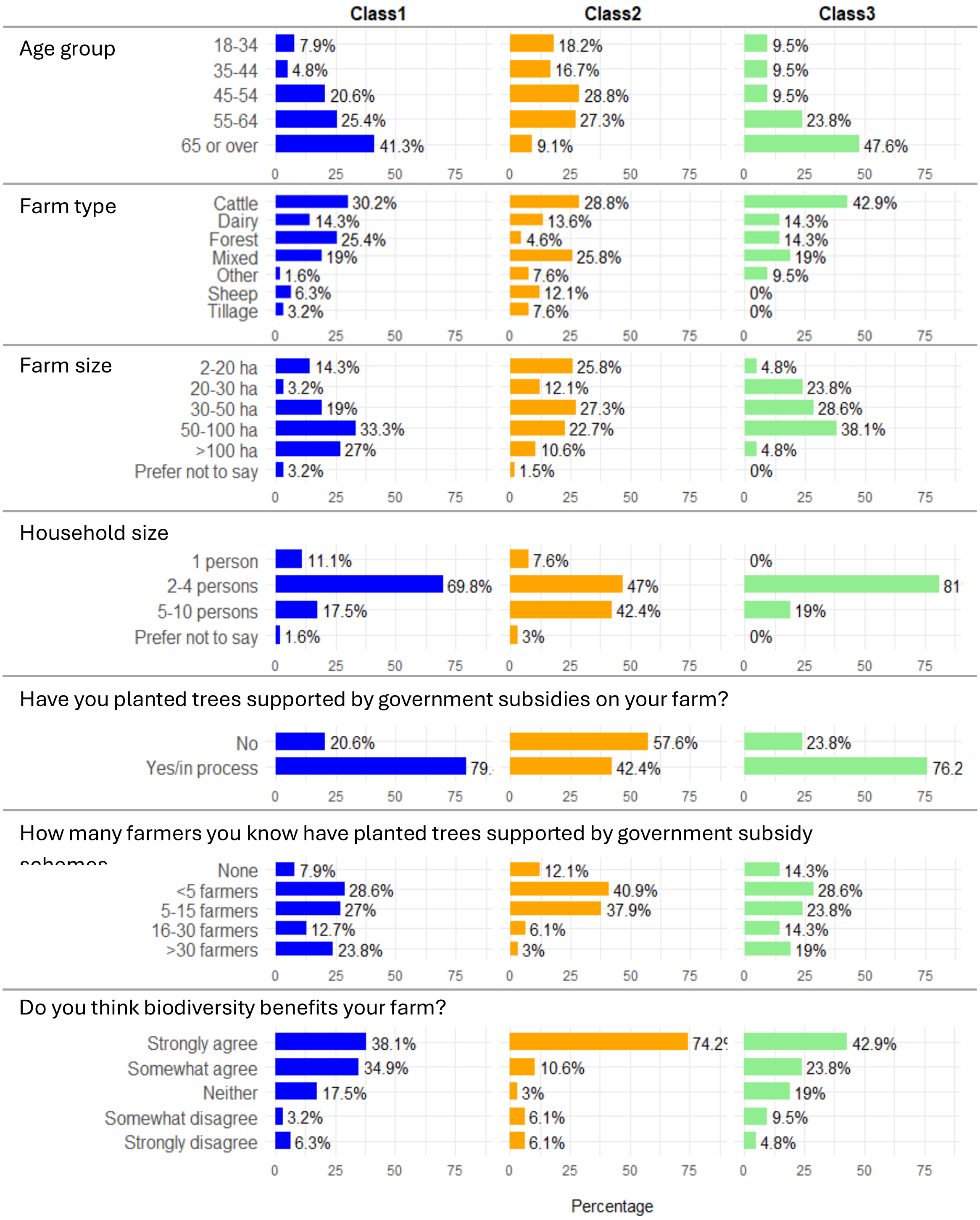
Class 3 comprises 14% of the survey participants, making it the smallest group. Similar to Class 2, this class is characterized by a significant opposition to afforestation, with a pronounced aversion to replanting requirements.

Demographically, this class includes the oldest segment of the sample, with 47.6% of its members aged 65 or above, which might influence their conservative approach to land use changes. A majority of this class, 81%, reside in smaller households of 2-4 members, and a big proportion, 42.9%, are primarily involved in cattle farming. These farmers manage medium to large farms, with 38.1% owning between 50–100 ha. Notably, a high percentage (76.2%) of them already have forests on their property, suggesting familiarity with forestry yet a reluctance to expand existing woodland.

Social connections within the forestry sector vary among members of this class: 19% have extensive networks, knowing more than 30 other forest owners, which contrasts with 14.3% who know no one within the forestry community. This class shows diverse opinions on biodiversity—42.0% strongly agree with the benefits of biodiversity to their farming operations, while 9.5% somewhat disagreeing and 4.8% strongly disagreeing with the benefits of biodiversity, reflecting the complexity of their experiences and perceptions.

To illustrate the characteristics of each class more vividly, Figure 2.2 provides a visual representation of the demographic attributes, farm characteristics, and attitudes toward biodiversity for each class.

Figure 2.2 Socio-Demographic and Farm Characteristics of Latent Classes



Note: this figure visually represents the percentage distribution of key characteristics across the three latent classes identified in the LC Model, aiding in the interpretation of how various factors correlate with class membership.

2.5. Discussion

This study provides new insights into Irish farmers' preferences for afforestation contracts, as revealed through their choices in a DCE, and quantifies their WTA compensation. By employing a RPL model and a LC model, the results uncover both general trends and heterogeneous preferences within the farming community. This section discusses the key results, places them in the context of the existing literature, and highlights policy implications and study limitations.

2.5.1. RPL Model: Farmers' Preferences for Afforestation Attributes

The RPL results show both mean preferences and substantial heterogeneity around these means—indicating that farmers differ widely in how they value each contract attribute. All attributes exhibit statistically significant mean effects, while several random parameters display large standard deviations, confirming that preference heterogeneity is an important feature of afforestation decision-making.

The most pronounced finding is farmers' profound aversion to replanting obligations, requiring €1,131/ha/year in additional compensation—the highest result for mWTA among all attributes investigated. As discussed in the introduction, replanting is a legal requirement in Ireland and remains one of the key barriers to afforestation (Wiemers and Behan, 2004; DAFM, 2023; McDonagh et al., 2010; Ryan et al., 2022). Farmers not only lose land-use flexibility but also face significant sunk costs, as afforestation can reduce land value relative to alternative agricultural uses (Ryan et al., 2018; Wiemers and Behan, 2004). The irreversibility of land-use change is a well-documented barrier to participation—not only in forestry but also in conservation schemes (Behan et al., 2006; Isik & Yang, 2004; Schatzki, 2003). Broch and Vedel (2012) reported similar findings that Danish farmers accepted significantly lower compensation in exchange for the ability to cancel conservation contracts. The substantial compensation required for replanting obligations may reflect both economic irreversibility and behavioural factors such as loss aversion and identity concerns, though this study design did not allow me to disentangle these mechanisms.

A strong preference for native forests over spruce-dominated plantation is also evident, with farmers requiring €696/ha/year more in compensation to plant spruce. This indicates substantial non-market valuation of environmental benefits, despite the longer rotation cycles and delayed timber revenues associated with native species. The considerable heterogeneity around this estimate (95% CI: €78-€1,550) reveals that while environmental considerations are important across the farming population, their relative weight varies substantially among individuals, suggesting that both "environmental stewards" and "commercial pragmatists" coexist within the farming community.

Farmers preferred longer-term financial support, requiring an additional €865/ha/year to accept a 20-year contract compared to a 50-year alternative, and €1,120/ha/year more relative to a 100-year contract. Extended payment periods provide financial stability and reduce exposure to future market and policy uncertainty, while also offering higher total contract payments over the lifespan of the agreement. While current afforestation schemes compensate for initial establishment costs and income loss over 20 years, financial returns primarily come from harvesting—occurring around 40 years for spruce and significantly longer for native forests. Moreover, although future timber revenues could, in theory, compensate for this long investment period, many farmers face borrowing constraints and cannot use expected harvest earnings as collateral (Phillips, 1999). This delay in realizing returns amplifies farmers' reluctance to commit to afforestation (Pannell et al., 2014).

Finally, the opt-out alternative's substantial mWTA (€955/ha/year) quantifies the baseline resistance to diverting land from current agricultural uses, contextualizing Ireland's persistent planting shortfalls. The extremely wide confidence interval for this parameter (€201-€1,802) underscores the diverse opportunity costs farmers face across different farm types and locations.

These results challenge the assumption that afforestation can be effectively incentivized through uniform subsidy increases. Instead, they underscore the need for institutional innovations—such as risk-sharing mechanisms and flexible contract terms—that reduce the irreversibility and temporal mismatch between costs and benefits.

2.5.2. LC Model: Identifying Farmer Segments and Heterogeneous Preferences

The LC model provides complementary insights by identifying three distinct farmer segments with varying attitudes toward afforestation. These differences suggest that afforestation decisions are shaped by a combination of economic considerations and environmental values.

Farmers in Class 1 were the most receptive to afforestation. They tended to be older, owned larger farms, had prior afforestation experience, and were more likely to know others who had planted trees. They may view afforestation as an investment and preferred spruce plantations due to their structured harvesting and thinning cycles, which provide more predictable financial returns. Similar trends have been observed in previous studies in Ireland and UK, where larger landowners and farmers with previous afforestation experience were more likely to participate in afforestation schemes (Crabtree et al., 1998; Duesberg et al., 2014; Frawley & Leavy, 2001; Howley et al., 2012; Ilbery & Kidd, 1992; Ní Dhubháín & Gardiner, 1994). This group's preferences suggest that financial income plays a critical role in afforestation decisions.

Class 2 farmers were the most resistant to afforestation, despite expressing a strong preference for native forests. They tended to be younger, had larger households, operated mixed farms, and owned smaller land holdings. Over half had never planted trees and lacked exposure to afforestation through their peers. Their demographic characteristics align with previous findings that younger farmers and those with children are less likely to engage in afforestation (Duesberg et al., 2014; Howley et al., 2012). Despite their environmental awareness—74.2% strongly agreed that biodiversity benefits their farm—these farmers may associate afforestation with regulatory burdens, such as mandatory replanting obligations and loss of land-use flexibility, rather than viewing it as a conservation opportunity. This indicates that their strong preference for native forests may not necessarily translate into afforestation participation unless schemes are carefully designed to align with their priorities. Targeted conservation incentives that emphasize landscape enhancement and biodiversity co-benefits could be more effective than standard afforestation grants for this group.

Class 3 farmers shared some characteristics with Class 1, such as older age and prior afforestation experience, yet they were strongly opposed to additional planting. A key differentiating factor was farm size: over 90% of Class 3 farmers had farms between 20–100 ha, whereas Class 1 farmers included larger landowners, with 27% owning farms over 100 ha. Their reluctance highlights a critical insight—prior afforestation experience does not necessarily lead to continued participation. Some farmers may have had negative experiences, such as lower-than-expected returns, regulatory burdens, or challenges in managing afforested land. This suggests that afforestation programs must not only incentivize initial adoption but also ensure ongoing support to maintain engagement.

This segmentation highlights a key policy challenge: afforestation decisions are not driven by a single dominant factor but rather by a mix of economic, environmental, and social considerations. As a result, a one-size-fits-all policy approach is unlikely to succeed (Ryan et al., 2018; Carroll et al., 2011). Instead, effective afforestation policies must account for farmer heterogeneity by offering targeted financial incentives, risk-mitigation strategies, and support mechanisms tailored to different segments.

2.5.3. Policy Implications

The findings of this study provide several important insights for the design of future afforestation policy in Ireland. The high mWTA associated with the replanting requirement quantifies the profound economic barrier created by irreversibility. This compensation premium represents the value farmers place on a critical real option—the right to alter future land use. Current subsidies fail to account for this lost option value, revealing a fundamental mismatch between incentive design and the full economic cost of permanent land-use change. Effective policy should internalize this cost, either through recalibrating payments to reflect option value or, more structurally, redesigning contracts to restore some flexibility. While removing replanting obligations entirely may be incompatible with long-term environmental objectives, Ireland's own Forest Strategy acknowledges that permanent afforestation is not optimal in all contexts—notably in the case of peatland 'legacy' forests where rehabilitation is now prioritised (DAFM, 2023a). A more flexible approach—such as conditional exemptions, long-term review clauses, or obligations differentiated by soil type and ecological suitability—could better reconcile farmer demand for flexibility with strategic environmental goals.

The preference for native forests over spruce-dominated plantations highlights the importance of forest type in farmers' decision-making. The significant mWTA for mainly spruce forest indicates that farmers perceive ecological and landscape benefits in native woodland that are not captured by current financial incentives. This supports differentiated payment structures that explicitly recognise non-market ecosystem services. In particular, native woodland schemes may require longer-term or higher annual payments relative to commercially oriented spruce plantations, reflecting their slower financial returns and their role in delivering biodiversity and climate benefits.

Farmers' strong preference for longer payment durations underscores the need to better align contract timelines with biological rotation cycles. Current 20-year premium periods fall short of the 35–45 year rotations typical for spruce and the even longer cycles for native forests. The compensation farmers require to accept shorter contracts suggests that temporal uncertainty is a central component of the cost–benefit calculus. Extending payment durations, or introducing partial supports beyond year 20, could therefore enhance the credibility and attractiveness of afforestation as a long-term land-use option.

The substantial unobserved heterogeneity revealed by the RPL and LC models demonstrates that Irish farmers do not form a homogeneous group. The existence of distinct preference segments suggests that uniform contract offerings may be insufficient to achieve widespread afforestation. Policy design could benefit from more flexible or modular contracts that allow farmers to select between different combinations of forest type, contract length, and land-use safeguards. Tailored advisory services and clearer communication regarding long-term financial and environmental implications may also help address divergent motivations and constraints.

Finally, although carbon and biodiversity credits were not included as attributes in the choice experiment, descriptive survey responses indicate a notable degree of farmer interest in these emerging income streams. This finding does not form part of the causal inference from the DCE results, but it nonetheless suggests that future work should examine how environmental markets might complement afforestation incentives. Such mechanisms may be particularly relevant for native forest schemes, where ecosystem service value is high but market timber returns are limited.

Together, these insights indicate that enhancing afforestation uptake will require a shift from uniform financial incentives toward contract designs that better accommodate farmers' preferences for flexibility, ecological forest types, and long-term security.

2.5.4. Limitations and Future Research Directions

While this study provides valuable insights into Irish farmers' afforestation preferences, several limitations warrant consideration. First, the sample composition reveals potential selection bias, with substantial overrepresentation of farmers who have already engaged with afforestation (63% versus approximately 10% nationally) and notable deviations in farm size and type distributions from national statistics. These imbalances, likely reflecting the voluntary recruitment strategy, may limit the generalizability of the WTA estimates to the broader farming population.

Second, the analytical scope focused exclusively on native forests and spruce-dominated plantations, excluding emerging options such as agroforestry and continuous cover forestry. Future research should incorporate these additional forest types to provide a more comprehensive assessment of afforestation pathways.

Methodologically, several constraints should be acknowledged. The reliance on stated preference data introduces potential hypothetical bias, as survey responses may not fully capture real-world decision-making under actual constraints. While I included contextual measures of social influence and risk perception through contract attributes, the absence of standardized experimental measures for risk aversion, time preferences, and behavioural constructs represents a significant limitation. The substantial mWTA for replanting obligations (€1,131/ha/year) likely reflects not only economic irreversibility but also unmeasured behavioural factors such as loss aversion, identity concerns, and option value. Similarly, my proxy for social influence—knowledge of other tree-planting farmers—cannot distinguish geographic proximity from professional networks or capture the strength of normative influences. Future research would benefit from incorporating experimental measures of these behavioural constructs and social norms to provide a more comprehensive understanding of the psychological drivers of afforestation decisions.

The survey design also presents a limitation relating to the use of colour coding in the choice sets. While intended to enhance readability, colour cues may influence perceived attractiveness of alternatives. Future experiments could test for such perceptual effects using controlled treatments or adopt uniform colour schemes to minimise bias.

Econometrically, while the random payment specification demonstrated superior fit, I maintained the fixed payment model for WTA stability. WTA-space models encountered convergence challenges, suggesting opportunities for alternative estimation approaches in future work. Finally, in the latent class analysis, demographic characterizations rely on modal assignment despite the probabilistic nature of class membership. Future work could incorporate probabilistic weighting into descriptive summaries or explore hybrid choice models that integrate psychological constructs with discrete class segmentation.

Despite these limitations, my findings provide robust evidence of the substantial preference heterogeneity and complex trade-offs characterizing farmers' afforestation decisions, offering important insights for policy design while highlighting avenues for methodological refinement in future research.

2.6. Conclusion

This study provides new evidence on the economic, behavioural, and institutional barriers that shape afforestation decisions among Irish farmers. By applying a DCE and advanced econometric models, I quantify the trade-offs that farmers face when offered afforestation contracts with varying attributes.

The results show that afforestation uptake is constrained not only by the opportunity cost of land but also by legal obligations, investment irreversibility, and uncertainty about future returns. Farmers exhibit strong preferences for native forests, longer payment durations, and especially flexibility in land-use commitments. These findings are not uniform: preference heterogeneity across farmer segments reveals that motivations range from commercial investment logic to ecological stewardship and regulatory avoidance.

From a land economics perspective, these results reinforce the need for policies that internalize both the external benefits of afforestation and the private costs of land-use change. Designing afforestation schemes that are adaptive, incentive-compatible, and responsive to farmer heterogeneity is essential for unlocking afforestation's full potential as a tool for climate mitigation and biodiversity conservation.

Chapter 3 Applying Real Options Theory to Farmers' Afforestation Decisions in Ireland

Abstract

Afforestation is central to Ireland's and the EU's climate and biodiversity strategies, yet farmer participation remains persistently low despite decades of generous incentives. This study applies Real Options Theory (ROT) to explain this paradox, emphasising the value of waiting under conditions of irreversibility and uncertainty. Based on 24 in-depth interviews with Irish farmers, it shows that hesitation is not a failure of rationality but its expression. Farmers described afforestation as uniquely risky, citing profound irreversibility (legal, financial, and socio-cultural), multidimensional uncertainties (policy, market, biological, and social), and the appeal of more flexible land uses. These factors elevate the option value of delay, rationalising inaction despite financial incentives. Theoretically, the paper extends ROT beyond price volatility to incorporate institutional and socio-cultural risks. Methodologically, it demonstrates the value of qualitative inquiry for revealing how farmers perceive and assign option value. Policy implications stress reducing irreversibility and uncertainty rather than merely raising payments.

3.1. Introduction

Afforestation is a cornerstone of climate and biodiversity policy, particularly in the European Union, where expanding forest cover is viewed as essential to meeting net-zero and ecological restoration targets (European Commission, 2025). Ireland represents a critical test case: with forest cover of just 11%—among the lowest in Europe—yet ambitious planting targets, its success is central both to national climate strategies and EU-wide objectives (DAFM, 2023a; Eurostat, 2024). Despite decades of generous financial incentives, however, farmer uptake has persistently lagged, with annual planting far below official goals (Ryan et al., 2014; DAFM, 2024a). Understanding this reluctance is of urgent policy relevance, given that farmers control most of the available land in Ireland for new planting.

Many research papers have sought to explain this persistent "afforestation gap." Some authors employed neoclassical models, particularly NPV comparisons, which often suggested that forestry is financially attractive relative to agriculture (Behan, 2002; Breen et al., 2010; O'Donoghue, 2022). Yet, generous premiums have repeatedly failed to translate into widespread adoption, exposing the limits of standard financial analysis. In response, an examination of behavioural approaches—such as the Theory of Planned Behaviour (TPB) (Ajzen, 1991; Rafiee et al., 2025; Irwin, 2023)—have highlighted the role of attitudes, social norms, and perceived control, while cultural capital and identity theories (Burton, 2004) emphasise how forestry can be seen as incompatible with "good farming." These perspectives are invaluable, but they tend to portray reluctance as cultural inertia, without fully accounting for the economic logic of delay in the face of profound irreversibility and uncertainty.

This paper brings ROT into the debate, showing that reluctance to afforest can be understood as a rational strategy. ROT emphasises that when investments are irreversible, uncertain, and long-term, the option to wait acquires real economic value (Dixit & Pindyck, 1994). Applying this lens, I argue that Irish farmers' hesitancy is not a policy failure to offer sufficient payments, but a logical valuation of the flexibility preserved by delaying. Moreover, by integrating socio-cultural and institutional factors into the ROT framework, the paper extends its scope beyond price volatility to capture identity, legacy, and governance as key drivers of option value.

While ROT has been applied to forestry and agriculture (Plantinga, 1998; Insley, 2002; Duku-Kaakyire & Nanang, 2004; Yemshanov et al., 2015; Regan et al., 2015), its use has been predominantly quantitative, relying on stochastic models with restrictive assumptions that may not capture the complex, lived experience of decision-makers (Andrikopoulos, 2005). A significant gap exists in qualitative, inductive research that explores how the core tenets of ROT— irreversibility, uncertainty, and flexibility—are perceived, experienced, and articulated by farmers themselves. Without this grounded understanding, economic models and subsequent policies risk being mis-specified, failing to address the real drivers of inaction.

This paper addresses this gap by employing a novel, qualitative approach to investigate Irish farmers' afforestation decisions through the interpretive lens of ROT. I conducted in-depth, semi-structured interviews with 24 farmers to explore their lived experiences and decision-making reasoning processes. My analysis demonstrates that farmer reluctance is not a failure of rationality but its expression. Farmers intuitively assign a high value to the option to wait due to profound perceived irreversibility (legal, financial, and socio-cultural), multi-dimensional uncertainties (policy, market, biological, social), and the high value of waiting, reflected in both attractive competing land uses and anticipation of better future schemes. By moving beyond mathematical modelling to foreground farmers' own narratives, this study provides a richer, more contextualised explanation for the afforestation gap. My findings suggest that effective policy must not only increase financial incentives but, more importantly, must systematically mitigate perceptions of irreversibility, reduce uncertainty and create new values to make current schemes more attractive than the valuable option of delay.

The remainder of the paper proceeds as follows. Section 3.2 reviews the literature on afforestation decision-making, highlighting the limits of NPV, behavioural, and socio-cultural models, and situates the contribution of ROT. Section 3.3 outlines the qualitative methodology. Section 3.4 presents the findings, structured around irreversibility, uncertainty, and the option value of waiting. Section 3.5 discusses the theoretical and policy implications of interpreting reluctance as rational, before Section 3.6 concludes.

3.2. Literature Review

3.2.1. Economic Analyses of Afforestation: Strengths and Limits of NPV

The NPV rule—rooted in DCF analysis—remains the dominant benchmark for evaluating investments across sectors (Graham & Harvey, 2001; Brealey et al., 2014). Its appeal lies in a transparent decision criterion ("invest if NPV > 0") and comparability across projects, which explains its extensive use in forestry and land-use applications (Sills & Abt, 2003; Cocks, 1965; Marra et al., 2003). In the Irish context, many studies have used NPV to compare forestry with agricultural alternatives, often reporting apparently favourable private returns to forest planting relative to conventional enterprises (Behan, 2002; Collier et al., 2002; Breen et al., 2010; O'Donoghue, 2022).

However, afforestation exposes structural limits of the standard NPV approach. First, under NPV, investment is conceived as an immediate and irreversible 'now-or-never' decision, followed by passive continuation thereafter (Dixit & Pindyck, 1994, 1995; Trigeorgis, 1996). It does not value the possibility that deferring investment may be valuable if future information reduces uncertainty. Second, forestry's unusually long horizons—roughly 35–45 years for commercial conifers and up to a century or more for broadleaves—magnify uncertainty about prices, costs, policy, and biophysical risks (Phillips, 2006; Donnellan & Hennessy, 2008). Over such horizons, small changes in discount rates can radically alter valuations, rendering static NPV comparisons fragile (Ross, 1995; Pindyck, 2007). Third, irreversibility is substantial: afforestation involves large sunk costs and, in Ireland, legal obligations to replant make exit extremely difficult, if not practically impossible (Pindyck, 1991; Howley et al., 2012). Attempts to "bolt on" uncertainty via higher, risk-adjusted discount rates are a blunt instrument that can distort decision thresholds and still fail to capture the value of managerial flexibility (Dixit, 1992; Baker & English, 2011).

These limitations help explain the disconnect between theoretical profitability and observed behaviour—well documented in studies of land-use change (Musshoff, 2012; Regan et al., 2015)—a paradox that is particularly visible in Ireland despite comparatively generous incentives (Breen et al., 2010; O'Donoghue, 2022). In short, a framework is required that explicitly values irreversibility, uncertainty and the flexibility to time, stage, or avoid commitment.

3.2.2. Beyond Economics: Behavioural and Socio-Cultural Models of Land-Use Decision-Making

Recognising the limitations of neoclassical NPV models to explain persistent non-adoption, scholars have increasingly turned to behavioural and socio-cultural frameworks to understand land-use decisions. These approaches reject the notion of the perfectly rational homo economicus and instead seek to explain how subjective perceptions, social influences, and personal identity shape behaviour.

The TPB (Ajzen, 1991) has been a particularly influential framework. It posits that behavioural intention is determined by an individual's Attitude towards the behaviour, the Subjective Norm (perceived social pressure), and Perceived Behavioural Control (ease or difficulty of performing the behaviour). This model has been directly applied to afforestation in Ireland. Rafiee et al. (2025) found that Irish farmers' intentions to adopt Small-Scale Afforestation Measures were most strongly influenced by Subjective Norms—the perceived expectations of influential others. While farmers held positive environmental attitudes, they remained concerned about economic returns and land permanence. The study also identified low Perceived Behavioural Control, citing administrative burdens and a lack of technical knowledge as critical barriers to adoption. Similarly, Irwin (2023), applying an extended TPB to agroforestry adoption, found that attitudes and moral norms (shaped by advisors and local farmers) explained 74% of the variance in intention, highlighting the powerful role of community influencers.

Complementing the TPB, other scholars have drawn on concepts like cultural capital (Bourdieu, 2011) and productivist identity to explain resistance to land-use change. Farmers often derive status and identity from being productive, food-producing custodians of the land (Burton, 2004; Silvasti, 2003). Afforestation, particularly with conifers, can be perceived as "giving up" on this identity, conflicting with deeply held notions of "good farming" (Schirmer & Bull, 2014; Carroll et al., 2011). This socio-cultural irreversibility—the fear of losing one's identity and social standing within the farming community—represents a significant non-financial cost that is invisible to NPV calculations (Burton & Paragahawewa, 2011).

These behavioural and socio-cultural models are invaluable for cataloguing what influences decisions, moving beyond purely financial metrics to include attitudes, norms, and identity. However, a gap remains. While they excellently describe the factors that correlate with reluctance, they are less adept at explaining the underlying economic rationality of delay and inaction in the face of significant uncertainty. They can sometimes risk framing farmer hesitation as a deviation from a rational norm (i.e., "irrational" resistance due to culture) rather than identifying conditions of irreversibility and uncertainty —that make delay a perfectly logical and strategic choice. This gap creates the need for a framework that can integrate the very real socio-cultural constraints identified by these models into a rigorous economic logic of decision-making under uncertainty.

3.2.3. Irish Policy and Institutional Context

Ireland provides a textbook case of the divergence between policy ambition and farm-level outcomes. Since the 1980s, successive governments have offered generous grants and premiums to incentivise private afforestation, particularly by farmers (Ryan et al., 2014; DAFM, 2014). Yet, despite targets of 8,000 hectares per year under the current Climate Action Plan, planting has fallen to little more than 2,000 hectares annually in recent years (DAFM, 2024a). With total forest cover at 11.6%, Ireland remains one of the least forested countries in the European Union, far below the EU average of 38.6% (Eurostat, 2024). This persistent underperformance, has prompted extensive research into why farmers—the primary target group for planting schemes—remain reluctant to participate. Several contextual features recur in the literature.

One of the most significant barriers to afforestation in Ireland is the permanent land use change that accompanies it. Under Irish law—as is the case in several other European countries—once land is converted to forestry, it is subject to a perpetual replanting obligation, which prevents its reversion to agricultural use (DAFM, 2023b; McDonagh et al., 2010; Ryan et al., 2022; Bauer & Kniivilä, 2004). This legally enforced permanence significantly limits land-use flexibility and substantially reduces the capital value of the asset. Consequently, landowners face a considerable sunk cost that locks them into a long-term commitment. Such irreversibility is widely viewed as a strong deterrent to afforestation (Wiemers & Behan, 2004; Ryan & O'Donoghue, 2016; Breen et al., 2010). This issue has become even more pronounced with significant increases in agricultural land prices (Breen et al., 2008; CSO, 2023).

The long-term nature of forestry investments adds another layer of complexity to decision-making. Unlike agriculture, which typically offers more stable and consistent financial returns, forestry income is mainly derived from annual premiums during the first 15–20 years. From around year 20 onwards, periodic income is generated through thinning, but substantial revenues only materialize at the final harvest, which occurs around year 40 for conifers and later for broadleaf species (Ryan & O'Donoghue, 2016; Donnellan & Hennessy, 2008; Philips, 2006). The transition from a guaranteed subsidy to reliance on volatile timber markets heightens financial uncertainty for farmers. Moreover, future timber prices, licensing uncertainties, and vulnerabilities to pests, diseases, and climate change further complicate financial planning for farmers (Phillips, 1999; Ryan & O'Donoghue, 2016).

Cultural and identity factors also play a pivotal role in shaping farmers' attitudes towards afforestation. Forestry has historically been weakly integrated into the farming identity in Ireland (Irwin, 2023). Many farmers view forest as only suitable for "marginal land,"(Ní Dhubháin and Gardiner, 1994; Duesberg et al., 2013) contributing to the widespread perception that it represents a "giving up on farming." The deeply ingrained connection between farming identity and agricultural practices makes the transition to forestry difficult for many farmers, especially when forestry is perceived as a permanent commitment that could sever their connection to farming traditions (O'Leary et al., 2000; McDonagh et al., 2010; Howley et al., 2012). These socio-cultural barriers are further reinforced by negative imagery associated with monoculture conifer plantations and clear-felling practices, which are often viewed as environmentally damaging (O'Leary et al., 2000).

Institutional and governance issues exacerbate the reluctance to adopt afforestation. The bureaucratic complexity involved in obtaining planting and felling licenses, combined with slow administrative processes, creates significant transaction costs for farmers (O'Donoghue, 2022; Irwin, 2022). Farmers also report low control and confidence in the system due to a lack of technical knowledge, limited access to expert advice, and the burden of administrative hurdles (Rafiee et al., 2025). These challenges make the afforestation process cumbersome and disempowering, further deterring farmers from engaging in long-term forestry investments.

While existing research has effectively identified a multifaceted array of barriers to afforestation, encompassing economic, socio-cultural, and institutional dimensions, it has not yet provided a coherent theoretical framework that explains why these factors lead to a preference for inaction.

3.2.4. Real Options Theory (ROT) in Forestry and Land-Use

ROT generalises the financial concept of options to real assets: decision-makers possess the right but not the obligation to invest, defer, stage, expand, or abandon as information unfolds (Myers, 1977; Dixit & Pindyck, 1994; Trigeorgis, 1996; Miller & Waller, 2003). Three ingredients make these options valuable: irreversibility, uncertainty, and managerial discretion (Kogut & Kulatilaka, 2001). Under ROT, investing immediately is optimal only when expected returns exceed both the cost of commitment and the economic value of waiting (McDonald & Siegel, 1986; Roche, 2003).

Forestry has long served as a fertile domain for ROT. Much work has focused on harvest timing under stochastic prices and costs, showing that delaying harvest often maximises value (Plantinga, 1998; Insley, 2002; Gjolberg & Guttormsen, 2002; Saphores, 2001). Applications have since extended to processing capacity, concessions, and plantation establishment, consistently demonstrating the value of flexibility through deferral, expansion, or abandonment (Duku-Kaakyire & Nanang, 2004; Rocha et al., 2006; Kallio et al., 2012; Simões et al., 2022; Rocha et al., 2024). In agriculture, ROT has similarly illuminated adoption decisions for organics, precision technologies, bioenergy, and climate adaptation, highlighting that deterministic NPV models systematically over-predict uptake by ignoring option values (Tozer, 2009; Kuminoff & Wossink, 2010; Nelson et al., 2013; Frey et al., 2013).

For land-use conversion—including afforestation—ROT has been used to show how irreversibility and stochastic returns raise the hurdle for switching (Zinkhan, 1991; Thorsen, 1999; Thorsen & Malchow-Møller, 2003; Schatzki, 2003; Isik & Yang, 2004; Isgin & Forster, 2006). Option values can be capitalised into land prices (Plantinga et al., 2002), and spatially explicit models that append option values to NPV better match observed conversion elasticities (Yemshanov et al., 2015). More recent work shows that when afforestation generates joint but uncertain environmental services (e.g., carbon, biodiversity), correlations among service values may expand the conditions under which conversion is attractive, though higher uncertainty still raises the value of waiting (Strange et al., 2019).

In Ireland, Wiemers and Behan (2004) applied ROT to farm forestry and concluded that farmers' reluctance was economically rational, given uncertainties in timber prices, agricultural returns and land values. Yet this analysis also illustrates the limits of conventional ROT modelling. First, most applications are quantitative and model-based, relying on stochastic processes (e.g., geometric Brownian motion) to simulate uncertainty and compute option values. While analytically elegant, this approach reduces uncertainty primarily to price volatility, underplaying risks from policy volatility, administrative processes, or ecological change. Second, models often impose restrictive assumptions to remain tractable, such as specific statistical distributions for returns, which may be far removed from the complexity of real-world environments (Andrikopoulos, 2005). Third, the socio-cultural dimensions of irreversibility—identity, stigma, intergenerational obligations—are almost entirely absent from quantitative ROT models, even though they materially shape "flexibility value" at the farm level.

By relying exclusively on quantitative methods, the literature has largely overlooked the rich, lived experiences of decision-makers and the qualitative nuances of how they perceive and respond to irreversibility, uncertainty, and flexibility.

3.2.5. Research Gap and Contribution

The literature on afforestation decision-making has evolved from neoclassical NPV models to behavioural and socio-cultural frameworks, each offering valuable insights but leaving critical blind spots. NPV models over-predict adoption by ignoring irreversibility and uncertainty; behavioural models capture attitudes and identity but often stop short of explaining the underlying economic rationality. ROT provides an economic rationale for waiting under uncertainty, yet its application in forestry has been narrowly quantitative, focusing on timber price volatility while neglecting policy, institutional, and socio-cultural risks.

Ireland exemplifies these limitations. Despite generous incentives, farmers face legal permanence, financial liabilities, institutional mistrust, and cultural resistance, creating a context where delay is not irrational inertia but a rational, strategic response. However, no framework has integrated these diverse barriers into a coherent explanation.

This study addresses three gaps:

- Theoretical: It extends ROT beyond market volatility to incorporate institutional and socio-cultural dimensions of irreversibility, reframing reluctance as a rational valuation of flexibility.
- Contextual: It uses the Irish case as a critical example of how permanence and uncertainty undermine even generous incentive schemes, with implications for afforestation policy.
- Methodological: It advances ROT research through a qualitative, inductive design, capturing how farmers themselves perceive and articulate irreversibility, uncertainty, and the option to wait.

By applying ROT as an interpretive lens to rich qualitative data, this study demonstrates that farmer reluctance reflects rational risk management rather than resistance. It provides a theoretically grounded basis for policy redesign: shifting from simply raising payments to engineering option structures that soften irreversibility, reduce uncertainty, and enhance flexibility.

3.3. Methodology

This study adopted an interpretivist research philosophy to explore the complex considerations and decision-making processes of Irish farmers regarding afforestation. An exploratory qualitative design was employed because it is well suited to examining nuanced attitudes, perceptions, and the underlying reasoning behind behaviours in contexts that are not yet fully understood (Creswell & Poth, 2016). The aim was to capture farmers' lived experiences without imposing a pre-defined theoretical framework during data collection, allowing themes to emerge inductively through reflexive thematic analysis (Braun & Clarke, 2006; 2021).

While the interviews were not developed using a specific theoretical model, the subsequent analysis incorporated ROT as an interpretive lens (Dixit & Pindyck, 1994). Such a hybrid approach—combining inductive theme generation with post hoc theoretical interpretation (Fereday & Muir-Cochrane, 2006; Nowell et al., 2017)—ensured that findings were firmly grounded in farmers' perspectives while also situated within a robust theoretical framework of investment under uncertainty.

3.3.1. Data Collection

A combination of purposive and maximum variation sampling was employed to assemble a diverse and information-rich cohort of participants (Patton, 2014). Purposive sampling ensured recruitment of active farmers with relevant experience, while maximum variation sampling introduced heterogeneity across farm enterprise type (dairy, beef, sheep, tillage, forestry), age, region, and prior forestry involvement—factors known to influence land-use decisions (Ní Dhubháín & Gardiner, 1994; Duesberg et al., 2014; Howley et al., 2012; Ryan & O'Donoghue, 2018; Vidyaratne et al., 2020).

Participants were recruited through two complementary channels, employing a combination of purposive and maximum variation sampling strategies (Patton, 2014) to assemble a diverse and information-rich cohort. First, respondents to a parallel quantitative survey on farmers' Willingness to Accept (WTA) for afforestation were invited to volunteer for follow-up interviews. This broader survey was distributed nationwide between June 2024 and January 2025. It was promoted through the Irish Farmers' Association (IFA) in its biweekly newsletters and featured in the Irish Farmers Journal. It was further disseminated by the Irish

Forest Owners, the Irish Agroforestry Forum, and the Carbery Group, who shared the survey with their networks. Respondents from this broad pool who provided contact information formed the first, purposive recruitment pool for the qualitative interviews. Second, to further ensure heterogeneity and capture perspectives beyond the initial survey cohort, additional farmers were approached directly at agricultural events, notably the National Ploughing Championships in September 2024.

In-depth, semi-structured interviews were conducted with 24 farmers between June and October 2024. Interviews were conducted online, lasted between 45 and 90 minutes, and were audio-recorded with informed consent. The resulting dataset comprised approximately 350,000 words of transcribed text. Thematic saturation was reached after 18–20 interviews, with subsequent interviews adding nuance but not novel themes (Mason, 2010).

The cohort reflected a broad cross-section of Irish farming. Participants ranged from under 35 to over 65 years. Nineteen men and five women took part, reflecting national farming demographics (CSO, 2024). Farm enterprises included dairy, cattle, sheep, tillage, mixed livestock, and dedicated forestry, with farm sizes ranging from 2 to 200 hectares. Roughly two-thirds had prior experience with afforestation, enabling comparisons between those with and without direct involvement. Table 3.1 presents the profile of participating farmers.

The interview covered broad, open-ended questions on farm background, awareness of forestry programmes, perceived benefits and drawbacks, financial incentives, biodiversity and climate considerations, cultural/community perceptions, and future plans. Questions were deliberately phrased to encourage farmers to elaborate on their priorities and reasoning, without steering responses toward any predefined theory. The full guide is provided in Appendix B1.

Table 3.1 Characteristics of Farmer Interview Participants (N = 24)

ID	Age Group	Gender	County	Farm Type	Farm Size (ha)	Afforested	Interview Date
F1	55–64	Male	Kilkenny	Sheep	50–100	Yes	22 Jul 2024
F2	<35	Male	Tipperary	Dairy	–	No	30 Jul 2024
F3	<35	Male	Cavan	Dairy	50–100	No	11 Sep 2024
F4	65+	Male	Cork	Cattle	30–50	Yes	30 Jul 2024
F5	55–64	Male	Clare	Mixed livestock &forest	50–100	Yes	30 Jul 2024
F6	45–54	Male	Cork	Sheep and forest	50–100	Yes	25 Jul 2024
F7	55–64	Male	Kilkenny	Tillage	30–50	No	18 Jul 2024
F8	45–54	Female	Wicklow	Recently purchased (no enterprise yet)	2–20	Yes	16 Jul 2024
F9	45–54	Male	Tipperary	Organic tillage&Mixed livestock	30–50	Yes	14 Oct 2024
F10	65+	Male	Roscommon	Cattle	50–100	Yes	18 Jul 2024
F11	55–64	Male	Cork	Forest	50–100	Yes	22 Jul 2024
F12	55–65	Male	Cork	Cattle	20–30	Yes	30 Jul 2024
F13	55–64	Male	Cork	Hobby farm	2–20	Yes	30 Jul 2024
F14	55–64	Male	Tipperary	Forest	50–100	Yes	22 Jul 2024
F15	<35	Male	Donegal	Tillage	–	No	25 Jul 2024
F16	55–64	Male	Kilkenny	Forest	50–100	Yes	15 Jul 2024
F17	45–54	Female	Wicklow	Sheep	20–30	No	11Oct 2024
F18	65+	Male	Cavan	Cattle	30–50	Yes	14 Oct 2024
F19	<35	Female	Sligo	Sheep& cattle	50–100	No	26 Jul 2024
F20	45–54	Female	Westmeath	Forest	–	Yes	16 Jul 2024
F21	45–54	Male	Tipperary	Forest	30–50	Yes	15 Jul 2024
F22	65+	Male	Cavan	Sheep	–	No	17 Sep 2024
F23	65+	Male	Tipperary	Cattle&forestry	100–200	Yes	18 Jul 2024
F24	65+	Male	Kilkenny	Mixed livestock &forest	100–200	Yes	22 Jul 2024

Note: this table presents the characteristics of the 24 farmers interviewed. A dash (–) indicates that information was not provided by the participant.

3.3.2. Data Analysis

The qualitative data analysis followed a hybrid thematic analysis approach (Fereday & Muir-Cochrane, 2006), combining inductive coding of farmer narratives with deductive integration into the ROT framework (Dixit & Pindyck, 1994; Trigeorgis, 1996). This process was operationalized through a structured, six-phase framework for reflexive thematic analysis (Braun & Clarke, 2006; 2021), adapted to incorporate theoretical integration.

The process began with repeated reading of the 24 verbatim transcripts to ensure immersion, accompanied by reflexive memos to capture early analytical impressions (Phase 1). Open coding in NVivo 14 generated 226 first-order codes, which were consolidated into 98 distinct codes reflecting farmers' own framings of afforestation (Phase 2). Research meetings during this phase helped calibrate coding decisions against the study's objectives.

Next, these inductively derived codes were integrated with ROT through deductive mapping (Phase 3). Sixty-two codes were identified as directly pertinent: 9 to Irreversibility, 38 relating to Uncertainty, and 18 to Flexibility (the option to wait). Within each pillar, related codes were grouped into sub-themes and broader themes (Phase 4). For example, "cumbersome application process" and "delays and uncertainty" were subsumed under the sub-theme *Licensing Complexity & Bureaucracy*, part of the broader theme *Policy and Administrative Uncertainty*. These themes were then refined and clearly named to capture both farmers' language and theoretical relevance (Phase 5). Finally, the themes were woven into a coherent narrative structured around the three pillars of ROT, illustrated with representative quotations to anchor interpretation in participants' voices (Phase 6).

The final analytical structure organised the 62 codes into 18 sub-themes and 9 overarching themes within the three ROT pillars. Although presented sequentially, the process was iterative, with constant movement between inductive insights and deductive framing. To enhance analytical rigour, a full coding trail was maintained, illustrative quotations were extracted for each code, and peer debriefing with colleagues was used to challenge interpretations and reduce subjectivity. Reflexive attention was also given to the researcher's disciplinary background in forestry economics, with inductive coding prioritised before ROT mapping to mitigate bias towards financial explanations.

3.4. Results

Analysis of the interview data revealed that the decision to afforest is not a simple calculation of premiums and grants. Instead, farmers engage in a complex assessment of irreversibility, uncertainty, and alternative land use options. The findings are organised around the three pillars of ROT, showing how high irreversibility and pervasive uncertainty inflate the value of waiting.

3.4.1. The Weight of Irreversibility

Irreversibility emerged as the most pervasive barrier to afforestation, fundamentally undermining farmer confidence. Forestry was consistently described as an irreversible land-use change, binding both land and future generations in ways that sharply contrast with the flexibility of agriculture. Farmers emphasised that once trees are planted, land is effectively "locked up" — legally, economically, and culturally — with little prospect of reversal, creating both sunk costs and intergenerational commitments. In this context, the decision to afforest was not viewed as a routine investment but as an irreversible transformation of family land, heightening the stakes and amplifying hesitation. Figure 3.1 illustrates how legal, financial, and socio-cultural irreversibilities cluster into distinct yet interconnected themes, each reinforcing farmers' perception of sunk cost.

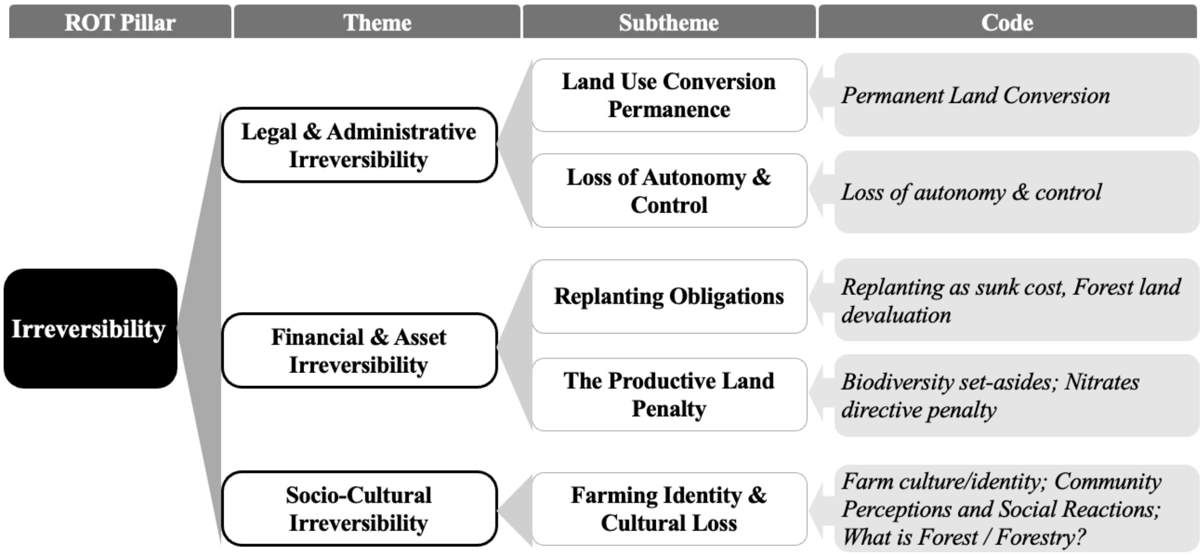
3.4.1.1. Legal and Administrative Irreversibility

A fundamental barrier to afforestation in Ireland is the legal reclassification of land from agricultural to forestry, a legal act perceived as permanent and irreversible. Many described this as a perpetual trap:

> *But the fact I can never ever go back to conventional farming… that's just the biggest regret now ever. [F6]*

This concern extends even to agroforestry, where farming remains the primary land use. Under current rules, however, the Department of Agriculture reclassifies such land as forestry [F9], thereby subjecting it to the same rigid obligations. This legal permanence creates a powerful psychological and legal barrier, with farmers feeling they are "*dictating to future generations*" [F21] and eliminating their options.

Figure 3.1 Coding Hierarchy for the "Irreversibility" Pillar



Note: this figure illustrates how raw interview codes were synthesised into sub-themes and broader themes under irreversibility pillar of ROT.

Closely linked to this legal permanence is the sense of diminished autonomy over one's land. Farmers repeatedly contrasted forestry with other agricultural enterprises, emphasising that crops such as tillage or livestock could be freely planted, harvested, or rotated, while forestry is subject to state approval at every stage. Securing licences to fell, thin, or replant was described not as a regulatory safeguard but as an erosion of property rights. As one farmer explained,

> *Why do we need the state to tell us when we can cut our forestry? [F13]*

Others expressed frustration at the cumulative effect of these requirements:

> *It's like all licences. It's a system of power that the government has over you… an asset that I have and I should be allowed to sell it as I see fit. And that is not the way. [F24].*

Such bureaucratic control symbolised a ceding of property rights, turning forestry into an activity under state supervision rather than private management. Within the Real Options framework, the legal and administrative irreversibility of afforestation represents the ultimate sunk cost. It completely eliminates the valuable option to alter land use in response to future market signals, policy changes, or family circumstances.

3.4.1.2.Financial and Asset Irreversibility

Beyond legal permanence, farmers emphasized how afforestation creates severe financial and asset-based irreversibilities. These are not one-time sunk costs but ongoing financial obligations and constraints that bind intergenerational wealth, fundamentally undermining the land's market value and flexibility.

(i) Replanting Obligation as a Sunk Cost

The statutory requirement to replant after harvesting was consistently highlighted as a unique financial burden. Farmers did not view this as a neutral cost of business but as an enforced, perpetual expense that eliminates any possibility of exit, locking future generations into a cycle of expenditure. This obligation transforms forestry from an investment into a permanent financial liability, *The big thing that you have to pay for the replanting, and that is a bit of a bugbear.[F16]*

This future financial burden contributes to the immediate devaluation of land upon planting, as farmers perceive afforested land as a 'sterilised' asset with severely limited resale potential, representing a significant sunk cost in itself.

The forest was valued at 5,000 Euro an acre. And the arable land was valued at 10,000.[F8]

Once they have planted it, the value of selling it, is gone way, way down.[F14]

(ii) The Productive Land Penalty: Biodiversity and Nitrate

Policy mechanisms designed to promote environmental goods were perceived as directly confiscating productive capital and imposing tangible financial penalties on farmers.

Mandatory non-commercial plantings, the broadleaf and biodiversity component,[3] were framed as a loss of income-generating land. Farmers argued that while they receive premiums on the entire area, the eventual timber payoff comes from less than half of it, so that premiums "*don't matter*" in the long run [F23]. This was seen as being forced to provide a "*public good, free of charge, indefinitely,*" a proposition farmers found economically irrational [F23].

An unanticipated financial penalty arises from the interaction with the agricultural policy, the Nitrates Directive. Land converted to forestry no longer counts toward the farm's stocking rate calculation, directly reducing the number of cattle the farmer can keep on the remaining land. This effectively punishes farmers for planting by constraining their primary agricultural income, a trade-off that was "*not envisaged at the time*" of investment [F24].

From a Real Options perspective, these factors constitute substantial, non-recoverable sunk costs. Consequently, forestry is not regarded as a productive investment but as a long-term liability that constrains intergenerational wealth.

[3] Farmers cited figures of "30% broadleaves plus another 10–15% biodiversity" [F23], reflecting their perception of the scheme's constraints. The official Afforestation Scheme, however, specify lower thresholds—for example, 20% broadleaves under FT11 *Mixed high forests: Diverse Conifer*, *20% broadleaves* and FT12 *Mixed high forests with mainly spruce, 20% broadleaves (DAFM, 2024b).*

3.4.1.3.Socio-Cultural Irreversibility: the Loss of Farming Identity

Farmers framed afforestation as an irreversible exit from a cherished identity, representing a permanent loss of legacy and social standing within the rural community. Forestry, particularly large-scale conifer planting, was negatively associated with landscape loss, economic decline, and the actions of external investment funds, not local farmers. As one farmer stated, "*the two communities are very separated, foresters and farmers*" [F3], highlighting a deep social schism. This transition from "farmer" to "forester" thus constituted a form of socio-cultural sunk cost that, for many, outweighed any financial incentive.

For participants, farming was described as a "*lifestyle*" [F18] deeply tied to family heritage, moral duty, and a personal connection to the land that transcends economics,

> *I die for this piece of land. It's ingrained in me so much. My DNA, our fields have all names and stories. [F6]*

Within this cultural framework, planting trees was widely interpreted not as diversification but as abandonment—a symbolic act of "*giving up on farming*" [F19], or even failure. As one participant noting,

> *Growing up, it was almost considered a failure if you ended up having to plant your farm. [F2]*

The "forester" identity was seen as separate and socially devalued, reinforcing cultural resistance. For many, afforestation was a permanent decision not just for themselves, but for all future generations, stripping the land of its agricultural purpose and their descendants of their farming heritage.

> *What you're doing to the future generations is you are dictating to them that I'm making the decision that land is in forestry, OK? And that is your choice of farming that I am making from you.[F21]*

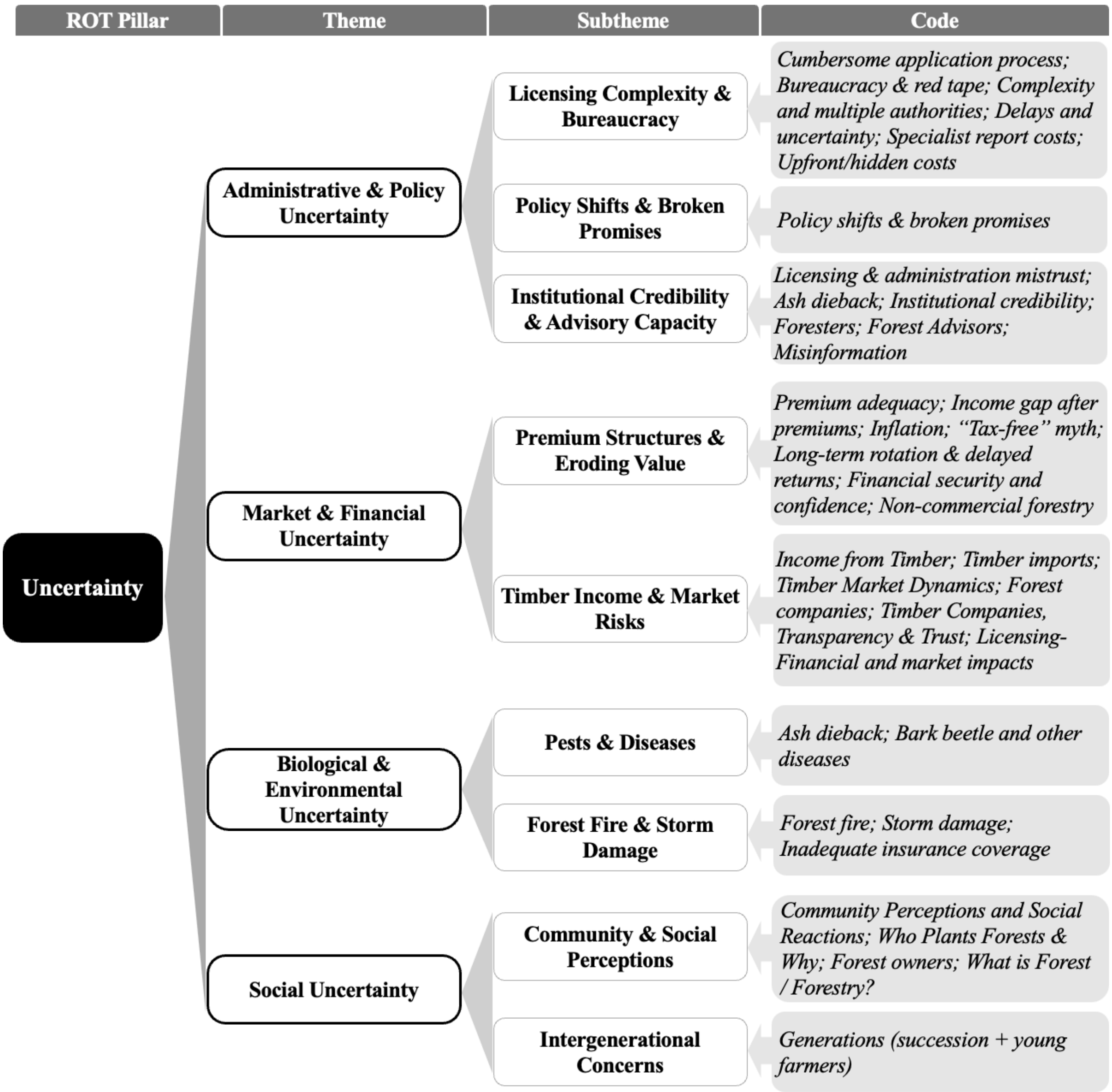
Within a Real Options framework, this socio-cultural irreversibility functions as a powerful non-financial sunk cost. The option to preserve farming identity and community standing carries immense value. Planting is perceived as extinguishing this option permanently—a loss no premium can offset.

Taken together, legal, financial, and socio-cultural irreversibilities form a triad that significantly inflates the option value of waiting by increasing the potential losses from a commitment to afforestation. For farmers, planting trees does not simply involve weighing present costs and future returns; it entails relinquishing autonomy over land, accepting permanent financial liabilities, and abandoning a deeply valued farming identity. Each dimension represents a sunk cost that extends across generations, diminishing both asset liquidity and cultural continuity. This helps explain why even generous premiums fail to offset reluctance: the real cost of planting lies not simply in foregone income but in the permanent forfeiture of flexibility, security, and heritage.

3.4.2. The Amplification of Uncertainty

While irreversibility loomed large in farmers' accounts, an equally powerful barrier to afforestation lay in the perception of uncertainty. Participants consistently characterised forestry as a gamble, vulnerable to unpredictable policy shifts, market volatilities, biological catastrophes, and social stigma. This perception stands in stark contrast to conventional farming, which operates within shorter cycles and more familiar institutional frameworks. Within a Real Options framework, such multi-dimensional uncertainties substantially increase the value of waiting rather than committing to planting. Figure 3.2 illustrates how these sources of uncertainty cluster into distinct yet interconnected themes, each amplifying farmers' perceptions of risk and reinforcing hesitation.

Figure 3.2 Coding Hierarchy for the "Uncertainty" Pillar



Note: this figure illustrates how raw interview codes were synthesised into sub-themes and broader themes under uncertainty pillar of ROT.

3.4.2.1.Policy and Administrative Uncertainty

Farmers identified policy and administrative instability as a primary deterrent to afforestation, creating a profound sense of risk and mistrust in long-term government commitments. This manifested in three interconnected areas:

(i) Licensing Complexity and Bureaucracy

The forestry licensing system was consistently described as protracted, unpredictable and costly. Obtaining approval for planting, thinning, or felling was widely perceived as a cumbersome process, involving multiple agencies, leading to lengthy delays and financial exposure from upfront costs for paper works and specialist reports that are not reimbursed if a license is denied. While a small number reported smooth approvals, the majority emphasised lengthy delays, contradictory requirements, and excessive paperwork that created financial insecurity and eroded confidence in forestry as a viable enterprise. As farmers explained,

> *It's even worse in forestry. You have to get approval from the Forest Service, and from the Regional Fisheries, and from the Bird Watch Island, and all the other statutory bodies. It takes forever. And if it's only a matter of applying for the licence, no big hassle. But all these bodies have to be consulted, and it takes forever.[F23]*

> *If you get your license, then you will get all the assessments. You get reimbursed. If you don't get your license, you're forked out.[F20]*

This intensive regulatory oversight, contrasted with other agricultural enterprises, framed forestry as a high-risk, administratively precarious investment.

(ii) Policy Shifts and Broken Promises

Farmers also highlighted the volatility of government policy as a key source of uncertainty. Frequent and sometimes retrospective changes to schemes created a climate of mistrust. Many participants referred to past experiences where policy reversals left them financially exposed or forced to change course unexpectedly.

> *Years ago, farmers were penalised for having a lot of trees… then they turned around and said, you need to plant more. And farmers are like, you told us to get rid of*

them… and now you want us to plant again. So we spend all this money to do that. [F19]

There is such a level of misunderstanding and mistrust out there… I think it started back 2014 when they changed the premiums. So it was a 20 year premium and then they brought back the premiums to 15 years… people then felt, hold on, I'm buying into something that's a permanent land use change, and halfway through, they're going to actually change the rules on us.[F20]

Such reversals reinforced the perception that any scheme could be changed, regardless of commitments already made, leaving farmers to shoulder disproportionate risks.

(iii) Institutional Credibility and Advisory Capacity

Underpinning these issues was a fundamental crisis of confidence in the institutions meant to support forestry. The Forest Service was frequently described as untrustworthy and unresponsive, with the handling of compensation for ash dieback reinforcing perceptions that state institutions were unwilling to share significant risks.

Trust has been lost… most forest owners have absolutely no faith in the Forest Service.[F23]

The way to handle the ash dieback is just deplorable as well. They're not on our side. I think it's like I sold my soul to the devil.[F6]

But in order not to set a precedent, they'll call it anything but a compensation package. It's a climate action…but that's the money that farmers are going to get, the 5,000 (Euro) per hectare has been classified under a different title so that it doesn't set a precedent because of the danger of other diseases coming in and the danger of the bark beetle coming in. [F16]

This mistrust was compounded by misinformation and limited advisory capacity. Farmers reported being misled about income (e.g., "tax free" returns) or unaware of legal replanting obligations until years after planting. Foresters were often reluctant to pursue alternatives such as agroforestry, while fewer than ten dedicated state advisors were available nationally [F24]. Together, these shortcomings reinforced the perception of a sector lacking credible, transparent, and supportive institutions.

For participants, the cumulative effect of these administrative uncertainties was to characterize forestry as a complex, volatile, and unsupported venture, which significantly raised the perceived risk of commitment.

3.4.2.2.Market and Financial Uncertainty

Beyond administration, farmers expressed deep scepticism about forestry's long-term financial viability. Harvest rotations of 35 to 150 years meant that forestry was often framed as a multi-generational investment with little relevance to current livelihood needs. Farmers consistently portrayed state supports as misaligned with the reality of long-term investment and timber markets as opaque, volatile, and structurally biased against the individual farmer.

(i) Misaligned Premium Structures and Eroding Value

The design of forestry premiums was a primary source of financial mistrust. Farmers highlighted three critical flaws that erode their value over the investment's long horizon:

The "*Income Vacuum*"[F16]: The 20-year premium period was seen as terminating far too early, ceasing long before harvest and creating a protracted period where land is "not economic reliable"[F16], and "absolutely nothing"[F13] after clearfell. This structure was seen as offering short-term income at the expense of long-term "financial security"[F1], failing to compete with continuous agricultural subsidies. The problem was acutely felt for broadleaves, with one farmer noting,

> *A 20-year premium on broadleaves is utterly inadequate... you're planting a crop that will leave you no money at the end of the day. That will require ongoing maintenance at your expense, and for which you don't get a cent from the state. [F23]*

Inflationary Erosion: The absence of index-linking was another grievance, locking farmers into fixed nominal payments while real costs and values shifted. This created great anxiety about future purchasing power, with one farmer stating,

> *I'm stuck at this rate now... what if inflation rises again to 8%, 9%, 10%? [F23]*

The "Tax-Free" Myth: Although the tax-free status of forestry income is a feature of the scheme, many farmers contested its practical value or felt misled about its scope, emphasizing that income remains subject to PRSI, USC, and other levies. This perception further deepened distrust in the official financial narrative, even when the theoretical benefit was acknowledged.

(ii) Timber Income and Market Risks

A spectrum of views on timber returns emerged from the interviews. A minority of participants, particularly forest owners, expressed strong optimism about the long-term value of timber, viewing it as a valuable, inflation-proof asset. As one noted,

> *It's an incredible financial return from timber... I think it's as an asset, you know, that's why all the investment funds are buying forestry because it's such a valuable asset.[F20]*

This perspective saw future demand for wood as a natural product ensuring its growing commodity value.

However, for the majority, this potential was overshadowed by significant market risks and structural barriers. Farmers described being price-takers in a volatile international market, where returns were a "gamble" [F19] decades in the future. The import from Scotland was seen as one of reason for drop. This inherent risk was severely exacerbated by licensing delays, which directly destroyed market value by preventing farmers from capitalizing on favourable price windows.

> *They couldn't get a license to cut it. Now the price has gone back down. [F14]*

The market was also seen as structurally underdeveloped:

> *So many of the small mills are closing or have closed… the only market we have is softwood. [F20]*

A power imbalance with large mills and forest companies fuelled distrust. Allegations of unethical practices, including under-measurement and missing loads, were common, summarised by the claim that "*People have been done out of rightful income*" [F16]. This lack of transparency and fairness framed the timber market as a hostile environment for individual landowners.

Farmers thus portrayed premiums as inadequate, eroded, and discontinuous, while timber markets were volatile, poorly regulated, and tilted toward industry actors. This combination of unreliable supports and unbalanced markets meant that for most, the potential for long-term gain was not a compelling reason to commit land, reinforcing the perception that forestry cannot be treated as a stable or bankable enterprise. This rationalises farmers' preference to wait rather than commit land to an uncertain future.

3.4.2.3.Biological and Environmental Uncertainty

Farmers perceived biological and environmental threats as catastrophic, potentially destroying decades of investment with limited recourse. These risks were uniquely potent as they represented a total loss of the asset's value and were often compounded by perceived institutional failures in risk mitigation and compensation, dramatically inflating the real option value of delay.

Pests and diseases were not merely a production risk but an existential threat to the entire investment. The ash dieback crisis served as a pivotal case study, transforming what was seen as a "*heart of rural Ireland*"[F16] into a liability and symbolizing a profound failure of state support and huge financial loss:

> *I should be expecting…35,000 to 40,000 pounds worth of (ash) butts logs. And I'm getting up to 5,000 for this.[F14]*

Others noted that many ash stands would simply be left to rot as it's financially doesn't make sense and difficult to get labour to take them out. As one farmer concluded,

> *The whole way that ash dieback has been treated has made us realise that if we plant, we're taking the risk". [F16]*

The bark beetle was seen as an even greater threat, given Ireland's reliance on Sitka Spruce, "*50, 60 percent of the national estate*"[F16]. Farmers criticised continued timber imports from Scotland as "*playing Russian Roulette*" [F14], with little confidence in port inspections or biosecurity. Farmer explained that contractual clauses could even leave farmers liable to repay grants if a plantation failed due to pests. For F16, this was existential:

> *Sitka spruce is the dairy of the forestry… if a bark beetle gets in, it would literally cut the ground from under the forestry industry.[F16]*

Together with memories of Dutch elm disease, these experiences created a cultural memory of forestry as especially vulnerable compared to agriculture.

Fires were described as devastating, sometimes malicious events that erased decades of planning overnight. One farmer recalled,

> *In 2017, my forestry was burnt… I should have been harvesting in 2026. That really destroyed my plans because it was my pension plan.[F6]*

While insurance sometimes provided relief, farmers emphasised restrictive rules (e.g. voided coverage after a limited number of claims, described as "*three strikes and you're out*" [*F6*]) and bureaucratic obstacles. One farmer reported payouts only after political intervention, reinforcing the perception of weak institutional backing.

Storms, by contrast, were viewed as unavoidable natural hazards. Farmers recounted windthrow losses in oak and Douglas fir but noted that appropriate species choice and planting design could mitigate damage. As a forest owner reflected,

> *If you plant your forests properly from the start, then wind becomes less of a damaging effect.[F20]*

The combination of existential, policy-aggravated biosecurity threats and the absence of reliable insurance or compensation for catastrophic loss frames forestry as an unacceptably risky gamble. Within an ROT framework, the high probability of a low-probability, high-impact catastrophe—coupled with the absence of a safety net—makes the option of waiting a rationally conservative strategy for risk-averse landowners.

3.4.2.4.Social Uncertainty

Beyond tangible risks, farmers also confronted significant social risks. Converting land to forestry—particularly with conifers—was often associated with community disapproval, creating fears of being stigmatised as someone who had harmed the local environment or weakened the farming fabric of rural life.

An exception is Wicklow, the county with the highest forest cover in Ireland, where a longer tradition of locally led planting has fostered stronger social acceptance [F19]. However, by contrast, in regions like Leitrim and West Cavan, resistance was especially pronounced, fuelled by past planting surges that created monoculture landscapes, cut farms off from one another, and hollowed out local economic activity [F3]. Campaigns such as *Save Leitrim* were cited as visible symbols of opposition, with roadside protests and imagery of conifers marked with red crosses [F19]. Farmers reported that even modest proposals, such as agroforestry extensions, could provoke objections from neighbours who assumed the worst:

> *I actually have an application signed up at the road here for an extension to our agroforestry, and it just raised a lot of people's attention… they're afraid I'm going to plant at the road, and when they see forestry, they only see Sitka spruce… everybody objects, it's a kind of a natural pastime for us here.[F18]*

Social uncertainty was also tied to intergenerational and distributional anxieties. Given forestry's long rotations—*"three or four generations"* [F1]— farmers expressed reluctance to make decisions that could constrain their successors:

> *You shouldn't be deciding for future generations what the land, what's done with the land. [F16]*

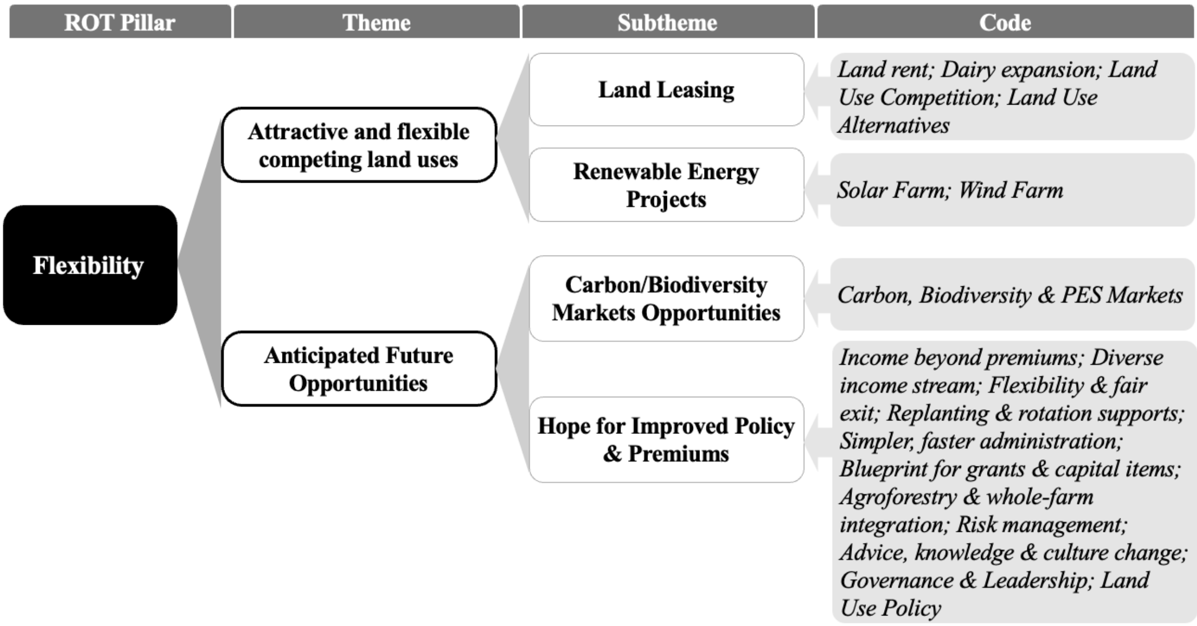
Together, these fears of community backlash and of binding future generations reinforced the perception that afforestation is socially risky, further raising the value of delaying investment.

In sum, these findings demonstrate that uncertainty in forestry extends far beyond financial returns to encompass institutional credibility, market instability, environmental vulnerability, and social acceptance. Farmers perceive afforestation not as a stable long-term enterprise but as a domain in which the "rules of the game" can change suddenly, risks are amplified across generations, and protection against loss is limited. Within the framework of ROT, such uncertainty increases the value of waiting: inaction becomes a rational form of risk management, not reluctance.

3.4.3. The High Value of Waiting

If irreversibility and uncertainty make forestry appear risky, the availability of alternative options and the anticipation of better future schemes make delay the rational choice. Farmers consistently compared forestry with other land uses—not only conventional farming, leasing, and renewable energy projects—but also with future opportunities such as carbon and biodiversity markets or reformed payment structures. Within a Real Options framework, this dual logic—preferring flexible alternatives today and preserving the option to wait for better terms tomorrow—explains why delaying afforestation is widely perceived as the most rational strategy (Figure 3.3).

Figure 3.3 Coding Hierarchy for the "Flexibility" Pillar



Note: this figure illustrates how raw interview codes were synthesised into sub-themes and broader themes under flexibility pillar of ROT.

3.4.3.1.Attractive and Flexible Competing Land Uses

For many farmers, the reluctance to afforest is not driven solely by the weaknesses of forestry itself but by the strength and flexibility of competing land-use options. Compared with mainstream agriculture, land leasing, and renewable energy projects, forestry appeared inflexible, uncertain, and financially inferior.

Tax-free leasing emerged as one of the strongest competitors to forestry, particularly in the context of dairy expansion. Farmers highlighted that 10–15 year leases to dairy farmers could generate €300–€400 per acre annually, and in some areas rents up to €700, dwarfing forestry premiums.

> *If you look at it purely economic because land rental and the income from land rental is income tax exempt. You know, so that that's actually killing forestry in a way.[F20]*

Unlike forestry, these leases preserve reversibility: land returns to the owner at the end of the contract with no replanting obligation. As one farmer observed,

> *After 10 years, you still have your land and you still have your option of what you want to do with it going forward.[F16]*

Renewable energy projects were also seen as attractive alternatives. Solar farms offered long-term but highly lucrative contracts, with farmers reporting offers of around €1,300 per acre annually. Wind turbines were also highlighted for their potential to deliver €20,000–€40,000 per turbine per year on 25-year contracts [F19, F24]. Importantly, farmers noted that these contracts did not permanently reclassify the land, and thus maintained some degree of reversibility, unlike forestry. While both solar and wind carried their own planning and community challenges, they were not associated with the same stigma or permanence as afforestation.

For many, simply retaining land in conventional farming remained more appealing than planting trees. Grassland was described as an "absolute asset" [F8], supporting flexible enterprises and benefitting from continuous Common Agricultural Policy (CAP) supports beyond any fixed period. Even when profits were modest, farming was viewed as a flexible, reversible land use that maintained both income and identity.

By contrast, afforestation schemes provided establishment grants and 20 years of premiums averaging €746–€1,142 per hectare (€300–€462 per acre). While thinning and final harvest revenues may materialise decades later, farmers repeatedly highlighted the "income vacuum" that follows the expiry of premiums, alongside permanent land reclassification, replanting obligations, and reduced asset value. Compared with alternatives that deliver higher, more predictable, and reversible income streams, forestry was rationalised as an inferior option.

Within the Real Options framework, this comparative landscape explains why the opportunity cost of committing to forestry is exceptionally high: planting trees not only generates uncertain returns but forecloses a portfolio of more attractive, reversible alternatives.

3.4.3.2.Awaiting Future and Better Options

Alongside competing land uses, many farmers expressed a desire to wait for improved forestry schemes, new markets, or institutional reforms before committing their land. This reflects the core logic of ROT: when commitments are irreversible and uncertainty is high, it is rational to delay investment until conditions become more favourable.

Farmers spoke enthusiastically about the potential of carbon and biodiversity credit markets, as well as broader Payments for Ecosystem Services (PES) schemes. While most acknowledged these markets are still in their infancy, many anticipated that credible, well-regulated systems could transform forestry into a viable enterprise.

> *There needs to be, I would believe, a financial mechanism in place in order to tell farmers "While you're being paid premiums for forestry standalone for a period of time, if you maintain that long-term taking land out of agricultural production for social good and for the deliverability of biodiversity, then it needs to be a kind of a new mechanism of payments in place for biodiversity good." [F1]*

> *(Carbon/biodiversity credit) that's what would really bring in forestry in a major way. If people could see this. Even let it be that the deciduous or whatever trees, they want to plant more nature's trees.[F14]*

This sense of waiting for credible PES schemes illustrates how farmers treat forestry as an option that may become more attractive in the future.

Alongside market innovations, farmers proposed a blueprint for policy reform. Central demands included long-term, index-linked payments to reflect forestry's permanence, equal grants for replanting and first planting, and reconstitution supports for losses from fire or disease. Some suggested tiered contracts—higher subsidies tied to permanence versus lower payments with exit options after one rotation. Calls also focused on governance reforms: a dedicated forestry minister, streamlined licensing, faster approvals, upfront payments, and simplified grant processes. Risk-management supports (e.g., biosecurity subsidies, fire prevention technologies) and expanded advisory capacity, including peer-to-peer learning, were also prioritised.

In this light, current hesitation is less a rejection of forestry than a calculated decision to wait for better terms. By deferring planting, they preserve optionality in the face of uncertain credit markets, inadequate supports, and inflexible obligations. From their perspective, afforestation today risks locking into an unattractive contract, whereas tomorrow may offer diversified revenues, stronger guarantees, and fairer governance.

3.5. Discussion

This study set out to resolve a central paradox in Irish land-use policy: the persistent reluctance of farmers to afforest land despite seemingly favourable financial incentives. The findings of this study suggest a different interpretation. Reluctance is not evidence of irrational behaviour or cultural barriers but the outcome of a rational calculus that assigns high value to the option of waiting under conditions of profound irreversibility, uncertainty and opportunity costs. Within a ROT framework, the Irish case illustrates how option values are "inflated" along three dimensions: (i) extreme irreversibility, encompassing legal permanence, replanting obligations, and cultural stigma; (ii) pervasive uncertainty, including policy volatility, market risks, ecological threats, and social disapproval; and (iii) the presence of abundant, flexible alternatives such as leasing and renewables. Together, these features make delay not only understandable but strategically optimal.

3.5.1. The Limitations of the NPV Paradigm and the Rationality of Delay

The interviews underline the inadequacy of the NPV paradigm, which fails to account for the option value of waiting in the face of irreversible and uncertain afforestation decisions.

The problem is categorical: NPV treats afforestation as a static capital investment (Dixit & Pindyck, 1995; Trigeorgis, 1996), whereas farmers perceive it as an irreversible commitment that competes with more flexible, reversible options. Rather than comparing the NPV of forestry against that of agriculture, farmers intuitively weigh the value of two real options: the option to plant immediately versus the option to defer and retain flexibility. The findings demonstrate that the latter option is rationally valued more highly because its payoff structure is far more robust to the spectrum of uncertainties identified.

This reinterpretation resolves the paradox of low uptake despite seemingly generous premiums. The hurdle rate for forestry is not defined solely by discounted cash flows but by the combined effect of irreversibility and uncertainty. When these are high, as in Ireland, the rational threshold for investment rises beyond what current schemes can offer. Farmers' behaviour thus reflects rational risk management rather than cultural conservatism.

3.5.2. The Sunk Cost Multiplier: Legal and Socio-Cultural Irreversibility

The findings on irreversibility demand a theoretical extension of traditional ROT. Financial sunk costs —such as forgone agricultural returns or land devaluation—are only part of the picture. The qualitative data reveals that irreversibilities are not additive; they are multiplicative, creating a collective barrier far greater than the sum of its parts.

At the core lies legal-administrative irreversibility: the permanent reclassification of land to forestry and the statutory replanting obligation, both of which have been highlighted in earlier Irish studies as critical deterrents (Wiemers & Behan, 2004; Ryan & O'Donoghue, 2016; Breen et al., 2010). This legal lock-in acts as the enforcement mechanism for all other sunk costs, removing future flexibility and binding subsequent generations. Crucially, it also magnifies socio-cultural irreversibility: the perceived loss of farming identity and social standing (Burton, 2004; Silvasti, 2003). It transforms a subjective cultural concern into an objective, economically relevant reality: the identity of "farmer" is not just threatened but legally extinguished for future generations.

The "productivist identity" prized in the behavioural literature (Burton & Paragahawewa, 2011) is not merely an attitude; it is an asset that generates a flow of cultural and social capital. Afforestation, due to its legal permanence, necessitates the complete divestment of this asset. Therefore, the premiums are not just "*payment for income foregone on the land that you put into forestry for the 20 years*"[F16], but also as an attempt to offset the social and cultural costs of exiting farming. Current schemes undervalue this, explaining why they repeatedly fail to clear farmers' adoption threshold. Within the ROT framework, irreversibility therefore acts as a "sunk cost multiplier," inflating the option value of waiting and making delay the rational strategy.

3.5.3. Institutional Credibility as a Missing Parameter in ROT

Most applications of ROT in forestry, model stochastic timber prices or input costs (Plantinga, 1998; Insley, 2002; Gjolberg & Guttormsen, 2002). Yet in the Irish case, the dominant uncertainties were institutional. Farmers repeatedly emphasised that risks came from the state: licensing delays, retrospective scheme changes, inadequate responses to ash dieback and inadequate capacity (Phillips, 1999; Ryan & O'Donoghue, 2016; Irwin, 2022; Rafiee et al., 2025). The state—usually assumed to be a stabilising partner—was treated as an unreliable counterparty. Promises of support were heavily discounted, as past reversals had shown that policy commitments could not be relied upon.

This positions institutional credibility as a stochastic variable in its own right, one that directly inflates the option value of waiting. In ROT terms, the state becomes a source of volatility rather than a mitigator of risk. Farmers' reluctance is thus not only a reaction to uncertain markets or pests, but also to policy instability and bureaucratic opacity. This extends prior ROT applications in forestry (e.g., Wiemers and Behan, 2004; Regan et al., 2015), which typically focus on timber price dynamics, by demonstrating that governance quality can be as decisive as biophysical uncertainty in shaping adoption thresholds.

3.5.4. Behavioural Theories as Inputs to the ROT Calculus

Behavioural models such as the Theory of Planned Behaviour and identity-based accounts have shown how attitudes, norms, and identity constrain afforestation (O'Leary et al., 2000; McDonagh et al., 2010; Howley et al., 2012; Rafiee et al., 2025; Irwin, 2023). The study findings confirm these dynamics but also reframe them: they are not departures from rationality but inputs into the option calculus itself.

Subjective norms—for example, the widespread view that "forestry is giving up farming"—constitute socio-cultural irreversibility: once planted, farmers lose not only land flexibility but also social standing. Attitudes about the value of farming life reinforce the perceived sunk costs of exit. Perceived behavioural control, meanwhile, is eroded by licensing bottlenecks, advisor shortages, and opaque schemes—factors that directly inflate institutional uncertainty (Rafiee et al., 2025).

In this way, behavioural variables are not separate from economic rationality but integral to it. ROT provides the integrative framework: cultural stigma, identity, and social pressure amplify irreversibility, while mistrust, misinformation and bureaucracy delays magnify uncertainty. The option value of waiting thus incorporates both financial and socio-cultural parameters. Behavioural insights do not contradict ROT; they extend and contextualise it. At the same time, ROT provides the underlying economic rationality that explains why certain attitudes and norms form and persist. It answers the "why" behind the "what" described by behavioural models.

3.5.5. The Land Portfolio: Managing a Suite of Competing Real Options

Perhaps the clearest evidence for the rationality of delay is that farmers do not evaluate afforestation in isolation. They act as portfolio managers, weighing forestry against a spectrum of other land-use options with different risk–return–flexibility profiles. This contrasts sharply with the static, single-project perspective of NPV and even with much of the ROT literature, which often models afforestation as a binary switch (Wiemers & Behan, 2004; Ryan & O'Donoghue, 2016; Breen et al., 2010).

In this portfolio framework, forestry emerges as structurally disadvantaged as showed in Table 3.2. Conventional farming and leasing provide steady or tax-advantaged income streams while maintaining reversibility and high land values. Renewable energy projects, though long-term, offer exceptionally high returns with only moderate irreversibility, as land can often revert to agriculture after contract expiry. By contrast, forestry combines low and delayed returns with extreme irreversibility—legal permanence, replanting obligations, and identity loss—making it the least attractive option in the set.

This comparative logic is central to the option value of waiting. Farmers will not exercise the forestry option until its expected payoff clears a much higher hurdle: not only must it outperform agriculture, but it must also exceed the opportunity value of leasing and renewables. Current schemes fall far short of this benchmark, which explains why "generous premiums" have failed to shift behaviour. The rational strategy is therefore to delay, preserving the more flexible, lucrative, and reversible options in the portfolio while awaiting future policy reforms or new markets (e.g., carbon credits) that might rebalance the calculus.

Table 3.2 Comparison of Land-Use Options in Ireland

Land-use option	Typical annual income	Duration & timing of returns	Flexibility & reversibility	Land sale values
Conventional farming (status quo)	Variable; based on the 10-year average of family farm income across all farm enterprises, €596/ha (€241/acre) (Teagasc National Farm Survey, 2014–2024).	Annually	High	€10,000-€18,000/acre [F3, F8, F14, F18,]
Leasing	€300–€700/acre, tax-free [F15, F22]	Variable, typically 10 years	High	€10,000-€18,000/acre [F3, F8, F14, F18,]
Solar farm	~€1,300/acre[F15]	25-40 years	Moderate (land reverts after contract, though infrastructure removal required)	Not reported
Wind farm	~€25,000-€40,000/turbine, index linked [F19, F24]	25 years	Moderate (land remains usable for grazing)	Not reported
Forestry	Premiums €746–€1,142/ha (€300–€462/acre) for 20 years (DAFM, 2024b); thinning at ~20 years; harvest after 35–100+ years	40-100+ years	Very low (permanent redesignation to forest land)	€5,000/acre [F8]

Note: this table presents a synthesis of farmers' perspectives from interviews. Figures are approximate, context-dependent, and intended to illustrate relative differences rather than precise financial returns. The reported 10-year average Family Farm Income refers to the national average across all farm enterprises, calculated from annual data in the Teagasc National Farm Survey (2014–2024), though actual returns vary substantially by enterprise and year. No interview data were available on land sale values for solar and wind projects.

3.6. Conclusion

This paper set out to explain the persistent reluctance of Irish farmers to afforest their land despite decades of ostensibly generous financial incentives. Drawing on interviews with 24 farmers and interpreted through the lens of ROT, the study demonstrates that reluctance is not a failure of rationality, but its expression. Farmers logically assign high value to the option of waiting in the face of profound irreversibility, pervasive uncertainty, and abundant competing land-use alternatives.

Three key insights emerge. First, legal and socio-cultural irreversibilities constitute sunk costs of extraordinary magnitude. The permanent reclassification of land, statutory replanting obligations, and the symbolic loss of farming identity together transform afforestation into an intergenerational lock-in that far outweighs short-term incentives. Second, uncertainty extends far beyond timber prices to include policy instability, licensing bottlenecks, ecological risks such as ash dieback and bark beetle, and the fragile credibility of state institutions. These risks are perceived as uninsurable and unpredictable, inflating the rational value of delay. Third, farmers view their land not as a single decision but as a portfolio of competing options. Compared to leasing, renewables, or conventional farming, forestry is perceived as uniquely inflexible and financially inferior, with future opportunities in carbon and biodiversity markets making deferral even more attractive.

By integrating behavioural insights on identity and norms with ROT's economic logic of irreversibility and uncertainty, this study advances both theory and policy. Theoretically, it extends ROT beyond market volatility to incorporate institutional credibility and socio-cultural irreversibility as critical drivers of option value. Methodologically, it demonstrates the value of qualitative inquiry in revealing how farmers themselves perceive and calculate these trade-offs. Empirically, it situates Ireland as a critical case of how high irreversibility and uncertainty can undermine even the most generous incentive schemes.

The policy implication is clear: raising premiums alone will not close the afforestation gap. What is required is a fundamental shift from purely financial incentives to option structure engineering—systematic reforms to mitigate irreversibility, reduce uncertainty, and enhance flexibility. Based on farmer perspectives, three priorities stand out:

1) Mitigating irreversibility. At the core lies legal-administrative irreversibility. Farmers proposed reversible contracts, such as opting for a lower subsidy with the right to exit after one rotation or a higher subsidy in exchange for permanence. Replanting obligations could be reformed with derogations in certain contexts (e.g., native woodland on marginal soils), restoring some element of choice. Equally, communication strategies should reposition forestry as "farming trees"—a form of diversification rather than abandonment of agriculture—helping to reduce the socio-cultural irreversibility tied to identity loss.

2) Reducing uncertainty. Stability and predictability are essential if forestry is to be viewed as a credible investment. Policy should therefore establish legally binding timelines for licence decisions, extend payments for longer-rotation species, and index-link premiums to inflation to preserve their real value. Robust, state-backed insurance schemes for pests, diseases, fire, and storm damage would further reduce exposure to risks that currently fall entirely on landowners. Together, these measures would signal the state's commitment to sharing risk and provide the predictability needed for long-term investments.

3) Creating value now. Finally, policy needs to ensure that forestry is more attractive today than the option of waiting for future markets or reforms. At present, the rational choice for many farmers is to defer, preserving optionality in the face of immature carbon and biodiversity credit systems. To change this calculus, government should accelerate the development of functioning ecosystem markets that provide farmers with tangible and tradable revenues. Equally, forestry supports should be bundled with other measures—such as renewable energy or organic farming schemes—so that planting trees becomes part of a diversified portfolio of resilient farm incomes. By delivering credible, accessible, and immediate value, such reforms would help make the forestry option more compelling than the default strategy of delay.

This study offers a rich qualitative account of Irish farmers' decision-making, yet its insights are not statistically generalisable. While the sample was diverse and achieved thematic saturation, it does not represent the full population of Irish farmers. A fundamental characteristic of this research is its explicit centring of the farmer's perspective. While this focus is critical for understanding the primary agents of land-use change, it inherently captures a single stakeholder viewpoint within the broader afforestation socio-ecosystem.

Consequently, the analysis reflects the subjective perceptions of farmers, which may incorporate inaccuracies or an incomplete awareness of recent policy evolutions and institutional initiatives designed to enhance support mechanisms. The recruitment methodology, reliant on volunteer participation, may have compounded this by introducing a self-selection bias. This approach can disproportionately attract individuals with strongly held convictions—either favourable or adversarial—towards afforestation, potentially marginalising the perspectives of those with neutral or moderate stances.

Notwithstanding these constraints, the application of purposive and maximum variation sampling ensured the inclusion of a diverse spectrum of farm enterprises and farmer profiles. Therefore, the contribution of this work should be interpreted as an in-depth, interpretive elucidation of the internal decision-making calculus of farmers, rather than an evaluative assessment of national afforestation policy efficacy. Future research could advance this agenda in four directions: (i) a large-scale survey to systematically measure farmers' perceptions of irreversibility, uncertainty, and willingness to plant, providing empirical validation of the option values identified in this study; (ii) formal ROT modelling to quantify option values—for example, by assigning probabilities to policy reversals—and explore ways to monetise socio-cultural sunk costs through discrete choice experiments or WTA studies; (iii) longitudinal research to capture how decisions evolve over time, particularly as new opportunities such as carbon or biodiversity markets mature; and (iv) comparative research across EU jurisdictions to shed light on the role of institutional design in shaping adoption—for example, whether Ireland's land reclassification rules explain its persistent underperformance relative to countries with more flexible frameworks.

In short, the paradox of Irish afforestation is not a failure of farmer rationality but a failure of policy design. Farmers are exercising the real option to wait because current schemes offer too little security, too little reversibility, and too few benefits compared to competing land uses. Recognising and addressing this option logic is essential if afforestation is to move from aspiration to reality, both in Ireland and in other jurisdictions grappling with similar challenges of land-use change under uncertainty.

Chapter 4 Valuing the Invaluable: a Review of Economic Valuations of Forest Biodiversity

Abstract

As global biodiversity declines at alarming rates, understanding its economic value is critical for mobilizing conservation action and designing effective policy tools. I present a systematic literature review and meta-analysis focused exclusively on the economic valuation of forest biodiversity, synthesizing evidence from 93 studies and 265 valuation observations worldwide. The analysis reveals substantial conceptual fragmentation and methodological diversity. Studies vary widely in how biodiversity is defined and measured, and rely on diverse valuation methods, with stated preference methods, particularly willingness to pay surveys, dominating the field. This meta-regression results show that valuation outcomes differ significantly across contexts and measurement scales: per-hectare valuations vary markedly with socio-economic, ecological, and methodological factors, while per-person valuations do not. Bridging the gap between ecological definitions of biodiversity and its economic valuation is essential to produce meaningful estimates that can guide conservation strategies, policy decisions, and innovative tools such as biodiversity credits. Only through interdisciplinary approaches can economic valuation effectively contribute to achieving global biodiversity goals.

4.1.Introduction

Biodiversity loss has emerged as one of the most critical environmental challenges of our time, threatening ecosystem stability and human well-being (Dirzo & Raven, 2003; Barnosky et al., 2011; Ceballos et al., 2015). Scientific evidence indicates that human activities are driving a rapid acceleration in species extinctions, raising concerns of a potential sixth mass extinction (Barnosky et al., 2011; Ceballos et al., 2015). In response, global policy efforts have intensified, exemplified by the Kunming-Montreal Global Biodiversity Framework and the EU's Nature Restoration Law, which aim to halt biodiversity decline by 2030 and beyond (CBD, 2022; European Union, 2024).

Alongside these policy advances, corporate and financial sectors have increasingly recognized the significance of biodiversity, reflected in emerging frameworks such as the

Corporate Sustainability Reporting Directive (CSRD), the Taskforce on Nature-related Financial Disclosures (TNFD), and the Science Based Targets Network (SBTN). These initiatives seek to integrate nature-related risks and dependencies into financial decision-making and promote standardized biodiversity reporting. Public awareness has also grown markedly; for example, the Union for Ethical Biotrade (UEBT) reported that awareness of biodiversity rose from 29% in 2009 to over 72% in 2022 across six surveyed countries, based on the question of whether the participants had heard of biodiversity and if they could select the correct definition (UEBT, 2022).

Forest ecosystems, covering approximately 31% of the global land area, are crucial for maintaining terrestrial biodiversity and sustaining critical ecological processes such as nutrient cycling, climate regulation, soil stabilization, and hydrological balance (FAO, 2022; Hilton-Taylor et al., 2009). Beyond their ecological significance, forest biodiversity has profound socio-economic and cultural value. Many indigenous and local communities depend directly on forest biodiversity for livelihoods, traditional knowledge, and cultural identity. Biodiversity-rich forests also support industries like sustainable forestry, ecotourism, and the bioeconomy, contributing to economic development and poverty alleviation (CBD, 2022; Colfer & Byron, 2001).

Despite this, biodiversity often remains undervalued in economic and policy decisions. Many of its benefits are non-market in nature and lack explicit monetary representation, and they are often poorly understood or under-appreciated by non-experts. As a result, efforts to protect, restore or prevent further biodiversity loss are frequently underfunded. Economic valuation offers a means to translate the ecological and social importance of biodiversity into terms that can inform the development of robust and relevant biodiversity conservation policies, guide investment decisions, and support innovative financial mechanisms, such as biodiversity credits and conservation finance (WEF, 2022) and targeted governmental incentives to support biodiversity protection. This valuation is especially crucial for forest ecosystems, where pressures from deforestation, land conversion, and climate change continue to threaten biodiversity and the ES upon which human societies depend. In this study I aim to highlight the need for a more consistent and comprehensive framework for defining, measuring, and economically valuing forest biodiversity.

Valuing biodiversity economically is inherently complex. Biodiversity is a multifaceted concept that encompasses the variability among living organisms at genetic, species, and ecosystem levels (UN, 1992). Ecological science provides rigorous taxonomies of biodiversity and, in the case of forests, identifies a range of specific indicators, such as forest bird diversity, as well as structural features including the presence of deadwood, vertical stand structure, and tree age distribution, all of which reflect habitat complexity and ecological integrity (Gregory et al., 2005; D. Edwards et al., 2012; Gao et al., 2015; Nordén et al., 2017). However, these taxonomies are seldom used to represent biodiversity in economic valuation studies, rather, biodiversity is represented using specific indicators or is presented as a general concept which is not linked to specific ecological metrics (Bartkowski et al., 2015; Farnsworth et al., 2015). This approach is based on the need for comprehensibility among non-expert respondents, and while it facilitates broader participation, it limits ecological specificity.

In terms of valuation methods used, various approaches exist to quantify the economic value of biodiversity, encompassing both market-based and non-market valuation methods. Among the most commonly used methods; direct market valuation, revealed preferences, stated preferences, and benefit transfer, the stated preferences approach has become the most widely used for biodiversity valuation (Atkinson et al., 2012; Bartkowski et al., 2015; Nijkamp et al., 2008). Stated preference method involves directly asking respondents to assign a monetary value to an environmental attribute or service, or to rank them based on preferences. Therefore, the effectiveness of stated preferences hinges significantly on respondents' familiarity with and understanding of biodiversity, and faces considerable challenges due to its subjective nature (Atkinson et al., 2012; Bateman et al., 2008; Nunes & van den Bergh, 2001b).

This study addresses several critical gaps in the understanding of how forest biodiversity is being economically valued by conducting a SLR and meta-analysis, synthesizing evidence from 93 studies, yielding 265 individual value estimates related to forest biodiversity. Specifically, I examine how forest biodiversity is defined and conceptualized in economic valuation studies; analyse the biodiversity indicators employed; review the valuation methods used; and identify key factors influencing valuation outcomes through a meta-regression analysis focused specifically on forest biodiversity values.

This review reveals considerable conceptual fragmentation in the literature: despite some studies incorporating multiple forest-specific biodiversity indicators to offer a more nuanced and ecologically grounded perspective, most valuations still rely on simplified or abstract proxies that fail to capture biodiversity's complex ecological attributes. I find that 71% of studies use stated preference methods, predominantly choice experiments which focus on the public's willingness to pay, with an underrepresentation of other stakeholder groups. This focus reflects the perceived importance of capturing societal preferences to justify conservation investments but relies on respondents having sufficient ecological literacy to form well-developed preferences. The meta-regression results demonstrate that valuation outcomes vary significantly by scale and context. Per-person valuations, which are dominated by stated preference methods, demonstrate little association with local ecological or socioeconomic conditions. In contrast, per-hectare valuations use a wider variety of valuation methods and are associated with factors such as national income, population density, forest biome type, forest size, valuation method, and the choice of biodiversity indicators. I also identify a bias in the geographic focus of the studies, with a marked underrepresentation of studies focused on Africa or South America.

The remainder of the paper is structured as follows: Section 4.2 describes the systematic review and meta-analysis methodology. Section 4.3 presents the literature review findings. Section 4.4 explains the econometric models and shares the meta-analysis results. Section 4.5 discusses these findings within the broader environmental economics context. Finally, Section 4.6 concludes the paper and suggests avenues for future research and policy development.

4.2. Data and Methods

While many economic valuation reviews analyse a diverse array of indicators and valuation methods for biodiversity valuation (Nunes & van den Bergh, 2001; Nijkamp et al., 2008; Bartkowski et al., 2015; Farnsworth et al., 2015), they focus on a broad range of ecosystems rather than focusing specifically on forests. Ojea et al. (2010) conducted a meta-analysis focused on forest biodiversity but relied primarily on just two broad indicators—the number of IUCN-listed species and the number of IUCN Red List species—thus offering only a limited perspective on the diversity of indicators used in economic valuation studies. Previous meta-analyses have explored how socioeconomic variables, ecosystem characteristics, and methodological choices affect ES valuation results (Nelson & Kennedy, 2009; Chiabai et al., 2011; Ratisurakarn, 2019; Taye et al., 2021; Grammatikopoulou &

Vačkářová, 2021), but limited attention has been paid to biodiversity as a specific valuation target within forest ecosystems. Consequently, there remains a critical gap in our understanding of how biodiversity is operationalized in forest valuation contexts, whether it reflects the ecological realities specific to forest ecosystems, what valuation methods are being applied, the challenges that they face, and how valuations vary across contexts, biomes, indicators, and valuation methods. Addressing this gap is essential to ensure that economic valuations of forest biodiversity provide ecologically meaningful, representative, methodologically-robust, and policy-relevant estimates for forest biodiversity conservation.

To address my research questions, I conducted a SLR, a method recognized for its rigor in synthesizing all relevant evidence according to pre-defined eligibility criteria (Higgins et al., 2019) of economic valuation studies related to forest biodiversity. This was followed by a meta-analysis, a quantitative synthesis technique that integrates results across studies using both market-based and non-market-based valuation approaches (Nelson & Kennedy, 2009; Chiabai et al., 2011; Ratisurakarn, 2019; Taye et al., 2021; Pisani et al., 2022; Hassin et al., 2024). This allowed us to identify the key factors influencing economic valuations of forest biodiversity and quantify the relative contributions of country-level, ecological, and methodological variables to observed variations in monetary valuation outcomes across studies. This combined approach allowed us to explore how forest biodiversity is economically valued across diverse contexts and methods.

4.2.1. Defining Biodiversity in Valuation Studies

Biodiversity is a multifaceted concept which both shapes and is shaped by ecosystem dynamics, influencing ecological processes, resilience, and the delivery of ES (Mace et al., 2012; Brockerhoff et al., 2017). In the context of economic valuation, the relationship between biodiversity and ES remains conceptually complex and contested. Some consider biodiversity as the foundation of all ES (Brockerhoff et al., 2017), while others consider biodiversity to be in itself an ES (Lele et al., 2013), and others again consider whether it should be seen as both an enabler of ecosystems as well as having 'intrinsic value' (Díaz et al. 2006). Many valuation studies implicitly treat biodiversity and ES as distinct but interrelated dimensions of environmental management (Daily, 1999; Balvanera et al., 2001; Singh, 2002; Chan et al., 2006; Mertz et al., 2007). Given this diversity of perspectives, there remains a lack of systematic understanding of how biodiversity is framed in economic valuation practice, whether primarily as a standalone concept or integrated within broader ES frameworks.

This conceptual diversity poses challenges for systematically identifying and comparing studies that specifically value biodiversity. Recognizing this complexity, I adopt an inclusion strategy which is aligned with the approach proposed by Bartkowski et al. (2015). Bartkowski and colleagues argue that proxies used in valuation studies should directly capture biodiversity attributes, rather than broader environmental concepts such as wilderness, general nature conservation, or undifferentiated ES. Accordingly, I included only studies that explicitly stated that their aim is to value biodiversity. This approach allowed us to analyse how biodiversity is conceptualized, framed, and measured in economic valuation studies without imposing strict taxonomic or ecological thresholds that might unduly restrict the evidence base.

4.2.2. Systematic Literature Review

For the purposes of this study, I considered a publication to be a forest biodiversity valuation study if it explicitly stated that its aim is to estimate an economic value for biodiversity within terrestrial forest ecosystems. This operational definition guided the search strategy and inclusion criteria.

I followed rigorous procedures for search, selection, and data compilation. This review combined searches of specialized environmental valuation databases with keyword-based searches of multidisciplinary academic literature. The SLR aimed to ensure comprehensive coverage of valuation studies conducted across diverse geographic contexts, valuation methods, and forest ecosystem types.

4.2.2.1.Data Sources and Timeframe

I extracted data from four primary sources. Three were dedicated environmental valuation databases widely used in ES research: the Environmental Valuation Reference Inventory (EVRI) (P. De Civita et al., 2023), the Ecosystem Services Valuation Database (ESVD) (Brander et al., 2023), and the Economics of Ecosystems and Biodiversity (TEEB) value database (Van der Ploeg & de Groot, 2010). The fourth source was the Web of Science (WoS) platform, which provided access to a broader set of peer-reviewed academic publications.

These sources together offered extensive coverage of valuation studies across different regions and valuation contexts. All databases were accessed as of May 2025. However, ESVD only includes papers up to 2023, and the TEEB database was last updated in 2010 and subsequently discontinued.

The timeframe for this SLR began with the release of the Millennium Ecosystem Assessment in 2005 (MEA), a landmark moment that spurred major interest in ES valuation (Acharya et al., 2019; Bateman et al., 2013; Fisher et al., 2009; Gómez-Baggethun & Martín-López, 2015).

4.2.2.2.Inclusion and Exclusion Criteria for Biodiversity Valuation Studies

I imposed the following specific inclusion and exclusion criteria:

- Only studies explicitly valuing forest biodiversity were included. General or aggregated valuations of forests (e.g., undifferentiated forest conservation benefits or total economic value) were excluded unless biodiversity was explicitly identified as a valuation focus, as these may include values not explicitly related to biodiversity such as carbon sequestration, water regulation, or recreation.

- Only studies using economic valuation methods, presenting valuations in monetary terms were included. Studies based solely on non-monetary valuation methods (e.g., qualitative/ordinal assessments or scoring techniques) were excluded. Studies using quantitative methods but reporting no significant biodiversity-related results were excluded.

- Only studies of terrestrial forest ecosystems were included. Valuations focusing on mangrove forests, kelp forests, urban forests, or agroforestry systems were excluded due to fundamental differences in ecosystem structure, biodiversity function, and valuation context.

- For studies conducted in mixed landscapes, only those where forests constituted at least 70% of the study area were included. Studies that lacked data on forest proportion or where forests were a minor component were excluded.

- Studies focused on related but distinct concepts that do not contain any mention of biodiversity, such as habitat provision, genetic resources, wildlife conservation, non-use value or option value, were excluded. While these elements may form components of biodiversity, their meaning and scope often differ and could not be assumed to align. For example, Rajiv Pandey et al., (2024) distinguished habitat services from biodiversity services.

- Only peer-reviewed journal articles published in English between 2005 and 2025 were included.

These criteria allowed for the inclusion of studies with varied methodological approaches and valuation frameworks, while maintaining conceptual coherence in the treatment of biodiversity.

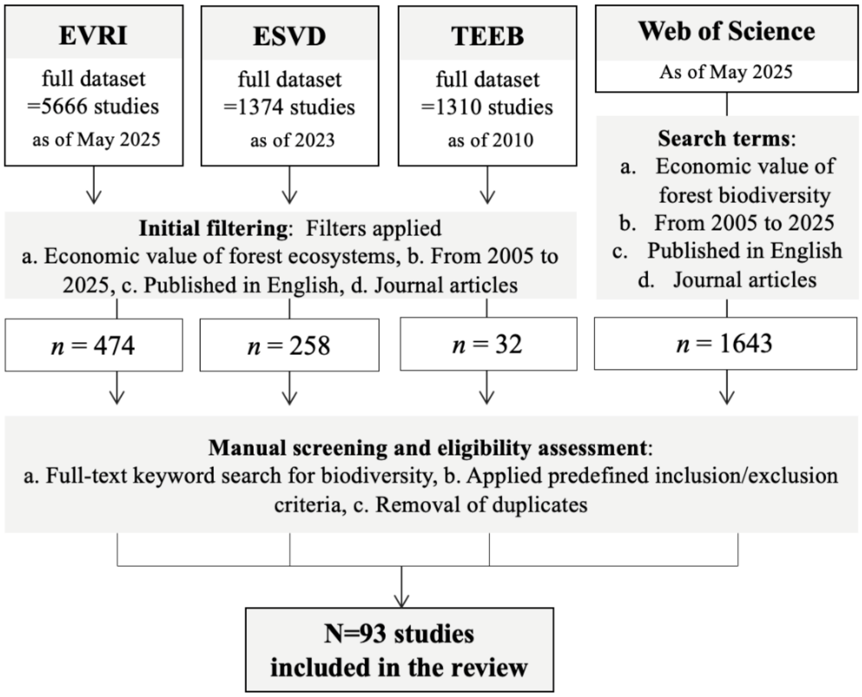
4.2.2.3.Literature Selection and Screening Process

The literature screening and selection process followed several sequential steps. First, I downloaded the full datasets from three valuation databases; EVRI, ESVD, and TEEB, and conducted a keyword search using WoS, all as of May 2025. I applied initial filtering using four basic criteria: (a) relevance to valuation in forest ecological zones, (b) publication date between January 2005 and May 2025, (c) published in English, and (d) publication as a peer-reviewed journal article. Appendix Table C1 lists the specific filters and search terms applied across each source. This step yielded a total of 764 studies from the three databases and 1,643 studies from WoS, giving an initial pool of 2,407 studies.

Next, I conducted a full-text keyword search using the term "biodiversity" across all 2,058 studies, to identify whether an economic valuation of biodiversity was present. If biodiversity in terrestrial forest ecosystems was found to be directly valued it was included, applying the inclusion and exclusion criteria specified in Section 2.1.2, and duplicate entries were excluded.

The final dataset comprised 93 studies, as listed in Appendix Table C2, that met all criteria and formed the basis for subsequent data extraction and analysis. Figure 4.1 illustrates the screening process and study selection flow.

Figure 4.1 Literature Screening Process



Note: this figure illustrates the key stages of the SLR. There is no specific filter for biodiversity in EVRI, ESVD and TEEB, therefore the initial filter included economic valuations of forest ecosystems, which was followed by a manual screening for biodiversity. For the WoS the initial search terms included economic value of forest biodiversity.

4.2.3. Database Compilation and Standardization

Following the screening and selection of relevant studies, I systematically compiled economic valuation data from the final pool of 93 studies into a unified database for analysis. Across these studies, I extracted a total of 265 valuation observations, reported in diverse monetary units, spatial scales, and temporal frames. To enable meaningful comparison and subsequent meta-regression modelling, extensive standardization procedures were applied.

Valuation estimates were originally reported using six distinct units: per hectare per year (35 studies), per household per year (27 studies), per person per year (21 studies), per hectare (lump sum, 7 studies), per visit (6 studies), and as one-time per-person payments (1 study). For studies reporting values on a per-household basis, conversions to per-person values were performed using average household sizes derived directly from the study data where available, or, alternatively, from external demographic sources such as the World Bank or from the relevant national statistical offices. Seven studies reported per-hectare values as lump sums without specifying an annual basis; these values were annualized using a perpetuity formula with a 2% discount rate. Observations reported as per-visit payments, or as one-time per-person payments were retained in the descriptive analysis but excluded from regression modelling due to their limited frequency and lack of comparability to annualized values.

Currency conversions were systematically conducted to ensure consistency across studies reporting values in 26 different currencies and 23 currency years. All values were first expressed in their respective local currencies where not already reported. For studies lacking local currency reporting, original exchange rates provided by the studies were used where available; otherwise, external exchange rates from Exchange-Rates.org were applied. Inflation adjustments were performed using the International Monetary Fund (IMF) GDP deflator series to update all monetary values to constant local currency terms for the base year of 2024. Subsequently, all values were converted into International Dollars (Int$) for 2024, using IMF purchasing power parity (PPP) conversion factors.

Several data issues required additional standardization approaches. In cases of ambiguous currency-year reporting, the survey year was adopted as the currency year where it was reported. If the survey year was unavailable, the year preceding the paper’s receipt date was used as a proxy.

Notably, 12 studies reported negative values. Four studies indicated negative values representing a WTA lower compensation for biodiversity improvements, while another 4 studies reported negative WTP values associated with biodiversity losses; these were treated as positive values reflecting the implicit positive valuation of biodiversity. The remaining 4 studies (5 observations) explicitly indicated negative WTP values for biodiversity improvements, which were retained as negative values in the analysis.

Several studies reported diverse values within the same study, arising from different scenarios, stakeholder groups, valuation methods, regression models or measurement units. In these cases, each distinct valuation result was recorded separately in the database, acknowledging that each represents a unique valuation of forest biodiversity under specific conditions or perspectives. Multiple valuation estimates also arose in studies employing choice experiment methods, where WTP values were reported for multiple attributes describing different dimensions of forest biodiversity (e.g., WTP for habitats of protected and endangered species, for specific plant and animal species, or for structural and landscape diversity of forests). In these instances, an aggregated approach was adopted to derive a single representative biodiversity value for the study by summing attribute-level WTP estimates that were explicitly presented as additive components of an overall biodiversity valuation in the original study. Aggregation was applied only when attributes were conceptually non-overlapping and jointly interpreted by the original authors as components of an overall biodiversity valuation. The number of observations extracted from each study and the corresponding details are listed in Appendix Table C2.

For studies with missing forest size information, forest area data were acquired from external sources such as World Bank Open Data or the relevant national and regional statistical office to ensure completeness of spatial variables in the analysis. Where forest biomes were reported differently or not explicitly stated, each study was categorised under the new IUCN Global Ecosystem Typology (v2.1) (Keith et al., 2022). Biome and ecosystem classifications were determined by mapping the study area locations onto the IUCN Global Ecosystem Typology map to achieve consistency in ecological categorization across the dataset.

After all standardizations and adjustments, the compiled database comprised 140 observations reported as Int$/ha/year from 42 studies, 116 observations reported as Int$/person/year from 48 studies, 8 observations in Int$/visit from 6 studies, and 1 observation in Int$/person from a single study. The full dataset was used for descriptive analyses, while two specific subsets (per-person/year and per-hectare/year) were used for the regression analyses. These two subsets were analysed separately, as they could not be systematically converted or aggregated due to differing contexts and frequent gaps in reporting population and forest area data across studies.

4.2.4. Meta-Regression Analysis: Variables and Modelling Approach

4.2.4.1. Variables Included in the Analysis

The dependent variables in the meta-regression were the standardized economic values of forest biodiversity, expressed in Int$ for the year 2024. Specifically, I constructed two separate models: one for valuations reported in Int$/person/year, and another for valuations in Int$/hectare/year, reflecting differences in the scale and interpretation of these two valuation units.

The choice of independent variables was informed by prior meta-analyses and valuation studies (Brander et al., 2006; Ojea et al., 2010; Taye et al., 2021; Grammatikopoulou & Vačkářová, 2021). Independent variables were grouped into four broad categories. The first group comprises country-specific socioeconomic characteristics, including population density (people per square kilometre), gross domestic product (GDP) per capita expressed in U.S. dollars, and the percentage of terrestrial land designated as protected areas. These variables capture broader national contexts that may shape public and stakeholder perceptions of biodiversity value. Higher population densities could indicate increased demand for alternative land uses such as housing and agriculture (Luck, 2007) and could reduce the value placed on biodiversity. Alternatively, a greater scarcity of biodiversity could increase its value. Wealthier countries may value biodiversity more due to their greater ability to allocate economic resources, but also have more resources to mitigate the effects of biodiversity loss and may thus undervalue the benefits of biodiversity conservation. Protected areas are often established to conserve biodiversity, a higher percentage of protected area could increase awareness and familiarity with forest ecosystems and lead to a higher valuation of forest biodiversity, or alternatively a greater amount of protected area could decrease the perceived need to conserve or restore biodiversity.

The second group captured forest ecosystem characteristics, incorporating forest biome zones and forest size, measured in hectares, to account for ecological and spatial variability in valuation contexts. Different biomes may carry varying biodiversity richness, conservation priority, and cultural significance, which could influence valuation outcomes. For example, tropical forests are often perceived as highly valuable due to their exceptional biodiversity and global ecological importance (Pillay et al., 2022), potentially resulting in higher valuations. In contrast, temperate or boreal forests might receive lower valuations if perceived as more abundant or less threatened. However, regional familiarity and cultural connections to certain forest types could also elevate local valuations regardless of biome rarity. Similar to protected areas, greater forest coverage in a country could increase awareness and familiarity with forest biodiversity, or reduce the perceived need to conserve or restore biodiversity.

The third group encompassed valuation method characteristics, distinguishing between different valuation approaches. Different methods may yield different valuations due to inherent methodological differences. Stated preference methods (choice experiments and contingent valuations) rely on subjective and hypothetic valuations. Benefit transfer methods rely on estimates derived from primary valuation studies and apply them to new policy contexts, with validity depending on the availability of robust ecological and socioeconomic data and the similarity between study and policy sites. Direct market pricing requires accurate estimates of values such as market prices, restoration, replacement or avoided costs.

The fourth group consisted of biodiversity indicators, which were classified into categories reflecting how biodiversity is conceptualized and measured in valuation studies. Different indicators vary in how tangible, visible, and emotionally salient they are to respondents, and thus how they are valued.

I classified biodiversity indicators into categories based on the framework proposed by Bartkowski et al. (2015). This framework organizes biodiversity indicators into six conceptual categories:

- Numbers, capturing species richness or diversity indices (e.g., Shannon–Wiener index);
- Species, focusing on particular species or groups, including endangered or invasive species;
- Genetics, relating to genetic diversity and option value;

- Habitat, emphasizing spatial or structural components of ecosystems, as well as biodiversity protection ES;
- Function, referring to ecological roles and system-level processes; and
- Abstract, where biodiversity is addressed in general or unspecified terms.

Additionally, I introduce a seventh category—Management—to accommodate indicators based on human interventions, such as forest management practices (e.g., delayed harvesting, buffer zone maintenance, prescribed burning).

Table 4.1 summarizes all variables included in the meta-regression analysis, including their measurement units and descriptive statistics for both the per-person and per-hectare datasets.

Table 4.1 Variables Included in the Meta-Regression

Variables	**Measurement/Categories**	**Per-person**	**Per-hectare**
Dependent variable			
Biodiversity value	Mean (SD) in Int$ (2024)	52 (83) Int$/person/year	172,732 (1,695,937) Int$/ha/year
A. Continuous variables (reported as mean (standard deviation))			
Population density	People per sq.km, 2022 level, World Bank	168 (130)	146 (137)
GDP per capita	GDP per capita in USD, 2023 level, World Bank	44,666 (20,682)	33,030 (20,578)
Terrestrial protected area cover	% of total terrestrial protected area, 2024 level, World Bank	28 (10)	22 (9)
Forest size	Forest area in hectares	5,142,399 (7,890,100)	2,846,013 (16,997,591)
B. Categorical variables (reported as count, n (% of dataset))			
Forest biome zone	1 = Temperate-boreal forests and woodlands (reference level)	94 (81.0%)	101 (72.1%)
	2 = Savannas and grasslands	10 (8.6%)	7 (5.0%)
	3 = Tropical-subtropical forests	12 (10.3%)	28 (20.0%)
	4 = Others (Polar/alpine /cryogenic/cross biomes)	-	4 (2.9%)
Valuation methods	1 = Choice experiment (reference level)	92 (79.3%)	27 (19.3%)
	2 = Contingent value	24 (20.7%)	2 (1.4%)
	3 = Benefit transfer	-	37 (26.4%)
	4 = Direct market price	-	55 (39.3%)
	5 = Others	-	19 (13.6%)
Indicators	1 = Abstract (reference level)	30 (25.9%)	23 (16.4%)
	2 = Species	22 (19.0%)	16 (11.4%)
	3 = Habitat	12 (10.3%)	18 (12.9%)
	4 = Multiple	52 (44.8%)	58 (41.4%)
	5 = Function	-	19 (13.6%)
	6 = Genetics	-	2 (1.4%)
	7 = Management	-	4 (2.9%)

Note: this table summarises the variables used in the meta-regression analysis, including their measurement and descriptive statistics. The dependent variable is reported as Mean (Standard Deviation). Per-person values are expressed in Int$/person/year and per-hectare values in Int$/ha/year. These valuation measures represent different scales and should not be compared directly in magnitude. Continuous independent variables are reported as Mean (Standard Deviation). Categorical variables are reported as counts (n) with column percentages (%), describing the composition of each dataset.

4.2.4.2. Econometric Model Specification

The meta-regression models were estimated to evaluate how country-level, ecological, and methodological variables influence biodiversity valuation outcomes, while accounting for potential heterogeneity across studies. For each dependent variable (per-person or per-hectare valuations), I estimated random effects models (REMs) to accommodate the hierarchical data structure, as multiple valuation observations were often derived from the same study.

For the per-person valuation dataset, the dependent variable exhibited significant skewness and included negative values indicative of negative WTP. To address these properties while preserving negative observations, I applied the inverse hyperbolic sine (IHS) transformation (Ravallion, 2017), which closely approximates a logarithmic transformation for positive values but accommodates zero and negative values without the need for arbitrary adjustments. In contrast, the per-hectare valuations were strictly positive but skewed, so a natural logarithmic transformation was applied to stabilize variance. A comparative overview of transformed versus raw data distributions is provided in Table 4.2.

All continuous independent variables were log-transformed prior to modelling to stabilize variance and reduce skewness, enhancing the robustness of regression estimates.

The general form of the meta-regression model for each dataset can be expressed as:

$$y = \alpha + \beta_c X_c + \beta_f X_f + \beta_v X_v + \beta_b X_b + \varepsilon$$

where y signifies the valuation per-person or per-hectare, α represents the intercept, β coefficients correspond to the respective variables within their categories, and ε denotes the random error, assumed to be independently and identically distributed.

All analyses were conducted using R software, employing packages suitable for mixed-effects modelling and meta-regression analysis. Model diagnostics, specification tests, and comparative performance metrics are reported alongside the estimation results in Section 4.4.

Table 4.2 Descriptive Statistics for Per-Person and Per-Hectare Outcomes (Raw Vs. Transformed Data)

	Per-person (Int$/person/year)		**Per-hectare (Int$/ha/year)**	
	Raw value	HIS transformed	Raw value	Log transformed
Mean	52.22	3.52	172732.2	7.54
Median	20.97	3.74	3098.59	8.04
Variance	6946.31	4.60	2.876204×10^{12}	9.03
Skewness	3.31	-1.85	11.43	-0.44
Kurtosis	19.98	7.93	133.4	3.13

Note: this table presents descriptive statistics (mean, median, variance, skewness, and kurtosis) for per-person and per-hectare outcomes, comparing raw data with transformed versions (Inverse Hyperbolic Sine (IHS) for per-person data and logarithmic (Log) for per-hectare data). Per-person values are expressed in Int$/person/year and per-hectare values in Int$/ha/year, and are therefore not directly comparable in magnitude.

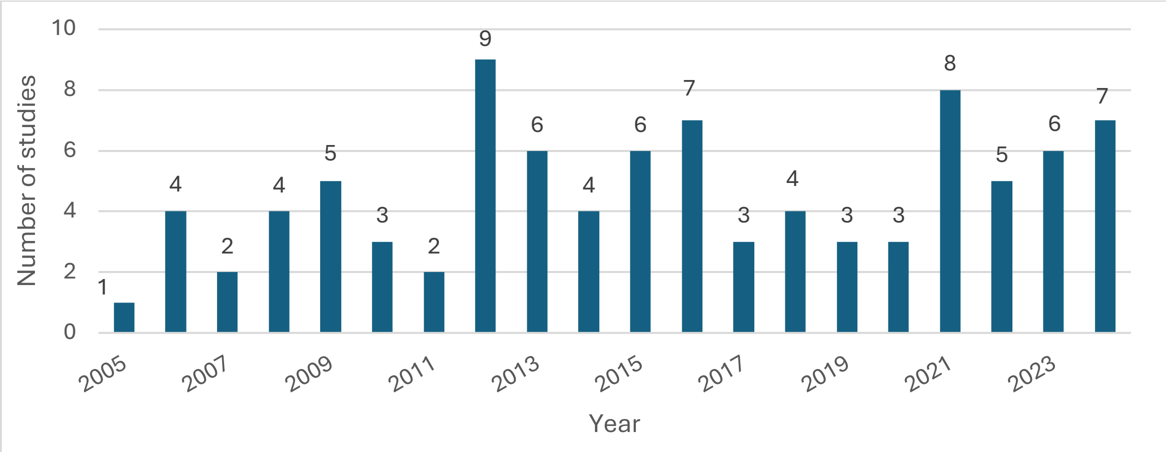
4.3. Descriptive Summary Statistics

4.3.1. Publication Trends

The number of studies published annually shows fluctuating but generally increasing interest in forest biodiversity valuation over the past two decades, similar to the increasing trend of publications observed in other meta-analyses on forest ES (Acharya et al., 2019; Taye et al., 2021).

Figure 4.2 illustrates the temporal distribution of publications included in the review. These trends underscore the continued relevance of economic valuation as a tool for informing forest conservation and biodiversity management decisions.

Figure 4.2 Trends in the Number of Studies over the Years



Note: this figure illustrates the annual distribution of studies included in the SLR and meta-analysis from 2005 to 2024. Data for 2025 are excluded because the literature search covers publications up to May 2025 only.

4.3.2. Geographic and Biome Distribution

The geographic distribution of studies included in the review reveals notable regional patterns and gaps in the valuation literature. Of the 93 studies analysed, more than half (n = 51; 55%) were conducted in Europe, reflecting the region's long-standing emphasis on environmental economics and biodiversity conservation. Within Europe, Germany was the most represented country, contributing 10 studies, followed by Spain (8 studies), Finland and France (6 studies each), and several other countries with smaller contributions.

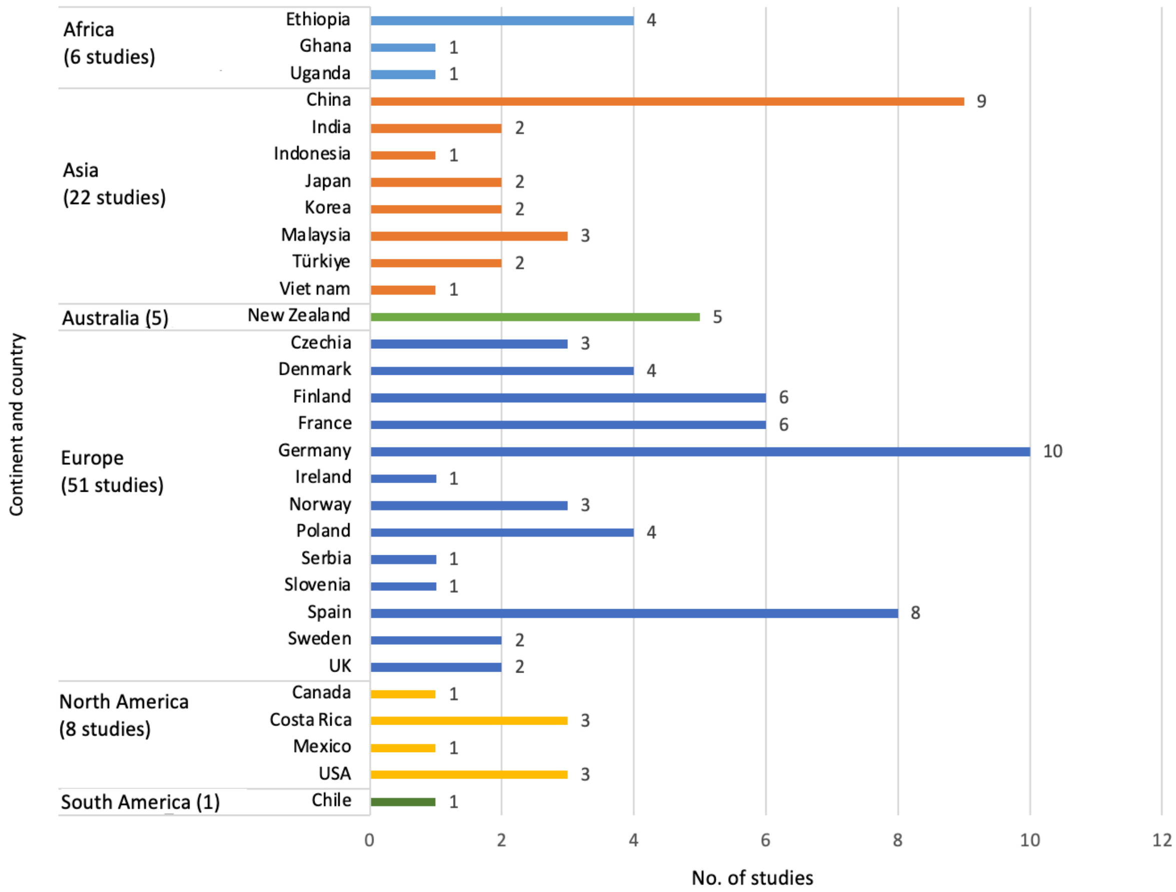
Asia accounted for 22 studies (approximately 23%), with China leading regional contributions (9 studies), followed by Malaysia (3), and several countries contributing 1 or 2 studies each. Oceania was represented solely by New Zealand, which contributed 5 studies. Africa contributed 6 studies (approximately 6%), with Ethiopia accounting for the majority (4 studies), while Ghana and Uganda contributed 1 study each.

North America contributed 8 studies (approximately 8%), with contributions from the United States (3 studies), Costa Rica (3), Canada (1), and Mexico (1). Although Costa Rica is often categorized as part of Central America, in this context it has been included under North America for consistency in regional grouping. South America was represented by only 1 study conducted in Chile, highlighting sparse valuation research from the continent despite its ecological significance. Figure 4.3 presents the distribution of studies by continent and country.

The biome distribution in the dataset largely reflects this geographic concentration. Of the 93 studies reviewed, 66 studies (approximately 71%) focused on temperate-boreal forests and woodlands, indicating a strong emphasis on temperate ecosystems. Tropical-subtropical forests were examined in 20 studies (21%), while savannas and grasslands accounted for 8 studies (9%). Only 1 study investigated a polar or alpine (cryogenic) biome, and 1 study spanned multiple biomes.

These patterns underscore the significant concentration of valuation research in temperate and northern hemisphere regions, both geographically and ecologically. Tropical, subtropical, and polar regions remain comparatively underrepresented despite their global biodiversity importance. This skewed distribution highlights critical gaps in the existing literature and raises questions about the generalizability of valuation estimates to underrepresented forest ecosystems.

Figure 4.3 Distribution of Studies by Continent and Country



Note: this figure presents the geographical distribution of studies included in the SLR and meta-analysis across continents and countries.

4.3.3. Valuation Method

The reviewed studies employed three broad categories of valuation approaches, with stated preference methods dominating (71%, n=66), followed by benefit transfer (16%, n=15) and direct market methods (7%, n=7). One study adopted both contingent valuation and choice experiment methods to compare the results (Meyerhoff & Liebe, 2008). Five studies applied niche methods like Emergy, Biodiversity Value of Remnants, Utility Function or Refined Monetary System of Environmental Economic Accounting (rSEEA). The distribution of different methods used is presented in Figure 4.4.

4.3.3.1.Stated Preference Valuation Approaches

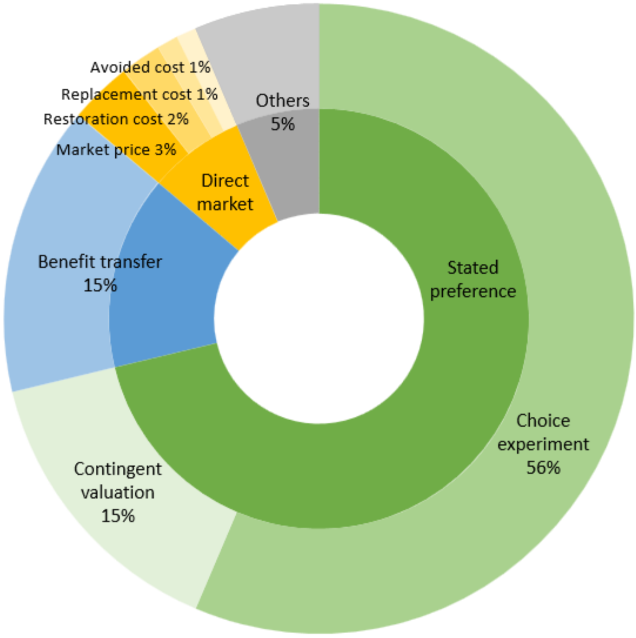
Stated preference methods were the most commonly employed valuation approach in the reviewed literature, featuring in 66 of the 93 studies (approximately 71%), with all such studies employing either choice experiments or contingent valuation.

(a) Choice Experiments and Contingent Valuation

Choice experiments were the predominant stated preference method, applied in 53 studies. This technique involves presenting respondents with hypothetical choice sets consisting of alternative scenarios that vary by different attributes and associated costs. Analysis of respondents' choices allows researchers to estimate marginal values for particular biodiversity attributes. In 20 studies, biodiversity was the primary valuation objective, while in 33 studies, biodiversity was included as one attribute among broader ES assessments or land use alternatives. In 2 studies, biodiversity was included as one of the levels within an attribute rather than as a standalone attribute (Broch & Vedel, 2012; Broch et al., 2013). These differences may affect the interpretation and comparability of results across studies.

The contingent valuation method, used in 14 studies, is simpler in design compared to choice experiments and typically elicits a single WTP value for a designed biodiversity scenario, while choice experiments allow respondents to evaluate trade-offs among multiple biodiversity attributes, enabling separate estimation of values for individual components across multiple scenarios.

Figure 4.4 Distribution of Valuation Methods Applied in Forest Biodiversity Studies



Note: this figure illustrates the relative use of different valuation methods in the reviewed forest biodiversity studies.

(b) Stakeholder Groups and WTP/WTA Analysis

Within stated preference studies, the stakeholder groups targeted varied substantially, reflecting diverse perspectives on forest biodiversity valuation. Of the 66 studies employing stated preference methods, 44 specifically focused on the general public, while others targeted visitors (12 studies), farmers (11 studies), forest owners (6 studies), firms (1 study), and officials (1 study). Some studies investigated multiple stakeholder groups simultaneously (Biénabe & Hearne, 2006; Koellner et al., 2010; Nordén et al., 2017).

In terms of valuation measures, WTP was the predominant metric, reported in 59 studies encompassing 132 observations, accounting for 87.6% of all stated preference observations. WTA, representing the minimum compensation individuals require for biodiversity losses, appeared in 9 studies with 17 observations. One study reported willingness to invest (WTI), reflecting stakeholders' intentions to invest resources in biodiversity conservation. Table 4.3 summarizes the distribution of WTP, WTA, and WTI metrics across stakeholder groups.

This diversity in stakeholder perspectives and valuation measures highlights both the richness and the complexity of stated preference approaches in capturing societal valuations of forest biodiversity. It also underscores the potential for heterogeneity in valuation outcomes depending on the target population and valuation context.

Table 4.3 Stated-Preference Valuations of Forest Biodiversity

	WTP	**WTA**	**WTI**	**Total**
Public	44 (115)			44
Farmers	1 (1)	2 (6)		3
Forest owners	1 (1)	7 (11)		8
Visitors	12 (17)			12
Firms			1 (2)	1
Officials	1 (1)			1
Total	59	9	2	69

Note: this table reports the number of studies using WTP, WTA, and WTI metrics by stakeholder group. Numbers in parentheses represent observation counts within each category. The total number of studies is 69 because three studies reported multiple stakeholder groups.

4.3.3.2.Benefit Transfer Valuation Approach

Benefit transfer is a widely used approach for estimating environmental goods and services values when primary valuation is constrained by time, funding, or data availability (Johnston et al., 2018). In the reviewed literature, 15 studies employed benefit transfer methods. Of these, the large majority (13 studies) applied unit value transfer, involving the adjustment and standardisation of previously published per-unit values. Two studies adopted more structured benefit transfer approaches by combining transferred base values with locally specific ecological indicators to improve contextual relevance.

Structured benefit transfer approaches help to mitigate limitations of basic unit value transfer by incorporating locally relevant ecological information, but require robust indicator selection and validation to ensure reliability. For example, Enríquez-de-Salamanca (2023) integrated vertebrate counts, endangered species presence, and plant richness metrics with transferred base values in Spanish forests. Similarly, Rajiv Pandey et al. (2024) developed a weighted system using flora and fauna diversity indices for Indian reserves.

The Chinese context presents 2 particularly noteworthy benefit transfer approaches. Two studies, built upon the equivalent weight factors developed by Xie et al. (2003), derived from a national survey of 200 ecologists, adapting of the Costanza et al. (1997) global ES values to the Chinese ecological context. Three studies, employed a framework grounded in China's national forestry industry standard[4] which provides a classification system that assigns standardized values to forest biodiversity service across seven tiers, ranging from 3,000 to 50,000 RMB per hectare per year, based on the Shannon-Wiener biodiversity index (Shannon, 1948). These approaches provide scalable solutions for policy and administrative decision-making, while also introducing consistency and transparency into valuation practices.

4.3.3.3.Direct Market Valuation Approach

Seven studies in the review employed direct market approaches to value forest biodiversity, accounting for approximately 8% of the total dataset. These studies represented four distinct methodological categories: market pricing (3 studies), restoration cost (2 studies),

[4] The *Specifications for Assessment of Forest Ecosystem Services in China* (LY/T 1721-2008) was an industry standard issued in 2008 by the State Forestry Administration. In 2020, it was upgraded to the recommended national standard GB/T 38582-2020 to further standardize valuation methods nationwide.

replacement cost (1 study), and avoided cost (1 study). Collectively, these methods demonstrate the diverse applications of revealed preference techniques in biodiversity valuation, relying on observable costs or market proxies.

Market pricing methods varied considerably in their implementation. Zhao et al. (2019) developed a regulatory-based valuation framework in China, calculating the total value of protected species based on conservation management fees and applying multipliers (e.g. 12.5× for first-class protected species, 16.7× for second-class species)[5] to reflect higher protection priorities. This regulatory approach equated management costs to biodiversity value. In contrast, Trifunov et al. (2013) employed a more conventional market perspective, quantifying biodiversity's contribution through the values of timber and non-timber forest product (NTFP), including medicinal plants and fruits. Bernard et al. (2009) adopted a market proxy system, combining voluntary conservation contract costs and revenues from research commercialization to estimate biodiversity maintenance values. These examples illustrate the flexibility of market-based valuation, though they also reveal how different proxies can lead to divergent estimates of biodiversity's economic significance.

Restoration cost methods were exclusively represented by Czech studies, reflecting regional methodological specialization. Pechanec et al. (2017) developed a points-based system that assigned ecological scores to habitats based on eight ecological characteristics, calculating total biodiversity value as the product of ecological points, national average restoration costs, and forest area. Similarly, Seják et al. (2018) used restoration costs derived from recent national projects to estimate biodiversity value.

The replacement cost approach was applied by Sumarga et al. (2015). This study calculated the projected costs of orangutan reintroduction programs as a proxy for the biodiversity value. Avoided cost methods were represented by Yao et al. (2021), who quantified biodiversity value through the avoided costs of water filtration services and flood damage mitigation.

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[5] Conservation management fee for terrestrial wildlife resources is derived from the *Measures for Collecting Fees for Protection and Administration of Terrestrial Wildlife Resources* (No. 72 [1992] of the Ministry of Forestry) and the *Protection and Management Fees for Capturing and Hunting National Key Protected Wildlife Resources*. The valuation multipliers—12.5× for first-class and 16.7× for second-class protected species—were introduced in the *Notice on How to Determine the Value Standards of National Key Protected Wild Animals and Their Products in Wild Animal Cases* (No. 44 [1996] of the Ministry of Forestry). First-class protected species are those classified as most endangered and granted the highest level of legal protection under national law. Second-class protected species are also protected but considered at lower risk.

4.3.3.4.Valuation Methods by Unit of Analysis

An important methodological distinction in the reviewed studies relates to how valuation methods are distributed across the two primary units of analysis. The per-person dataset comprised only stated preference methods, including 36 choice experiment studies and 12 contingent valuation studies, reflecting the predominance of survey-based approaches for individual-level valuation estimates. In contrast, the per-hectare dataset incorporated all valuation methods identified in the review. It included 14 choice experiment studies and 1 contingent valuation study from stated preference methods, 15 benefit transfer studies, and 7 studies employing direct market approaches, and 5 studies used other valuation methods.

4.3.4. Biodiversity Measurement in Valuation Studies

4.3.4.1.Conceptualization and Framing of Biodiversity

The conceptualization of biodiversity in the reviewed valuation literature revealed two different approaches: considering biodiversity as an ES or as a standalone attribute of an ecosystem. Twenty-three studies explicitly framed biodiversity within the ES framework, though terminology varied largely—from generic references such as “biodiversity” to more specific terms like “biodiversity protection,” “biodiversity maintenance,” or “biodiversity improvement.” Despite the shared ES framing, only a few studies specified the classification of biodiversity within the ES typology: four identified it as a supporting service and one as a regulating service. The remaining studies did not explicitly classify biodiversity within a particular ES category, underscoring an overall lack of consensus on how biodiversity should be defined and categorized in the ES framework.

Furthermore, the adoption of standardized ES classification systems was limited. While CICES (Common International Classification Of Ecosystem Services) and IPBES offer the most recent frameworks, only 1 study utilized CICES. Instead, older systems were more commonly employed, including TEEB (5 studies, 4 of which were published between 2021 and 2024), Xie’s framework (2 studies), the MEA (1 study), and hybrid approaches combining MEA with TEEB or Total Economic Value (TEV) frameworks (2 studies). This methodological path dependence suggests a lag in the alignment of valuation studies with contemporary ecological standards.

In contrast, the majority of studies (70 out of 93) conceptualized biodiversity as a standalone value domain rather than embedding it within the ES framework. These studies encompassed diverse valuation perspectives, including biodiversity's intrinsic value, its role in delivering economic benefits, functional importance, avoided loss value, and broader conservation-oriented values (e.g., protection, preservation, enhancement). Some focused on biodiversity as an outcome of forest management, while others emphasized the existence value of rare or threatened species. This standalone framing often led to simplified representations of biodiversity, operationalized through abstract WTP measures or through narrow proxies that captured only selected ecological dimensions.

4.3.4.2.Biodiversity Indicators Used in Valuation Studies

Given that biodiversity measures and representation in socio-economic valuation often diverge from those found in ecological research, I systematically analysed the types of indicators employed across studies to assess their relevance, complexity, and alignment with ecological concepts.

The most common valuation method, choice experiments, typically include multiple attributes reflecting aspects of biodiversity, which may not always directly correspond to ecological indicators. Studies which adopted benefit transfer and restoration cost methods typically apply standard unit values to specific biodiversity-related characteristics. For the purposes of this analysis, I collectively refer to all such attributes or characteristics as biodiversity indicators, which while not ecological metrics per se, are central to many valuation scenarios and play a key role in shaping the outcomes of biodiversity valuation.

Table 4.4 provides a detailed overview of how biodiversity indicators are applied within socio-economic valuation studies which I classify using the framework proposed by Bartkowski et al. (2015), including an additional category for management-related indicators.

Table 4.4 Classification of Biodiversity Indicators Used in Forest Valuation Studies

Indicator(s)		**Classification (Bartkowski et al., 2015)**	**No. of studies**
No indicator			26
WTP/WTA for biodiversity/biodiversity conservation/protection/maintenance, participation in specific programs/contracts		Abstract	20
ES-biodiversity protection/maintenance/conservation		Habitat	6
One indicator			39
Protected/conserved forest area		Habitat	9
Number of endangered/threatened species		Species	5
Shannon–Wiener index		Number	4
Species richness		Number	2
Forest management measures		Management	2
Tree	Number of tree species	Species	3
	Consist of broadleaves tree	Habitat	2
	Number of habitat trees	Species	1
Bird	Number of bird species	Species	2
	Bird population	Species	2
	Possibility of endangered birds' extinction	Species	1
Value of rare and endangered animal and plant		Species	1
Flora richness		Species	1
Uneven-aged forestry		Habitat	1
Provision of forest products		Function	1
The cost of reintroducing Orangutan		Abstract	1
Avoided cost of water filtration and flood damage		Function	1
Two indicators			6
Flora diversity (Shannon–Wiener Index), fauna diversity (species richness)		Number + Species	1
Conservation of genetic diversity, number of native birds species		Genetics + species	1
Forest species number, leaving trees to age, die and decay		Number + management	1
Forest management (setting aside an area of the forest, allowing old trees to decay naturally)		Management	1
Value for future pharmaceutical research and coffee breeding		Genetics	1
Donations with voluntary contractual arrangement, user fees for research activities and share of benefits for discoveries and commercialisation		Abstract	1
Multiple indicators			22
Habitat for endangered and protected species, species diversity, forest stand structure, landscape diversity		Habitat + species	5
Target species, internationally protected sites, legally protect area		Habitat + species	2
Natural ecological processes, rare species of fauna and flora, ecosystem components		Habitat + species	2

Forest stand structure, tree species, dead wood, trees with high ecological value	Habitat + species	2
Area of set-aside, tree age variation, tree species composition	Habitat + species	1
Number of forest bird species, number of rare forest bird species, geographical spread of biodiversity	Habitat + species	1
Matureness, naturalness, diversity of plant species, diversity of animal species, rareness of biotope, rareness of species, vulnerability, threat to existence	Habitat + species	1
Genetic variation, population structure, number of native species (bird), number of invasive alien species, keystone elements, area involved in the programme	Habitat + species	1
Forest canopy cover, abundance of large native invertebrates, abundance of native birds, health of within-forest plants.	Habitat + species	1
Variety of sound, colour, smell, tress for natural decomposition	Habitat + species	1
Number of species, endangered species, vulnerable species, species richness indicator	Species + number	1
Natures gifts, research and education, climate regulation, water regulation, sense of experience, charismatic species, non-charismatic species for coniferous woodland	Function + species	1
Chances of observing animals with scenic attraction, existence of endemic orchid species, additional protection for an endemic amphibian	Species	1
Frequency of hearing bird brown kiwi calls, Giant Kokopu seen, managed Kakabeak shrubs, Bush Falcon sighted in drives	Species	1
Delay timber harvest, maintain streamside management zone width, undertake prescribed burning, control invasive species	Management	1

Note: this table summarises the biodiversity indicators used in the reviewed valuation studies, along with their classification based on Bartkowski et al. (2015), and reports the number of studies for each indicator type.

Out of the total studies reviewed, 26 did not adopt explicit biodiversity indicators. Instead, these studies directly elicited respondents' WTP or WTA compensation for biodiversity conservation, or they used benefit-transfer methods to value the ES of biodiversity protection. These fall under the "Abstract" or "Habitat" categories, reflecting a common approach in economic valuation where biodiversity is treated as a general concept rather than being linked to specific ecological metrics.

Among the studies that employed explicit indicators, most selected only one primary indicator. The most frequently used indicator was the area of protected or conserved forest habitat, which appeared in 9 studies. This was followed by the number of endangered or threatened species, a metric that likely appeals to respondents due to its clear conservation relevance. The Shannon–Wiener index, a widely recognized numerical measure of species diversity, was also frequently employed.

Bird-related metrics emerged as important proxies for forest biodiversity across studies. These included the total number of bird species, populations of specific birds, the likelihood of bird extinction, and the frequency of hearing bird calls. Indicators related to trees were also common, particularly those measuring the number of tree species or the presence of specific types such as broadleaved trees, habitat trees, and trees of high ecological value.

Studies that employed multiple indicators tended to capture biodiversity in a more ecologically comprehensive manner. These often incorporated features of forest habitat, such as stand structure, tree age variation, and the presence of deadwood, attributes critical for sustaining ecosystem resilience and supporting a wide range of species. Such multidimensional approaches suggest a closer alignment with ecological understandings of biodiversity.

In some cases, indicators were framed in ways that made them particularly relatable to the public. For example, some studies described biodiversity in terms of sensory experiences; how often animals are seen or heard, or the variation in sound, colour, and scent within a forest.

When comparing ecological biodiversity indicators with those used in economic valuation, notable differences emerge. Ecological indicators are typically grounded in scientifically rigorous measures across multiple levels of biological organization, from genetic and organismal diversity to community and ecosystem structures, using dimensions such as phylogenetic, structural, and functional diversity. These indicators are derived from field-based research, genetic analysis, and long-term ecological monitoring, with an emphasis on ecosystem function, resilience, and conservation status. Based on these standards, most economic valuations of biodiversity would not be considered ecologically-robust biodiversity valuations, echoing Farnsworth et al.'s (2015) observation that only 9 out of 136 studies reviewed by Bartkowski et al. (2015) would qualify as valuations of biodiversity under a stricter ecological definition.

By contrast, indicators in economic valuation studies are shaped by methodological pragmatism and the need for comprehensibility among non-expert respondents. For instance, studies often elicit WTP for generic improvements in biodiversity without specifying scientific metrics. While this facilitates broader participation, it may limit ecological specificity. Nonetheless, studies that adopt multiple or more detailed indicators, especially those addressing habitat composition, forest management practices, or species-specific attributes, offer more nuanced representations of biodiversity. These studies can act as valuable bridges between ecological integrity and societal preferences.

4.3.5. Data Gaps and Missing Information

My dataset reveals notable gaps and inconsistencies in the reporting of key information essential for interpreting and comparing economic valuations of forest biodiversity which limit both the ecological validity and the economic comparability of valuation outcomes.

Despite the ecological focus of biodiversity valuation, surprisingly few studies provided comprehensive descriptions of the forest ecosystems under investigation. Only 11 studies explicitly defined the forest biome and ecosystem, while 22 studies specified the type of forest as natural, plantation, or mixed. Tree species composition was mentioned in 46 studies, yet fundamental ecological attributes such as soil type and forest life stage were reported in only 8 studies each. Information on the protection status of forests was included in 35 studies, leaving substantial gaps in understanding the conservation context for over half of the dataset. Notably, 32 studies did not report any data on forest size, a key spatial variable with significant implications for both ecological assessment and economic valuation. These omissions suggest a disconnect between the ecological complexity of forest biodiversity and how it is operationalized in economic valuation studies.

Another significant gap concerns the reporting of the currency year for valuation estimates. Accurate currency-year data are crucial for adjusting monetary values for inflation and exchange rates, enabling meaningful comparison across time periods and geographic contexts. However, only 33 of the 93 studies explicitly stated the currency year associated with their valuation figures. This omission complicates efforts to standardize values across studies and undermines the comparability of economic metrics—a challenge previously highlighted by Bartkowski et al. (2015).

4.4. Evaluating the Factors Affecting Valuations of Forest Biodiversity

4.4.1. Model Diagnostics and Specification Tests

Model diagnostics and specification tests were conducted separately for the per-person and per-hectare meta-regression models to assess variance behaviour, residual properties, and the appropriateness of the random effects specification.

4.4.1.1. Per-Person Regression Estimation

Following the IHS transformation, residual analysis for the per-person model indicated improved variance stabilization, although residuals continued to deviate from normality. The Breusch–Pagan test for heteroscedasticity was not significant ($\chi^2 = 12.38$, $p = 0.261$), suggesting that variance heterogeneity was effectively addressed. However, the Shapiro–Wilk test indicated persistent non-normality of residuals ($W = 0.848$, $p < 0.001$), a common occurrence in meta-analyses that aggregate data from heterogeneous studies (Brander et al., 2006; Barrio & Loureiro, 2010) .

Model specification tests supported the use of a REM. The Hausman test indicated no significant differences between fixed and random effects coefficients ($\chi^2 = 1.81$, $p = 0.936$), favouring the efficiency of the REM. The likelihood ratio test for the random intercept was not statistically significant ($\chi^2 = 2.31$, $p = 0.129$), suggesting that between-study variance was modest. However, I retained the random effects specification given the presence of a non-negligible intraclass correlation coefficient (ICC = 0.133), the hierarchical data structure, and established recommendations for meta-analytic models that account for potential clustering effects. The REM demonstrated superior fit compared to an OLS specification, reflected in a lower root mean square error (RMSE = 1.761 vs. 2.000 for OLS) and a lower Akaike Information Criterion (AIC = 513.7 vs. 514.0). The marginal R^2 was 0.131, and the conditional R^2 was 0.246, indicating moderate explanatory power. Additional details on model comparison were provided in Table 4.5.

Multicollinearity diagnostics confirmed that relationships among explanatory variables were acceptable for interpretation. The maximum generalized variance inflation factor (GVIF) was 7.28, which was below typical thresholds, indicating no multicollinearity issues (Table 4.6).

4.4.1.2.Per-Hectare Regression Estimation

In the per-hectare model, residual heteroscedasticity persisted under OLS estimation (Breusch–Pagan test, $p < 0.001$), and residuals deviated from normality (Shapiro–Wilk, $p = 0.022$). The likelihood ratio test confirmed significant between-study variance (LRT $\chi^2 = 111.46$, $p < 0.001$), supporting the appropriateness of a random effects specification. The Hausman test similarly indicated no significant bias in random effects estimates ($\chi^2 = 4.26$, $p = 0.235$).

The REM exhibited substantially better fit compared to OLS, with a lower AIC (500.4 vs. 609.9) and reduced residual variance ($\sigma^2 = 0.864$ vs. 1.998). The ICC was 0.852, indicating that 85.2% of the total variance was attributable to between-study heterogeneity. Marginal and conditional R^2 values were 0.443 and 0.917, respectively, reflecting strong explanatory power of the model overall. Additional details on model comparison were provided in Table 4.5.Multicollinearity diagnostics similarly confirmed acceptable levels, with all GVIF values below 6.77 (Table 4.6).

Table 4.5 Model Comparison for Per-Person and Per-Hectare Specifications (REM Vs. OLS)

Model	AIC (weights)	BIC (weights)	RMSE	Sigma	R² Adjusted	R² Conditional	R² Marginal	ICC
Per-person dataset								
REM	513.7	549.5	1.761	1.86		0.246	0.131	0.133
OLS	514.0	547.0	2.000	2.10	0.04			
Per-Hectare dataset								
REM	500.4	559.2	0.739	0.864		0.917	0.443	0.852
OLS	609.9	665.8	1.865	1.998	0.558			

Note: this table compares the performance of REM and OLS for per-person and per-hectare specifications.

Table 4.6 Multicollinearity Diagnostics for Per-Person and Per-Hectare Models

	Per-person			Per-hectare		
	GVIF	Df	GVIF^(1/(2*Df))	GVIF	Df	GVIF^(1/(2*Df))
Log(Population density)	1.574207	1	1.254674	1.752139	1	1.323684
Log(GDP per capita)	4.004864	1	2.001216	2.891558	1	1.700458
Log(Protected area)	1.966703	1	1.402392	1.867436	1	1.366542
Biome	7.184044	2	1.637164	1.782688	3	1.101148
Log(Forest size)	2.080348	1	1.442341	1.058098	1	1.028639
Valuation Method	1.766818	1	1.329217	6.143702	4	1.25474
Indicator	2.892697	3	1.193669	6.771078	6	1.172793

Note: this table presents multicollinearity diagnostics for the Per-Person and Per-Hectare models, including the Generalized Variance Inflation Factor (GVIF) and its degrees of freedom (Df).

4.4.2. Random Effects Meta-Regression Results

Table 4.7 presents the estimated coefficients and standard errors from the random effects meta-regression models for both the per-person and per-hectare valuation datasets. Overall, the results reveal distinct patterns across the two dependent variables, reflecting differences in valuation contexts, scale, and methodological choices.

4.4.2.1.Per-Person Valuation Results

In the per-person model, the only variable found to have a significant association with per-person valuations was the savannas and grasslands, which exhibited a weakly positive association with valuations compared to the reference category of temperate-boreal biome ($\beta = 1.43$, $p < 0.10$). Other biome categories, as well as socioeconomic variables, the choice of valuation method and the type of biodiversity indicators used, were not found to be significant in the per-person model. These findings suggest substantial heterogeneity in per-person valuation estimates that is not fully explained by the available moderators, consistent with the modest explanatory power indicated by the marginal R^2 value of 0.131.

The per-person dataset only includes stated preference valuation methods, which by their nature are highly subjective and hypothetical. One explanation for the results may be that per-person valuations largely capture existence or bequest values of forest biodiversity that are highly subjective and are poorly explained by easily measurable independent variables. Individuals' WTP for biodiversity conservation may be driven by a moral imperative rather than a utility-driven calculation (Kahneman & Knetsch, 1992; Nunes & van den Bergh, 2001b; Farber et al., 2002; Cori et al., 2021).

Table 4.7 Results of REM Estimations: Per-Person and Per-Hectare Valuation of Forest Biodiversity

Category	Variables	Per-Person	Per-Hectare
	Constant	2.93 (7.01)	25.91 (6.20) ***
Country-specific metrics	Population density (Log)	-0.34 (0.26)	-1.11 (0.46) **
	GDP per capita (Log)	0.32 (0.51)	-1.30 (0.49) **
	Protected area (Log)	-0.22 (0.73)	-0.24 (1.04)
Forest characteristics	Forest biome zone (Ref.= Temperate-boreal forests and woodlands)		
	Savannas and grasslands	1.43 (0.78) *	2.57 (1.51) *
	Tropical-subtropical forests	-0.64 (1.64)	-0.218 (0.52)
	Others		-0.375 (0.67)
	Forest size (Log)	0.007 (0.11)	-0.15 (0.04) ***
Valuation methods	Valuation methods (Ref. = Choice experiment)		
	Contingent value	0.46 (0.67)	-0.95 (2.50)
	Benefit transfer		2.06 (1.11) *
	Direct market		3.61 (1.48) **
	Others		-0.53 (1.21)
Biodiversity indicators	Indicators (Ref. = Abstract)		
	Habitat	-1.10 (0.86)	0.70 (1.17)
	Species	-0.79 (0.83)	-1.17 (1.18)
	Multiple	-1.00 (0.72)	0.08 (1.50)
	Function		-3.48 (1.96) *
	Genetics		-7.15 (2.07) ***
	Management		-0.97 (1.82)
	N	116	140
	R2 (cond.)	0.246	0.917
	R^2 (marg.)	0.131	0.443

Notes: this table presents coefficients and standard errors (in parentheses) from REM estimations for per-person and per-hectare valuations. *** p<0.01, ** p<0.05, * p<0.1.

4.4.2.2.Per-Hectare Valuation Results

By contrast, the per-hectare valuation model revealed several significant associations, with both contextual and methodological factors.

Among country-specific variables, higher population density was significantly associated with lower per-hectare biodiversity values ($\beta = -1.11$, $p < 0.05$), suggesting that valuations tend to decrease in more densely populated regions, which contrasts with findings from Ojea et al. (2010). Luck (2007) found that species-rich areas often coincide spatially with high human population density, suggesting that conservation conflicts are likely greatest where people and biodiversity overlap. This spatial overlap may contribute to the observed negative relationship, as intensified land-use competition in densely populated regions may mean that economic priorities such as urban development, agriculture, or infrastructure expansion overshadow biodiversity conservation. Lower familiarity with forest biodiversity among urban populations may also depress non-use valuations (Straka et al., 2025). Although economic theory suggests that scarcity should increase value, this relationship may be complicated by competing land-use priorities. Notably, the population density variable is measured at the national level, which may not be representative of the particular forest region being valued.

Similarly, GDP per capita displayed a negative relationship with per-hectare valuations ($\beta = -1.30$, $p < 0.05$), which also contrasts with prior meta-analyses of the valuation of forest ES, where higher income levels generally correlate positively with ES valuations (Ojea et al., 2010; Grammatikopoulou & Vačkářová, 2021; Taye et al., 2021). An explanation for this result may be that in wealthier countries, people may feel less direct reliance on forest biodiversity for livelihoods, subsistence resources, or cultural identity, in contrast to many indigenous and local communities in lower-income countries who depend on forests for essential needs and traditional knowledge. Wealthier societies also have greater capacity to mitigate the effects of biodiversity loss through technological substitutes, imports, or environmental regulation, potentially reducing the urgency or perceived marginal value of conserving local forest biodiversity.

Larger forest size was found to be strongly associated with lower per-hectare values ($\beta = -0.15$, $p < 0.001$), possibly reflecting diminishing marginal value as the spatial extent of forest areas increases. This finding aligns with global valuation patterns observed for wetlands

(Brander et al., 2006) and forests (Ojea et al., 2016; Acharya et al., 2019), supporting economic scarcity principles whereby marginal values decrease as the quantity of the resource expands.

Biome type exhibited a similar result to the per-person model, with savannas and grasslands valued significantly higher than the reference category of temperate-boreal forests ($\beta = 2.57$, $p < 0.10$). These findings partially diverge from previous meta-analyses of forest ES. For example, Taye et al. (2021) reported the highest ES valuations for mangrove forests globally, followed by temperate forests, then tropical-subtropical, and finally boreal forests. Similarly, Ojea et al. (2010) observed higher valuations for temperate conifer forests compared to Mediterranean forests in a global context. However, the biome classifications differ from those used in those studies, and all of the savanna observations ($n = 7$) originate from studies in Spain, creating a geographically concentrated sample that may influence the results.

Unlike per-person valuations, per-hectare valuation studies employed a wider range of valuation methods. Methodological choices were significantly associated with the per-hectare biodiversity valuations in the analysis. Direct market valuation methods were associated with substantially higher valuations ($\beta = 3.61$, $p < 0.05$), likely reflecting their use of observed costs such as restoration expenditures, in contrast to the hypothetical valuations elicited by stated preference techniques. Benefit transfer methods were also associated with higher valuations ($\beta = 2.06$, $p < 0.10$), consistent with Brander et al.'s (2006) findings for wetlands.

Biodiversity indicators also had significant associations with per-hectare valuations. Studies employing genetic indicators exhibited a strong negative association ($\beta = -7.15$, $p < 0.01$) while function-based indicators were also negatively associated with valuations ($\beta = -3.48$, $p < 0.10$). This suggests that non-visible biodiversity components or attributes linked to ecosystem processes and system-level functions are systematically undervalued, likely due to low familiarity and challenges in conveying their ecological significance to non-expert stakeholders in valuation contexts (Farnsworth et al., 2015), compared to more tangible or charismatic biodiversity elements. However, genetic indicators were represented by only 2 observations, while function-based indicators had 19 observations, 15 of which came from a single study, potentially limiting generalizability.

Overall, these findings highlight the importance of both contextual factors and methodological choices in shaping economic valuations of forest biodiversity at the per-hectare scale. The per-hectare model exhibited high explanatory power, with a marginal R^2 of 0.443 and a conditional R^2 of 0.917, indicating that both fixed effects and between-study variability contributed substantially to explaining valuation outcomes.

4.4.3. Robustness and Sensitivity Analyses

To assess the robustness of the results, I also conducted sensitivity analyses which excluded observations identified as outliers, defined as those with absolute Pearson residuals exceeding 2.5 standard deviations. In the per-person model, removing 15 outlier observations led to a substantial improvement in fit, with the conditional R^2 increasing from 0.246 to 0.912 and RMSE decreasing from 1.761 to 0.362. However, the exclusion of these cases rendered the previously marginally significance of temperate-boreal biomes insignificant, suggesting some sensitivity to extreme values. No additional variables became significant in the cleaned model.

For the per-hectare model, excluding 32 outliers yielded modest improvements (conditional R^2 increased from 0.917 to 0.979). Key relationships persisted: GDP per capita remained significantly negatively associated with valuations, direct market methods continued to have positive associations, and genetic indicators were consistently associated with lower valuations. However, the significance of forest size diminished after outlier exclusion, indicating some dependency on influential cases. Detailed sensitivity analysis results for both models are provided in Table 4.8.

Overall, the results of these robustness tests support the appropriateness of the model specifications, transformations, and estimation approaches applied. While some sensitivity to outliers was observed, particularly in the per-person dataset, the main methodological and ecological relationships remained robust across alternative specifications.

Table 4.8 Sensitivity Analysis of Per-Person and Per-Hectare REM Valuation Model (Full Vs. Cleaned Sample)

	Per-person		**Per-hectare**	
Variables	Full Sample	Cleaned Sample	Full Sample	Cleaned Sample
Constant	2.93 (7.01)	6.11 (5.26)	25.91 (6.20) ***	22.78 (6.21) ***
Population density (Log)	-0.34 (0.26)	-0.11 (0.17)	-1.11 (0.46) **	-1.14 (0.51)**
GDP per capita (Log)	0.32 (0.51)	-0.07 (0.38)	-1.30 (0.49) **	-1.38 (0.50) ***
Protected area (Log)	-0.22 (0.73)	-0.56 (0.68)	-0.24 (1.04)	0.18 (1.18)
Forest biome zone (Ref.= Temperate-boreal forests and)				
Savannas and grasslands	1.43 (0.78) *	0.23 (0.46)	2.57 (1.51) *	2.95 (1.52)*
Tropical-subtropical forests	-0.64(1.64)	-1.80 (1.32)	-0.22 (0.52)	-0.05 (0.29)
Others			-0.38 (0.67)	-0.35 (0.36)
Forest size (Log)	0.007 (0.11)	0.008 (0.09)	-0.15 (0.04) ***	-0.010 (0.03)
Valuation methods (Ref. = Choice experiment)				
Contingent value	0.46 (0.67)	-0.06 (0.38)	-0.95 (2.50)	-0.47 (2.47)
Benefit transfer			2.06 (1.11)*	2.64 (1.09) *
Direct market			3.61 (1.48) **	4.31 (1.44) **
Others			-0.53 (1.21)	-0.66 (1.28)
Biodiversity indicators (Ref. = Abstract)				
Habitat	-1.10 (0.86)	-1.05 (0.83)	0.70 (1.17)	1.12 (1.23)
Species	-0.79 (0.83)	-1.06 (0.66)	-1.17 (1.18)	-0.26 (1.18)
Multiple	-1.00 (0.72)	-0.71 (0.64)	0.08 (1.50)	1.06(1.46)
Function			-3.48 (1.96)*	-2.48 (2.14)
Genetics			-7.15 (2.07) ***	-6.73 (2.07) **
Management			-0.97 (1.82)	
N	116	101	140	108
AIC (weights)	513.7	288.1	500.4	313.1
BIC (weights)	549.5	322.1	559.2	366.8
RMSE	1.761	0.362	0.739	0.362
ICC	0.133	0.896	0.852	0.955
R2 (cond.)	0.246	0.912	0.917	0.979
R^2 (marg.)	0.131	0.159	0.443	0.531

Notes: this table presents coefficients and standard errors (in parentheses) from REM estimations for per-person and per-hectare valuations for the full sample and for the cleaned sample where outliers have been excluded from the dataset.

*** p<0.01, ** p<0.05, * p<0.1.

4.5. Discussion

This study provides the first comprehensive meta-analysis focused explicitly on the economic valuation of forest biodiversity. By integrating evidence from 93 studies and 265 observations, this study offers new evidence on how forest biodiversity is conceptualized, measured, and valued across diverse contexts.

My aim was to address a knowledge gap about how forest biodiversity is currently defined and quantified in valuation studies, identify the methodological approaches used, and explore the key factors that influence valuation outcomes. My findings align with longstanding critiques in the literature that biodiversity valuation remains conceptually fragmented, geographically skewed, and methodologically inconsistent (Bartkowski et al., 2015; Farnsworth et al., 2015).

Although publication activity has increased over the past two decades, particularly following global initiatives such as the Millennium Ecosystem Assessment in 2005 and TEEB, the annual number of studies remains modest, suggesting that biodiversity valuation has yet to become a mainstream research focus (Taye et al., 2021). Moreover, the existing literature exhibits a geographic and biome bias, with a predominant focus on Europe and Asia. Regions like Africa and South America, despite their high levels of biodiversity, remain particularly underrepresented, highlighting a critical gap in valuation evidence that could influence global conservation priorities and policy development (Christie et al., 2012; Bartkowski et al., 2015; Acharya et al., 2019). In addition, many studies continue to rely on abstract or simplified biodiversity measures, using a wide variety of valuation methods, with significant data gaps which hamper synthesis of results across the literature. The meta-regression results show that valuation outcomes are highly sensitive to valuation methodologies and context-driven socio-economic and ecological factors.

Taken together, these results underscore that biodiversity valuation is a complex construct shaped by how biodiversity is defined, who is surveyed, and the methods applied. This has important implications for using valuation outcomes in policy and conservation planning. The remainder of this discussion is structured to reflect the key themes emerging from this analysis.

4.5.1. Conceptualizations and Measures of Forest Biodiversity

A central insight from this review is the profound variability in how forest biodiversity is conceptualized and measured across valuation studies. This variability reflects a persistent tension between the ecological complexity of biodiversity and the methodological constraints of economic valuation exercises.

My analysis shows that the majority of studies (75%, 70 studies) frame biodiversity as a standalone concept rather than explicitly situating it within an ES framework. This standalone framing typically treats biodiversity as an intrinsic conservation goal, leading to valuations expressed in abstract terms such as WTP for "biodiversity protection" or "conservation". For example, as Dymond et al., (2007) stated that "We define biodiversity value as the contribution made towards a conservation goal". While this framing resonates with non-use values and ethical considerations, it risks oversimplification, limiting the practical utility of valuation results for designing targeted interventions or assessing trade-offs among biodiversity components.

Conversely, a smaller subset of studies (25%, 23 studies) framed biodiversity within an ES context, likely influenced by concepts such as the 'habitat services' category introduced in the TEEB framework (de Groot et al., 2010; Bartkowski et al., 2015). However, even within this group, considerable ambiguity persists. Terminology often remained vague (e.g., "biodiversity maintenance"), and adoption of the most recent classification systems such as CICES or the IPBES framework is rare. Only 5 studies explicitly classified biodiversity within a specific ES category (four as supporting service, one as regulating service), highlighting a critical lack of consensus on biodiversity's functional role within ecosystems for valuation purposes. This ambiguity, whether biodiversity is valued as an underlying supporting structure, a direct regulator, or an independent entity, fundamentally shapes valuation outcomes and severely hinders the comparability and aggregation of values across studies.

Compounding these conceptual challenges is widespread simplification in how biodiversity is measured. Echoing Farnsworth et al. (2015), the review reveals that many studies (39 studies) employ highly simplified proxies for biodiversity—protected area designations (9 studies), counts of endangered species (5 studies), or symbolic references such as bird diversity (5 studies)—rather than capturing biodiversity's multidimensional ecological reality. Moreover, 26 studies did not use specific ecological indicators at all, instead valuing biodiversity as a broad, conservation concept or as part of general ES assessments. Such simplifications risk conflating biodiversity with broader notions of naturalness or relying on attributes that are cognitively accessible but ecologically incomplete.

Nonetheless, some studies adopted more nuanced approaches. Among the studies reviewed, 22 studies adopted multiple biodiversity indicators, an approach more consistent with ecological assessment practices, allowing for a more nuanced representation of biodiversity's multidimensional nature. These studies often combined species presence, habitat attributes, and ecosystem functions, improving ecological validity and enhancing the relevance of valuation estimates for conservation planning. Furthermore, several studies employed forest-specific indicators, including forest bird diversity, tree species composition, structural features like deadwood presence and tree age variation, forest management practices, and landscape diversity, providing valuable ecological detail and helping to capture the unique conservation values associated with forest ecosystems.

Ultimately, this gap between ecological complexity and valuation practice reflects an inherent constraint of economic methodology. As Christie et al. (2006) observed, biodiversity concepts bifurcate into ecological definitions and anthropocentric definitions. Socio-economic valuation necessarily operates within the latter paradigm, as value is fundamentally anthropogenically assigned. When eliciting public preferences, indicators must align with human perception, cultural context, and cognitive processing limits. Abstract indicators (e.g., "high level of biodiversity") or sensory proxies (e.g., "frequency of bird calls") emerge not as scientific failures, but as necessary adaptations to make the concept biodiversity easily understood by stakeholders. This aligns with the perspective that biodiversity value represents "the contribution of an item to meeting a specific [human] goal" (Dymond et al., 2007). Valuation thus inherently prioritizes manifestations of biodiversity that are easily understood by non-experts over ecologically comprehensive measurements. While ecologists rightly caution that such simplifications capture only partial dimensions of biodiversity, socio-economic valuation remains indispensable for articulating biodiversity's societal relevance and securing support for conservation initiatives.

4.5.2. Methodological Approaches and Study Designs

This review highlights a diverse methodological landscape in forest biodiversity valuation, dominated by stated preference methods, which accounted for 71% of the studies analysed. This dominance indicates that most biodiversity valuations are both subjective and hypothetical in nature, as well as facing the challenges inherent in quantifying non-market values, a trend consistent with earlier reviews (Nijkamp et al., 2008; Atkinson et al., 2012; Bartkowski et al., 2015).

Within stated preference methods, choice experiments emerged as the predominant technique, used in 53 studies, surpassing contingent valuation, which was used in 14 studies. While contingent valuations may overlook the underlying ecosystem properties and biodiversity that support ES (García-Llorente et al., 2011), choice experiments can decompose biodiversity into discrete attributes, enabling estimation of marginal values for specific components. However, this methodological strength can also be a limitation: biodiversity often becomes fragmented into isolated indicators rather than represented as an integrated ecological system. When treated as one attribute among many or even reduced to one level within attributes (e.g., Broch & Vedel, 2012; Broch et al., 2013), biodiversity's distinct contribution often becomes blurred, complicating cross-study comparability and policy interpretation.

A notable feature of the valuation landscape is the pronounced focus on eliciting the general public's WTP, evident in 44 studies. This focus reflects the perceived importance of capturing societal preferences to justify conservation investments. However, it introduces two critical limitations. First, stated preference methods assume respondents possess sufficient ecological literacy to form well-developed preferences, an assumption often unmet in practice (Christie et al., 2006; Defra, 2002). When biodiversity is framed abstractly (e.g., "WTP for conservation") or represented via narrow proxies, respondents may value perceived naturalness or symbolic attributes rather than biodiversity's multidimensional essence (Farnsworth et al., 2015). Second, the strong focus on public WTP coincides with limited empirical attention to stakeholder groups directly involved in land-use decisions. Farmers and forest owners, key agents in land-use decisions, appeared in only 11 studies collectively, despite their prominence in WTA analyses (Table 4.3). This imbalance highlights a clear need for further valuation research that explicitly examines land managers' perspectives, particularly in relation to compensation and incentive design. The near absence of firm valuations (only 2 studies) further neglects the role of corporate actors in biodiversity finance, despite growing environmental, social and governance (ESG) commitments.

Benefit transfer methods, used in 16% of studies (15 studies), demonstrate adaptive responses to practical constraints, such as limited time or funding. Recent innovations have enhanced their ecological relevance. Hybrid approaches, for instance, integrate localized indicators such as vertebrate counts or flora diversity indices (e.g., Enríquez-de-Salamanca, 2023; Pandey et al., 2024), marking significant progress beyond simple unit transfers. Similarly, China's standardized framework (LY/T 1721-2008) exemplifies a policy-driven solution, linking Shannon-Wiener biodiversity thresholds to tiered monetary values. Nonetheless, such standardization risks oversimplifying the inherently context-dependent relationships between biodiversity and human well-being. As Johnston and Rosenberger (2010) caution, benefit transfer accuracy diminishes when site-specific ecological, socioeconomic, or cultural factors are inadequately accounted for.

Direct market valuation methods, though underrepresented at 8% (7 studies), reveal profound conceptual debates about how biodiversity value should be measured. Regulatory cost approaches, such as those applied by Zhao et al. (2019), equate bureaucratic management costs with biodiversity value, while market-pricing studies conflate biodiversity with extractive outputs like timber or non-timber forest products (e.g., Trifunov et al., 2013). Restoration cost methods, exemplified by Pechanec et al. (2017), offer more ecologically grounded valuation estimates. The range of proxies employed, from avoided damage costs (Yao et al., 2021) to replacement costs (Sumarga et al., 2015), highlights ongoing tensions in the field: Are we measuring biodiversity's intrinsic functions, or simply the costs of its absence? This ambiguity echoes Christie et al.'s (2006) distinction between ecological definitions of biodiversity and anthropocentric, value-driven perspectives.

4.5.3. Factors Associated with Biodiversity Valuation Outcomes

The meta-regression analysis reveals a fundamental dichotomy in how economic values for forest biodiversity are associated with contextual and methodological factors. The stark contrast in explanatory power between per-person and per-hectare models underscores that valuation outcomes are intrinsically scale-dependent, reflecting distinct theoretical foundations and policy applications.

The near absence of significant associations of per-person values with contextual factors is particularly striking. This suggests that individuals' WTP for biodiversity conservation may reflect societal values that transcend local socio-economic and ecological conditions. Such findings indicate that existence or bequest values often operate as moral imperatives rather than strictly utility-driven calculations (Kahneman & Knetsch, 1992; Nunes & van den Bergh, 2001b; Farber et al., 2002; Cori et al., 2021). Beyond instrumental value, this suggests that policy tools tapping into intrinsic motivations, such as conservation donations, ethical product branding, or voluntary certification, could be effective, though they will require strategies to engage moral commitment.

By contrast, per-hectare valuations exhibited significant associations with several contextual and methodological factors. Higher population density and GDP per capita were linked to lower per-hectare biodiversity valuations, diverging from earlier studies of forest ES where these factors often correlated positively with value (Ojea et al., 2010; Grammatikopoulou & Vačkářová, 2021; Taye et al., 2021). This pattern suggests that in wealthier or more urbanized contexts, biodiversity's non-use values may be deprioritized amid competing economic pressures. Context is thus crucial for land-use policy: mechanisms like PES or biodiversity offsets must carefully account for local socio-economic conditions, forest size, and spatial dynamics to avoid systematically undervaluing biodiversity in precisely the regions facing the greatest conservation pressure.

Methodological choices also emerged as significant drivers of valuation differences. Direct market valuations and benefit transfer approaches tended to have higher per-hectare values compared to stated preference methods, consistent with earlier findings of methodological bias. This underscores the urgency of methodological standardization. Developing consistent protocols for valuation methods, as well as applying benefit transfer cautiously with appropriate adjustments, is essential for generating credible and comparable biodiversity values.

Equally important is how biodiversity itself is measured and communicated in valuation studies. The results highlight the systematic undervaluation of genetic and functional biodiversity indicators compared to more visible or charismatic attributes. This likely reflects challenges in conveying the ecological importance of less tangible components to respondents, leading to lower willingness to pay. Communicating this "invisible value" effectively remains a key priority. Innovative communication and educational strategies are needed to make abstract ecological functions and genetic diversity more tangible for stakeholders, ensuring that valuations reflect the full spectrum of biodiversity's ecological and societal importance.

Taken together, these findings emphasize that advancing biodiversity valuation requires integrating robust methods, nuanced understanding of context, and thoughtful engagement with ethical and communicative dimensions to inform effective and equitable conservation policy.

4.5.4. Study Limitations

While this review and meta-analysis provides new insights into the economic valuation of forest biodiversity, several limitations should be acknowledged.

A primary limitation is the geographic and biome bias present in the available literature. As highlighted in Section 4.3, more than half of the studies included in this review originated from Europe, with far fewer studies representing tropical, subtropical, or polar regions. This concentration restricts the global generalizability of the findings and may bias the meta-regression results toward contexts more typical of temperate and boreal regions.

A second limitation stems from missing data in primary studies. Key variables, including the currency year, forest size, and detailed ecosystem characteristics, were frequently absent. it introduces uncertainty into currency standardization procedures and potentially reducing the precision of size-related estimates.

A further limitation relates to the inclusion of valuation estimates derived from benefit transfer studies. Because benefit transfer relies on values generated in primary valuation studies, there is a possibility that the same underlying primary estimates may enter the meta-analysis multiple times—once through the original study and again through subsequent benefit transfer applications. While benefit transfer observations are included to examine systematic differences across valuation methods, the summary statistics and meta-regression results should be interpreted as descriptive and comparative, rather than as inputs for subsequent benefit transfer applications.

Another limitation concerns the need to infer biome classifications for many studies. Only 11 studies explicitly defined the forest biome or ecosystem. For the remainder, biome classifications were inferred based on study locations using the IUCN Global Ecosystem Typology (v2.1). Although this approach provides a standardized categorization, it introduces potential misclassification errors, especially for studies conducted in regions with ecological transitions or heterogeneous landscapes.

The meta-regression models also faced statistical constraints that should be noted. Despite employing transformations to stabilize variance, residual heteroscedasticity and non-normality persisted, particularly in the per-person valuation model. The analysis demonstrated sensitivity to outliers, with key relationships, such as the effect of forest size, changing substantially when extreme values were excluded. Additionally, some subgroups, including polar biomes and genetic biodiversity indicators, were represented by very few observations, limiting the statistical power and reliability of subgroup analyses. These limitations suggest that certain results, especially those concerning less frequently studied biomes or indicator types, should be interpreted with caution.

4.5.5. Directions for Future Research

The results of this review and meta-analysis identify several critical directions for future research that could advance both the scientific rigor and policy relevance of forest biodiversity valuation.

First, future research should prioritize underrepresented high-biodiversity regions, including tropical and subtropical forests and savannas, to ensure that valuation outcomes reflect the full diversity of global forest ecosystems. Developing valuation protocols that can adapt to diverse ecological and cultural contexts, such as co-designed indicators with indigenous and local communities, will be essential for producing meaningful and locally relevant valuation data.

Second, bridging the gap between ecological complexity and valuation praxis represents another significant research frontier. Future studies should explore innovative approaches to translate these multidimensional ecological characteristics into metrics more easily understood by non-experts. Promising avenues include testing sensory-based indicators such as soundscapes or olfactory diversity (King et al., 2024) to enhance public comprehension and adopting standardized frameworks like CICES, SEEA EA or IPBES to link biodiversity attributes more explicitly to ES.

Third, improving methodological transparency and reporting standards remains a critical need. This review identified substantial gaps in reporting essential study details, such as currency year, forest size, biome classifications, and valuation context, with 63% of studies omitting some of these key variables. Adopting standardized reporting protocols, akin to CONSORT-style checklists in medical research, could significantly enhance the comparability of valuation studies and facilitate more robust meta-analytical synthesis.

Fourth, expanding stakeholder inclusivity is also crucial for future biodiversity valuation research. Incorporating diverse perspectives through methods such as co-developing valuation instruments with rights-holders and integrating local ecological knowledge into indicator selection could lead to more equitable and practically relevant conservation strategies.

Finally, research should focus on understanding how valuation results translate into policy and conservation outcomes. Future research should pursue longitudinal analyses tracing the journey from valuation estimates to policy adoption and on-the-ground biodiversity outcomes. Quasi-experimental designs comparing areas with and without valuation-informed conservation investments could provide valuable evidence of the practical utility and limitations of economic valuation as a policy tool.

Collectively, these directions suggest that future research must transform biodiversity valuation from an academic exercise into a catalyst for real-world change. This requires embedding valuation studies in underrepresented ecosystems, co-designing methods with marginalized stakeholders, and rigorously tracking how valuation figures shape conservation decisions and ecological outcomes. Only through such interdisciplinary and context-sensitive efforts can biodiversity be valued not merely in economic terms but as a cornerstone of sustainable and equitable forest management.

4.6. Conclusion

My findings reveal significant methodological advances and growing attention to biodiversity valuation in recent decades. Yet, persistent challenges remain, including geographic and biome biases, reliance on abstract or simplified indicators, and gaps in reporting essential study details. The meta-analysis demonstrates that biodiversity valuations are shaped by complex interactions among methodological choices, socio-economic factors, and ecological contexts. While per-person valuations appear to be driven by broad societal values, per-hectare estimates are more sensitive to contextual factors such as national income, population density, and valuation methods.

These insights underscore the need for more ecologically precise, geographically inclusive, and methodologically transparent approaches to valuation. Bridging the gap between ecological complexity and economic valuation is essential to ensure that valuation outcomes can meaningfully inform conservation strategies and policy decisions. Only through such interdisciplinary efforts can economic valuation become a reliable tool for informing conservation strategies and contributing to global biodiversity goals.

Chapter 5 Conclusion

5.1. Revisiting the Research Aim and Question

This chapter integrates and interprets the findings from the three empirical studies presented in Chapters 2–4. Together, these studies address the central question of this thesis: *How can economic theory and valuation methods inform the design of effective policies to incentivise long-term afforestation and biodiversity provision under conditions of landowner reluctance?*

The discussion proceeds by synthesising insights across the three analytical components—the DCE, the ROT-informed interview analysis, and the global meta-analysis of biodiversity valuation—to build a coherent understanding of the afforestation paradox. While each chapter addresses a distinct dimension of the problem—quantification, explanation, and valuation—they converge on a shared insight: persistent under-adoption of afforestation is not the result of irrationality or ignorance but a rational response to a policy and market environment characterised by irreversibility, uncertainty, and misaligned incentives.

By integrating behavioural realism into economic analysis, this thesis contributes to both theory and practice. The remainder of this chapter synthesises the key findings from the three studies, discusses their theoretical and policy implications, highlights the methodological and empirical contributions, acknowledges limitations, and outlines directions for future research and global application.

5.2. Summary of Key Findings

The findings of the thesis can be grouped under three broad themes corresponding to its empirical components: valuation and preferences, decision-making under uncertainty, and global valuation evidence.

5.2.1. Valuation and Preferences

The DCE (Chapter 2) investigates the behavioural and economic drivers of afforestation decisions among Irish farmers through a DCE involving 150 participants. The study estimated farmers' WTA financial compensation for key contract attributes—forest type, replanting obligations, payment duration, and annual premium—using RPL and LC models.

The RPL results quantify the compensation required to incentivize afforestation under varying contract conditions. Farmers would require an additional €955/ha/year to adopt an afforestation contract over maintaining their current land use. Once engaged in forestry, the strongest aversion concerned the statutory replanting obligation, for which farmers required €1,131 per hectare per year in additional compensation to accept the constraint—the highest mWTA value among all attributes. This underscores how legal irreversibility and loss of land-use flexibility act as principal deterrents. Farmers also exhibited a clear preference for native forests over spruce plantations, willing to forgo €696 per hectare per year for native species, reflecting environmental awareness and alignment with Ireland's Forest Strategy 2023–2030 emphasis on biodiversity-enhancing afforestation. Longer payment durations (50- and 100-year schemes) were also valued, indicating the importance of financial security and temporal alignment between costs and benefits.

Latent-class analysis revealed strong heterogeneity across farmer types. One segment—older, larger-scale landowners with prior forestry experience—displayed pro-afforestation preferences, often favouring spruce due to predictable harvest cycles. A second, more environmentally conscious but younger group preferred native forests yet resisted participation because of perceived regulatory burdens. A third group, comprising mid-sized family farmers with prior but negative afforestation experiences, expressed the greatest opposition to further planting. These distinct behavioural profiles confirm that afforestation uptake is shaped by diverse motivations, experiences, and risk attitudes.

Overall, Chapter 2 demonstrates that afforestation policy in Ireland suffers from a mismatch between policy instruments and farmer preferences. Financial incentives alone cannot offset perceived irreversibility, policy uncertainty, and cultural identity concerns. Effective policy must therefore differentiate by farmer segment and prioritise flexibility—such as extending payment horizons, and embedding adaptive contract mechanisms—to realign private incentives with public environmental objectives.

5.2.2. Decision-Making under Uncertainty

The Chapter 3 deepens the interpretation of farmer behaviour through a qualitative study informed by ROT. Drawing on 24 in-depth interviews with Irish farmers, the study re-examines afforestation reluctance not as irrational conservatism but as a rational response to irreversibility, uncertainty, and alternative opportunities.

The thematic analysis organised findings under the three pillars of ROT—Irreversibility, Uncertainty, and Flexibility—supported by 62 codes and nine overarching themes. Irreversibility emerged as the dominant concern. Farmers consistently described forestry as a permanent land-use change that binds both land and future generations. The statutory replanting obligation and legal reclassification of farmland to forestry constituted the most tangible form of "lock-in," magnifying both financial and cultural sunk costs. Farmers equated afforestation with a loss of family farming identity, seeing the act of planting as a symbolic departure from productive agriculture.

Uncertainty was pervasive across institutional, ecological, and market domains. Farmers cited licensing delays, inconsistent policy reforms, vulnerability to disease, and fluctuating timber prices as reinforcing their reluctance. The combination of these risks elevated the option value of waiting—a central tenet of ROT. In their view, deferring investment preserved flexibility until policy, market, or technological conditions improved.

Finally, the option to wait was exercised deliberately as a strategic choice. Many participants expressed optimism that forthcoming policy innovations—particularly carbon and biodiversity credit markets—could transform forestry's value proposition by providing long-term, performance-based revenues. They viewed current schemes as inadequate interim arrangements and preferred to hold land in reserve until more credible market or policy mechanisms materialised. This aligns directly with ROT's prediction that when irreversibility is high and uncertainty unresolved, delaying investment is economically rational.

The study thus reconceptualises non-adoption not as resistance but as rational risk management. It extends ROT beyond quantitative finance into the behavioural and institutional domains of land-use policy, showing how legal, social, and identity-based irreversibilities interact multiplicatively to inflate hurdle rates for investment. By doing so, it bridges economic and sociological understandings of landowner behaviour, providing a powerful interpretive framework for policy design under deep uncertainty.

5.2.3. Global Valuation Evidence

The Chapter 4 provides the first comprehensive meta-analysis dedicated specifically to the economic valuation of forest biodiversity, synthesising 93 studies and 265 individual value estimates. The analysis addressed three overarching questions: how biodiversity is defined and measured in valuation studies; what methods are applied; and which contextual and methodological factors explain variation in reported values.

The results reveal profound conceptual and methodological fragmentation in the existing literature. Approximately 75 per cent of studies treat biodiversity as a standalone concept rather than situating it within an explicit ecosystem-service framework, resulting in ambiguous or abstract expressions of value. Only a small subset of studies classified biodiversity according to recognised frameworks such as CICES or IPBES. This lack of definitional consistency constrains the comparability and transferability of valuation outcomes across regions.

The meta-regression results confirmed that valuation outcomes depend strongly on methodological choices and contextual conditions. Direct market valuation and benefit-transfer approaches produced significantly higher per-hectare values than stated-preference methods, revealing systematic methodological bias. Socio-economic and ecological variables also influenced outcomes: higher national income and population density were generally associated with lower per-hectare valuations, while larger forest size correlated with diminishing marginal value, consistent with economic scarcity principles. In contrast, per-person valuations—dominated by stated-preference studies—showed limited association with observable moderators, reflecting the subjective nature of willingness-to-pay for non-use values. Additionally, non-visible components of biodiversity—genetic and functional indicators—were markedly undervalued compared with more tangible or charismatic attributes. This suggests persistent communication and cognitive barriers in conveying the ecological importance of less perceptible biodiversity dimensions.

Collectively, the findings demonstrate that forest-biodiversity valuation remains dominated by methodological heterogeneity, geographic bias toward temperate regions, and an over-reliance on stated-preference data. These weaknesses limit the reliability of valuation evidence for informing market mechanisms such as biodiversity credits or PES. The paper concludes that advancing biodiversity valuation requires greater methodological standardisation, improved contextual transparency, and more explicit integration of ecological science into economic frameworks.

Taken together, the three papers construct a coherent narrative of the afforestation challenge from complementary angles, showing that the afforestation gap is rooted not in irrationality or inadequate payment levels but in systemic valuation and decision-making failures—

economic, institutional, and behavioural. Addressing these requires policies that internalise non-market values, reduce perceived irreversibility, and create credible, flexible, and diversified reward mechanisms for ecosystem stewardship.

5.3. Policy Implications: Designing for Uptake

The three studies presented in this thesis collectively demonstrate that the persistent shortfall in afforestation uptake cannot be attributed to inadequate payments alone. Rather, it reflects deeper structural and behavioural constraints: legal irreversibility, policy volatility, cultural resistance, and limited recognition of non-market ecosystem benefits. Policy interventions must therefore move beyond compensating for lost agricultural income toward restructuring the risk–return and trust landscape of afforestation, aligning financial mechanisms, institutional design, and social legitimacy.

5.3.1. Redesigning Afforestation Incentives

The DCE reveal that farmers are more responsive to contract flexibility and security than to incremental increases in premium levels. Extending payment durations beyond the current 15–20 years would better reflect forestry's temporal profile and reduce perceived risk. Long-term or even permanent payments—particularly for native woodland, where timber revenues are minimal—could provide an income stream comparable to the ongoing supports available under general agricultural payment schemes. Such continuity would recognise forestry as a legitimate land-use enterprise delivering public goods, rather than as a temporary environmental measure, thereby strengthening its financial and institutional credibility among farmers.

To address the legal and financial irreversibility of afforestation, reversible or conditional contracts could be introduced. Farmers might opt for lower payments in exchange for the right to exit after one rotation, or higher payments in exchange for permanence. Reforming the replanting obligation to include derogations for native species or marginal lands would restore some element of choice and align with ecosystem restoration objectives. Additionally, mechanisms such as advance timber purchase agreements or afforestation bonds, as proposed in earlier policy analyses (Ryan et al., 2022), could provide farmers with upfront liquidity while transferring part of the long-term risk to the state or private investors. Such innovations would convert forestry from a rigid investment into a more manageable, phased commitment.

5.3.2. Strengthening Institutional Credibility and Reducing Policy Risk

The Real Options analysis underscores that policy instability and administrative inefficiency amplify the perceived value of waiting, thereby rationalising inaction. Long delays in licence approvals, shifting eligibility criteria, and inconsistent communication have weakened trust in state institutions. To restore confidence, policy must prioritise predictability, transparency, and credibility.

This could include statutory timelines for licence decisions, index-linking premiums to inflation to maintain real value, and embedding long-term afforestation targets in legislation insulated from short-term political cycles. Establishing state-backed insurance against pests, disease, or storm damage would further demonstrate the government's commitment to sharing risk. However, the slow and uncertain response to the ash dieback crisis severely undermined farmer confidence in forestry policy (Irish Farmers' Association [IFA], 2024). Extending comparable levels of support to forestry as those provided for losses in traditional agriculture would signal parity of treatment across land uses and reinforce the perception of the state as a credible co-investor rather than a distant regulator. Such measures would not only lower the option value of delay but also signal that the state is willing to share uncertainty rather than transfer it entirely to private landowners.

5.3.3. Integrating Socio-Cultural Dimensions into Policy Design

The qualitative evidence highlights that reluctance toward afforestation is not simply economic—it is also deeply cultural. Many farmers perceive forestry as a symbolic retreat from productive agriculture and as a threat to multigenerational continuity. Overcoming this requires reframing forestry as a legitimate, productive, and honourable form of land stewardship.

Policy narratives should shift from "planting trees" to "farming trees." Promoting agroforestry, mixed-use landscapes, and native woodland creation can bridge the perceived divide between forestry and agriculture. Demonstration farms, peer networks, and advisory services led by respected local farmers could help normalise forestry as a component of resilient land management rather than a departure from farming identity. Co-designing afforestation schemes with farmer organisations and community groups would enhance legitimacy, foster ownership, and rebuild trust in forestry institutions.

5.3.4. Returning to Forests as Multi-Functional Ecosystems

Beyond redesigning incentives, the findings point to a more fundamental requirement: forests must be recognised and governed as multifunctional ecosystems rather than treated primarily as timber-producing assets. Forests generate a wide range of ecosystem services, including carbon sequestration, biodiversity habitat, water regulation, soil protection, landscape amenity, and cultural value. Many of these services exhibit public-good characteristics and are therefore not fully reflected in private land-use decisions.

Yet policy frameworks frequently value only a subset of these services, most notably timber and, more recently, carbon (O'Donoghue, 2022), while underrepresenting biodiversity and other non-market ecosystem functions. This incomplete valuation weakens the economic case for biodiversity-enhancing forestry and reinforces reliance on timber harvest as the dominant long-term revenue source.

Addressing this imbalance requires integrating the broader bundle of ES into policy design. This may involve enhanced public payments linked to biodiversity and habitat quality, differentiated support for native and mixed-species forests, or the development of ES and blended finance mechanisms that reward measurable ecological outcomes. Recognising forests as providers of multiple public goods is therefore not an environmental add-on, but a structural prerequisite for aligning private incentives with long-term ecological and societal objectives.

5.3.5. Integrating Market-Based Mechanisms and Innovative Finance

A consistent message across both the DCE and interview findings is that farmers view emerging carbon and biodiversity credit markets as potentially transformative—but not yet credible. Currently, the rational choice is to wait, preserving optionality until these markets mature. Accelerating their establishment could therefore change the decision calculus by creating immediate, tradable value streams.

The introduction of the EU Carbon Removals and Carbon Farming Regulation (CRCF, 2024/3012) and the global momentum behind the Kunming–Montreal Global Biodiversity Framework open new opportunities for Ireland to design credible, transparent, and science-based nature markets. A national high-integrity carbon and biodiversity credit registry, governed by independent verification standards, could allow companies to purchase offsets that count toward CSRD compliance. Farmers could thus benefit from a second income stream linked to verified ecosystem outcomes, reducing dependence on static subsidies.

Such markets must, however, be underpinned by robust valuation science. As the meta-analysis demonstrates, current biodiversity valuation is fragmented and inconsistent, limiting the credibility of credit prices. Establishing transparent valuation protocols, drawing on standardised metrics of ecosystem function, service flow, and spatial context, would be essential for scaling biodiversity finance while maintaining environmental integrity.

5.3.6. Emphasising Communication and Cognitive Alignment

Equally important is the role of communication in enabling effective forest policy. The research demonstrates that valuation and policy design cannot operate solely at the level of technical optimisation; they must also engage with how ecological concepts are understood by landowners and the broader public. The disconnect identified in Chapter 4 between scientific definitions of biodiversity and public interpretation highlights a critical governance challenge: if biodiversity is to be funded, whether through taxation or private finance, its meaning must be sufficiently intelligible to those who bear its costs. Overly complex or technocratic framings risk undermining legitimacy and support. Effective afforestation policy therefore requires not only financial engineering but communicative clarity: translating ecological complexity into socially meaningful narratives that resonate with farmers' identities and public values. In this sense, communication is not a peripheral consideration but a foundational component of credible and durable ecosystem finance.

5.3.7. Toward an Integrated Policy Architecture

The combined evidence of this thesis points to the need for a systems approach to afforestation policy—one that integrates financial, institutional, and cultural dimensions rather than treating them as separate domains. In practical terms, this means coordinating afforestation with agricultural, climate, and rural development policies to ensure coherence in land-use incentives. Aligning forestry premiums with agri-environmental payments under the CAP could reduce competition between sectors and promote multifunctional land stewardship.

An integrated governance framework should also embed adaptive management principles, enabling continuous learning and iterative adjustment based on monitoring outcomes. This adaptive capacity is crucial for managing the uncertainties inherent in long-term environmental policy and for maintaining legitimacy across successive policy cycles.

5.3.8. Concluding Reflections on Policy Design

Across all three studies, the overarching policy message is clear: raising premiums alone will not close the afforestation gap. What is required is the design of a forestry policy that recognises and mitigates the major barriers to afforestation uptake by irreversibility, reduces uncertainty, and creates immediate, diversified value for landowners.

Specifically:

- Mitigate irreversibility by reforming legal and financial constraints (e.g., flexible contracts, revised replanting rules, longer payment horizons).
- Reduce uncertainty through institutional credibility, predictable licensing, insurance schemes, and inflation-indexed supports.
- Create present value by supporting the development of carbon and biodiversity markets that reward measurable ecological outcomes.

In sum, afforestation policy must evolve from a static subsidy model to a dynamic risk-sharing partnership between farmers, the state, and the private sector. Only through such institutional and financial innovation can Ireland—and other nations facing similar challenges—mobilise the landowner participation required to achieve their forest, climate, and biodiversity ambitions.

5.4. Contributions to Knowledge

This thesis makes four interrelated contributions to the literature on environmental economics, land-use decision-making, and forest policy. Together, they advance theoretical understanding, methodological practice, and empirical evidence on the economic and behavioural drivers of afforestation, while also providing actionable insights for policy and finance.

5.4.1. Theoretical Contributions

The thesis advances the theoretical understanding of land-use decision-making by integrating ROT with behavioural and institutional economics. Traditional neoclassical approaches, grounded in NPV logic, conceptualise afforestation as a static investment decision—an immediate choice between forestry and agriculture based on discounted cash flows. By contrast, this thesis demonstrates that afforestation under uncertainty is better understood as a dynamic and sequential decision, where the option to wait has quantifiable value.

Through the qualitative analysis of farmer interviews, this research extends ROT beyond its conventional domain of financial and resource investments to incorporate institutional, social, and identity-based sources of uncertainty. It reveals that legal irreversibility (the replanting obligation), policy volatility, and cultural identity collectively elevate the option value of delay. In doing so, the thesis contributes a behavioural interpretation of ROT, showing that hesitation to plant trees is not evidence of irrationality but a rational response to irreversible and uncertain conditions.

In parallel, the integration of ROT with stated-preference evidence from the discrete choice experiment bridges two previously separate literatures—quantitative economic modelling and qualitative behavioural inquiry—demonstrating how formal investment theory can be operationalised to interpret real-world land-use behaviour. This conceptual synthesis offers a new lens for analysing environmental policy design under deep uncertainty.

Furthermore, Chapter 4 contributes a conceptual-theoretical extension to environmental economics by examining how biodiversity is conceptualised and valued within economic frameworks. It identifies the persistent gap between scientific and public understanding of biodiversity, demonstrating that economic valuation necessarily operates at this intersection. The analysis suggests that achieving effective biodiversity finance requires acknowledging a “good enough” public understanding of biodiversity—one that balances scientific rigour with communicative accessibility. In other words, valuation must translate ecological complexity into socially intelligible and policy-relevant terms. This insight extends theoretical thinking in biodiversity economics by emphasising that the legitimacy and scalability of biodiversity funding depend not only on ecological precision but also on cognitive and communicative alignment between science, policy, and society.

5.4.2. Methodological Contributions

Methodologically, the thesis develops and applies an innovative sequential mixed-methods design that combines three complementary analytical approaches: (1) DCE for quantifying preferences and willingness to accept compensation; (2) qualitative thematic analysis informed by ROT to interpret behavioural rationales; and (3) systematic review and meta-regression to situate national findings within the global valuation evidence base.

This triangulated design moves from quantification to interpretation to synthesis, allowing the thesis to capture the full complexity of afforestation decision-making—from explicit preference structures to underlying reasoning processes and global valuation patterns. The sequential use of DCE and ROT represents a novel methodological pairing, where quantitative and qualitative insights inform and validate each other.

The meta-analysis of forest biodiversity valuation further contributes to methodological development by applying a mixed-effects meta-regression model to identify and control for clustering, publication bias, and methodological heterogeneity. This statistical approach enhances transparency and comparability in environmental valuation synthesis, providing a replicable framework for future meta-analyses in the field.

Collectively, these methodological innovations demonstrate how combining stated-preference modelling, behavioural theory, and evidence synthesis can yield more robust and policy-relevant insights than any single approach alone.

5.4.3. Empirical Contributions

Empirically, this thesis offers a comprehensive and multidimensional analyses of afforestation in Ireland, drawing on original survey and interview data from over 150 farmers. The discrete DCE provides quantitative evidence of the magnitude of farmers' reluctance to afforest, revealing that even substantial financial incentives cannot fully offset aversion to irreversibility and perceived loss of flexibility. The LC model uncovers significant heterogeneity across farmer segments, identifying distinct profiles—from financially motivated large-scale farmers to environmentally conscious but cautious smallholders—thereby challenging one-size-fits-all policy approaches.

The qualitative study adds depth by uncovering the micro-level rationalities that underlie these preferences. It documents how farmers interpret forestry as a permanent and identity-threatening land-use change. These findings reveal the complex interplay between economic logic, institutional trust, and cultural meaning in shaping afforestation behaviour.

At the global scale, the systematic review and meta-analysis synthesise over two decades of forest biodiversity valuation studies, exposing methodological fragmentation and geographic biases that undermine the credibility of valuation evidence. The analysis identifies clear patterns—such as the systematic undervaluation of genetic and functional diversity—and provides empirical parameters for improving the design of biodiversity valuation and credit markets. Together, these studies provide a rich empirical foundation linking micro-level decision-making with macro-level valuation systems, bridging scales that are often treated in isolation.

5.4.4. Policy Contributions

Beyond its theoretical and empirical advances, this thesis contributes conceptually to how environmental policy and governance are understood and designed. It reframes afforestation policy not as a question of increasing compensation, but as a problem of risk allocation, institutional credibility, and behavioural alignment. In doing so, it advances a framework for policy analysis that links economic reasoning with institutional and cultural dimensions of land-use governance.

First, the thesis introduces the notion of option structure engineering—a policy design approach that applies Real Options logic to make long-term environmental investments more attractive. By recognising that the option value of waiting stems from irreversibility, uncertainty, and inflexibility, this framework shows that policies which reduce these constraints—through flexible contracts, extended payment horizons, and predictable regulation—can increase participation without necessarily raising compensation levels. It thus provides a practical bridge between investment theory and policy design under uncertainty.

Second, it contributes to the literature on environmental governance and trust by demonstrating that institutional credibility and procedural reliability are as critical as financial incentives. This finding expands the focus of afforestation policy from payment design to the institutional architecture through which policy is delivered and perceived.

Third, by connecting national evidence with global valuation patterns, the thesis extends the policy conversation from forestry incentives to nature finance mechanisms. It highlights that effective biodiversity and carbon markets depend on rigorous valuation foundations and transparent governance frameworks. In doing so, it provides a conceptual bridge between micro-level behavioural insights and macro-level policy innovation, offering guidance for integrating afforestation, biodiversity, and carbon strategies under coherent, risk-aware governance systems.

Together, these contributions move policy debates beyond the traditional focus on financial adequacy toward a more comprehensive understanding of how incentive design, institutional credibility, and valuation integrity interact to enable the forest transition.

5.5. Limitations

While this thesis offers a multi-dimensional analysis of afforestation behaviour, valuation, and policy design, several limitations must be acknowledged in relation to its methodological scope, data representativeness, and theoretical generalisability, and interpretive framing.

As with most stated-preference and interview-based studies, the analyses are limited by potential hypothetical bias, sample size, and representativeness. The survey and interview participants were diverse but not nationally exhaustive, and their responses may not perfectly reflect real-world behaviour under actual financial risk. The focus on farmers also excludes perspectives from non-farming landowners and institutional investors who increasingly influence land-use dynamics. Future studies could expand the dataset, combine stated and revealed preference approaches, or use longitudinal designs to track behavioural change over time.

The application of ROT to afforestation represents a novel but partial translation from finance to socio-environmental decision-making. In this thesis, option value is interpreted qualitatively rather than estimated quantitatively, and the framework is adapted to capture institutional and cultural uncertainty. While this approach yields rich insight, it remains interpretive rather than formally modelled. Extending it with quantitative simulation or hybrid behavioural–economic models could further operationalise the concept of flexibility in land-use policy.

The meta-analysis in Chapter 4 relies on secondary data and published studies, which may be affected by publication bias and inconsistent biodiversity definitions. Although mixed-effects modelling and standardised coding were applied to control for these issues, residual heterogeneity remains.

Empirically, the thesis is situated in Ireland—a country with distinctive land tenure, farm structure, and regulatory institutions. These features make it an ideal case for exploring afforestation barriers but limit the direct generalisability of the results. Nonetheless, the underlying mechanisms identified—irreversibility, uncertainty, and institutional trust—are broadly relevant across temperate agricultural economies. Comparative applications in other policy and cultural contexts would test the robustness of these insights.

By articulating these limitations transparently, the thesis lays the groundwork for cumulative scholarship—where future research can extend, refine, and operationalise the frameworks developed here to advance the global forest transition agenda.

5.6. Global Relevance and Future Directions

5.6.1. From National Experience to Global Insight

While this thesis is anchored in Ireland, its findings resonate far beyond national borders. The structural, behavioural, and institutional barriers that constrain Irish afforestation mirror those observed across many temperate, developed economies: fragmented policy frameworks, declining rural trust in environmental institutions, and a heavy reliance on short-term subsidy instruments. By diagnosing these failures through a combination of valuation analysis and Real Options reasoning, the thesis provides a transferable framework for understanding why landowners worldwide hesitate to engage in long-term ecosystem restoration despite substantial financial incentives.

More broadly, the Irish experience exemplifies a central paradox of contemporary environmental policy: ambitious targets without credible implementation pathways. As nations strive to meet the Paris Agreement and the Kunming–Montreal Global Biodiversity Framework, the insights generated here demonstrate that achieving transformative land-use change requires more than additional funding. It demands a reconfiguration of risk, trust, and time within policy design—a challenge that transcends national contexts.

5.6.2. Advancing Global Nature Finance

The findings also speak directly to the rapidly evolving field of nature finance, particularly the design of biodiversity credit markets. The meta-analysis reveals that current valuation evidence remains fragmented, methodologically inconsistent, and geographically biased—conditions that threaten the credibility and scalability of emerging credit systems.

Addressing these weaknesses is essential if biodiversity markets are to mobilise private capital effectively and equitably. This thesis contributes by identifying the empirical parameters and valuation frameworks necessary for a high-integrity global biodiversity market: explicit ecological definitions, transparent benefit-transfer functions, and meta-analytic baselines for price discovery. These principles align with the UN SEEA framework, the OECD's Policy Guide on Natural Capital and the Economy (2021), and the EU's Carbon Removals and Carbon Farming Regulation (2024/3012).

In practical terms, the thesis suggests that global biodiversity finance must evolve from fragmented pilot schemes to institutionally embedded markets, supported by clear standards for measurement, reporting, and verification (MRV). By coupling robust valuation with the risk-sharing principles derived from ROT, policymakers can create instruments that are both economically credible and socially acceptable.

5.6.3. Integrating Climate and Biodiversity Policy

The research reinforces the necessity of integrating climate and biodiversity agendas. Too often, carbon-focused mitigation policies overlook ecological co-benefits or, worse, incentivise monocultures that degrade biodiversity. The thesis demonstrates that policy instruments can—and must—be designed to capture synergies between carbon sequestration, biodiversity restoration, and rural livelihoods.

In the EU context, this calls for alignment between the Nature Restoration Law, the Common Agricultural Policy's eco-schemes, and Member States' Forest Strategies. Globally, similar coherence will be vital within the post-2030 biodiversity financing architecture, including the Global Environment Facility and multilateral development banks. The empirical and theoretical tools developed here—stated-preference valuation and Real Options-based behavioural modelling—offer replicable frameworks for assessing how such integrated policies perform under uncertainty.

5.6.4. Directions for Future Research

Building on these contributions, several avenues merit further exploration:

Quantitative integration of Real Options and choice modelling. Future work could formally embed option-value parameters within econometric choice models to estimate the monetary value of waiting and flexibility in environmental investments.

Longitudinal behavioural studies. Tracking farmer or landowner decisions over successive policy cycles would reveal how changing incentives, markets, and social norms reshape participation.

Cross-country comparative analysis. Applying the mixed-methods framework developed here to other European or Global South contexts would test its generalisability and illuminate how governance structures mediate afforestation behaviour.

Valuation of co-benefits in emerging biodiversity markets. As biodiversity credits move toward implementation, research should evaluate how different valuation metrics influence equity, transparency, and environmental integrity.

Institutional design and governance of nature finance. Future studies could examine the optimal balance between public oversight and private innovation in credit certification, risk management, and benefit-sharing.

Collectively, these directions extend the thesis's interdisciplinary agenda, bridging environmental economics, behavioural science, and sustainability governance.

5.7. Overall Conclusion

This thesis set out to understand why, despite strong policy ambitions and generous financial incentives, afforestation rates in Ireland—and by extension, across much of Europe—remain persistently below target. It argued that this paradox cannot be explained by inadequate compensation alone, but by a deeper combination of valuation and behavioural failures: how societies measure the benefits of forests and how landowners perceive the risks of planting them.

Across three integrated studies, the research revealed that these failures are intertwined. The choice experiment demonstrated that farmers' willingness to accept afforestation contracts is driven less by payment size than by contractual flexibility, security, and trust in policy. The Real Options analysis reframed this reluctance as a rational response to irreversibility, uncertainty, and identity concerns, rather than as irrational resistance. The meta-analysis of global biodiversity valuations, in turn, exposed the methodological fragmentation that weakens the evidence base for designing credible, market-linked instruments such as biodiversity credits. Together, these studies construct a coherent narrative: the afforestation gap reflects not apathy or ignorance, but a logical response to structural, institutional, and informational constraints.

Theoretically, the thesis bridges environmental economics and behavioural decision theory by extending Real Options logic into socio-institutional contexts, demonstrating that waiting can be rational when policy credibility and flexibility are low. Methodologically, it advances a sequential mixed-methods framework that links micro-level decision-making with global valuation evidence, offering a replicable model for other sustainability transitions. Empirically, it provides a comprehensive examinations of Irish afforestation behaviour, situating it within global efforts to value and finance forest ecosystem services.

The overarching policy message is that raising payments will not close the afforestation gap. What is required is institutional and financial innovation that shares risk, reduces irreversibility, and creates immediate, diversified value for landowners. Designing such "option structures" demands not only better economics but better governance—stable rules, trusted institutions, and recognition of the cultural meaning of land stewardship.

More broadly, the Irish case illuminates a universal insight for sustainability policy: transformative change depends as much on the architecture of incentives and institutions as on the scale of ambition. Afforestation, like many nature-based solutions, sits at the intersection of ecological urgency and human uncertainty. By integrating valuation, behaviour, and finance, this thesis contributes a framework for navigating that uncertainty—transforming hesitation into informed participation.

In conclusion, the central lesson is that the transition to sustainable land use will succeed not when policies compel compliance, but when they make environmental action the rational, trusted, and rewarding choice. Achieving this alignment between private rationality and public purpose is both the challenge and the promise of the global forest transition.

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Appendix A. Supplementary Material for Chapter 2

Appendix A1 Composition of Native and Broadleaf Species in the Irish Forestry Programme 2023–2027

Forest Type 1 (Native Forests): Common alder (Alnus glutinosa), Downy birch (Betula pubescens), Silver birch (B. pendula), Wild cherry (Prunus avium), Pedunculate oak (Quercus robur), Sessile oak (Q. petraea), Rowan (Sorbus aucuparia), Hazel (Corylus avellana), Hawthorn (Crataegus monogyna), Grey willow (Salix cinerea), Scots pine (Pinus sylvestris) and Holly (Ilex aquifolium).

Table A2 WTA Estimates from Random Payment Model (€/ha/year)

Attribute	Median_WTA	CI_lower	CI_upper	mWTA
ASC	-1058.0077	-1911.618	-10.68296	-1030.7892
Native forest	-660.0674	-1679.577	-73.64224	-721.8738
No replanting	-1161.2452	-2055.768	-601.21668	-1209.2581
50-year payment	-892.3983	-1427.393	-441.00411	-901.7279
100-year payment	-1149.1497	-1703.64	-539.95143	-1139.2879

Note: WTA estimates were derived using simulation methods based on the random-payment RPL specification. Because the payment parameter is random, WTA values follow a ratio distribution that can exhibit skewness and heavy tails. To address this, WTA distributions were generated using 10,000 draws from the estimated parameter distributions, and median WTA values with 95% simulated confidence intervals (2.5th and 97.5th percentiles) are reported. Estimates reflect the additional annual compensation (€/ha/year) required relative to the reference level of each attribute.

Table A3 Model Fit Statistics Comparison

Model	LogLik	Pseudo_R2	Adj_R2	AIC	BIC
RPL Random ASC, Fixed Payment	-532.64	0.1517	0.1342	1087.28	1135.65
RPL Random ASC, Random Payment	-529.32	0.1570	0.1379	1082.63	1135.39
RPL Fixed ASC, Fixed Payment	-560.22	0.1078	0.0919	1140.44	1184.41
WTP Space model	-590.25	0.1046	0.0910	1190.50	1212.48

Note: Model comparison across RPL specifications and WTP-space model. RPL Random ASC, Random Payment shows best fit (lowest AIC/BIC) but fixed payment specification used for primary WTA interpretation due to ratio estimation stability. All RPL models use 1,000 Halton draws.

Appendix B. Supplementary Material for Chapter 3

Farmer Interview Questions

1. Background Information

- Can you tell us about your farming background and the type of farming you engage in?
- How long have you been farming, and how much land do you manage?

2. Awareness and Understanding of Forestry Programs

- What forestry schemes are you currently aware of?
- Have you participated in any forestry programs in the past? If so, which ones?
- How well do you think the current forest programs are communicated to the farming community?

3. Benefits and Drawbacks of Forestry, and the recommendations

- Can you describe any barriers that have prevented you from taking part in forestry programs?
- What benefits, if any, do you think forestry offers to your farming practice and the broader community?
- What changes would encourage you to participate more actively in forestry schemes?
- What kind of support would you need from the government or other organizations to consider expanding into forestry?

4. Financial Incentives and Supports

- What role do financial incentives play in your decision-making process regarding forestry?
- Are the current financial incentives sufficient to motivate you to participate? Why or why not?

5. Biodiversity and climate

- Are the issues of climate change or biodiversity on your mind when you work with forestry?

- Are there any other measures within your work do you do to support biodiversity and nature?
- How do you think biodiversity and nature are thriving doing / well in your areas?

6. Culture and community

- Has tree planting effected, or will effect, your local community? If yes, what kinds of effects?

7. Future Prospects

- What is your vision for the future of your farm?
- What do you see as the main challenges and threats to farms like yours currently?
- Looking ahead, do you see a role for forestry in your farming strategy?

8. Additional Insights

- Is there anything else you'd like to share about your experiences or opinions related to forestry and farming?

Appendix C. Supplementary Material for Chapter 4

Table C1 Database-Specific Filter Terms

Data source	Biome-related filters	Document type	Year of Publication
EVRI	For ‘General environmental assets’ column, choose all options contains the following key words: ▪ Forest ▪ Woodland ▪ Trees or plants ▪ Rainforest	For ‘Document Type’ column, choose: ▪ Journal	For ‘Publication year’ column, choose all options below: ▪ 2005 ▪ 2006 ▪ … ▪ 2025 (the database is up to 2025)
ESVD	For ‘Biomes’ column, choose all options below: ▪ Tropical and subtropical lowland rainforest ▪ Tropical and subtropical dry forests ▪ Tropical and subtropical mountain ▪ Tropical heath forests ▪ Tropical and subtropical forests ▪ Temperate forests and woodlands ▪ Temperate rain or evergreen forests ▪ Temperate deciduous forests ▪ Temperate pyric forests ▪ Boreal and montane forests and w. ▪ Boreal Coniferous forests ▪ High mountain forests ▪ Temperate grassy woodlands ▪ Grassy woodlands and dry grassland ▪ Seasonally dry tropical shrublands ▪ Seasonally dry temperate heath ▪ Shrublands and shrubby woodlands		For ‘Year_Pub’ column, choose all options below: ▪ 2005 ▪ 2006 ▪ … ▪ 2023 (the database is up to 2023)
TEEB	For ‘Biomes’ column, choose all options below: ▪ Forests ▪ Tropical Forest ▪ Multiple Ecosystems ▪ Woodland		For ‘Year of Publication’ column, choose all options below: ▪ 2005 ▪ 2006 ▪ … ▪ 2010 (the database is up to 2010)
WoS	For the WoS search, I used combinations of the following keywords in the title, abstract, and keyword fields adopted and tailored from Bartkowski et al. (2015) : “economic valu*”, “contingent valuation”, “choice model*”, “choice experiment”, “conjoint analysis”, “monetary”, “WTP”, “willingness to pay”, “WTA” , “benefit transfer” in combination with “biodiversity” and “forest” or “woodland”. The search was limited to peer-reviewed journal articles published between 2005 and 2025, in English.		

Note: The biome-related filter terms were tailored to the specific classification systems and search capabilities of EVRI, ESVD and TEEB as these three databases have different structures and classifications. Only EVRI provides an option to filter by document type, for which I selected ‘journal’ whereas ESVD and TEEB do not offer this feature. Within WoS I conducted the search using keywords. An asterisk (*) was employed as a wildcard to capture variations in terminology.

Table C2 Overview of reviewed studies on the economic valuation of forest biodiversity

Reference	Valuation method	Indicator type	No. of observations
(Naidoo & Adamowicz, 2005)	CE	Species	2
(Biénabe & Hearne, 2006)	CE	Abstract	2
(Horne, 2006)	CE	Abstract	1
(Matta et al., 2007)	CE	Management	1
(Matero & Saastamoinen, 2007)	BT	Species	1
(Dymond et al., 2007)	Others	Abstract	12
(Meyerhoff & Liebe, 2008)	CV	Multiple	4
(Boman et al., 2008)	CV	Habitat	1
(Garcia et al., 2009)	CV	Abstract	4
(Meyerhoff et al., 2009)	CE	Multiple	4
(Lindhjem & Navrud, 2009)	CV	Habitat	2
(Bernard et al., 2009)	MP	Genetics	1
(Czajkowski & Hanley, 2009)	CE	Multiple	4
(Czajkowski et al., 2009)	CE	Multiple	1
(Meyerhoff & Liebe, 2009)	CE	Multiple	4
(Li et al., 2010)	BT	Habitat	1
(Yousefpour et al., 2010)	Others	Species	2
(Koellner et al., 2010)	CV	Abstract	2
(Getzner, 2010)	CV	Abstract	1
(Garcia et al., 2011)	CV	Abstract	3
(Liebe et al., 2011)	CV	Multiple	1
(Broch & Vedel, 2012)	CE	Habitat	5
(Reichhuber & Requate, 2012)	BT	Genetics	1
(Niu et al., 2012)	BT	Species	1
(Thiene et al., 2012)	CE	Multiple	8
(Upton et al., 2012)	CE	Habitat	2
(Christie & Rayment, 2012)	CE	Multiple	4
(Meyerhoff et al., 2012)	CV	Abstract	1
(Cerda, 2013)	CE	Species	1
(Broch et al., 2013)	CE	Habitat	1
(Shoyama et al., 2013)	CE	Species	1
(Trifunov et al., 2013)	MP	Function	3
(Rabotyagov & Lin, 2013)	CE	Management	1
(Tyrväinen et al., 2014)	CE	Species	2
(Czajkowski et al., 2014)	CE	Habitat	4
(Campbell & Tilley, 2014)	Others	Habitat	2
(Yao et al., 2014)	CE	Species	2
(Meyerhoff et al., 2015)	CE	Species	2
(Dupras et al., 2015)	BT	Habitat	1
(Lindhjem et al., 2015)	CV	Abstract	3
(Vedel et al., 2015)	CE	Management	2
(Sumarga et al., 2015)	Replacement	Function	1
(Zhang et al., 2015)	BT	Habitat	1
(Brahic & Rambonilaza, 2015)	CE	Multiple	4
(Abdullah et al., 2015)	CV	Abstract	4
(Górriz-Mifsud et al., 2016)	CE	Species	6
(Ninan & Kontoleon, 2016)	BT	Abstract	1
(Rambonilaza & Brahic, 2016)	CE	Multiple	2
(Oviedo & Yoo, 2017)	CE	Species	1

(Varela et al., 2017)	CE	Species	4
(Pechanec et al., 2017)	Restoration	Multiple	33
(Nordén et al., 2017)	CE	Multiple	3
(Tait et al., 2017)	CE	Multiple	1
(Zhang et al., 2017)	Others	Habitat	1
(Fujino & Kuriyama, 2017)	CE	habitat	1
(Mäntymaa et al., 2018)	CE	Species	2
(Bakhtiari et al., 2018)	CE	Multiple	4
(Soliño et al., 2018)	CE	Species	2
(Weller & Elsasser, 2018)	CE	Species	2
(Seják et al., 2018)	Restoration	Abstract	1
(Martínez-Jauregui et al., 2019)	CE	Multiple	1
(Yao et al., 2019)	CE	Abstract	1
(Zhao et al., 2019)	MP	Species	1
(Melo-Guerrero et al., 2020)	CE	Management	1
(Nitanan et al., 2020)	CE	Species	2
(Nie et al., 2020)	BT	Species	1
(Soliño et al., 2020)	CE	Multiple	1
(Elsasser et al., 2021)	CE	Species	1
(Başkent, 2021)	BT	Multiple	2
(Yao et al., 2021)	AC	Function	15
(Juutinen et al., 2021)	CE	Habitat	1
(Abildtrup et al., 2021)	CE	Abstract	4
(Kefale et al., 2021)	CE	Species	1
(Lin et al., 2021)	BT	Habitat	1
(Cori et al., 2021)	CE	Habitat	3
(Truong, 2022)	CV	Abstract	1
(Campos et al., 2022)	Others	Abstract	2
(Wu et al., 2022)	BT	Species	1
(Enríquez-de-Salamanca, 2023)	BT	Multiple	5
(Baskent, 2023)	BT	Multiple	2
(Abebe et al., 2023)	CV	Abstract	1
(Mantymaa et al., 2023)	CE	Species	2
(Musa & Shahrudin, 2023)	CV	Abstract	1
(Frings et al., 2023)	CE	Species	2
(Plevnik & Japelj, 2023)	CE	Habitat	1
(Son et al., 2024)	CE	Abstract	4
(Admasu, 2024)	BT	Habitat	2
(Kim et al., 2024)	CE	Multiple	4
(Liu et al., 2024)	CE	Number	2
(Pandey et al., 2024)	BT	Multiple	16
(Arthur et al., 2024)	CE	Abstract	2
(King et al., 2024)	CE	Multiple	2
(Son et al., 2025)	CE	Abstract	4

Note: this table lists all 93 studies included in the systematic literature review and meta-analysis. For each study, the reference, valuation method employed, type of biodiversity indicator used, and number of observations extracted are provided. Abbreviations: AC=avoided cost; BT=benefit transfer; CE=choice experiment; CV=contingent valuation; MP=market price; Restoration=restoration cost; Replacement=replacement cost.