Additionality, Efficiency, and Spatial Targeting for Ecosystem Services Auctions

Systematic review, expert consultation, and application to European case studies

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Abstract

Background: Auction methods have attracted growing interest as a means of overcoming information asymmetries to efficiently allocate contracts involving payments for ecosystem services (PES). However, evidence-based practical information is scarce and research priorities are unclear.

Objective: Through four studies, this thesis synthesizes current knowledge on ES auctions, applies it to case studies drawn from two international European research projects (NOBEL and SINCERE), and proposes several possibilities for a novel mechanism based on the ECOSEL approach developed by Tóth et al. (2010).

Summary: *Study 1* consists of a systematic review of the ES auction literature published in the last decade. *Study 2* uses these results to design and implement a consultation with 35 international experts using the Delphi method. *Study 3* applies these lessons to three NOBEL and SINCERE auction cases, highlighting key design innovations. *Study 4* presents a theoretical critique of the ECOSEL approach, identifying several important limitations in the mechanism and suggesting modifications (primarily drawn from choice modelling and voting methods theory) to address them.

Conclusion: Theoretical integration and empirical testing of the suggested ECOSEL modifications is a reasonable next step. Generally, the potential for innovative allocation mechanisms to improve PES efficiency is highlighted, but risks should be carefully considered. Further scholarly attention—particularly relating to practical guidance, ethics, and legitimacy issues—is strongly indicated.

Keywords: payments for ecosystem services; auctions; Pareto methods; efficiency; additionality; spatial targeting

Resumo

Apresentação: Os métodos para leilão de serviços de ecossistema têm sido objeto de um interesse crescente por parte da academia . Em situações caracterizadas por informação assimétrica, estes métodos podem melhorar a eficiência da alocação dos contratos de pagamentos para serviços de ecossistema(SE). Porém, a experiência da sua aplicação é limitada e as prioridades de investigação não estão muito bem definidas.

Objetivo: Esta dissertação pretende a) fazer uma síntese do conhecimento relativo a leilões para SE; b) aplicar-se os resultados desta síntese em análise de casos de estudo inscritos em dois projetos de investigação internacionais (NOBEL e SINCERE) e c) analisar a possibilidades de desenvolvimento de um novo mecanismo de leilão baseado no conceito ECOSEL desenvolvido por Tóth et al. (2010).

Visão geral: O *Relatório 1* consiste numa revisão sistemática da literatura sobre leilões de SE publicada na última década. O *Relatório 2* descreve uma aplicação do método Delphi para consulta de 35 especialistas internacionais relativa a mecanismos de pagamento de SE. O *Relatório 3* utiliza os resultados da síntese de conhecimento disponível para análise de três casos de estudo dos projetos NOBEL/SINCERE, identificando vários aspetos de interesse académico. O *Relatório 4* desenvolve uma análise crítica do mecanismo ECOSEL e propõe, modificações para promover a sua aplicabilidade. Estas envolvem considerações relativas à teoria de votação e à valorização dos recursos ambientais (modelação de escolhas).

Conclusão: As modificações propostas no ECOSEL devem ser analisadas em uma forma mais rigorosa e submetida a testes empíricos. Esta dissertação evidencia o potencial de mecanismos inovadores para melhorar a eficiência de pagamentos para SE mas caracteriza os riscos associados à sua aplicação.. Em particular, sugere a necessidade de aprofundamento da investigação destes mecanismos e destaca dúvidas éticas e considerações de legitimidade.

Palavras-chave: pagamentos de serviços de ecossistema; leilões; métodos de Paretos; eficiência; adicionalidade; segmentação espacial

Resumo Estendido

Os métodos para leilão de serviços de ecossistema têm sido objeto de um interesse crescente por parte da academia . Em situações caracterizadas por informação assimétrica, estes métodos podem melhorar a eficiência da alocação dos contratos de pagamentos para serviços de ecossistema(SE). Porém, a experiência da sua aplicação é limitada e as prioridades de investigação não estão muito bem definidas.

Esta dissertação pretende a) fazer uma síntese do conhecimento relativo a leilões para SE; b) aplicar-se os resultados desta síntese em análise de casos de estudo inscritos em dois projetos de investigação internacionais (NOBEL e SINCERE) e c) analisar a possibilidades de desenvolvimento de um novo mecanismo de leilão baseado no conceito ECOSEL desenvolvido por Tóth et al. (2010).

O *Relatório 1* consiste numa revisão sistemática da literatura sobre leilões de SE publicada na última década. Uma pesquisa do Scopus produziu uma seleção inicial de 64 artigos, dos quais 56 foram incluídos na amostra final. Aquela amostra foi analisado para temas e lacunas. Cinco temas principais foram identificados: (1) eficiência e eficácia, (2) dinâmicas da informação, (3) como gerir objetivos múltiplos, (4) considerações contextuas, e (5) ética e equidade.

O *Relatório 2* descreve uma aplicação do método Delphi para consulta de 35 especialistas internacionais relativa a mecanismos de pagamento de SE. O painel de especialistas foi composto por (1) participantes nos projetos NOBEL e SINCERE, (2) pesquisadores identificados por publicações, e (3) especialistas recomendados por meio de amostragem de bola de neve. Dois rodadas de pesquisa foram realizados. O painel avaliou a eficiência econômica, descoberta de preços, e a participação como as principais vantagens da leilão de serviços ecossistema. Concluímos que os leilões de serviços de ecossistema constituam um mecanismo interessante para a descoberta de preços e a alocação de contratos.

O *Relatório 3* utiliza os resultados da síntese de conhecimento disponível para análise de três casos de estudo dos projetos NOBEL/SINCERE, identificando vários aspetos de interesse académico. Os casos de estudo incluem um leilão reverso de preço discriminatório na Dinamarca, um leilão reverso de preço uniforme na Bélgica, e um leilão no estilo ECOSEL em Portugal. O principal objetivo deste capítulo é facilitar o intercambio entre NOBEL e SINCERE.

O *Relatório 4* desenvolve uma análise crítica do mecanismo ECOSEL e propõe, modificações para promover a sua aplicabilidade. O Relatório 4 examina três afirmações: que ECOSEL é (1) uma ferramenta de aquisição econômica, (2) que fornece informações sobre os valores de serviços de ecossistema, e (3) é uma ferramenta de decisão participativa. Discuto aspectos de cada afirmação, e sugiro possíveis modificações. Estas envolvem considerações relativas à teoria de votação e à valorização dos recursos ambientais (modelação de escolhas).

As modificações propostas no ECOSEL devem ser analisadas em uma forma mais rigorosa e submetida a testes empíricos. Esta dissertação evidencia o potencial de mecanismos inovadores para melhorar a eficiência de pagamentos para SE mas caracteriza os riscos associados à sua aplicação.. Em particular, sugere a necessidade de aprofundamento da investigação destes mecanismos e destaca dúvidas éticas e considerações de legitimidade.

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1. Introduction

1.1 Background

By the time a cork oak (*Quercus suber*) planted Portugal today is ready for its first debarking at roughly 30 years of age, more than 9.7 billion people will likely share this planet (Kim et al. 2017; UN 2017, 2019). Another 1.5 billion can be expected to join them before a new a spruce seedling in Finland completes a standard rotation of roughly 60-80 years (ibid.; Pyörälä et al. 2014; Kilpeläinen et al. 2017). This demographic transition will unfold in tandem with several other megatrends, including (to name just a few): rural outmigration coupled with urban expansion (Retief et al. 2016); increased demand for agricultural products without a proportionate increase in available agricultural land area, with concerning implications for water and topsoil (ibid.; von Witzke & Noleppa 2016; Kuhn et al. 2016); more frequent and severe meteorological anomalies linked to advancing climate change (Ummenhofer & Meehl 2017; Swain et al. 2020); and, more generally, growing anthropogenic pressure across scales on the natural systems that support life on Earth (Laurance 2019; Latty & Dakos 2019). These trends intersect and interact in ways that complicate long-term planning efforts, creating decision spaces characterized by complex trade-offs, under pervasive uncertainty, on time horizons that are directly relevant to forestry decisions being made and executed right now.

Unfortunately, current institutions and frameworks for making these decisions exhibit significant limitations when it comes to evaluating the kinds of problems most relevant to this cluster of crises. Under the right conditions, markets (decentralized decision-making institutions) efficiently allocate private goods, but they are prone to failure in situations featuring non-excludability, non-rivalry, externalities, or non-convexities producing local optima—that is, when public goods and common pool resources are at stake. Conversely, centralized, top-down, command-and-control instruments are not known for their capacity to efficiently manage trade-offs and often struggle to incorporate the heterogeneous preferences and priorities of local stakeholders (Aligica 2014; Morello et al. 2017). A number of market-based instruments (MBIs) like subsidies and certification mechanisms have been developed in an effort to encourage the provision of vital non-market ecosystem services (ES) like carbon storage, pollination, biodiversity, recreational value, and erosion control (Pirard 2012; Garcia, Abildtrup, & Stenger 2018). Despite encouraging results in many cases, there is no silver bullet; each MBI type features its own set of strengths and weaknesses. Certification, for instance, may allow suppliers to charge a premium for adhering to certain standards, but does not necessarily make trade-offs explicitly (Bloomfield 2012; Gueneau 2013). Similarly, flat-rate subsidies designed to incentivize the adoption of best management practices (BMPs) do not account for opportunity cost heterogeneity, reducing budgetary cost-effectiveness (Groth 2011).

Payments for ecosystem services (PES) have attracted growing attention as a market-based approach with the potential to partially correct this gap (Farley & Costanza 2010; Salzman et al. 2018). Setting aside some definitional disagreements for now, PES generally refers to scenarios involving payments from the beneficiaries of a well-defined ES to the supplier (typically a landowner), with those payments conditioned on the provision of the service. As with other MBIs, the ability of PES to produce socially optimal outcomes generally requires some means of inferring the value of non-market goods. Traditionally, this is achieved using *revealed preference* methods like travel cost or hedonic pricing, *stated preference* methods like contingent valuation or choice experiments, or a hybrid approach. These methods, too, have their unique sets of strengths and weaknesses based on data requirements and the nature of the inference involved. In addition to valuing the underlying ES, PES design also involves establishing the baseline for calculating payments. This can be a subjective and occasionally contentious process due to the existence of information asymmetries: an ES supplier's opportunity costs of provision are often private information, so in the course of a negotiation there is an incentive to present these costs as higher than they really are in order to secure higher levels of compensation. Over-paying for ES provision may limit the number of parcels that can be enrolled in the scheme, reducing cost-effectiveness. This is one reason that Wunder et al. (2018) highlight spatial targeting as a feature of sophisticated PES mechanisms: by focusing efforts on high-value, high-threat, and low-cost locations, budget-constrained programs can maximize their impact.

Most auction methods attempt to create a strategic dilemma to induce providers to reveal private opportunity cost information (Study 4, Box 1). Perhaps the most familiar example involves a a government agency with a fixed budget to compensate landowners for conserving parcels, with the agency's objective being to conserve the largest area possible. Without access to private information about landowners' opportunity costs, the agency cannot determine the optimal level for a flat subsidy. Instead, it implements a conservation tender, informing landowners that they can submit bids representing the lowest price they would accept to forgo development. The agency then arranges the submitted bids from lowest to highest and begin signing contracts until the budget is exhausted. Landowners are informed that if their bid is accepted, they will be paid according to the first bid that the agency rejected. Because your bid mainly determines your likelihood of winning (rather than the compensation you will receive), there is an incentive to submit the lowest bid you can tolerate—to reveal your opportunity cost of provision. This is just one of many potential designs.[1] A number of large-scale public programs have implemented variants of this basic format; famous examples include the Conservation Reserve Program (USA) and BushTender (Australia) (Everard 2018)..

In experimental settings, games based on forward auctions (i.e. those featuring one seller and many buyers) have been used as a valuation tool. In forestry, Tóth et al. (2010) describe an innovative decentralized decision-making method called ECOSEL based on the forward auction format, combined with elements of crowdfunding that resonate with some PES research involving Lindahl pricing (e.g. Chakrabarti et al. 2019). In the optimization-assisted ECOSEL approach, a landowner puts bundles of different ES up for auction. Stakeholders then coordinate and compete over multiple rounds, pooling their bids in support of their preferred bundles. If the winning bundle meets or exceeds the landowner's opportunity costs, the auction is considered successful: bids to losing bundles are refunded (a subscription game), money is transferred, contracts are signed, and the landowner implements a management plan designed to produce the selected ES bundle.

Research context

NOBEL and SINCERE are European research initiatives aimed at identifying innovative market-oriented approaches for supporting ES supply, and both feature pilot demonstrations involving auction-based mechanisms. In NOBEL, a format based on the ECOSEL model is used in several pilot demonstrations: optimization tools are used to identify Pareto efficient ES baskets and establish reserve prices, while stakeholders pool funds to collectively bid on their preferred baskets (Tóth et al. 2010). SINCERE uses reverse auctions, where landowners bid against one another to supply ES at the lowest public cost. Study 3 considers auctions in NOBEL and SINCERE.

1.2 Problem Statement

Despite a growing body of research exploring the use of auction methods in PES, evidence-based practical information for designing and implementing auctions (including best practice recommendations) is difficult to locate. This thesis aims to contribute to this gap in three ways:

(1) systematically review the recent (i.e. published in the last decade) literature on ES auctions;

(2) based on these findings, conduct an expert consultation using the Delphi method in order to identify areas of consensus regarding the design and application of auction methods;

(3) facilitate knowledge sharing and cross-fertilization between NOBEL and SINCERE by applying lessons learned to an analysis of the auction pilots in each project; and

(4) critically evaluate the novel ECOSEL-style approach to be adopted in the Portuguese pilot demonstration, suggesting key concerns and potential improvements.

1.3 Chapter Outline

Chapter 1 introduces key concepts and clarifies the main problem area that this research seeks to address. *Chapter 2* describes the first study, a systematic literature review. *Chapter 3* describes the second study, an expert consultation using the Delphi method. *Chapter 4* describes the third study, an analysis of three pilot examples. *Chapter 5* offers a brief conclusion.

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[1] For the purposes of this thesis, this example can be described as a *reverse auction* (i.e. one buyer and many sellers) using a *uniform ascending first-rejected price rule*.

2. Study 1: Systematic review

2.1 Abstract

Ecosystem services auctions offer potential efficiency improvements over other mechanisms for PES contract allocation, but research on the use of these tools appears to be fragmented across multiple disciplinary areas. In order to identify potential knowledge gaps and major threads in the scholarly discourse, a systematic review of peer-reviewed journal articles discussing ES auctions published in the last decade was performed. A search of the Scopus database returned an initial sample of 64 articles; after screening, 56 were included in the final corpus, which was subjected to thematic content analysis. Five major themes were identified: (1) efficiency and effectiveness; (2) information dynamics; (3) balancing multiple objectives; (4) contextual considerations; and (5) ethics and equity. Potential gaps in the literature were highlighted, including the need for practical guidance, crowding in/out, and balancing multiple objectives under uncertainty. Efforts to coordinate research and systematize this body of literature may be a worthwhile investment.

2.2 Introduction

This chapter reports the results of a systematic review of the recent (published in the last decade) literature on auction methods in the context of ecosystem services. After collecting articles, a thematic content analysis was performed in order to identify and characterize the major strands of the ES auction literature and highlight commonly-cited gaps. The overarching themes identified in the literature center on issues relating to: (1) *efficiency and effectiveness*; (2) the importance of *information dynamics* (e.g. asymmetries, uncertainty); (3) the design and use of *multi-objective* auctions; (4) how to manage *contextual considerations* (e.g. auctions in the developing world, sociocultural values, policy frameworks, institutional capacity); and (5) critiques relating to *ethics and equity*. The vast majority of the sampled literature speaks specifically to reverse auctions. A handful of sources describe experimental formats approximating more traditional (outside the ES context) forward formats with one seller and many buyers, particularly with reference to the use of Lindahl pricing or as a response to variants on initial property rights allocations (e.g. landowners provide their WTP for the right to develop versus submitting bids indicating their WTA to conserve).

Before turning to the analysis, a brief terminological clarification might be useful. In the PES literature, some authors distinguish between *efficiency* and *cost-effectiveness*, but this distinction is made inconsistently. Here, *efficiency* refers to total welfare maximization, usually relative to cost, and *effectiveness* refers to the realization of predefined performance objectives above the status quo baseline (Martin et al. 2014, p. 217). *Cost-effectiveness* refers to objective achievement relative to the costs that would have been incurred to achieve comparable results by an alternative means.[2] A closely related concern in the PES literature is *additionality*, or the production of ES additional to the status quo baseline. Establishing a baseline can be challenging; a PES scheme may yield zero additionality if a landowner is paid to perform an action they would have performed anyway (e.g. selling carbon credits for trees that would not have been harvested under any circumstances), or negative additionality if the payment allows the landowner to undertake even more damaging activities at another location (*leakage*) (Wunder et al. 2008; Jack & Santos 2017). *Conditionality* is achieved if the landowner only receives payment if the terms of a PES contract are fulfilled ("you only pay for what you get") (Wunder et al. 2018, p. 145). This may be evaluated using either a *results-based* approach (environmental outcomes are measured empirically), or a *performance-based* approach (the landowner demonstrates conformity with certain guidelines or executes a prescribed action, like switching from synthetic to manure-based fertilizer) (Thompson 2017; Andeltová et al. 2019).

Relative to other reviews of comparable size, this chapter provides detailed summaries of key sources. The reason for this is the situation of Study 1 within the thesis: the results of the systematic review were integral in identifying topics for the Delphi study. In other words, this chapter serves as a standalone review and also as a basis for developing of Studies 2-4. This latter goal necessitated a slightly more in-depth approach in some cases.

[2] i.e. A program *P* might be efficient if it achieves a desired result at an acceptable cost, but if other programs reliably produce the same result even more cheaply, *P* is not a cost-effective choice.

2.3 Methodology

2.3.1 Data collection

The Scopus database was searched for peer-reviewed journal articles published since 2010 containing the terms "auction" and "ecosystem services" in the title, abstract, or keywords. The initial search returned an initial sample of 64 articles, five of which were eliminated during data cleaning: one duplicate (the more recent version was retained), one non-English article, and three book chapters. The remaining articles were reviewed for relevance, and three more were eliminated, producing a final sample of 56 articles. This sample includes a handful of articles that are not specifically focused on auctions, but which were retained because they offer substantive comments on auction methods and their relationship to other tools.

2.3.2 Analytic protocol

After screening, a thematic content analysis was performed using NVivo 12 and NVivo-Mac 20.1.0 (QSR International). Although deductive approaches to content analysis have been used to interrogate decision-making in the ES context (e.g. van Oudenhoven et al. 2018; Bingham 2020 [under review]), in this case an inductive approach was selected. The orientation is not retrospective but exploratory, aimed at identifying nascent themes and gaps in an ongoing scholarly discourse to inform the Delphi consultation, which is an approach rooted in forecasting under uncertainty and geared toward finding consensus when no single authoritative answer is available.[3]

Thus, this study implemented a qualitative approach to thematic content analysis drawn from grounded theory (Charmaz 2006, 2008) and adapted from the methods described in, e.g., Brunet et al. (2014), Wuelser and Pohl (2016), Schubert et al. (2018), and Dubray et al. (2019).[4] An overview is available in Appendix 1. This process can be loosely divided into three stages: initial, focused, and thematic coding (Charmaz 2006, 2008; Wolfswinkle, Furtmuller, & Wildrom 2013; Schubert et al. 2018). Initial (or "free") coding involves analyzing a text by classifying each line according to its topic. A descriptive process of summarization and reduction, free coding is bottom-up and the level of abstraction produced is low, yielding a large number of initial codes: relevant sections are classified on their own terms, without considering the larger conceptual structures that these classifications might produce later. In focused coding, a slightly higher level of abstraction is achieved by collecting initial codes into clusters and categories; loose themes begin to take shape. Thematic coding involves adopting a more synthetic focus on associations and potential hierarchical relationships between categories and clusters, producing a more integrated thematic structure (Wolfswinkle et al. 2013).[5]

In the interest of consistency, each coding phase is performed multiple times before moving to the next: once the end of the corpus is reached in one phase, the coder returns the beginning and performs the same protocol until subsequent iterations fail to produce substantive changes, at which point the next phase begins (ibid.). However, it is important to note that these phases are also not rigidly sequential: it is not uncommon that a conceptual structure emerging in a later stage requires a modification to the coding approach used in an earlier one, either to improve coherence or simply as a reflection of the coder's evolving understanding of the material. If a change is made, the whole process begins again. Because this process has both iterative and recursive elements (Wuelser & Pohl 2016), it can be time-consuming for large volumes of data. Although this methodology aims to improve the reliability of qualitative analysis, it is important to acknowledge that it is inherently subjective: the final structure is vulnerable to the coder's biases and blind spots. To address this, some advocate for the use of multiple coders to evaluate consistency; in other cases a single coder is

[3] The Delphi method is discussed in more detail in Study 2 below.

[4] For an alternative, practical treatment of reverse auctions organized by functional area (rather than discursive themes), Thorsen et al. (2018) is strongly recommended.

[5] When theory generation is a primary objective, considerable effort may be invested in this final stage; in the present study, simply defining themes and considering their mutual relationships was deemed sufficient to characterize the state of the literature and provide an evidentiary basis for developing Studies 2 and 3.

preferentially used to avoid issues relating to inter-coder reliability (e.g. Brunet et al. 2018).[6] This study used a single-coder approach.

Both for logistical and practical reasons, complete coding coverage was limited to the abstracts of auction-focused articles. This is because other sections (introductions in particular) often cover similar background information, so requiring complete coding coverage of all fulltexts was not only not feasible, but would have produced large, seemingly dominant themes on generic and uncontroversial topics, which are secondary to the focus of this research. Instead, relevant passages in the body of the article were selected according to the researcher's judgment in order to better characterize the essential information contained in the abstract, which by definition foregrounds a study's novel elements. Methodological and design discussions were strongly emphasized.

2.4 Results

This section summarizes the major thematic groups that emerged from the thematic content analysis protocol described above. For each theme, relevant passages and perspectives are discussed.

2.4.1 Efficiency & effectiveness

Considerations of efficiency and effectiveness were the dominant theme identified in the present review, encompassing enough text that subthemes were required to provide additional structure. It can be helpful to think of these subthemes in terms of the sophisticated PES design features outlined by Wunder et al. (2018): additionality, spatial targeting, and conditionality. Because they are familiar to this study's intended audience, these labels were borrowed and applied to the subthemes, but the themes themselves were constructed inductively (i.e., the operational definitions proposed by Wunder et al. have not been deductively applied).

Additionality

Additionality is cited a key consideration in the abstract of three sampled articles. Narloch et al. (2011) identify a gap in current knowledge surrounding the relationship between additionality, social equity, and conservation goals framing payment targeting. Ulber et al. (2011) use additionality as a criterion for evaluating the performance of a conservation procurement auction aimed at boosting biodiversity in agricultural fields. More recently, Lundberg et al. (2018) compare the additionality produced by fixed payments and two reverse auction subtypes (uniform and discriminatory pricing) using an agent-based model (ABM). For an auction-framed approach to ABM, see Zhu et al. (2011).

Conditionality

Despite being a central concept in the PES literature, term *conditionality* did not appear in any of the titles or abstracts of the sampled articles.[7] It is possible that conditionality is assumed to be a feature of ES auctions or implicit to discussions about efficiency, but given the finding by Wunder et al. (2018) that only a small minority of PES both monitor conditionality and sanction breaches, the omission may be more difficult to dismiss. Still, a number of articles raised closely related concerns. Compliance verification, for instance, is a small step removed from making payments conditional on ES provision. Jindal et al. (2011) conducted a monitoring survey almost two years after the completion of reverse auction pilot in rural Tanzania, noting that winners "felt peer pressure to comply with contracts" (abstract). Whitten et al. (2013) highlight the importance of understandability in ES contracting in conservation procurement auctions and suggest that "post-contract support" and carefully designed monitoring strategies may improve outcomes, as landowners are sensitive to transaction costs.[8] Leimona and Carrasco (2017) offer a detailed examination of non-compliance as measured by tree survival following an auction for watershed services among coffee farmers in Indonesia, finding associations with labor availability and land ownership duration. Interestingly,

[6] The advantages of this approach (and variations) have been subject to extensive debate (e.g. Charmaz 2006, 2008; Bryant & Charmaz 2010; Yu et al. 2011; Wolfswinkle et al. 2013; Terry et al. 2017; Mohajan 2018)

[7] One article described a field experiment involving a reverse auction in which participants received periodic payments conditional on the survival of planted trees (Jack & Cardona Santos 2017)

[8] The researchers also highlight the connection between different phases of the auction and contracting process, noting that onerous "monitoring and cross compliance elements" may deter participation (p. 86; *see* discussion of participation as a subtheme below).

previous conservation applications were associated with non-compliance while final bid level did not effectively predict it, raising questions about the extent to which the auction successfully revealed the cost of the management change for farmers, who may have viewed the process more as a game than a means of allocating binding contracts (abstract).

Monitoring compliance with prescribed activities is closely related to scholarship on certification, specifically the distinction between process- and performance-based models (Hanley et al. 2012; Teytelboym 2019).[9] As with true conditionality, this is not to suggest that monitoring is universal in field tests or payment cases: Whitten et al. (2017) note that while landowner bids in procurement auctions always consist of a price, they only sometimes include a measure for the offered services. Groth (2011) highlights the use of a performance-based approach using a species richness index to the cost-effectiveness of procurement auction case study in Germany, although the comparison is with fixed flat-rate PES schemes rather than with performance-based models.

Spatial considerations

Spatial targeting is the third sophisticated PES design feature identified by Wunder et al. (2018). Here, spatial considerations include directing payments to low-cost, high-threat areas as well as seeking to engage with landscape-level ecological issues like contiguity. Related concerns also feature prominently in the recent literature on ES auctions: 12 of the articles in the sample explicitly raised spatial considerations in their abstracts, and several proposed innovative auction designs specifically to boost efficiency through improved spatial coordination.

Reeson et al. (2012), for instance, suggest that spatial coordination between multiple landowners to provide landscape-scale benefits in procurement auctions might be improved by spreading bidding across multiple rounds (with the total ideally undefined) while updating bidders on the location of other bids. In one laboratory experiment, participants were rewarded for winning bids and told their chances of winning would be increased if their parcels were contiguous with others; this design increased coordination and decreased rent seeking (p. 1625-26). However, parcel values were standardized; in real applications, parcels are likely have different values across multiple ES, and biophysical models may be required for the decision-maker to optimize bids and select winners cost-effectively. Computational tractability could represent an important constraint, as arithmetic increases in the number of bids produce exponential growth in the number of possible packages. Transaction costs are likely to rise as additional rounds are performed, and bidder learning may enable more strategic bidding and rent extraction in subsequent applications. Lundberg et al. (2018) simulate this effect in a simple discriminatory auction using an agent-based model.

Iftekhar, Hailu, and Lindner (2012) expand on this problem with a review on the use of combinatorial designs applied to the context of conservation auctions. This approach—which allows landowners to submit bids on bundles or baskets rather than an individual service like tree planting—has gradually gained traction in ES market creation. By exploiting functional and spatial synergies across services, the aim is to increase landowners' potential benefits while improving cost-effectiveness of public bodies' allocation of resources to conservation or other ES-oriented projects. Banerjee, Kwasnica, and Shortle (2015) describe an iterative model that scores and ranks bids to encourage contiguous winners; in one notable treatment, bidders were informed of the auctioneer's desired spatial configuration, resulting in increased rent-seeking but no efficiency boost.

Polasky et al. (2014) describe a different approach to accessing spatially-dependent benefits via reverse auctions while attending closely to the efficiency impacts of information asymmetries.[10] The researchers adapt the Vickrey-Clarke-Groves design to create a mechanism where payouts are calculated independently from the landowner's initial bid. Bid level only influences the probability of winning, so landowners are encouraged to reveal their true opportunity costs.[11] Armed with complete information, the auctioneer can use cost and contiguity criteria to select winners (p. 6249).[12] The

[9] Baird et al. (2014) classify as performance-based any bid selection mechanism that takes environmental benefits into account (p. 424).

[10] This resonates with a subtheme of this dissertation: incentive compatibility.

[11] See Study 4, Box 1 for a brief explanation of the logic underlying variants of Vickrey auctions

[12] Although situated within the spatial targeting subtheme to avoid redundancy, this model has fairly clear links to the additionality subtheme above—provided that landowners know their opportunity costs.

payout is then calculated on the basis of each parcel's ES contribution, including benefits only realized at larger scales.[13]

Where Reeson et al. (2011) use the auction mechanism to solve the land allocation problem directly by modifying the bidding protocol to discourage rent seeking, then, Polasky et al. (2014) entice landowners to reveal their opportunity costs, transforming the task into a spatially explicit optimization problem. The latter can be performed in a single round, reducing some transaction costs and uncertainty. Both designs assume that landowners have an accurate understanding of their own opportunity costs—an important simplification that may not always translate to reality. The approach by Polasky et al. (2014) is limited from an optimization perspective because it does not enable the elicitation of management cost functions for different within-parcel provision levels, but yields estimates for binary *develop/conserve* decision variables. This may be adequate or not depending on factors like the ES targeted, parcel size distribution, and the inclusion of other objectives.

Krawczyk et al. (2016) expand on Reeson et al. (2011) more directly through a laboratory experiment incorporating heterogeneity in the conservation value of (and opportunity costs for) available parcels, comparing discriminatory and uniform pricing and testing the effects of a lock-in rule and communication between bidders. Communication effects were not significant under uniform pricing, a result the researchers attribute to the difficulty of creating contiguity (corridors) with this mechanism. The discriminatory pricing mechanism more readily facilitated contiguity and thus higher cost-effectiveness. Communication enabled coordination but also collusion, so the impacts of these dynamics on cost-effectiveness appear to have cancelled each other out. Locking in the initial bids of provisional winners appeared to reduce rent-seeking over the course of the multi-round auction without inducing initial bid inflation (p. 1625). In a field experiment, Liu et al. (2019) report some paradoxical effects of spatial agglomeration bonuses on bidder behavior and auction performance (e.g. lower bids in the treatment group by bidders hoping to capitalize on the bonus). Results were mixed on the ability of the bonus to "induce a bidding pattern in favor of contiguous conservation", although participants' understanding of the incentive system may have played a role (abstract).[14]

Fooks et al. (2016) break down some of these considerations along the dimensions of demand and supply to produce four combinations of design features: on the demand side, the buyer's spatial preferences does or does not influence bid selection, while on the supply side, sellers receive network bonuses, or do not (p. 2). Through a combination of laboratory and field experiments, the researchers find that network bonuses used in the absence of targeting produce suboptimal social welfare outcomes. When used together, however these elements may reinforce one another to improve environmental and social benefits, with bonuses expanding and improving the set of bids made available for the selective spatial targeting step—although the bonuses constituted an added cost that may reduce economic efficiency (p. 19).

Iftekhar and Latacz-Lohman (2017) also approach the problem through simulations comparing combinations of design features (here, two pricing mechanisms and four bid selection criteria) and stopping rules to cost-effectively produce a single wildlife zone from multiple contiguous parcels. The bid selection criteria reflect different levels of awareness on the part of participants (bidders and auctioneers) about ES benefits provided by each parcel; different modes of group formation are simulated. The uniform-price ascending format allowed landowners to submit bids individually, with the auction terminating once a satisfactory wildlife zone is formed. In the discriminatory-price auction, landholders formed group bids (transaction costs of group formation

[13] The researchers emphasize scale issues: the "value generated by an individual parcel, and hence the payment between a landowner and the regulator, is a function of land uses on all parcels and so can only be determined once all bids have been submitted." (p. 6249).

[14] McGrath et al. (2017) also stress participant understanding in field auctions, suggesting that practice rounds should be included. Whitten et al. (2013) suggest making simplicity a major mechanism design consideration on top of additional assistance like information workshops.

were neglected). In both models, economic cost-effectiveness was maximized when landowners and auctioneer both knew the biodiversity values of the sites (*bid-per-value ratio* scenario) (pp. 17-18). [15]

Lewis and Polasky (2018) build on Polasky et al. (2014) to develop a mechanism to facilitate decision-making in problems involving both spatial considerations and uncertainty.[16] The mechanism is designed to simultaneously address several discrete components needed to internalize externalities at the landscape level under climate uncertainty.[17] Considering Polasky et al. (2014) to produce overly static results that fail to account for climate on relevant timescales, Lewis and Polasky (2018) introduce dynamism into the tool by way of two-part bids in which landowners estimate their opportunity costs of foregoing development at two time points (now, and in a future period). As in the earlier version, incentive compatibility is achieved by decoupling payment from bid amount. In an interesting extension, the researchers show that the effectiveness of the mechanism is preserved regardless of the initial property rights distribution: the same optimal allocation be achieved whether the regulator pays landowners to conserve, or landowners pay the regulator for the right to develop, per Coase (1937, 1960).

Another spatial issue relates to where ES benefits are realized. Conte and Griffin (2019), for instance, investigate the implications of including private benefits realized on-site in ES bid scoring designs using an induced-value experiment. The idea is to reduce opportunity costs and increase participation, but it runs the risk of allowing landowners to "double dip", enjoying the benefits of their conservation while being compensated for doing so (or increasing returns by selling ES into several markets despite the fact that the ES were produced by a single action), compromising additionality. The considerations can be complex and contextual, but the existence of risk-benefit trade-offs associated with including on-site private benefits in bid scoring is worth mentioning.

Summary

Although broadly defined, the theme of efficiency and effectiveness is the most prominent identified in this review. It is not the central focus of every article, but it is almost always mentioned. In a departure from other areas of the PES literature, the term *additionality* is infrequently invoked, but it is implicit in most discussions. The treatment of the conditionality is also scattered: this aspect is often viewed as important enough to mention, but treated as incidental to the core focus on designing and testing mechanisms to achieve cost-effective agreements. There may be a knowledge domain issue at work here, with issues relating to compliance being conceptualized as addressable through generic auditing and certification tools: auction research seems mostly interested in setting up a game that results in a good deal, while ensuring that the ES are actually delivered is a separate issue.

In fact, auditing compliance and sanctioning noncompliance entail costs, and those costs may vary not only on a parcel-by-parcel basis, but also as a function of the spatial arrangement of contracts as a whole. Uncertainties about the stringency of oversight and how burdensome demonstrating compliance might be could also constitute a transaction cost with implications for mechanism design, optimality assessment, and bidding patterns. Thus, there may be justification for integrating these considerations into the auction design process explicitly. At the same time, the issue is complex and may be difficult to formalize theoretically for the purposes of generalizable simulations: nuanced sociocultural relationships and dynamics (e.g. gender relations, education, trust, wealth distribution) may directly influence both the propensity and capacity for compliance (see 2.4.4).

Spatial considerations constituted the most extensive subtheme, going well beyond the notion of spatial targeting as constructed by Wunder et al. (2018), although targeting is implicit in many of the discussions surrounding cost-effective budgetary allocation. More interesting are efforts to use the auction tool to efficiently generate spatial coordination and access benefits only realized at scales larger than individual parcels. On paper, these advanced methods appear promising, but it is difficult

[15] "Economic" is specified here because the study evaluates cost-effectiveness on a budgetary basis as well. Budgetarily, cost-effectiveness was maximized when landowners lacked information on the environmental value of their parcels but the auctioneer did not (*mixed total bid/bid value ratio* scenario).

[16] Issues relating to uncertainty and risk represent a separate theme, receiving a focused discussion below.

[17] These components are: spatial dependencies, asymmetric information, dynamics that change the net benefit function over time, uncertainty about future net benefits, and irreversible decisions (pp. 20-21)

to obtain a global view of real-world payment cases and their underlying design features; the extent to which these advanced designs have been tested in practice is unclear.

Lesson: Additionality is implicit in most ES auction efficiency/effectiveness discussions.

Lesson: Compliance is a potentially important issue, but one that appears to cross disciplinary boundaries and knowledge domains (social interactions, microeconomic considerations, contract factors, learning effects, performance standard design, index construction, etc.). This topic probably warrants closer consideration within the auction field.

Lesson: Using auctions to generate spatially-coordinated benefits is an active and theory-rich niche that emphasizes advanced mechanism design and bid selection features.

Lesson: Approaches to designing auctions for spatial coordination are diverse; coordination can be introduced in either a centralized manner (e.g. administrator obtains truthful cost information for all bids, and then uses spatially explicit models to optimize allocation) or decentralized manner (e.g. iterative bidding enabling landowners to coordinate their bids to improve their odds of winning).

Lesson: Incentive compatibility is a central consideration in auction design, but is not a prerequisite for achieving a cost-effective outcome.

2.4.2 Information dynamics

For this section, note that the themes identified in this review are not strictly isolated, but rather interwoven with one another.[18] The distribution and exchange of information like budgets, opportunity costs, ecosystem functioning, and so forth, are important determinants of the ability of any PES arrangement—or market exchange, for that matter—to produce an efficient result. A close reading, however, suggests that discussions of these issues are sufficiently focused to merit consideration in their own right.

Asymmetries, adverse selection, and moral hazard

The power of unequally distributed information can cut both ways. An important difference between PES and typical commodity transactions relates to the intangibility of many ES. In order to give specificity to contracts, efforts must be made to concretize the exchange codified in the proposal. The decision to award a contract hinges on assumptions about the capacity of a parcel to provide the ES given certain management: adverse selection may occur if the buyer is unable to distinguish high-value parcels from low-value ones and pay accordingly. After a payment is made, evaluations may be performed to determine whether or not the manager has complied. These information-gathering activities constitute transaction costs that decrease the efficiency of the exchange, but if the buyer cannot monitor the provider's actions, moral hazard arises. Thus, neglecting these activities also carries efficiency risks, since payments may fail to increase, and potentially even decrease, the level of the desired ES either locally or globally (lack of additionality, leakage). Depending on mechanism design and context, there is evidence that auctions can either mitigate or magnify these costs.

With respect to designing auctions to mitigate the costs of assessment and monitoring, Crossman et al. (2011) develop and test a series of indicators at both landscape and site scale, using them to quantify site priority and rank bids in a real-world conservation procurement auction. The idea is to give the auctioneer a basis for evaluating whether landowners' proposed opportunity costs of conservation (bids) are balanced out by ES provision.[19] The inclusion of site-specific indicators did not have a major impact on bid ranking; thus, "landholder engagement, information sharing, and trust-building" may be a better investment than granular indicators, potentially increasing the efficiency of the PES scheme depending on the number of sites and average cost of assessment.[20]

With respect auctions magnifying the costs of assessment or monitoring, note that Crossman et al. (2011) are primarily concerned with examining indicator effects on bid ranking, and do not

[18] In early iterations, information dynamics was folded into a broader version of the efficiency theme.

[19] Collecting information for site-specific indicators is more costly than using landscape-scale indicators.

[20] Ultimately, standardized and broadly-accepted means of measuring some categories of ES commonly targeted by conservation tenders, such as those based on biodiversity, is a more persistent and pervasive technical problem not limited to the auction context, but relevant to continued investor and policymaker interest in PES more broadly (Ferguson et al. 2016). Ferguson et al. (2016) note that investor interest in market-based instruments more generally would hinge partly on the reliability of systems to measure outcomes.

evaluate the cost-effectiveness of the auction itself relative to alternatives. Using a series of induced-value laboratory experiments, Arnold et al. (2013) find discriminatory reverse auctions to underperform both using taxes to internalize negative externalities and doing nothing in terms of social surplus (abstract), which is at least superficially contrary to the prevailing view (e.g. Narloch et al. 2011; Reeson et al. 2011). The reason has to do with *adverse selection*, whereby landowners who are most likely to provide an ES in the absence of a PES scheme—e.g., because they already derive benefits from conservation that exceed the foregone gains of development—are able to submit lower bids and win auctions; thus, the budget is expended purchasing services that would have been provided for free.[21] In other words, under discriminatory mechanisms many landowners are likely extract informational rents approaching the entirety of the payments they receive (zero additionality). The authors suggest that design modifications or the inclusion of a screening mechanism may limit these effects. The initial property rights assignment matters: in conservation auctions, landowners have the right to develop and are paid not to, despite having access to hidden information about their previous management intentions (p. 410). A fixed tax on development is a less flexible instrument that may not be as accommodating to heterogeneous landowners, but it avoids the property rights arrangement underlying the adverse selection problem.[22] The adverse selection problem might be partially alleviated via site assessment and monitoring, but this increases the transaction costs. Threat indicators might offer another means of limiting this source of inefficiency.

One possible reason for the apparent conflict between Arnold et al. (2013) and the dominant view of auctions as highly efficient mechanisms has to do with the distinction between efficiency and cost-effectiveness. Auctions are often treated as *cost-revealing* or *price discovery* mechanisms: a way of enticing landowners to reveal truthful information about their expected costs or foregone gains associated with a given management alternative (Narloch et al. 2011, p. 1842; Leimona & Carrasco 2017).[23] In some cases, the transaction itself is secondary to the revelation of preference, and the auction functions as a kind of gamified non-hypothetical choice experiment. This partly addresses the asymmetric information issue, but additional data is still needed to evaluate potential ES benefits and discriminate between high- and low-threat parcels. Swallow (2013) considers a scenario where, in the absence of a well-designed ES market, landowners deliberately "[create] a real or credible threat" to status quo ES provision as a profit-seeking strategy (moral hazard) (pp. 39-40). In this scenario, the mechanism induces behaviors that are actively harmful, placing previously secure resources in jeopardy. The risk of moral hazard might also be elevated, for example, in a scenario where landowners are paid to engage in predator control, which is difficult to monitor and can result in shirking if payments are conditional on actions rather than outcomes (process-based) (Hanley et al. 2012, pp. 6-7). Mitigating this risk requires information about (1) the landowners' true costs of providing the predator control service, and (2) a way to measure its effects (ibid.). Care must be taken to avoid conflating cost revelation/price discovery with expected benefit and threat, particularly when evaluating the economic efficiency (or cost-effectiveness as a proxy) of auction payments.

Jindal et al. (2013) highlight the separation between these functions, describing a pilot auction carried out in rural Tanzania with the intent of eliciting information about management changes that landowners would be willing to adopt at different price points, which can then be used to set prices in a range of PES scheme designs. This strategy falls somewhere between laboratory experiments and large-scale conservation tenders. Similarly, the mechanisms proposed by Polasky et al. (2014) and Lewis and Polasky (2018) to decouple bids from payments illustrate the importance of distinguishing between price discovery and other functions. This distinction is also stressed by Smith and Swallow (2013) and Uchida et al. (2018). Rolfe et al. (2018) suggest that the significance of the price discovery function depends on the practice change the auction is designed to induce: tenders aimed at restoring

[21] This study appears to be among the first to experimentally investigate the contribution of adverse selection specifically in the context of discriminatory reverse auctions.

[22] See Lewis & Polasky (2018) for a more flexible alternative.

[23] The inability of (typically public) buyers to access private information about the provider's costs and activities, leading to either "an adverse selection problem in which low-cost producers have an incentive to mimic high-cost producers, or a moral hazard problem in which the producer has no incentive to adopt cost-cutting measures once the contract has been awarded" (Arnold et al. 2013, p. 389).

environmental systems "involve more cost components" than conservation set-asides, so price discovery is a more important function in the former cases than the latter one (p. 18).

While asymmetric information about management intentions may tend to favor landowners, the opposite can be true when it comes to ES potential, where the auctioneer knows what it is looking for and may have access to indicator sets, assessment, and modelling capabilities that enable it to forecast ES response to management alternatives more precisely than landowners themselves.[24] An induced-value laboratory experiment found that maintaining this asymmetry is not always in the auctioneer's interest: sharing information about ES can improve the quality of submitted bids, thereby "counteract[ing]", at least partially, the effects of other informational rents and marginally improving efficiency, depending on bidding procedure (Conte & Griffin 2017, pp. 571, 585). Banerjee and Conte (2018) find that a "bid-menu" format allowing landowners to submit bids for a variety of management practices in light of provided information about environmental quality rankings for those practices offers a potentially viable solution (abstract).

Just as public bodies may find it difficult to ascertain management intentions and assess threat, landowners too may struggle with uncertainties regarding regulatory intentions and threats to the status quo from above. For instance, a landowner may suspect that if the auction fails to achieve an authority's desired conservation goals, then it may pursue those goals by enacting new regulations—potentially imposing a burden greater than the opportunity costs estimated when formulating an auction bid. Holmes (2017) finds experimentally that the threat of new regulation limits rent seeking, but also that authorities should exercise caution before pursuing this strategy: bid inflation is constrained, but if the authority has to follow through on the threat, adverse selection costs may increase (p. 590). In reality, the picture is likely to be much more complex, as there is a spectrum between specific regulatory threats and a landowner's felt danger that unspecified regulatory actions could be undertaken depending on auction outcome. Such perceptual dynamics are likely to be heavily influenced by context and past experience.

Private information between bidders is just as important to auction dynamics as asymmetries between landowners and public agencies seeking to procure ES efficiently. After all, it is uncertainty about other bids that induces truthful opportunity cost disclosure in the context of designs where bid level influences the probability of winning while only establishing a lower bound for payment (e.g. first-rejected price designs). Using numerical simulations, Iftekhar and Latacz-Lohmann (2017) find that the cost-effectiveness of discriminatory-price auctions relative to uniform-price ascending auctions is influenced by bidder uncertainty about the number of competitors as well as the most expensive bid (abstract). In a laboratory experiment where bidders knew the value of their parcels but not those of their neighbors, Krawczyk et al. (2016) also found discriminatory pricing to be more cost-effective than uniform pricing. Bidders used a communication feature to obtain spatial coordination bonuses but do not appear to have used it to effectively collude and inflate prices, an important limitation that might be addressed by attempting to replicate the experimental results under conditions featuring "experienced bidders [...] more time for reflection, and higher stakes" (p. 44).

Opportunity costs, ES benefits, and threat do not constitute an exhaustive list of areas where incomplete information can influence auction outcomes. Banerjee et al. (2015) show that information about the functioning of the auction mechanism and bidder dynamics can also come into play. Using an iterative auction design primarily geared toward achieving spatial coordination, the researchers find that the disclosure of auctioneer goals were associated with more rent-seeking, which increased with further iterations as bidders become more familiar with the dynamics of the game (pp. 411, 424-26). Similarly, Reeson et al. (2011) find that limiting learning effects by not disclosing how many rounds a multi-round auction will be performed reduces rent-seeking.[25] Messer et al. (2016) use induced-value experiments to obtain estimates of the relationship between the provision of public information about the results of previous auctions to bidders on the one hand and the rent-seeking behaviors exhibited by those bidders in the current auction on the other. The results suggest that the provision of information about past auctions has an effect similar to that described by Banerjee et al.

[24] Landowners may also have incomplete information about the costs of adopting proposed management changes, which can alter bidding behavior in auction settings (Wichmann et al. 2017).

[25] The need for biophysical models to facilitate the selection of optimal bid arrangements is stressed.

(2015): bidders leverage this knowledge to extract higher rents. This effect is counteracted partly when they are made aware of budgetary constraints unique the current auction (Messer et al. 2016). Using an agent-based model, Lundberg et al. (2018) simulate learning effects by allowing agents to copy their neighbors' successful bids in discriminatory price auctions, finding fairly rapid increases in conservation costs when provision costs are randomly distributed across the landscape (p. 355).

Scenarios in which bidders have incomplete knowledge about an auction itself can also have implications beyond strategic bidding in laboratory experiments. As discussed below, such asymmetries can also have social implications in field settings. In a pilot auction in Indonesia, McGrath et al. (2017) finds that farmers who perceive the information provided by the auctioneer to be of high quality were more likely to view the process as fair and be satisfied with its outcomes (p. 47).[26] Such field research builds on past experimental work like that by e.g. Vogt et al. (2013) testing the effects of communication between principal and agents in the context of a series of auctions structured to model a public good dilemma combined with an effort-level game[27]:

> Relational contracting proved important, with effort levels and profits tending to be higher when auctioneers and bidders entered into consecutive contract relationships. In the communication treatment there was no evidence of price competition, as auctioneers were more likely to accept high-priced bids. [...] an overall higher price level did not lead to efficiency losses, since contractors realized higher effort levels in return, establishing a "social gift exchange" (abstract).

Landowners' informational rents are typically framed in a negative light due to the accompanying reduction in fiscal efficiency, but this is an economic judgment, not a moral or poltical-economic one. With conservation auctions typically implemented in rural areas and growing interest in expanding their use in the developing world, Wunscher and Wunder (2017) note that these tools can be deployed to stimulate rural economies and support marginalized communities as much as to obtain ecological benefits. If this objective is included, policymakers may find informational rents to be tolerable or even desirable when viewed as poverty-alleviating income transfers (abstract).

Summary

The research reviewed in this subsection presents a view of ES auctions as processes of accumulating and rearranging information between silos: about intentions and the status quo, and therefore prices, costs, and threats; about lands, the biophysical processes that produce ES, and the expected effects of management alternatives on the quality and quantity of those services; about the dynamics of the auction as a game; and about the other actors engaged in it, including their trustworthiness, and potentially the kinds of coordination and competition they can undertake. This process is largely designed to limit efficiency costs due to informational rents, adverse selection, and moral hazard.

Lesson: Failure to limit adverse selection and moral hazard can critically compromise the efficiency of auctions, even to the point of creating perverse outcomes worse than doing nothing.

Lesson: Game-theoretic information is not the only relevant kind; the interactions that constitute an auction (or series of auctions) can have symbolic value as well, serving to reveal or even construct social relationships and shaping perceptions of trust and fairness.

Lesson: Sometimes information asymmetries can be exploited for the gain of one party, but in other cases outcomes can be improved by deliberately revealing information.

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[26] Issues relating to participant understanding, social dynamics, legitimacy, and trust are discussed below.

[27] The effort-level game took place after the contract was awarded: using a slider, bidders selected the degree to which they would fulfill the contract. Higher fulfilment required higher effort, which was constructed as a deduction from their wage; however, bidders "were informed that their choice has implications for the realized contracted dividend that was to be shared among all market participants", enabling the simulation of the public goods aspect by offering an opportunity to free-ride (p. 14). Auctioneers were able to review bidders' cumulative effort history in subsequent rounds.

2.4.3 Multiple objectives

Land management interventions may have differential impacts on ES and policy goals, and thus auctions considering multiple criteria of interest often entail trade-offs. Narloch et al. (2011), for instance, describe agrobiodiversity conservation auctions in the Andes designed to test multicriteria cost-effectiveness targeting of three goals: an area measure as a proxy for genetic diversity, a farmer participation measure as a proxy for traditional knowledge, and a community group participation measure as a proxy for inter-community geneflow (p. 419). The bids selected by each targeting rule (and by a combined rule with arbitrary criteria weights) differed significantly, indicating that the auctioneer would have to make trade-offs between these goals.

Attempts to incorporate multiple objectives into auction mechanism design can take several forms. Although it adopts a forward auction-like format, the ECOSEL platform developed by Tóth et al. (2013) offers an example that is fairly intuitive and in which the relationship between objectives is made quite explicit.[28] Mathematical programming is applied to produce a Pareto frontier, which is used to visualize efficient trade-offs between three objectives (e.g. a financial objective, carbon sequestration, an index of old trees).[29] Several points on this frontier, representing combinations (bundles or baskets) of these objectives are selected and put up for auction. Interested parties such as ES beneficiaries bid on their preferred bundles over multiple rounds. The bundle that generates the largest bid sum is selected, provided that sum is sufficient to offset the financially optimal plan (which is used as the baseline scenario) and the remainder is paid to the landowner to implement a management plan to provide that bundle. Here, the objectives are selected *a priori* and all optimal combinations are determined; the auction-style game serves as a mechanism for identifying which, if any, of these combinations is both preferable to the bidders and economically feasible for the landowner. This format enables stakeholders to recognize, and explicitly make, trade-offs between multiple objectives (Roesch-McNally et al. 2016).

Crossman et al. (2011) offer a very different (but much more common) approach to incorporating multiple objectives into auction methods: a site priority index. After developing a set of indicators, the Analytic Hierarchy Process (AHP) is used to derive weights using expert input and calculate a spatial layer to select bidders and bids(p. 31). Landowners in high priority areas were invited; the priority score was used in conjunction with an impact factor (based on field officers' subjective judgments) to rank the bids.[30] Relative to ECOSEL, this approach can readily[31] accommodate a set of a large number of alternatives, but there is no way to ensure that this set contains the most efficient one (although this is not to say that this method cannot reliably produce very good solutions). It more flexibly incorporates areas of interest where biophysical models may be lacking (since the AHP exercise relies on expert judgments) but the result is also more subjective.

Iftekhar et al. (2012) examine yet another strategy aimed more at the improving cost efficiency by exploiting synergies between projects producing multiple values: combinatorial auctions. In this method, landowners submit a basket of projects designed to consider "cost and environmental benefit synergies" or economies of scale; the auctioneer assesses "complementarities" between the packages to select winners (p. 82). Like ECOSEL (and unlike site prioritization), this approach does not appear to have been implemented at any meaningful scale in the ES context. Unlike ECOSEL, it seems to rely heavily on landowner judgments and planning abilities to develop efficient proposals. It also creates a potentially very difficult challenge for the auctioneer: developing a suitable winner determination problem that goes beyond aggregate priority scoring (ibid.).

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[28] Forward auctions are designed to make a sale at the highest price—a crucial consideration for Study 3 below. Technically, ECOSEL is not an auction at all because bids are pooled and refundable if provision points are reached, making it a type of public good subscription game.

[29] An abbreviated explanation is provided here; see Study 4 for a detailed look at ECOSEL.

[30] Cost was only included in some rankings, as the focus of the paper is to compare the results produced by different approaches.

[31] ECOSEL's mathematical programming component can also address a large number of objectives in principle, but as the number of objectives grows, the task of interpreting Pareto maps and selecting alternatives quickly becomes more complex, so for practical reasons participatory Pareto methods typically focus on just a few key objectives (Tóth et al. 2010; Garcia-Gonzalo et al. 2015; Marques et al. 2019).

Polasky et al. (2014) and Lewis and Polasky (2018) describe a fairly generalized method that can easily be adapted to incorporate multiple objectives (see above). This strategy uses auctions to discover prices, which are fed to a spatially explicit mathematical programming model.[32] In Polasky et al. (2014), the optimization problem is simplified by defining a benefit function from ecosystem models, and the management alternatives are reduced to a binary conservation decision. However, it seems straightforward to expand this problem by including multiple ES or management alternatives; the innovation is not the optimization formulation, but its merger with a price-revealing auction. Lewis and Polasky (2018) significantly increase the complexity of the tool by integrating risk.[33] In doing so, they seek to describe a mechanism that:

> [...] truthfully reveals asymmetric information at the landowner scale to maximize the present value of the stream of social net benefits (as opposed to biophysical goals) from landscape pattern under uncertain climate change impacts and irreversible land-use change (p. 22).

This mechanism is also based on a binary decision to either conserve (in which case the parcel is considered to produce ES benefitting the public) or irreversibly develop (in which case it produces a private benefit for the landowner, e.g. agricultural revenue) a given parcel. In the 2018 formulation, this decision is made for two sequential time periods: the decisions made at T1 establishes the landscape available at T2, so given complete information a decision maker determines an optimal spatial arrangement using stochastic dynamic programming (p. 23).[34]

A parcel conserved in the first period may be either conserved or developed in the second, depending on net benefits as determined by the climate state. Risk-averse or risk-seeking behaviors on the part of either landowners or the regulator alters the land use pattern, as development revenues are not considered to be impacted by climate to the same degree as ES produced by conservation (p. 30) Like the assumption that landowners know their own costs and benefits, this simplification may only partially approximate reality. The authors highlight several other contextual factors that might result in the mechanism failing to behave as intended, including scenarios where collusion between landowners is more likely or where bidders do not trust the regulator to honor its payment calculation after opportunity costs are revealed (in which case bidders may not bid truthfully) (p. 31).[35]

Summary

Land management decision-making invariably requires navigating multiple objectives and interests; trade-offs abound. The scholarly literature has sought to bring auctions to bear on this problem through sophisticated mechanism design and bid selection procedures. These approaches differ in their degree of (de)centralization, the stage at which objectives are balanced in the decision-making process, and the degree of engagement with issues relating to uncertainty and risk. Despite impressive technical innovations, field trials of these sophisticated designs are needed.

Lesson: Multiple objectives can be addressed through either *a priori* or *a posteriori* approaches. In the studies considered above, the former typically involve weighting criteria, while the latter utilize optimization.[36]

Lesson: Forward auctions using *a posteriori* approaches (e.g. ECOSEL) may facilitate participatory decisions where stakeholders make trade-offs between ES, but this approach does not contain mechanisms for promoting budgetary cost-effectiveness (the hallmark reverse auctions).

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[32] See 2.4.1 subsection on *spatial considerations* for a summary of this tool.

[33] Issues relating to uncertainty and risk are raised with some frequency in the sampled literature, but framed in a variety of ways. The majority of this subtheme is consolidated under either the section on information dynamics above (how incentives impact strategic decision-making in the face of uncertainty, asymmetric information, and potential threat), or the section on contextual factors below (how context creates uncertainty, and how risk influences situated behaviors and contextual decision-making). In the case of Lewis and Polasky (2018), it made the most sense to consider producing efficient outcomes under conditions of risk and uncertainty as an additional objective for the auction design to achieve.

[34] Complete information means information about each parcel's current ES contribution, the opportunity costs of conservation, and current climate state in each period (which is assumed to impact benefits and is constructed in this paper as the major source of risk).

[35] Contextual factors like this feature prominently in the literature and are discussed in the following section.

[36] This is not to suggest that *a priori* approaches exclude optimization methods (e.g. goal programming); however, this sample did not contain any studies using *a priori* mathematical programming approaches.

Lesson: Combinatorial auctions and ECOSEL-style approaches may provide landowners with greater flexibility to submit multi-objective management plans tailored to their own perceived capabilities. In combinatorial auctions, trade-offs are made by the principal in selecting bids, but trade-offs at the management plan level may not be optimal.

2.4.4 Contextual considerations

While there is no hard and fast line between these themes, by *contextual considerations* I mean factors which have direct relevance to auction design and performance, but which are typically omitted from laboratory experiments. Game theoretic discussions of the core features of mechanism design, issues relating to the number of participants or information disclosure, auction-specific communication, market scale, incentive structures, and analyses of effectiveness and efficiency are not considered contextual and are treated elsewhere (Whitten et al. 2017). Instead, contextual considerations include variables like culturally situated issues relating to signification and symbolic exchange, institutional capacity and civic trust, and social values and identities, for example.

Auctions in low-income countries

Over the last decade, the number and scope of PES schemes has grown, but the use of ES auctions in low-income countries remains limited and largely experimental (Wünscher & Wunder 2017). On the one hand, this may present opportunities for well-designed auctions to improve the impact of limited budgets. On the other, PES in the developing world are more frequently implemented with social and economic objectives like poverty alleviation in mind, so a tool which uses competition as an engine of efficiency may not be ideal (Jindal et al. 2013). Either way, auctions in the developing world are likely to face unique issues and constraints. For Whitten et al. (2017), tthe differences are moderate but not necessarily insignificant. Wünscher and Wunder (2017) summarize:

> Imperfect markets and information about production systems, high subsistence incomes, high variability in prices and yields, and risk-averse behavior all constitute characteristics [of low-income countries] that conservation tenders may be particularly suited to address. Conversely, lack of expertise and infrastructure can hamper tender design and the dissemination of information to potential participants. Some of these challenges can be dealt with, but solutions unavoidably increase transaction costs which, in turn, may affect scalability (abstract).

Jindal et al. (2013) describe a pilot second-price uniform auction in Tanzania with 251 tree planting bids submitted by local farmers. Given the unfamiliar nature of the tool, concepts (e.g. opportunity costs) were carefully explained and practice mock auctions were conducted prior to the actual bidding; the researchers also collected demographic data.[37] The highly local nature of the exercise posed both risks and benefits: the researchers carefully included design elements aimed to discourage collusion—the risk of which they perceived to be elevated—but also observed that social pressure within the community facilitated compliance:

> [Winners] said that almost everyone knew who had won [...] Those who did not receive payment did not want to see the winners take the money without complying, because they were acutely aware that low bidders had prevented them from winning contracts (p. 78).[38]

Leimona and Carrasco (2017) conducted another second-price uniform auction for watershed ES in rural Indonesia, with participating farmers generally having "low education levels, low asset endowments, and small plot sizes" (abstract). As in Jindal et al. (2013), several practice rounds were held before the real bidding round to accustom the participants to the process (Leimona & Carrasco 2017, p. 635). Unlike Jindal et al. (2013), Leimona and Carrasco (2017) elect not to make an upfront payment but instead provide payments in installments, with later installments conditional on

[37] Low incomes also influenced contract design: to encourage the participation of poor people, short-duration contracts with upfront payments were used in place of conditional ones (p. 76).

[38] Participants also cited the transparency of the process as a major advantage relative to other initiatives, where "prominent" members of the community were perceived as receiving preferential treatment in contract awards (p. 78).

compliance (monitored by state foresters accompanied by a village leader). The researchers made understanding a key focus of the research, collecting data on participants' understanding of (a) *technical factors* associated with the auctioning and contracting process; (b) *social relationship factors*, including information flow and relationships between bidders, winners, and communities; (c) *environmental perception factors* related to providing ES of interest (p. 635). Although the auction was initially intended to serve a price discovery function to fix payments in a subsequent non-auction-based PES scheme, the issue of compliance was examined. Non-compliance was associated with "labor availability constraints, short duration of land ownership, and [...] previous conservation applications" (pp. 632-35). As in the Tanzanian auction, the Indonesian participants suggested that compliance was driven more by "honesty" than utilitarian self-interest, though sanctioning non-compliance rather than terminating payments could alter the priority of these factors (pp. 639-40).

Andeltová et al. (2019) conducted a field experiment in Kenya to explore gender as a factor in auction dynamics and outcomes "in developing countries where gender-related inequalities are prevalent" (abstract). Gendered differences were identified in relation to risk perception and tolerance as well as conservation outcomes (tree survival), with the latter being interpreted as a function of gender-based disparities in daily work allocation.[39]

Mechanism design often treats bidders as homogeneous, theoretical mechanism design analyses often construct auctions in a vacuum and treat bidders as homogeneous, rational utility maximizers. In this subsection, we have seen the importance of macroeconomic context and microeconomic realities—so what about the bidders themselves? Who participates in auctions, why, and what are the consequences of these processes of recruitment and self-selection?[40] Due to the preponderance of scientifically-motivated field experiments and the relative dearth of functioning auction-based PES in the developing world, these questions constitute a gap in the sampled literature.

Determinants of participation must instead be extrapolated from data drawn mainly from higher-income countries. Palm-Forster et al. (2017) finds that uncertainty about the costs of compliance often discourages farmer participation in agri-environmental auctions; thus, offering insurance against crop losses for conforming with practice changes can improve participation (albeit at the expense of higher transaction costs).[41] Rolfe et al. (2018) highlight underparticipation in developed country auctions and identify risk factors discouraging participation at each step of a three-stage decision process model.[42] Once again, however, this is an approach that conceptualizes participants as utilitarian and which may not account for less rational social drivers.

Sociocultural values

To understand auction-relevant social values, it may be worthwhile to consider social values in relation to PES and MBIs more broadly. Cooke and Corbo-Perkins (2018) offer a useful primer on some of the relevant ideological conflicts, including objections to neoliberal environmental governance and efforts by private landowners to "co-opt or resist the rationalities of MBIs in the practice of private land conservation" (abstract). Auction theory envisions bidders as rational utility maximizers, but in practice they may wish to subvert the process due to a basic discomfort with—if not necessarily a coherent objection to—the basic market-based ideological paradigm within which auctions reside. Others may wish to exploit auctions to achieve ends only tangentially related to the core problem of attempting to determine an acceptable price for inducing a management change.[43]

Cooke and Corbo-Perkins identify four key tensions between conservation practice in Australia and the EcoTender reverse auction program. First, an EcoTender tool designed to make bids

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[39] Women were more likely to help maintain planted trees and contribute to family caretaking than *vice versa*.

[40] The issue of participation is probably nowhere more critical to auction success—nor more underexplored—than in the case of ECOSEL-like designs relying on stakeholder bidding. Given its relevance to the NOBEL cases, this make-or-break issue receives separate treatment in the special subsection on *Crowdfunding* below.

[41] This uncertainty is commonly overlooked in theoretical literature, which assumes bidder knowledge of opportunity costs.

[42] Prospective participants must simultaneously decide: (1) am I willing to change my practices? (2) am I willing accept contractual obligations about these changes? (3) how do I determine the price that I am willing to accept if I enter a bid? (p. 1).

[43] This is a concern for NOBEL's Austrian case study, for example.

more competitive in exchange for agreeing to permanent constraints on land use resulted in underbidding: rather than increasing bids to reflect reduced option value as intended, conservation-oriented landowners accepted a financial loss because they viewed permanent legal protection as desirable (p. 175). Second, only a minority priced their own labor into submitted bids, instead viewing conservation activities as part of their stewardship responsibility; those who included their labor costs often undervalued them (p. 176). Third, some landowners managing novel ecologies as a result of previous restoration work faced unexpected challenges, ranging from poorly-suited EcoTender criteria to unexpected costs triggered by landscape-scale habitat interactions emerging from restoration efforts with insufficient spatial coordination (p. 177).[44] Fourth, the auction tool does not provide a means of communication between winning bidders at any stage of the contracting process (likely to reduce collusion); some participants felt this discouraged knowledge-sharing, increased feelings of isolation, and undermined and the formation of "collaborative, cross-boundary conservation networks" (p. 178). The core functions of the mechanism (price discovery, inducing competition, limiting rent seeking) make sense in a market logic. In the contexts featuring a strong and salient conservation ethic, however, it may impose unnecessary costs on some landowners while also limiting their capacity to behave as proactive stewards.[45] It would likely have been difficult to identify these dynamics in the absence of qualitative research.

In contexts where payments for land management labor are more standard—as in the Indonesian and Tanzanian field experiments—the auction method was viewed as a fairer way to allocate contracts than alternatives, which may be more prone to bias in favor of influential individuals (Jindal et al. 2013; Leimona & Carrasco 2017). McGrath et al. (2017), however, find that fairness and satisfaction may be a phenomenon perceived mainly at the level of individual participants. At the community level, auction outcomes can alter dynamics and impact relationships between winners and losers.[46] Community perceptions of auction fairness were mediated by ethnic group membership (some groups being considered indigenous and others viewed as migrants) as well as the economic status of farmers: disadvantaged and less educated groups assigned lower fairness ratings to the auction. This could reflect different levels of understanding of the process or indicate that insufficient procedural equity aggravated pre-existing tensions (p. 48).[47]

Auctions are competitive allocation tools, but bidders may not view one another as equally legitimate competitors. Perceptions of in-group and out-group status, the legitimacy of existing land tenure structures, and social hierarchies may influence perceptions of the mechanism and its impacts on networked community relationships; in turn, social values can impact auction performance.[48] And although winners are often the focus of ES auction follow-ups, losers engage in discourses surrounding the process and its outcomes as well. Participants invest time, effort, coordination, and even emotional labor in hopes of earning income, and may feel that these investments were squandered if their bid is rejected for not being competitive enough:

> [Feeling one's bid was unfairly rejected] is especially likely where social norms are shaped by egalitarian traditions and where concepts such as competitiveness and commoditization of biodiversity-related resources are poorly understood and even rejected. Introducing competition among communities may undermine existing pro-social norms underlying collective action (Narloch et al. 2011, p. 423).

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[44] Whitten et al. (2013) identify the provision of post-contract support as an often-overlooked issue in the ES auction literature that warrants additional attention (abstract).

[45] Nonetheless, the more typical case is likely that described by Ulber et al. (2011), in which the impact of socioeconomic factors other than opportunity cost on bid prices is to inflate them—although, again, the proposition that bidders have perfect knowledge of their opportunity costs and expected transaction costs is questionable at best.

[46] One reason that PES are often analyzed as interventions in complex and situated socio-ecological systems.

[47] Banerjee et al. (2015) suggest that relinquishing information about spatial coordination priorities, even at the risk of enabling collusion, may be useful to support perceptions of fairness by reducing the risk that participants view clusters of contracts as evidence of a biased process (p. 411).

[48] e.g. By providing compliance pressure, as in Jindal et al. (2013).

In sum, culturally contingent values and perspectives impact auctions, and auctions impact community dynamics and carry social weight. In Andeltová et al. (2019), traditional gender roles influenced tree survival, but the burden of contract compliance was unequally shared by genders. In Narloch et al. (2011), trade-offs maintaining traditional knowledge and maximizing genetic diversity were identified. Fostering trust and perceptions of fairness can pay dividends in later auctions, such as by reducing site assessment costs or improving effectiveness (Crossman et al. 2011; Vogt et al. 2013).

Policy and scale

Auctions' ability to achieve management, efficiency, or effectiveness goals often depends significantly on political and institutional support (Whitten et al. 2017). Including auctions in agri-environmental policies like the EU CAP can stimulate research, but practical guidelines for designing auctions to suit specific contexts are scarce (Groth 2011). Policy frameworks and regulatory regimes help define these contexts (ibid.; Holmes 2017). Other relevant policy-contextual factors include the existence of other programs with similar aims and legal frameworks for private contract enforcement (Hanley et al. 2012). The mechanisms proposed by Polasky et al. (2014) and Lewis and Polasky (2018) are designed to address the shortcomings of alternative instruments.[49]

Messer et al. (2017) offer a more policy-focused analysis that considers institutional support in the form of established auction programs and budgetary consistency. The first element mostly relates to learning effects, while the second has to do with bidder behavior under uncertainty (e.g. stochastic budgetary changes modulates perceptions of risk when attempting to inflate prices). Liu et al. (2019) offer a useful qualitative exploration of introducing new land management tools in the rural Chinese policy context, which features centralized decision-making, limited action space for NGOs, and a strong preference for policy "realism" over theoretical work or experiments using "contrived" laboratory samples (p. 866).[50] Baird et al. (2014) stress that institutional capacity typically constrains performance-based interventions like reverse auctions that account for environmental benefits.

Summary

Policy elements are important contextual factors with a direct influence auction design and outcomes. Although this review located a number of studies highlighting policy features relevant to specific cases, however, no focused analyses of the interaction between policy context and auction dynamics were identified.

Lesson: ES auctions in low-income countries may encounter a different set of objectives and constraints than those in richer countries. Large-scale auction-based environmental policy tools from are unlikely to be directly transferable from one context to the other.

Lesson: Behavioral and sociocultural factors influence auction performance and auction outcomes.

Lesson: Improvements in participants' understanding of the mechanism can have paradoxical effects: it can enable bid inflation, but also promote perceptions of fairness.

2.4.5 Equity

While considerations relating to equity are implicitly normative, this review did not locate any analyses of ES auctions focused specifically on ethics. Absent an explicit ethical framework, it is not always obvious what authors mean by *equity*. Nonetheless, concerns relating to equity represent the last major theme identified in the review.

Jindal et al. (2013) identify substantial trade-offs between "cost efficiency and maximizing participation by poor households" in a pilot auction in rural Tanzania; there is also some suggestion that the PES scheme may have negatively impacted the land rights of local women (abstract). The Indonesian auction case by Leimona and Carrasco (2017) also found that farmers with larger parcels tended be more successful, possibly due to economies of scale. In both cases, the participants viewed the mechanism itself as relatively transparent and fair, specifically noting that its outcomes did not appear to be unduly influenced by social status or influence. The Kenyan field experiment by

[49] Specifically, voluntary incentive programs on the one hand and top-down land use regulation on the other.

[50] Liu et al.'s discussion of how these features of the policy landscape informed the experimental design is useful, but the policy context is not the focus of the study.

Andeltová et al. (2019) indicates that targeting the participation of women may simultaneously improve gender equity and auction effectiveness—albeit at the risk of exacerbating gendered labor inequities (abstract).[51] All three studies clearly view outcome equity as a relevant consideration in evaluating both auction performance the suitability of auctions for broader applications.

There is a case to be made that the efficiency-effectiveness-equity trade-offs discussed in the PES literature may be particularly acute when it comes to auctions. Narloch et al. (2011) argue that attempting to equitably distribute funds rather than strictly allocate contracts to the most competitive bidders might "undermine the main motivation between using (competitive) conservation auctions" in the first place (p. 423).[52] This view clashes with Wunscher and Wunder's (2017) contention that informational rents can be viewed as poverty-alleviating income transfers in some circumstances.

Discussions about equity are also sometimes couched in terms of social values, so that stated ethical values of participants are prioritized over any (often unstated) ethical expectations on the part of the researchers (e.g. Cooke & Corbo-Perkins 2018). Farley et al. (2015) and Leimona and Carrasco (2017) focus on the practical need to ensure that stakeholders *perceive* relevant processes as fair and equitable. For McGrath et al. (2017), however this is not an auction-specific concern: the case for "incorporating justice into conservation" is pragmatic as much as it is ethical or moral, since interventions that are perceived to be just are more likely to succeed.

Summary

Equity is commonly mentioned as a variable of interest in the recent ES auction literature, but focused discussions of equity (or the implicit ethical frameworks that give equity significance as a potential objective) are scarce. When these issues are discussed, they are typically couched in practical terms or framed indirectly, such as constructing equity as an expectation of auction participants that must be met for pragmatic reasons, rather than as a discrete policy goal.

Lesson: It is important to distinguish between distributional and process equity when examining ES auctions.

Lesson: Using auctions to promote distributional equity may conflict with the dominant efficiency orientation of auctions.

Lesson: Equity appears to be a more salient consideration in auction literature focused on the developing world; inequity fault lines are typically context-dependent.

2.4.6 Contrast with other tools

Although comparisons between auctions and other instruments usually do not delve very deeply into the details of auction design, they can be useful in clarifying the auction niche. As above, the considerations enumerated in this section always interact with context. Lundberg et al. (2018) find that even in cases where auctions *should* be the most efficient allocation mechanisms from a theoretical perspective, the relative effectiveness of various PES models can be determined by a range of variables, including:

- baseline compliance with program standards among participants
- correlation between opportunity costs and ecosystem services in the landscape
- heterogeneity in costs and budget size (p. 347).

Pirard (2012) distinguishes reverse auctions from other MBIs primarily on the basis of their price discovery capability, but also cites competitive disincentives to free-ride or extort rents. Narloch et al. (2011) stress auctions' ability to surmount information asymmetries, access price information, and produce cost savings, but also cite transaction and learning costs. For Narloch et al., auctions' procedural fairness is debatable: on the one hand, participants do not contribute to mechanism design; on the other, they typically enjoy wide latitude in terms of establishing their price and structuring their offers. Arnold et al. (2013) found that adverse selection rendered a discriminatory reverse auction

[51] Gender equity is evaluated "in terms of access to project decision-making, trainings and cash" (ibid.). The risk of exacerbating gender inequality may be inherent in awarding ES contracts regardless of the allocation mechanism, since women are more likely to assist in maintenance (p. 21).

[52] *see* Study 2 for more on this topic.

inferior to either doing nothing or utilizing an externality-correcting tax under budgetary limitations: in attempting to acquire parcels at the lowest cost, reverse auctions assign property rights in a way that undermines effectiveness and enables owners to extract information rents (ibid.; Groth 2011).

The requisite level of governmental involvement and institutional capacity can also differentiate auction-based approaches from some other MBIs (Baumber et al. 2019). Unlike private-sector-driven instruments like voluntary certification, auctions rely on institutional action to "create market structures and the methodologies and eligibility rules that enable the markets to function", much like offsets or tradeable credits (p. 178). However, although auctions usually require the government to act as a buyer, they do not necessarily require it to engage in valuation in the traditional sense; this differentiates auctions from markets for biodiversity offsets, for example:

> While both offsets and auctions can be used to encourage rehabilitation of degraded land, they differ in terms of the stakeholders they involve, the funding sources they present, and their impact on other ecosystems (p. 177).[53]

Like many other MBIs—and unlike some command-and-control approaches—some worry that auctions risk "crowding out" non-economic motivations for protecting ES (p. 179; Cooke & Corbo-Perkins 2018). Others, however, argue that auctions can have the opposite effect, "crowding in" intrinsic motivations because bidders' price their desire to engage in stewardship into their bids: "In a context of intrinsic motivation, bids are likely to understate costs." (Chan et al. 2017, p. 114). When auctions allow landowners to propose their own conservation/stewardship actions, this effect could be magnified, with bidders proposing actions they are intrinsically motivated to perform and are willing to do so even if their apparent opportunity costs are not met (p. 118). Effects of this nature are likely to be highly context-dependent, and understanding them may require significant qualitative research efforts.

The locus of decision-making is also relevant when comparing auctions to other tools: the principal decides who receives contracts. This contrasts with open enrollment programs, where the principal fixes a compensation scheme and participants decide freely whether or not to enroll (Hanley et al. 2012). Auctions can also be differentiated from other instruments on the basis of the transaction costs they pose: in establishing bid selection criteria, the principal determines the information requirements for prospective bidders. Submitting a bid is a "gamble to obtain a contract with the government"; collecting the necessary information and going through the process without any guaranteed payout can discourage participation (Ferguson et al. 2016, p. 18). Informational requirements for the principal can also be substantial, from ranking bids to evaluating performance post hoc.

Although auctions are typically conceptualized within the MBI paradigm, they can be combined with top-down regulatory approaches as well. Farley et al. (2015) consider of a cap-and-auction tool for a US state-level institution tasked with managing common pool resources. This variant is structured as a forward auction with the property rights allocation placing the burden on the developer to obtain the right to develop (e.g. the institution auctions off emission allowances or harvest permits). Instead of paying private landowners, public bodies capture rent that can be allocated to more sustainable management, reinvested in energy transitions or other infrastructure, or returned to taxpayers as a dividend:

> Cap-and-auction schemes ensure that everyone who uses common assets must pay the same price, with resulting revenue spent on the common good, while taxes on rent ensure that no one captures unearned profits from common assets; both policies ensure *proportional equivalence between benefits and costs*. (pp. 72, 77-78).

A detailed survey of environmental policy instruments and MBIs is beyond the scope of the present discussion. However, this section has presented several key dimensions typically used to differentiate ES auctions from other tools in the recent literature, and it has sought to do so without dwelling too long on ground that has already been covered in more detail above.

Summary

[53] Offsets impact two areas in one exchange (degraded and conserved); auctions only focus on one at a time.

In comparative discussions, auction methods are typically distinguished from other tools by their price-discovery capacity, relationship with free riding and rent seeking, the nature of government intervention required, and the locus of decision-making. The form and type of transaction costs associated with auction methods also appears to be unique.

2.5 Discussion

The recent literature on ES auctions is innovative and dynamic, but also perhaps somewhat fragmented across disciplines. Despite several well-established and large-scale public programs using on reverse auction methods, such as the CRP in the US and Eco/BushTender in Australia, this body of literature is only moderately developed. Debates persist about the basic characteristics of the auction tool: does it achieve dramatic efficiency gains by virtue of its unique capacity to overcome information asymmetries, or is it actually much *less* efficient than simpler tools like screening contracts due to its inability to effectively address issues like adverse selection and moral hazard? Part of the issue has to do with the diversity of potential designs[54] in combination with the often-overriding importance of both context and implementation. More advanced mechanisms may achieve greater efficiency on paper, but pose higher participation and transaction costs due to information requirements or the simple pedagogical challenge of ensuring that bidders understand the mechanism well enough to enter rational bids (but not so well that they begin to devise strategies for collusion or effective rent seeking!). Legal frameworks, cultural expectations, data availability, and notions of legitimacy and fairness can all enter the equation for auction field trials. Although less common in the sampled literature, research based on field trials or case studies with a qualitative component can raise interesting questions about motivation, participation, ideology, and other hidden contexts—contexts that more rigidly constructed, highly quantitative approaches may struggle to detect or navigate. Mixed-method approaches for testing new methods in new settings could be useful, particularly with respect to illuminating the nexus between design, actor, and context.

The objective of this review was to identify the foci and boundaries of an unfolding scholarly conversation, not to make definitive determinations about the state of the art or engage in in-depth methodological critiques. Nonetheless, its broader goal is to provide a touchpoint for future discussion. A brief selection of topics that might benefit from further attention is provided below.

2.5.1 Potential gaps

Practical guidance. Although the theoretical and empirical knowledge base is growing, practical guidance for designing and implementing ES auctions given specific goals, constraints, and contextual variables is scarce (Groth 2011; Whitten et al. 2013; Chan et al. 2017). This might include a focused discussion of risk factors associated with auctions failing to achieve their objectives, major advantages and disadvantages relative to other tools, best practices, and design frameworks.

Regulatory threat. The impact of explicit or implied regulatory threats, or prospective bidders' felt danger that a failed auction could trigger additional regulation, appears to be a potentially significant consideration that has only been characterized in a preliminary way (Holmes 2017).

Crowding in, crowding out. Further research into the relationship between auction methods and intrinsic motivation for stewardship, including crowding in/out, is likely indicated (Chan et al. 2017; Cooke & Corbo-Perkins 2018).

Efficiency-effectiveness-equity trade-offs. The relevance of efficiency-effectiveness-equity trade-offs, the ethical frameworks used to guide auction assessments, and the operationalization of justice and social equity in auction research are all relevant considerations cited in the review that have not been subjected to in-depth analysis (Leimona & Carrasco 2017; McGrath 2017). A related consideration that warrants further examination is the notion of tolerating inefficiencies by considering them as a poverty-alleviating cash transfer (Wunscher & Wunder 2017).

Field trials for sophisticated designs. This review identified mpressive theoretical work in advanced auction designs for achieving spatially coordinated outcomes and integrating uncertainty

[54] Variables include e.g. information sharing, communication, time, number of rounds, bid selection criteria, the algorithm for determining payment, the use of bonuses, the nature of bids, lock-in rules between rounds, and the integration of impact measures.

and risk, but field trials using these tools are limited or nonexistent (Reeson et al. 2011; Banerjee et al. 2015; Polasky et al. 2014; Lewis and Polasky 2018).

Operationalizing context. Research into the role of institutional capacity, policy context, and the demographic profile of auction participants, appears to be a potentially lucrative area for future research—particularly if linked to developing-developed country contexts (Messer et al. 2017; Liu et al. 2019; Andeltová et al. 2019).

Forward formats. With a few narrow exceptions (e.g. Tóth et al. 2010; Lewis & Polasky 2018; Chakrabarti et al. 2019), discussions of ES auctions involving elements of the traditional "forward" many-buyers-one-seller format are rare. The articles that do discuss auctions with these elements assemble them in quite diverse ways. Forward formats to generate higher prices and engage larger numbers of stakeholders, rather than (or in combination with) reverse formats aimed at gaining landowner participation at the lowest possible price, may expand the available toolset.

Multi-criteria optimization. Although auction methods have been applied to a wide variety of ES, the recent literature shows limited engagement with multi-objective optimality. Efforts to use indices to score bids on ecological value or promote contiguity (e.g. Crossman 2011; Reeson et al. 2012; Polasky et al. 2014; Banerjee et al. 2015) suggest that the topic is of interest. However, most designs engage with either binary conserve-develop decisions; if multiple management alternatives are permitted, landowners are allowed to combine them as they prefer, leaving the procurement agency to predict ES implications. These approaches do not make trade-offs between multiple ES in an explicit, quantitative way. Tóth et al. (2010) combine Pareto methods involving three decision variables with auctions, but in an unusual forward format that has not undergone field trials. It may be worthwhile to explore the integration of multi-criteria optimization with ES auctions.

Priorities for the field. This review failed to locate a clear agenda for ES auction research and praxis moving forward. There are fairly distinct threads in the literature, but it is difficult to get a global sense of the domains that are expected to drive future developments in ES auctions, or those which should be prioritized in future research or policy initiatives. Although not technically a research gap, efforts to facilitate dialogue within the field could pay dividends moving forward.

2.5.2 Limitations

This review relied on a search of a single academic database (Scopus), limited to peer-reviewed journal articles. Thus, only a subset of the recent ES auction literature was accessed. A more comprehensive approach would involve querying multiple databases, identifying additional articles by examining reference lists in the preliminary sample, and even conducting reverse citation searches. The inclusion of academic books or gray literature could also alter the findings above: the dearth of practical guidance on ES auctions was an important gap identified in this review, but this type of guidance may well exist in another form than a peer-reviewed journal article.[55]

Working with a significantly larger sample, of course, would require a different analytic approach than the one used here, which provided detailed summaries and elaborated on themes and questions to set the stage for Study 2. A standalone systematic review of the auction literature would likely benefit from a more comprehensive sampling protocol and a less fluid framework for analysis, breaking studies down along dimensions of interest to compare them directly rather than seeking to identify discursive themes and threads in the literature.

2.6 Conclusion

This chapter reports the results of a systematic review of 58 peer-reviewed journal articles relating to ES auctions published in the last decade. The sample was collected using a search of the Scopus database, screened, and subjected to a form of thematic content analysis drawn from grounded theory. Five major themes in the sampled literature were identified: (1) efficiency and effectiveness; (2) information dynamics; (3) balancing multiple objectives; (4) contextual considerations; and (5)

[55] One example is a report prepared for the Danish Environmental Protection Agency, which was a valuable resource in conceptualizing and designing this thesis but which did not meet the criteria for inclusion in the systematic review (Thorsen et al. 2018; *see also* Lundhede et al. 2019).

ethics and equity. An additional section highlighting features commonly used to differentiate auctions from other MBIs is also included.

The broader goal of this study was not to comprehensively review the auction literature, but to locate major landmarks and boundaries in current scholarly discourse and set the stage for an expert consultation in Study 2. Thus, possible knowledge gaps were emphasized: notably, practical guidance, the role of regulatory threat, crowding in/out of other stewardship motivations, field trials for sophisticated design features, how to engage with context, the use of forward formats, the potential for multicriteria optimization, and meta-discourses about priorities for the field. Overall, this body of literature features significant breadth and diversity and engages multiple disciplines and research modalities, from neoclassical economics and dynamic programming to ES indicator assessment and qualitative explorations of ideology, institutions, and social signification. Additional efforts to integrate and operationalize this colorful field are recommended.

3. Study 2: Expert consultation (Delphi survey)

3.1 Abstract

Background: Ecosystem services auctions have attracted growing attention from researchers and land managers, but the literature is fragmented and offers limited practical guidance. **Objective:** A 35-expert Delphi survey was conducted to identify areas of consensus in the ES auction field. **Methods:** The panel was composed of (1) NOBEL/SINCERE participants, (2) active ES auction researchers identified by publications, and (3) experts recommended through snowball sampling. Two survey rounds were performed; in the second, panelists were informed of emerging areas of consensus identified in the first. **Results:** The panel rated economic efficiency, price discovery, and stakeholder engagement as the primary advantages of auctioning ES, and low participation, complexity, and transaction costs as the primary disadvantages. Top risk factors for auction failure were low participation, participants' difficulty understanding the mechanism, and risk and uncertainty on relevant time horizons. Policy, technology, and experimental results are likely to drive future developments in ES auctions, but the link between theory and practice needs improvement. Field auctions typically do not effectively account for risk or produce spatially-coordinated outcomes. The relationship between auctions and distributional equity is controversial. A conceptual framework for evaluating the minimum number of participants needed to limit collusion-induced inefficiency was proposed and endorsed by the panel. **Conclusion:** ES auctions are a novel price discovery and/or contract allocation mechanism offering potential efficiency improvements over alternatives. Successful auctions are informed by social, biophysical, and policy dynamics in addition to economic ones. A diverse body of theoretical and laboratory research explores sophisticated mechanisms to improve efficiency, achieve spatial coordination, and account for uncertainty, but field data is lacking.

3.2 Introduction

The systematic review presented in Study 1 above identified major threads, topics of interest, and potential gaps in the recent ES auction literature. Study 2 consists of a two-round expert consultation aimed at clarify the state of the art and forecast possible developments in the field. A panel of 34 experts from three categories was recruited. A first round questionnaire inquired about the strengths, weaknesses, risk factors of ES auctions, as well as focused questions about the capabilities of advanced designs and theory-practice discourse. A mix of open-ended and Likert items were used. The second round questionnaire closely followed the structure of the first round, but with a focus on emerging consensus: topical importance ratings and majority opinions from the previous round were disclosed to the panel, and panelists were asked to explain opinions that diverged from the apparent consensus or "average" perception of respondents. After the second round, results showed strong (but incomplete) agreement on most items and no reduction in variability in the two rounds for the few items without consensus, so a third round was not performed. A conceptual framework for specifying minimum participation requirements was endorsed by all panelists who evaluated it.

3.3 Methods

3.3.1 Delphi method

The Delphi method is an iterative process of structured communication between experts that is applied in areas characterized by a high degree of uncertainty, such as forecasting in the absence of workable models or identifying urgent challenges in emerging areas of research or practice that have not yet been well-characterized:

> The Delphi method consists of an iterative process of individual expert consultation and knowledge accumulation repeated until a certain degree of judgment convergence is attained. This technique is applied in many cases of environmental assessment in which ecological knowledge is lacking, data are missing, or are unsuited to empirical modelling (Scolozzi, Morri, & Santolini 2012, p. 136).

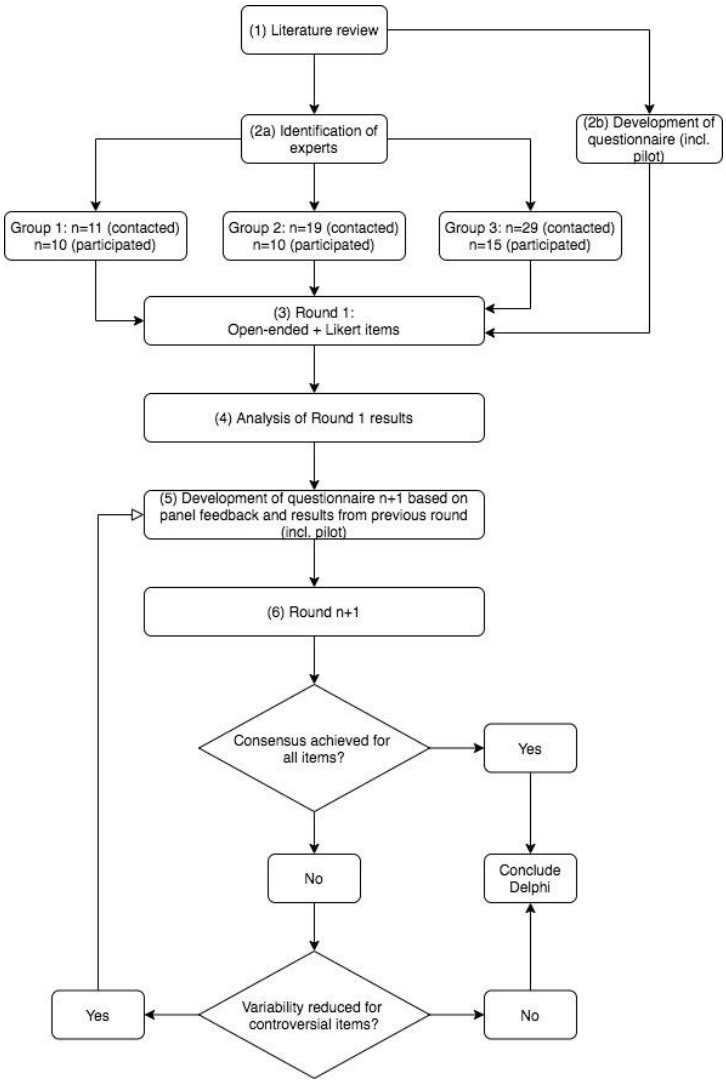
The basic format and protocol of the process is fairly simple and relatively easy to generalize (after all, the system was designed as a means of encountering new problems and synthesizing

experts' best-guess predictions under conditions of uncertainty). Filyushkina et al. (2018) offer a useful summary of the basic process. To our knowledge, the Delphi method has not been previously applied to investigate environmental auctions of any format. Fortunately, it has been utilized in areas closely related to the present research. These studies offered a useful guide to developing the methodological approach used here (see Appendix 1).

3.3.2 Sampling

For this study, the expert panel was recruited from three groups: NOBEL/SINCERE project participants, researchers identified during the systematic review, and subject matter experts recruited through snowball sampling.

Figure 1: Delphi process overview[56]



(1) Project participants (n=10): The first category is composed of NOBEL (n=5) and SINCERE (n=5) project participants who provided some input into the design of auction case studies. This group is not limited to formally designated auction designers or managers and includes members with auction experience who provided input about the auction case studies during project meetings.

[56] Figure loosely adapted for the present study from Filyushinka et al. (2018, p. 181)

(2) External researchers (n=10): The second category was identified during the course of the systematic review. All researchers with three or more publications that appeared in the systematic review sample were contacted, asked if they would be willing to participate in a Delphi survey relating to environmental auction methods, and invited to suggest 2-3 other top experts they felt should be included (snowball sampling).

(3) Subject matter experts (n=15): The suggestions from group (2) were collected into a third list and the same process was repeated until all suggested experts had been contacted. This group included academic researchers as well as scientists working for other research organizations and government agencies (e.g. USDA Economic Research Service, CSIRO Land & Water).

An initial outreach email was sent to 61 potential panelists (11, 19, and 31 from subsamples 1, 2, and 3, respectively). The initial outreach email briefly introduced the author, the study, and the plan for the survey. Of these, 42 responded to express interest in participating in the panel and were sent a formal invitation containing a link to the first round survey and an individualized access token.

The deadline was extended by several days in order to facilitate the inclusion of several key experts who had not been able to respond. An additional expert attempted to complete the survey a week after the extension and was excluded from the panel. In total, thirty-five panelists completed the first-round survey (80% response rate). One panelist only answered a handful of items and left a note indicating that they did not feel they had adequate expertise in ES auctions specifically; their responses were eliminated and the panelist was not invited to the second round. Thus, the final response rate for the first round was 77%. With the exception of the eliminated panelist, all 34 participants who completed a first round survey were invited to the second round, and 32 (94%) completed the second round survey.

3.3.3 Round 1 questionnaire

The initial bank of potential questions for the first round questionnaire was based on a consideration of (a) the systematic review presented in Study 1, and (b) the focused review of previous applications of the Delphi method presented earlier in this chapter. Specifically, the results of the systematic review were used to identify major topics of interest and potential gaps in existing knowledge. The methodological review was used to prioritize topics that could be best addressed using the Delphi panel, and then to refine those topics into questions suitable for the method.

After a draft was developed, a pilot test was performed with a non-expert and one auction expert to verify that the questions were understandable and to obtain an estimate of the time required to complete the survey. Based on these results, several substantive revisions were made and a second pilot study was performed with a different expert, who provided feedback that conflicted with the previous pilot. The survey was revised again to find a midpoint between these preferences. The disagreement centered on response format: one expert preferred to explain their ideas through open-ended responses for some questions, while the other felt this was too taxing for the panelists and preferred to select from a list of fixed response categories. The final version included a compromise format with short open-response items followed by a hint suggesting possible answers, but emphasizing that respondents were not confined to the list. This final version was sent to the sample, who were told they had one week to complete the survey. A reminder was sent after a few days, and an additional, personalized reminder after the deadline was extended.

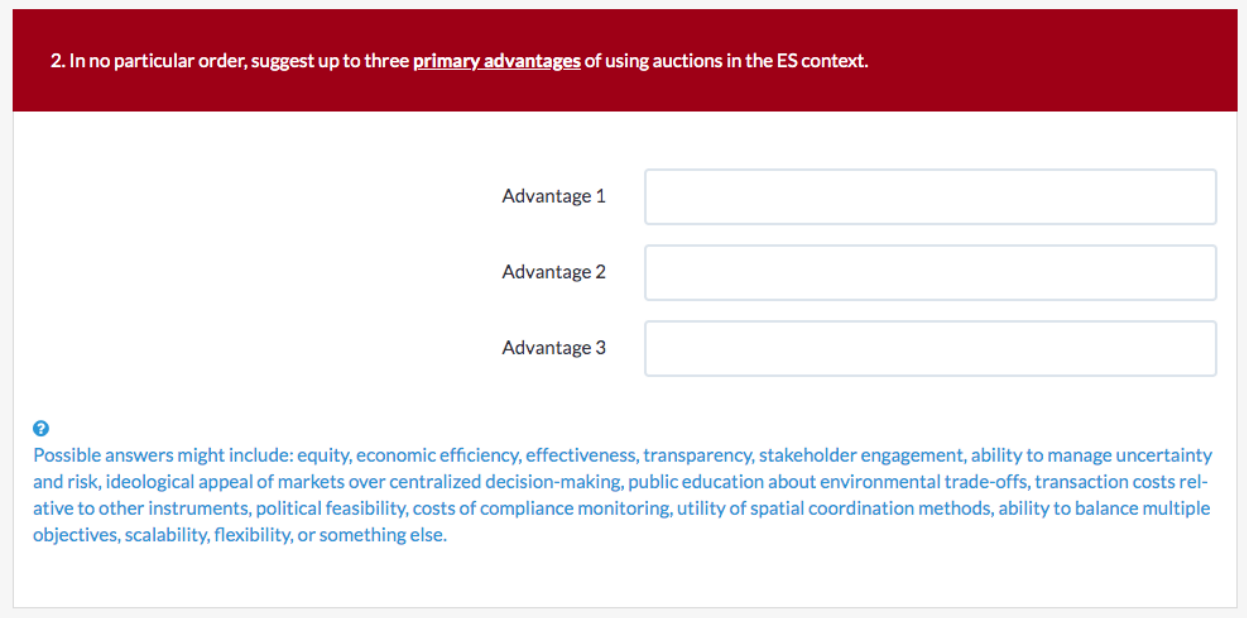
The first round questionnaire opened with a brief (~300 word) explanation of the study background and context, an outline of the subsamples, an overview of the survey structure, and a clarification of terminology (specifically, the distinction between forward and reverse formats). It also included a bolded instruction: "If you do not feel qualified to respond to a given question, you can leave it blank." Next, it presented a consent item, asking panelists if they would be willing to disclose their participation with the rest of the panel in the second round, so they could better evaluate possible consensus positions. Panelists were assured that their anonymity would be preserved in reporting results, and that their individual answers would not be shared with the rest of the panel. Two panelists declined and the rest consented. All questions in the survey were optional (i.e. it was possible to advance to the next question without providing an answer to the current one). One question was displayed at a time, but the interface enabled panelists to navigate both forward and

backwards in the questionnaire. Panelists could also save the survey and return later to complete it. The introductory text encouraged panelists to skip any questions they did not feel qualified to answer.

Round 1, Section 1 (R1S1)

The first section consisted primarily of six items. First, four structured[57] open-ended questions asked panelists to make a forecast about ES auctions, suggest advantages and disadvantages, and identify risk factors associated.[58] Panelists were invited to give up to three responses for each question. While we would have preferred to leave these questions open to interpretation to avoid biasing the sample, we were cognizant of the feedback from the pilot study indicating that this could pose a cognitive burden for a long survey targeting busy experts, so hints of possible answers were provided as tooltips beneath the answer fields (Fig. 2). Suggested answers were drawn from the systematic review and pilot results. The fifth question asked panelists to estimate the minimum number of auction participants that would be required to reduce the risk of bidders colluding and significantly reducing outcome efficiency. The sixth question provided a comment field for panelists to explain their reasoning, but were reminded that this field was optional.[59]

Figure 2: Example of a structured open-ended question (R1)



Round 1, Section 2 (R1S2)

The second section consisted of eight four-point Likert items (Strongly Disagree – Strongly Agree). No neutral value was included (forced-choice), but a "No answer" option was available. Two matrix-style items were used to evaluate, firstly, whether the current knowledge base was sufficient to design auctions capable of performing certain functions (e.g. produce spatially-coordinated outcomes, promote equity), and secondly, whether these functions were typically executed satisfactorily in practice. An additional matrix compared forward auctions to reverse auctions in terms of transaction costs, multi-objective capacity, and informational rents. The remaining five questions featured just one rating task each and addressed stakeholder engagement, the role of biophysical models, the prevalence of multi-objective auctions, the quality of the link between theory and practice, plus one question offering an abbreviated summary of an ECOSEL-like forward auction model and asking panelists to evaluate whether it could form the basis of a viable PES model. The survey concluded with an open-ended item inviting panelists to comment freely on the survey or the topic.

[57] Panelists were invited to give up to three responses for each question.

[58] These tasks (forecasting, evaluating novel innovations, and identifying risk factors in emerging practice areas) for which the Delphi method is uniquely well-suited.

[59] The survey introduction indicated that all fields were optional and encouraged panelists to skip those they did not feel qualified to answer; this comment field just included an additional reminder.

3.3.4 Round 1 analysis

Open-ended (R1S1) responses were analyzed inductively following a simplified version of the coding process described in Study 1. All responses for each question were collected as a text document and coded by topic. The most prominent topics were identified using NVivo's frequency analysis function. The Likert items (R1S2) were analyzed using descriptive statistics in order to identify items with consolidation around answers with positive or negative valence. Questions that showed viable emerging consensus were then selected for the second round survey. Emerging consensus was generally identified either in the case of a clear (~60%) majority support for a given item. Extreme responses (Strongly [dis]agree) received 50% more weight than moderate responses in determining emerging consensus around a given pole. As discussed in the results section below, no emerging consensus was identified for seven items (questions, or in the case of matrices, sub-questions). These included all four forward auction items.

3.3.5 Round 2 introduction

The second round questionnaire opened with a brief welcome message explaining the research philosophy and conceptual approach: namely, that the Delphi method was chosen for this study partly because it is not an extractive method, but aims to facilitate structured communication in groups and build consensus, and that for this reason, design the second round had been designed in a way that would include as many responses from Round 1 as possible, rather than focusing on the most popular suggestions. The welcome message also acknowledged that fixed response categories can be frustrating and encouraged participants to leave comments. Finally, the list of panelists who had previously consented to be named was presented.

Round 2, Section 1 (R2S1)

After the coding and frequency analysis of the qualitative data from the open-response items (R1S1), the five categories with the most responses were identified. We considered several options for presenting the R1 results to panelists in a way that could express both the diversity of submitted responses and cases in which one answer was suggested with unusually high frequency. Ultimately, we divided the number of responses in each category by the total number of responses, then multiplied by 4 (an arbitrary factor selected to convert the resulting percentages into a more readable 10-point scale) to produce an "importance score." The purpose of this score was simply to communicate to the panel the degree of consolidation around these top categories.[60] To avoid concealing interesting but less-popular suggestions from the panel, a sixth, miscellaneous category was also included, which listed categories that did not make it into the top five. This final category was arbitrarily assigned a score one point lower than the score of the fifth-ranked category, or equal to it if the fifth category was 2 (to leave room for panel to adjust the score downwards).

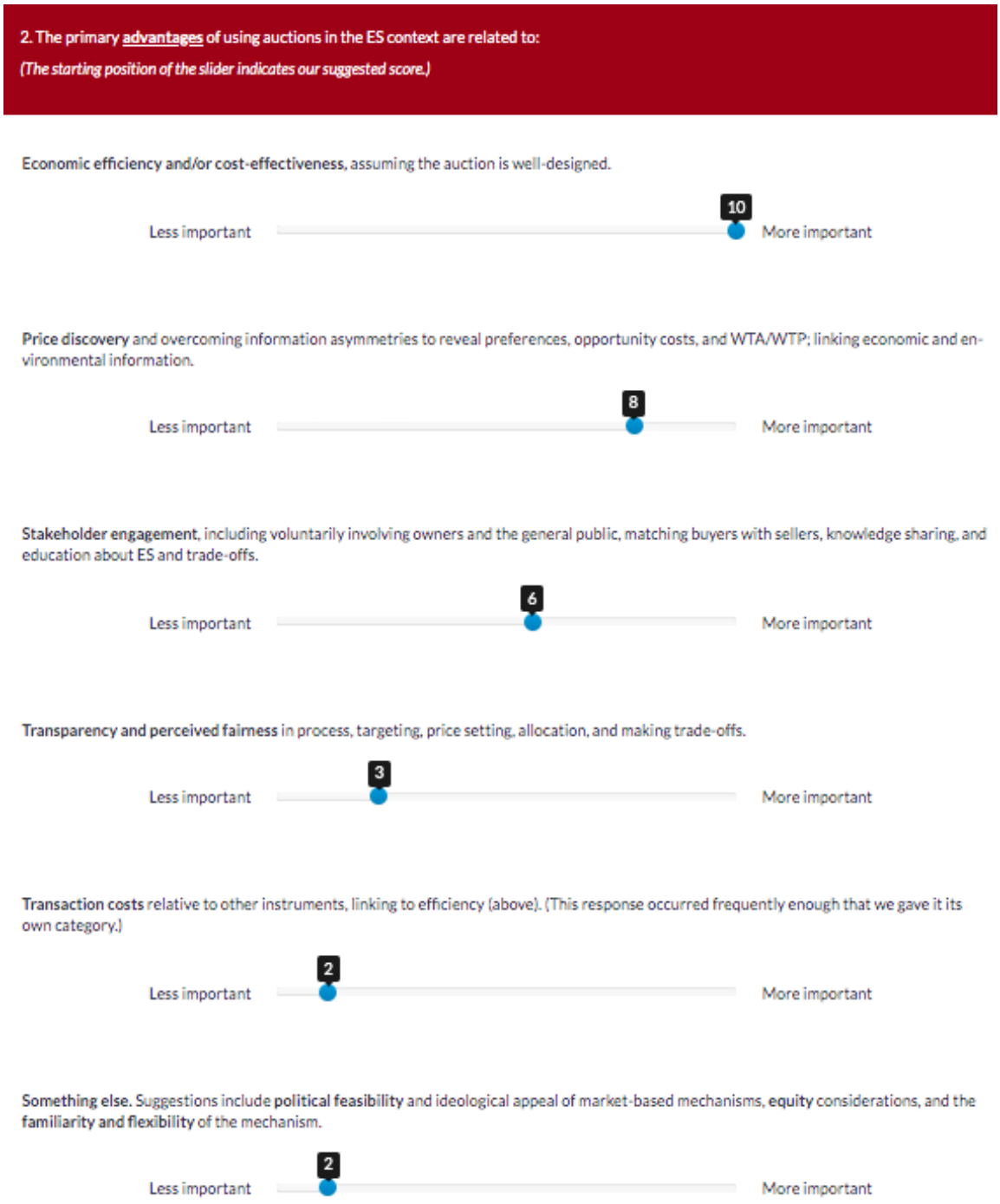
The wording of each question in R2S1 closely paralleled that used in the previous round. After each question, the six categories were presented, with one slider corresponding to each category (Fig. 3). The slider represented a 1-10 scale with one pole labeled "less important" and the other scale labeled "more important" (Fig. 3).[61] The starting position of the slider indicated the importance score derived from the panel's R1 responses as described above. For each question, panelists were asked to consider each category and adjust any sliders as they saw fit; if they felt the assigned score was reasonable or if they were unsure, they were asked to leave the slider where it was. Results showed that the initial suggested value was a strong predictor of the final ratings given to each sub-question by the panel's aggregated responses. Each slider question was followed by an optional comment box.

[60] We considered using an alternative formula for calculating the score relative to the most popular category (so the top category always received an importance score of 10), but preferred the method above because it communicates the relative degree of consolidation around top categories and gives some sense of the diversity of answers received: when most sliders are clustered to the right of the scale, it signifies more consolidation around the top categories; when they are clustered to the left, it signifies a greater diversity or heterogeneity of responses that could not be grouped together, producing more, smaller categories.

[61] It was explicitly noted in the survey that "less important" did not mean "unimportant" since all categories had been suggested as being potentially important in the previous round.

As in the previous round, R2S1 concluded with a closed-ended question featuring a comment box.[62] Based on the coding and frequency analysis, a loose conceptual framework was proposed, listing four primary clusters of factors determining the minimum number of bidders needed to mitigate the risk of collusion undermining outcome efficiency, as well as several additional miscellaneous considerations. Panelists were asked to endorse the statement, or disagree and leave a comment. Comments were aggregated and subjected to a brief qualitative analysis following the protocol described above.

Figure 3: Example of a slider question (R2S1)



[62] The comment box was tagged "optional" as a reminder, but again, all items were optional and skip-able.

Round 2, Section 2 (R2S2)

R2S2 simplified the four-point Likert scale from the previous round to produce dichotomous Agree – Disagree questions, with a "no answer" option and a comment box. The majority position was indicated and panelists were asked to leave a comment explaining their reasoning if they chose to endorse the minority position. In the instructions at the beginning of the section, panelists were informed that most minority positions were supported by roughly 1 in 3 respondents.[63] The question wording was generally identical to the previous round, although the order of questions was modified slightly in order to avoid biasing results: for instance, an item asking about the link between theory and practice was moved to the beginning of section, since later items appeared to suggest that the panel felt this link with sub-par with respect to some topics (see results below). Of the items with emerging consensus, all but one were included in Round 2.[64]

The variability of responses to seven R1 questions was determined to be too high to be effectively treated through the Delphi methodology. Out of respect for the respondents' time, and in the interest of producing a more focused R2 questionnaire limited to closed-ended and quick response questions, six of these items were excluded from R2, and participants were asked if they would be willing to participate in a focus group in the future to address topics where consensus was not reached. However, one high-variability item was included as an experiment. Of the seven no-consensus questions, only two were candidates.[65] They asked about the adequacy of the knowledge base for designing auctions in a way that can (1) account for seasonal risk, or (2) improve equity (respectively). The former appeared to hinge more on technical considerations and appeared to receive more attention in the systematic review presented in Study 1; the latter was the topic of a number of comments from Round 1 and appeared to be a more contentious point in the scholarly literature. The seasonal risk question may have provided another datapoint on the theory-practice link, but the equity question seemed to involve potentially more substantive issues about how auctions should be deployed, what objectives are legitimate, and thus had the potential to clarify the auction niche to some degree. Based on this somewhat subjective assessment, the equity question was included as the experimental no-consensus item, with a hint requesting that all panelists leave a comment as there was no clear majority.

3.3.6 Round 2 analysis

The slider questions were analyzed using descriptive statistics. The importance score itself is largely arbitrary; the focus was on roughly establishing the relative rank between the categories, the variability decrease with respect to R1, the degree of consensus around a range on the scale, and identifying the sliders most likely to be adjusted. The dichotomous choice questions were analyzed to see whether consensus grew, remained static, or reversed. Comments were analyzed qualitatively as described above to clarify the nature and number of arguments used to support minority positions.

3.3.7 Stop decision

The most desirable stop criterion for a Delphi study like the one described here is to achieve perfect consensus for all items; or, if this is not feasible, to characterize points of disagreement in-depth and clearly identify the questions that would have to be addressed to resolve them. However, it is typical for studies using the Delphi method to modify (or avoid establishing) a quantitative threshold for consensus. Scolozzi et al. (2012) tolerate high heterogeneity in experts' estimations, choosing to provide descriptive statistics to characterize the distribution; Uthes and Matzdorf (2016) and Rodríguez-Ortega et al. (2018) follow a similar approach. Ribeiro et al. (2014), in turn, set the threshold for consensus at 66%, while Bond et al. (2015) considered statements "endorsed" at agreement levels above 80%, asked panelists to re-rate statements with 75-80% agreement, and rejected statements with lower levels of agreement.

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[63] In reality, this figure ranged from 10-39%.

[64] An analysis of the results from the previous round rendered the excluded questions redundant.

[65] The forward auction items were rejected because panelists' comments made clear that there were differing interpretations of the format and the question itself. A question on adverse selection was excluded, because it seemed likely that the division here represented experts' individual experience.

Our study followed the response-distribution approach for the quantitative rating items (R2S1), although the previous step of quantifying qualitative response categories and suggesting an importance score should not be overlooked (i.e. we inferred an implicit average panel score prior to the numerical rating task). For the dichotomous-choice items, Bond et al.'s (2015) endorsement threshold of 80% was achieved for 7 in 10 R2 statements. At this point, we considered conducting a third round in hopes of constraining the response distributions for the numerical rating items and improving consensus around the dichotomous-choice items. However, a third round would have meant simply presenting the three controversial rating items to the panel again in an identical format as the previous round and hoping for a different result (the degree of consensus did not change between R1 and R2 for these items). Additionally, communications with the panel suggested that the non-response rate was likely to increase in the third round; since most minority positions were endorsed by a very small proportion of panelists, even a minor increase in the non-response rate would make it difficult to differentiate between improved consensus and non-response bias. Since satisfactory consensus was achieved for most items, an additional round seemed unlikely to bring additional clarity, we determined that a third round was not justified and terminated the process after two rounds. A focus group will be considered to clarify in-depth the specific points of disagreement.

3.4 Results

3.4.1 Advantages, disadvantages, risks, development drivers

Generally speaking, the degree of consensus (SD, IQR) was stronger around sub-questions with higher importance scores, with more variation around low-ranked items. The panel's mean rating diverged from the suggested value by more than 1 point in just five (21%) of the 24 slider-based sub-questions, and this divergence never exceeded 1.5 points.[66] There was only one question in which participants' ratings altered the relative importance rank between sub-questions ("experimental results" moved up to displace "cross-functional synergies" as the third-most-important driver of expected developments in ES auctions) (see Appendix 2).

Table 1: Ranked responses, mean importance score, SD, and percentage of respondents who accepted the proposed score

Darker shading emphasizes higher mean scores, larger SD, and higher percentage.

Topic	Mean score	SD	% Accept	Examples & Notes
1. In the coming years, the **most significant developments** in ES auctions are likely to come from:				
1.1 Policy developments	7.5	0.96	59.4	Changes allowing more instrument formats, improved targeting, or reduced transaction costs; market creation; policymaker receptiveness
1.2 Technology	7.2	0.89	62.5	Tools that reduce monitoring costs, improve measurement, or enable more functional ES markets; IT or data science innovations

[66] The five sub-questions where the mean diverged from the starting value by at least 1 point were related to (1) transparency and perceived fairness as an advantage of ES auctions; (2) transaction costs as an advantage of ES auctions; (3) complexity and skill requirements as a disadvantage of ES auctions; (4) transaction and learning costs as a disadvantage of ES auctions; and (5) adverse selection and moral hazard as disadvantages of ES auctions. In all cases, the mean rating represented an increase over the suggested value (i.e. the panel rated these items as being *more important* than initial value suggested).

	1.3 Experimental results	6	1.39	34.4	Large-scale field, web, and administrative experiments; other efforts to test theory, clarify the auction niche, or identify success factors. Case study results may improve policymaker receptiveness, linking to policy (above)
	1.4 Cross-functional synergies	5.4	1.29	62.5	ES certification, DSS integration, internet solutions, blockchain, merging administrative data and field experiments, technology-law interactions, insights from behavioral economics
	1.5 New applications in new contexts	4.3	1.15	62.5	Engagement with new environmental issues; tailoring tools to developing country contexts with variable property rights regimes
	1.6 Something else	3.6	1.28	78.1	Theoretical work and **auction design** (spatial coordination, benefit scoring, better metrics, joint bidding, facilitating participation), **markets and funding streams** (energy, natural capital, private sector innovation), responses to **exogenous pressures** (ecosystem, social), and **equity** aspects
2. The primary **advantages** of using auctions in the ES context are related to:					
	2.1 Economic efficiency and/or cost effectiveness	9.7	0.8	84.4	Assuming auction is well-designed
	2.2 Price discovery	8	0.6	68.8	Overcoming information asymmetries to reveal preferences, opportunity costs, and WTA/WTP; linking economic and environmental information
	2.3 Stakeholder engagement	6	1.19	50.0	Voluntarily involving owners and the general public, matching buyers with sellers, knowledge sharing, and education about ES and trade-offs
	2.4 Transparency and perceived fairness	4.4	2.04	56.3	In process, targeting, price-setting, allocation, and making trade-offs
	2.5 Transaction costs	3.1	1.8	53.1	Relative to other instruments, linking to efficiency (above)
	2.6 Something else	2.6	1.23	68.8	**Political feasibility** and ideological appeal of market-based mechanisms, **equity** considerations, and the **familiarity and flexibility** of the mechanism
3. The primary **disadvantages** of using auctions in the ES context are related to:					
	3.1 Low participation	6.6	0.9	46.9	Contributors include cost barriers, political economy issues, cognitive burden, education, lack of understanding of mechanism and bid formulation, and incomplete stakeholder engagement
	3.2 Complexity and skill requirements	5	1.3	46.9	Administrative hurdles (especially implementation), design complexity, and technical expertise needs. Possible tension between instrument complexity and boundedly rational participants
	3.3 Transaction and learning costs	5	1.34	53.1	Can be high both for bidders and administrators; significant preparation and information requirements; contribute to low participation

	3.4 Equity and perceived fairness	3.8	1.51	59.4	These considerations might be excluded depending on objectives. Better-resourced participants may have more influence over auction outcomes and appear to benefit disproportionately
	3.5 Adverse selection and moral hazard	3.2	2.13	68.8	Potentially producing economic inefficiencies or lack of additionality. Related: lack of adequate, accessible metrics for evaluating impact and measuring compliance
	3.6 Something else	2.7	1.55	78.1	**Political feasibility**/ideological objections; **compliance monitoring**; issues of **coordination** between multiple objectives/programs (accounting for interdependencies or conflicts); **uncertainty** of outcomes and risks for landowners and authorities; **lack of familiarity** with the mechanism by key actors; **funding and cost** issues; and **crowding out** stewardship motivations.
4. The most common **risk factors** contributing to auctions failing to efficiently achieve their objectives include:					
	4.1 Low participation	7.3	1.26	65.6	Insufficient enrollments/bids, non-broad participation by eligible parties, possibly due to transaction costs or low trust
	4.2 Lack of understanding	5.8	0.99	56.2	Participants do not understand the mechanism or the rules well enough
	4.3 Risk, uncertainty, and time horizon	5.3	1.15	53.1	Risk of adverse outcomes and opportunity cost risk (winner's curse), lack of long-term commitment or capacity to provide ongoing support; alternatively, excessively long contract duration
	4.4 Compliance concerns or poor contract design	4.8	1.29	46.9	Low compliance, inadequate planning and monitoring for post-auction phase, technological limits on measurement accuracy, excessively restrictive contracts
	4.5 Auction design issues	4.8	1.47	46.9	Design may be poorly suited to objectives, too complex, hampered by restrictions like scale issues (or failure to pilot-test before implementation), or may over-emphasize secondary goals like avoiding large payouts
	4.6 Something else	3.4	0.91	78.1	**Capability issues** (inadequate execution planning, lack of expertise, insufficient training for on-the-ground implementers), **lack of coordination** with other instruments, **difficulty linking auction outcomes to ES provision** (e.g. due to lack of site assessment/indicators), **lack of proper advertising** or low awareness, failure to overcome **information asymmetries, rent seeking, collusion.**

The largest SD (2.13) was observed for item #3.5: adverse selection and moral hazard received a low mean importance score as a disadvantage, but one panelist strongly disagreed, assigning this sub-question the maximum possible importance score (10). The largest IQR (2.38) was observed for item #2.5: transaction costs received a low mean importance score as an advantage, but one panelist assigned transaction costs a score of 9.5. Both were the lowest-rated categories for their questions, excepting the miscellaneous "Something else." Individual dissenters aside, the consensus was relatively strong around median scores. One in three sub-questions had an IQR smaller than half a point, roughly 60% smaller than 1.5 points, and none larger than 2.5 points.

The remainder of this subsection summarizes responses to the ranking items listed in Table 1. For written comments, note that statements reflect the opinions of individual panelists.

1. Promising areas for development

Respondents rated the following areas as the most likely to produce significant developments in ES auctions moving forward (in descending order): policy developments, technology, experimental results, cross-functional synergies, and new applications in new contexts. As indicated above, this was the only group of items in which the relative ordering of topics changed between R1 and R2. The largest SD and lowest percentage of respondents accepting the suggested importance score (1.39 and 34.4%, respectively) for any item in the three top-ranked themes for each question were for *#1.3 Experimental results*. Respondents increased the score for this topic enough to move it up once place in the relative rankings. The suggested score for the miscellaneous response category "something else" was accepted without modification by 78.1% of the panel for every item group.

Written comments for this question either emphasized a suggested example, a relationship between suggested examples, or indicated additional promising areas omitted from sub-questions. The following promising areas and drivers for the future development of ES auctions were suggested: (1) interactions between administrative data, field experiments, and lab experiments; (2) behavioral insights; (3) funding as a critical limitation[67]; (4) the need for more pilots, particularly in developed nations; (5) private sector demand for auction methods driven by growing CSR focus; (6) better integration of non-economic success factors related to social norms and institutional background[68]; (7) automating monitoring and feedback through improved integration with GIS tools and remote sensing; (8) new visions for ES and the co-creation of partnerships between actors; (9) improved receptiveness to a high proportion of unsuccessful bidders to gain policymaker buy-in; (10) improvements in stakeholder communication to increase familiarity and comfort with auction tools; and (11) growing recognition by policymakers and political interests of the need for a development models that are cognizant of ES needs for resilient societies.[69]

2. Advantages

Respondents rated the following areas as the most significant advantages associated with the use of ES auctions (in descending order): economic efficiency and/or cost-effectiveness; price discovery; stakeholder engagement; transparency and perceived fairness; and transaction costs. With the exception of *#2.4 Transparency and perceived fairness* (SD 2.04), variability was relatively low (SD 0.6-1.8). A greater proportion of respondents (84.4%) accepted the proposed score of 10 for *#2.1 Economic efficiency and/or cost-effectiveness* than for any other item. Comments stressed the importance of political feasibility and transparency. The necessity of assessing and quantifying benefits and costs was highlighted as an advantage over other mechanisms, which may be less systematic or transparent in this regard. One comment offered a word of caution about MBIs, which may conflict with values surrounding conservation. At minimum, this necessitates a careful and diplomatic communication strategy when introducing the concept of auctioning ES.

3. Disadvantages

Respondents rated the following areas as the most significant disadvantages associated with the use of ES auctions (in descending order): low participation, complexity and skill requirements, transaction and learning costs, equity and perceived fairness, and adverse selection and moral hazard. Standard deviations ranged from 0.9-2.13. Excluding the miscellaneous category, 46-69% of the panel that accepted the suggested importance score without modification.

Low participation was repeatedly stressed as a fundamental disadvantage associated with past ES auction experiences with complex connections with other suggested disadvantages for this rating question: bidder participation can be impacted by uncertainties related to targeted environmental outcomes, the regulator's capacity to incentivize conservation contracts, and degree of political

[67] With respect to funding, it was suggested the auction niche is characterized by adequate but not unlimited funding in conjunction with low transaction costs.

[68] "This means a closer collaboration between economists, psychologists, and social/political scientists, so that the interactions between incentives, institutions, and behaviors are better captured."

[69] Illustrated by the development of the European Green Deal, the European Bioeconomy Strategy, ongoing EU policy developments seeking to accelerate climate preparedness and resilience, and the environmental components of the COVID-19 pandemic.

support (which can lead to funding competition between programs or mechanisms). One panelist observed that the disadvantages enumerated in the remaining sub-questions—complexity and skill requirements, transaction and learning costs, equity and perceived fairness, and adverse selection and moral hazard—are all so "intimately linked" to performance issues that it is difficult to assign them individual importance scores. Apart from participation, contract issues were suggested as a pervasive implementation-related disadvantage due to lack of enforceability and conditionality. A lack of familiarity with ES auctions was identified as a disadvantage specific to the EU context. One panelist suggested that the disadvantages enumerated in the sub-questions would be better characterized as potential risks that should be addressed through auction design or implementation; if they are not, then the presence of any of these "disadvantages" may serve as an indication that the auction failed.[70]

4. Risk factors

The most common risk factors contributing to auctions failing to efficiently achieve their objectives were (in descending order): low participation; lack of understanding; risk, uncertainty, and time horizon; compliance concerns or poor contract design; and auction design issues. Standard deviations ranged from 0.91-1.47. Excluding the miscellaneous category, 46-66% of the panel accepted the suggested score without modification.

Several comments stressed the importance of risk and uncertainty, compliance, contract design issues (leading to low participation), and transaction costs as risk factors for auction failure. One panelist again reported difficulty in separating the risk categories for each sub-question from the fundamental issue of participation. However, another panelist disputed the notion that low participation should be viewed as a risk factor for failure, although in the context of an argument that strongly emphasized how failure should be defined.[71] Briefly, this panelist suggested that barring a scenario with an inappropriate contract design, auctions threatened by low participation (e.g. due to low participation) could be salvaged by making small process modifications, such as extending bid submission deadlines. A success-failure spectrum was suggested in which *failure* signified a scenario in which either (a) available funds went unspent, or (b) the mechanism was demonstrated to be egregiously inefficient. An auction might be deemed highly successful, by contrast, if (a) it was demonstrably more efficient than the available alternative approaches, and (b) no efficiency losses are identified that could have been avoided in a cost-effective manner. Most auctions would fall somewhere between these extremes in practice.

3.4.2 Conceptual framework: minimum participation

Based on a qualitative analysis of Round 1 responses, Round 2 proposed the loose conceptual framework in Box 1; panelists were asked to either agree, disagree, or leave a comment. The survey noted that unlike the preceding slider questions, the numbered elements of the framework were not ranked by order of importance.

This framework was endorsed by all responders.[72] Despite only being specifically prompted to leave a comment if they rejected the framework, approximately one-third of the panel chose to provide written suggestions to improve it. The substance of these comments was classified into four categories. The most prominent stressed the importance of some element of the framework in Box 1: notably, the number of times the auction is repeated, the use of consultants, the availability of a realistic policy alternative (enabling the principal to "walk away" and reject all bids), and highlighting that the framework as a whole illustrates the importance of practical context in a field that is often dominated by theoretical work.[73] One comment noted that the market power of potential colluders, an element identified in Box 1, could vary by location in the case of spatially explicit auctions.

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[70] Sub-questions were based on an R1 question asking panelists to list three disadvantages associated with using auctions in the ES context.

[71] For reference, the text of the prompt framing the sub-questions read: "The most common risk factors contributing to auctions failing to efficiently achieve their objectives include..."

[72] The *endorse* response category read "Seems reasonable to me" while the *reject* response read "This summary is misleading or inaccurate (comment below)". The option to reject the framework was not selected by any of the panelists. Ten percent declined to respond. The survey's introductory text instructed panels to skip any questions they did not feel qualified to answer.

[73] This latter observation was followed by a call for more thorough and systematic research into the contextual factors impacting on auction performance.

Box 1: Proposed conceptual framework for evaluating minimum participant needs

For field auctions, the minimum number of participants needed to mitigate the risk of bidders successfully colluding and undermining efficiency is a function of four main clusters of factors.

(1) **The social and geographic distance between actors**, including social capital, communication networks, and shared sociocultural norms;
(2) **The odds of winning,** a function of the ratio between the available budget and the expected payment, between the number of potential and actual bidders, and/or between the number of units available and the number of units to be procured (reserving the option to reject all bids can also amplify bidders' strategic dilemma);
(3) **The design and management of the auction**, including the use of uniform or discriminatory pricing, multiple rounds or repeated auctions, and the confidentiality of reserve prices, bids, and outcomes; and
(4) **The participation of consultants** shared by multiple bidders.
Other relevant factors include the **heterogeneity** of bids and actions; the **market power of colluding subgroups**; program **goals**, including the specific ES at stake; and **national context**, with likely differences between developed and developing countries.

Anecdotally, this number often ranges between 2 and 100 in panelists' individual experience.

The next category suggested additional considerations to include in the framework: for instance, the relationship between design complexity and the need for participants to understand the program, which may increase the signal-to-noise ratio and thus require a larger pool of bidders. Another panelist argued for the expansion of the heterogeneity consideration to include *bids, actions, and opportunity costs* and speculated (based on observed discussions about payment differentials in workshops) that a sort of honor-between-thieves logic may be at work in collusion attempts:

> Heterogeneity of costs is quite important because the initial rule for collusion is some form of equal payment, but this breaks down if my costs (opportunity and actions) are [an order of magnitude greater than yours] [...] it becomes harder for the low cost to collude with the high cost [...] My feeling is that a fairness-type condition applies—there is a feeling that all should benefit (i.e. profit), but at some level benefits should not be too different.

A third category took issue with the assumptions underpinning the framework. One comment, for instance, indicated it might be more helpful to think in terms of a continuous scale than a clear threshold for the minimum number of bidders: increasing the size of the bidder pool might reduce the signal-to-noise ratio in bids, implying that one should generally seek to increase the size of the pool rather than focusing on some minimum acceptable number. Another took this logic farther, effectively arguing that collusion is a red herring: when there are too few bidders, the collusion concern is eclipsed by the risk of the auction being perceived as a failure due to a lack of participation and interest or the limited value of the options under consideration in the first place. Thus, in practice, collusion is incidental to the core problem of under-participation.

A fourth category took issue with the notion with the anecdotal addendum in Box 1 placing the lower bound at two bidders. One panelist rejected this as a reasonable threshold, while another was skeptical but left the possibility open, provided that both bidders could not win. This is in more or less accordance with the responses from the previous round that identified two as a lower bound for preventing collusion.[74] Nonetheless, it is safe to say that even if it is theoretically possible to avoid

[74] The R1 comments suggesting this threshold were: "It really depends on the degree to which the bidders know one another. If this is a one-time interaction between anonymous strangers, you may only need two or three bidders to avoid collusion" and "If there are many possible bidders and no clear reasons people are not participating, a minimum of two bidders creates a strategic behavioral dilemma. You also have to include the provision that you will not necessarily fund any bids."

collusion under such circumstances, two bidders is hardly ideal: it may represent a technical lower bound, but not one that is likely to be satisfactory in practice.

In sum, the framework proposed in Box 1 was generally regarded by the panel as a reasonable summary of the issue at stake, with about 30% of respondents (including many who endorsed it) offering suggestions to further qualify or refine it. None indicated that the summary itself was misleading or fundamentally incomplete with respect to collusion, although one panelist considered collusion itself to be less consequential than other risks associated with low participation.

3.4.3 Auction theory, practice, and dynamics

With the exception of the one non-consensus item included, emerging consensus observed in the first round was consolidated in the second, and strong majorities were achieved for most items (Table 2). Of the ten dichotomous Agree-Disagree items, at least 80% of the overall panel supported the majority opinion on seven items (1-7). The panel as a whole broadly agrees that non-bidding stakeholders typically do not exert much influence over auction outcomes (though they may inform design) (#1), that the link between research and practice is suboptimal (#2), and that biophysical modelling plays a major role in auction cost-effectiveness (#3). Among responders (i.e., ignoring those who declined to answer a given item), an additional 3 items would cross into the green zone in the table below: that is, 90% of those who answered support the majority opinion on six items. In addition to the consensus items already mentioned, responders also strongly agree that in practice, real-world auctions do not do a very good job of accounting for seasonal risk (#5), promoting distributional equity (#6), or producing spatially-coordinated outcomes (#7).

Table 2: Positions grouped by degree of support[75]

Bullets indicate support across entire panel. Asterisks (*) indicate support among responders (i.e. eliminating "no answer").

Position	>90% support	>80% support	>65% support
1. Although the preferences of non-bidding stakeholders may indirectly impact auction outcomes, they usually **do not** directly influence the auction itself.	●		
2. Innovations accepted by the scientific community are **not often adopted** in practice (the link between auction theory and practice is suboptimal).	●		
3. The cost-effectiveness of auctions **depends heavily** on the accuracy of biophysical models predicting how management alternatives affect ES provision.	●		
4. The current knowledge base is probably **not sufficient** to reliably design auctions that can account for longer-term sources of uncertainty and risk, such as climate.		●	
In practice, real-world auctions typically **do not** successfully…			
5. … account for uncertainty and risk on seasonal or shorter timescales.	*	●	
6. …promote greater equity in the distribution of environmental/economic benefits.	*	●	
7. … produce spatially coordinated outcomes.	*	●	
The current knowledge base **is sufficient** to reliably design auctions that can...			
8. ... produce spatially coordinated outcomes.			●
9. ... optimize across multiple objectives.			●
10. ... promote greater equity in the distribution of environmental/economic benefits.			

[75] Statement wording adjusted from the questionnaire for brevity, and to reflect consensus-disagree positions.

Despite its dim view of spatially-coordinated auctions in the real world, a moderate majority (75%) concur that the knowledge base is adequate to design auctions that can reliably achieve this (#8). Similarly, a somewhat weaker majority (69%) of the panel consider the current knowledge base to be sufficient to design auctions that can optimize across multiple objectives (#9).[76] These results suggest that the link between theory and practice, with which the panel expressed some dissatisfaction (#2), may be particularly weak with respect to spatial coordination and multi-objective designs.

The no-consensus position (#10) was presented to the panel with a note indicating that there was no majority position identified in the previous round, and asking them to explain their reasoning regardless of their answer.[77] In R2, the result was even more contested than before: responders were perfectly divided (22% supported, 22% opposed). The majority declined to answer, but this question received more comments than any other (see 3.4.4).

3.4.4 Minority positions

The topics in this subsection relate abbreviated summaries of comments following the dichotomous choice items described above. Generally, these are minority opinions, since the survey prompted those who departed from the majority view to comment specifically; however, although all panelists could comment if they wished. These topics do not contain citations because they reflect the judgments of individual panelists; that is, these are relatively raw results that have been subjected to only a preliminary descriptive analysis to facilitate summarization.

1. Do non-bidding stakeholders typically influence auctions?

A large majority of the panel agrees that the answer is no, but the minority offered some qualifications. Non-bidding stakeholders with material relationships to bidders may influence bidding behavior by offering outside options, and eligible bidders who decline to participate directly affect outcomes, since low participation is a major vulnerability for auctions. Non-bidding stakeholders can also attempt to exert influence over auction design and administration—sometimes in unexpected ways, as one panelist illustrates with an anecdote:

> We have modified auctions based on feedback from stakeholders who were not eligible to bid (e.g. statutory authorities and NGOs working in the area), only to discover that they don't know what they were talking about and are protecting their patch.

Another panelist suggested that in the most common scenario, non-bidding stakeholders do not exert an influence simply because they are unlikely to hear about the auction in the first place.

2. Is the link between theory and practice satisfactory?

A large majority of the panel disagreed with the notion that innovations accepted by the scientific community are often adopted in practice. Unusually, most of the comments for this question did not defend the minority position, but instead elaborated on the problem. Auctions represent an active research field but are not much used in the real world; part of the issue may involve persistent disagreements between economists on the one hand and natural scientists on the other, and sub-optimal discourse between these fields. The translation between theory and practice may feel slow to auction researchers, but it may not be slower than in other areas; academic researchers are incentivized to over-innovate, which may conflict with policy needs for simplicity and ease of communication.[78] One defense of the minority position noted that innovations have to be tested, while

[76] In R1, we observed disagreement about the adequacy of the current knowledge base for multi-objective designs, and agreement that most auctions deal with one or two objectives, so real-world multi-objective field auctions were trimmed from the Round 2 survey.

[77] There was an emerging consensus after R1 that *in practice* auctions did a bad job accounting for seasonal risk or improving equity, but apparently strong disagreement about whether or not existing auction knowledge was advanced enough to achieve them in theory.

[78] One panelist took issue with the question wording, noting that the core statement ("Innovations accepted by the scientific community are often adopted in practice") was incongruent with the explanatory rephrasing ("i.e., there is a good link between auction theory and practice.")

another cited collaborations between academic economists and large technology firms in designing auctions and determining optimal strategies.

3. Is ES auction cost-effectiveness dependent on the accuracy of biophysical models?

Yes, according to the majority: an auction is only as good as its metric, although this may depend on the nature of the problem and its policy goal. Evaluating cost-effectiveness requires a means of evaluating how actions convert to outcomes.

Only two panelists dissented from the majority opinion. One noted that auction performance hinges more on social aspects than ES models and is more about behavior than natural science. The other (who stressed that their answer was based on dated literature) argued that when costs and benefits are heterogeneous, cost-effectiveness is driven by which factor is *more* heterogeneous. Since model outputs are typically less heterogeneous than bids, cost-effectiveness should be driven more by cost data (bids) than benefit data (models).

4. Is the current knowledge base sufficient to account for long-term risk?

Most panelists who left comments for the minority position (that the knowledge base is sufficient to account for long-term risks) did so by qualifications. Mechanisms cannot account for cognitive quirks in how humans make long-term decisions, for instance. Similarly, the knowledge base regarding auction mechanisms may be sufficient, but its application is constrained for practical purposes due to limitations associated with modelling, computational challenges, contractual considerations, and outcome uncertainty—with some feedbacks likely to exist between these latter considerations and the mechanism design itself. With respect to mechanism design, the theoretical literature features discussion of option values and other tools and heuristics that has largely been overlooked by practitioners, and that are particularly useful when there is adequate cost heterogeneity; thus, the limitation lies not with auction participants, but with risk-averse designers reluctant to try new methods. Finally, one panelist noted that the issue may be a matter of degree and risk source: "While we can't perfectly account for all risks [...] for many major risks, including climate, we could get pretty close."

5. Do real-world auctions account for short-term risk?

Comments supporting the minority view (that real-world auctions typically do a good job of accounting for risk on seasonal or shorter timescales) broke down along lines similar to those identified in the previous question. If auctions do not do a good job of accounting for risk, the mechanism is not to blame—its purpose is not to "teach people how to appropriately balance time and risk!" Auctions, then, may fare no worse than other existing schemes in this regards. There is also a market efficiency argument that can be made: auctions can be thought of as a method for "aggregating peoples' beliefs about the likelihood of near-term scenarios." The element of risk traditionally enters the process at the level of participant decision-making, not mechanism design:

> The question is whether the information that is provided to bidders [...] accounts for uncertainty and risk appropriately. Auctions are not models that are supposed to account for this or that. They are policy/market mechanisms.

Finally, one panelist noted that designers may make trade-offs between accounting for short- and long-term risks in the design and contracting phases—for example, tolerating short-term "failures to improve" short-term metrics in order to prioritize ecological outcomes that can only be evaluated on longer timescales.

6. Do real-world auctions promote distributional equity?

In this case, about twice as many panelists chose to comment as endorsed the minority position (that auctions typically do a good job of promoting distributional equity). Some centered on the definition of equity, the design of the auction, and secondary effects: auctions can increase net benefits while incorporating threshold rules to increase participation, or they could potentially generate information that can be used to promote equity through policy if the theory-practice connection is improved. Auctions may also improve perceptions of process equity by offering a transparent allocation mechanisms, if the implementation is sufficiently straightforward and barriers to participation are not too high. Several panelists argued that considerations related to distributional

equity are either outside the scope of, or even antithetical to, auctions as a tool—although it is still possible to claim process equity. Everyone has a chance to bid, but outcomes are not "fair":

> [The statement that auctions do a good job of promoting greater equity in the distribution of benefits is nonsensical.] Auctions, by their very nature, reward those who can do a better job of delivering environmental benefits. That's what markets are all about!

Thus, trade-offs may exist between different objectives for applying auctions: "Is the goal [...] to maximize social surplus, auctioneer revenues, or to measure how people value [ES] in terms of monetary commitments?"

7. Do real-world auctions produce spatially coordinated outcomes?

Only a single panelist answered in the affirmative, but nine elected to provide comments. The bulk of these comments centered around the notion that real-world examples of spatial coordination in auction ES auctions are either nonexistent or extremely rare; thus, there is no basis for evaluating the question. One panelist suggested that this may change within the next 5-10 years.

8. Is the knowledge base sufficient to design spatially coordinated auctions?

Although 75% answered yes, this question produced the third-weakest majority and third-largest number of comments. The majority of dissenters—and several panelists who left a comment to qualify their support for the majority opinion—offered specific critiques of the current knowledge base, coupled with varied expressions of certainty. At one end of the spectrum was a panelist who was the most-frequently-recommended during the snowball sampling phase:

> No, the majority is clearly wrong, given the existing literature and evidence. However, it is a very active area of research, so I would say that [we] will soon be able to agree with this statement. For the time being, however, I think it is still premature to agree.

The sentiment that the basics of spatial coordination problem have been explored but are not yet sufficiently developed to be considered adequate was a fairly common one. The most widely-cited limitation is the theoretical nature of the current knowledge base, which is premised primarily on laboratory experiments "using stylized set-ups" and researcher-led pilot trials in the field with conflicting results. One possible reason is that current methods for spatial coordination may be prohibitively costly or have excessively high case-specific information requirements to work well in practice. Even on a theoretical level, some panelists suggested that trade-offs in spatial coordination methods and interactions between planning units have not been satisfactorily explored. Dissemination and accessibility also might help explain why spatially coordinated auctions are so rare in practice.

9. Is the knowledge base sufficient to reliably design optimal multi-objective auctions?

A small majority of respondents agreed that the knowledge base is sufficient to reliably design auctions that can optimize across multiple objectives. This was the weakest majority observed for any question where the R1 emerging consensus was indicated, and received the second-largest number of comments of any question in the R2 survey (following #10 below, where all respondents were asked to comment regardless of their dichotomous choice selection).[79]

The first category of concern centered in information accessibility and quality: multi-objective optimization may be possible in principle, but "you need good information on the relative values of the various objectives, which is not something that an auction can help you discover." As projections, these values are subject to uncertainty and risk, which auctions may be poorly equipped to handle; additionally, models require inputs in the form of empirical data.

Context dependence was another major concern among dissenters. On paper or in a laboratory, it may be possible to design auctions that optimize across multiple objectives, but remove common simplifying assumptions that cannot be taken for granted in field contexts (e.g. that participants are profit-maximizers) and optimality may become much more difficult to demonstrate. In practice, metrics can vary widely from auction to auction, and metrical differences often entail differences in auction design, so standardized methods for multi-objective auctions—a potential prerequisite for reliability—is likely to prove elusive:

[79] Roughly 10% more panelists declined to answer than answered in the negative.

> Experimental results still seem somewhat context-specific, suggesting that the deviation from assumed conditions in which auctions can overcome information asymmetries and collusion in the conservation context means that more applied work (as opposed to theoretical predictions) is needed to achieve reliability across multiple contexts.

Other panelists cited complexity and theorization as key limiting factors alongside empirical gaps: "Designing multiple good auctions which work well (what does that mean, actually?) is really complex", necessitating an extremely robust knowledge base.

> Theoretical work is sparse and it is difficult to evaluate whether the algorithms and heuristics [...] especially in experimental auction research give the best possible solutions [...] I believe that more theoretical work is needed.

One panelist suggested that the knowledge base may exist, but not be sufficiently "accessible or traceable," noting that their experience designing multi-objective auctions required significant improvisation, drawing on academic research and other subsidy models to inform decision decisions.

Finally, actually running multi-good auctions also requires competencies beyond the game theory of auction design, such as "methodical and social skills" to "appropriate[ly]" handle auction processes. One panelist was more optimistic. Although they felt the knowledge base remains inadequate to reliably design auctions capable of optimizing across multiple objectives, they noted: "We're not far off though, and should be wary of over-complicating such issues."

10. Is the current knowledge base sufficient to design equity-promoting auctions?

This question was the topic of the only no-consensus item included in Round 2, and the most-commented-upon item in the survey. The largest comment themes involved (1) defining equity, and (2) suggesting that equity considerations are beyond the scope of auctions.

With respect to definitions, panelists noted that *equity* signifies different things to different people in different contexts. From this starting point, comments fell into two subcategories. The first noted that the question could not be meaningfully interpreted without an operational definition: equity within the group of suppliers might be constructed very differently than equity within the group of beneficiaries. The second suggested that equity could be operationalized in different ways if equity were to be included as an objective in the auction design phase, for instance:

> I think the current knowledge base is sufficient to reliably design auctions that can promote a specified target in this area, but it is difficult to target a single measure and truly promote equity in distribution.

With respect to scoping issues, a number of panelists acknowledged that it might be theoretically possible to design an auction aimed at promoting some measure of equity, but argued that other tools would likely be better suited the job. Auctions are competitive process, so depending on how and with reference to whom equity is defined, auctions may not be an appropriate mechanism. A related category of comment pointed out that equity has not been treated as a priority in auction research, leading to a gap in current knowledge. In principle, equity-promoting mechanisms might be conceivable, but further work would be required to develop and test those mechanisms.

Some panelists suggested that equity should be constructed as a secondary effect, external to the mechanism itself. Reverse auctions might generate information that policymakers could use to promote equity through other, more targeted policies. Depending on the design, forward auctions might offer an opportunity for stakeholders lacking capital to engage in coalition-building to crowdsource support and generate more equitable outcomes:

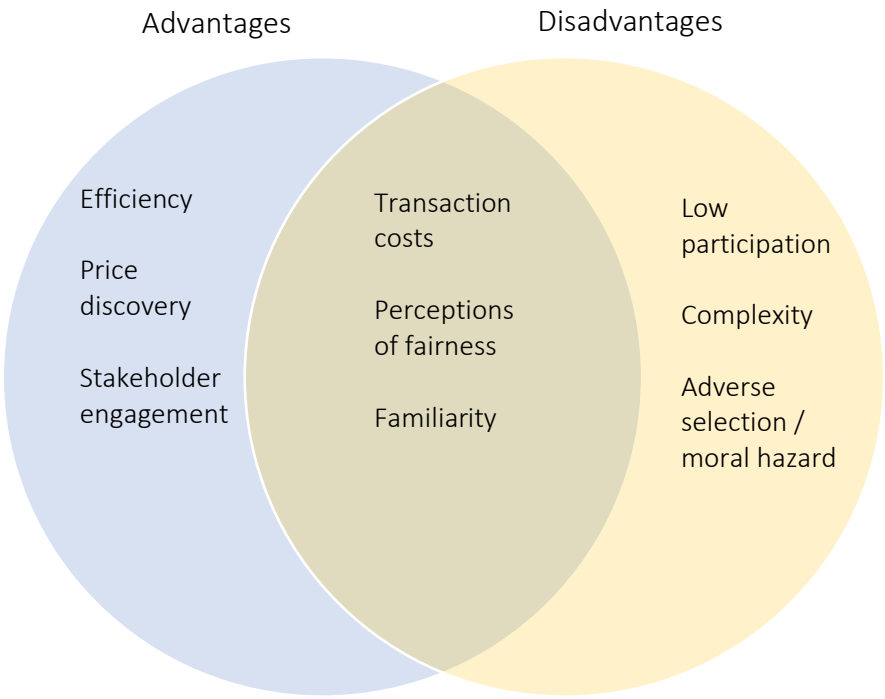
> Can the same thing be said about the mechanisms we currently use for this purpose such as legislation, environmental lawsuits [...], or environmental activism and protests? I would think that the transaction with auctions is much lower.

Finally, some suggested that secondary knowledge gaps were the main obstacle. Targeting one equity metric might be possible, but there are too many gaps to adopt a comprehensive approach that connects and coordinates different services.

3.5 Discussion

These results can contribute to the identification of ES auction research priorities, and perhaps facilitate the development of a more coordinated research agenda for the field. In Table 2, Topic 1 offers a list of general subject areas that panelists considered likely to have significant impacts on the field in the coming years (policy, technology, experiments, synergies between different disciplines or functional areas), paired with illustrative suggestions for each.[80] Topics 2 and 3 clarify the auction niche in a concise way: the tool's main strengths lie with its economic cost-effectiveness, ability to induce participants to reveal private opportunity cost information, and as a framework to engage stakeholders.[81] Its weaknesses center on persistent difficulty engaging satisfactory numbers of participants, its complexity and skill demands, and transaction and learning costs associated with its use.[82] Topics 3 and 4 emphasize current weak points—participation, understanding of mechanism, and issues related to risk, uncertainty, and time horizon—most of which do not appear to be inherent in the auction mechanism itself.[83] Instead, many of these weak points might instead be addressed through further research and outreach: field trials, capacity building, and efforts to familiarize policymakers and the public with these tools.

Figure 4: Advantages, disadvantages, and overlap



[80] For further reading on policy and institutional considerations, see e.g. Holmes (2017), Messer et al. (2017), Whitten et al. (2017), and Baumber et al. (2019). For the significance of technology (with respect to measuring outcomes without introducing excessive transaction costs), see e.g. Groth (2011), Crossman et al. (2011), Hanley et al. (2012), and Ferguson et al. (2016). For examples of interdisciplinary approaches and cross-synergies, see Tóth et al. (2010), Cooke and Corbo-Perkins (2018), and Andeltová et al. (2019).

[81] For cost-effectiveness: Groth et al. (2011), Iftekhar & Latacz-Lohman (2017), Lundberg et al. (2018). For price discovery: Narloch et al. (2011), Pirard (2012), Jindal et al. (2013), and Leimona & Carrasco (2017). For stakeholder effects: Farley et al. (2015), Roesch-McNally et al. (2016), and Chan et al. (2017).

[82] For participation, see e.g. Jindal et al. (2013), Palm-Forster et al. (2017), and Rolfe et al. (2018). For complexity (including the significance from a participant understanding perspective and in terms of institutional capacity), see e.g. Whitten et al. (2013), Baird et al. (2014), McGrath et al. (2017).

[83] For risk and uncertainty, see Ferguson et al. (2016), Wünscher and Wunder (2017), Lewis and Polasky (2018), and Andeltová et al. (2019). For considerations relating to time horizon, see Jindal et al. (2013) and Leimona and Carrasco (2017).

Some of these results are suggestive of partial conflicts or paradoxical effects. Transaction costs, for instance, appeared as both an advantage (2.5) and disadvantage (3.3) associated with the use of auctions.[84] This is likely because auctions seem to reduce some transaction costs (e.g. those associated with information asymmetries) while introducing new ones (e.g. learning how to navigate the mechanism, landowners accurately estimating opportunity costs with an uncertain payoff) relative to other tools. Similarly, perceived fairness was featured as an advantage (2.4) and as a disadvantage (3.4).[85] As an advantage, it was often associated with transparency and process equity: given a well-defined, understandable mechanism, participants can identify clear *a priori* rules determining the selection or rejection of a bid or the price awarded.[86] As a disadvantage, this concern was more associated with distributional considerations: auctions may enrich the already wealthy, who can leverage economies of scale to out-compete smaller landholders. Finally, *familiarity* was suggested by panelists in R1 as both an advantage and disadvantage, and was included under the miscellaneous category in R2 (2.6, 3.6).[87] The reasons for this are not quite clear, as written responses did not offer much elaboration. It can be speculated that this is dependent on a combination of mechanism design (*what* is familiar) and stakeholder category (*to whom* it is familiar). Future study might seek to examine the boundaries and implications of familiarity with auctions.[88] Another interesting finding is that while most of the panel either endorsed suggested importance scores in R2 or made very slight alterations of ~1 point in either direction, individual panelists occasionally strongly rejected low ranks assigned to certain items. This may offer an interesting subject for future inquiry.

The conceptual framework for evaluating the minimum number of participants needed to reduce the risk of collusion was widely endorsed by the panel (Box 1). This is not to say it is definitive: it is a simplified summary, and one that may assign an unjustified importance to potentially collusive behavior in field auctions. Nonetheless, collusion is a major point of contention in the theoretical auction literature, and quantifying the extent and effects of collusion is a salient subject of inquiry in the literature on experimental auctions in laboratory settings (Study 1). The framework in Box 1 raises questions about the extent to which findings associating a given level of observed collusion in contrived laboratory settings with certain mechanism designs or rule-sets are transferable to practical field applications, as the proposed conceptual framework highlights the importance of a number of procedural and contextual factors. Although the importance of contextual factors has received growing attention in the literature—particularly, but not exclusively, in the context of comparing auctions in developed and developing countries—as one panelists observed, the impact of these external factors has not yet been systematically explored or effectively operationalized.[89]

Focus areas for theoretical innovations in mechanism design are also suggested by the results. The panel was divided but showed signs of cautious optimism about the possibility of designing auctions capable of optimizing across multiple objectives, accounting for near- to medium-term uncertainty, or producing spatially coordinated outcomes, although it was markedly more pessimistic that any of these occurs in a satisfactory way in practice (Table 3). Even panelists who were more bearish on the theoretical literature in these areas were inclined to think that innovations would soon make such designs feasible and robust. Spatial coordination, multi-objective optimization, and integrating uncertainty and risk, therefore, appear to be promising areas for auction theoreticians.[90]

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[84] For transaction costs and learning-related issues, see e.g. Narloch et al. (2011), Reeson et al. (2011), Hanley et al. (2012), and Lundberg et al. (2018).

[85] For more on fairness and transparency, see e.g. Vogt et al. (2013), Jindal et al. (2013), Banerjee et al. (2015), and McGrath et al. (2017).

[86] For more on equity concerns, see e.g. Jindal et al. (2013), Leimona and Carrasco (2017), McGrath et al. (2017), and Andeltová et al. (2019)

[87] Familiarity is related to learning effects, see Reeson et al. (2011), Jindal et al. (2013), Banerjee et al. (2015).

[88] This study may be extended with qualitative interviews on this topic.

[89] For work engaging with contextual considerations, see e.g. Wünscher & Wunder (2017), Cooke and Corbo-Perkins (2018), Andeltová (2019), and Liu et al. (2019). Although not specific to auctions, Rodríguez-Robayo and Merino-Perez (2017) suggest using the socio-ecological systems framework to more systematically "contextualize context" in PES.

[90] For multiple objectives and spatial considerations, see e.g. Tóth et al. (2010) (forward auctions), Crossman et al. (2011) (indices and prioritization), Reeson et al. (2012) (multi-round auctions), Polasky et al. (2014) (optimization), Krawczyk et al. (2016) (communication), Fooks et al. (2016) (bid selection and network

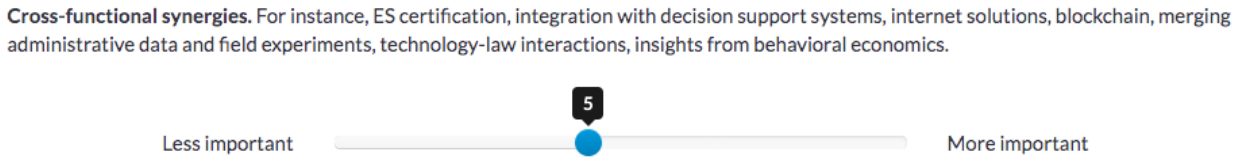
Again, however, these results also underscore the importance of strengthening connections between the natural sciences, economists working on ES auctions, and policymakers. The panel broadly agreed that the accuracy of biophysical models is a crucial factor in determining the cost-effectiveness of such auctions, and that the link between auction theory and practice leaves something to be desired.[91]

Finally, the relationship between auction tools and considerations relating to equity and environmental justice warrants further debate. Even the possibility of designing auctions capable of promoting greater equity in the distribution of environmental or economic benefits was controversial, with some panelists suggesting how auctions might be designed to amplify the voices of marginalized groups and others arguing that promoting distributional equity is fundamentally out-of-bounds for competitive, efficiency-oriented market instruments like auctions.[92] Delving into this controversy may lie outside the scope of the present study, but our results suggest that this topic would benefit from explicit engagement by auction researchers, policy experts, and ethicists, for example.

3.5.1 Limitations

This study carries two major limitations: one related to research philosophy, and one related to round limits and consensus. Unlike a typical survey (where the goal is to transfer information from participants to researchers), this study conceptualized the Delphi method as a means of facilitating structured communication between a large group of time-constrained experts. Thus, rather than randomizing rankings or taking measures to avoid acquiescence bias, bias was, to some degree, baked in as an intended effect: panelists were intended to interact and influence one another. R2 questions were designed to communicate as much information about R1 results as possible; emerging consensus positions were highlighted. In some cases, the effort to share suggestions with the rest of the panel complicated the response tasks. Consider, for example, the following R2 item.[93]

Figure 5: Example Round 2 rating subquestion: "In the coming years, the most significant developments in ES auctions are likely to come from..."



The label *Cross-functional synergies* was developed by the researcher during the thematic analysis of qualitative answers from R1. However, the rating task also includes examples of the kinds of responses from R1 that fell under this theme (the non-bolded text in the figure above). These examples were included not only to clarify the label—which on its own was open to interpretation—but also to communicate the kind and variety of responses received in the previous round, which other panelists might find or novel or thought-provoking, encouraging them to consider different dimensions of the question or the field's boundaries or possible future directions.[94] From a survey design perspective, however, the decision to include these examples likely introduced some noise into the results, as illustrated by the following two comments:

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bonuses), Iftekhar and Latacz-Lohman (2017) (pricing and bid selection), Lewis and Polasky (2018) (spatial coordination and uncertainty), Conte and Griffin (2019) (including on-site private benefits in bid scoring), and Liu et al. (2019) (aggregation bonuses).

[91] Although one panelist cautioned against glossing over divisions within academia itself: "A major issue is that in a large number of cases the scientific community (biological and natural scientists) does not list to nor agree with economists."

[92] In contrast to distributional considerations, note that elements of procedural fairness (e.g. transparency) were cited among the advantages associated with auction methods relative to other tools in the rating questions.

[93] This sub-question corresponds to entry 1.4 of Table 2 above. It is a useful example because it represented one of the broadest themes of any of the survey.

[94] This kind of sharing could potentially facilitate ES auction discourse outside the narrow objectives of the survey's data collection function, and was considered a valid secondary goal in our research philosophy.

Comment 1: I increased [the score] [...] but the category was so broad it tempered my answer. I don't see much promise for blockchain, but I see a lot of potential for administrative experiments.

Comment 2: [Changing a score] captures a lot of stuff, some of which is and some of which is NOT important. So the change is the average of several possibly not-in-the-same-direction rescores!

These comments describe one possible algorithm, but it is not the only way to evaluate the question. Others may have based their rating tasks on the labels alone and chosen to skip reading the examples, or may have had conflicting responses to different examples in a single rating task and simply decided not to touch the slider at all, leaving the default value to be recorded. The focus on communication also meant that there was no control group to test (for instance) the magnitude of the effect of the suggested score, since communicating that score to the panel was a secondary function of the survey. In short, trade-offs exist between more sharing of previous results in R2 and discrete, well-defined tasks with a demonstrably high degree of inter-rater reliability—although this is also a result the decision to initiate R1 with open-ended questions to begin with.

The other major limitation relates to the treatment of imperfect or absent consensus and the decision to terminate the Delphi process after two rounds. In an ideal world, the process might be allowed to continue with an increasing focus on a shrinking number of controversial items until full consensus is achieved, or disagreements that cannot be resolved are characterized in depth. This consultation deviated from that ideal at two stages: first, with the decision to drop the forward auction items and two no-consensus items from the R2 survey; and second, with the decision to terminate the process despite the persistence of a couple of low-consensus topics (Table 3) and several rating items with large standard deviations (Table 2).[95] The issues raised in the eliminated forward-auction items appear to require more data, and perhaps a more specialized panel, in order to address effectively; hopefully, the NOBEL pilot demonstrations will contribute to this. The low-consensus topics from R2 are also interesting and generated large comment responses and warrant further exploration, perhaps through qualitative interviews or focus groups.[96]

3.6 Conclusion

Auctions offer a potentially attractive mechanism for efficiently allocating PES contracts and inducing suppliers to reveal private opportunity cost information that can be used to evaluate efficiency or inform policy design (Study 1). The literature on ES auctions encompasses fairly active theoretical and laboratory work and a growing list of field experiments exploring auctions in context, but the incorporation of auction methods into the environmental policy and land management toolbox has been inconsistent.

This study reports the results of a two-round Delphi survey on ES auctions with a panel of 35 experts. The areas rated most likely to produce significant developments in ES auctions in the coming years were policy, technology (particularly with respect to measuring and monitoring tools), and experimental results (notably, field experiments). The primary advantages of auctions relative to other tools hinge on economic efficiency or cost-effectiveness, price discovery, and stakeholder engagement, while major disadvantages include persistent participation problems, complexities associated with mechanism design or implementation, and the unique transaction and learning costs associated with these tools. Insufficient participation was identified as a major risk factor for auction failure, alongside a lack of understanding of auction mechanisms by participants (entailing learning costs) and issues relating to risk and uncertainty, both of which can contribute to low participation and limited funding allocations. Transaction costs, perceived fairness, and familiarity were all listed as both advantages and disadvantages, suggesting some paradoxical effects (e.g. reductions in some transaction costs and increases in others when auction methods are used). The details of these competing effects (or opposed perceptions), including their net impact, might be an interesting topic for future study.

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[95] *see* subsection "Methods – Stop Decision" for rationale.

[96] This is being considered as a small extension of the present study to better clarify the results.

A loose conceptual framework for identifying the minimum number of participants needed to avoid significant efficiency losses due to collusive behavior was synthesized from R1 responses and endorsed by all panelists who evaluated it (and 90% of the panel as a whole). The framework consisted of four main factors: (1) the social and geographic distance between actors, (2) the odds of winning, (3) the design and management of the auction, and (4) the participation of consultants shared by multiple bidders (Box 1). In addition to these major factors, several relevant considerations were highlighted, including the heterogeneity of bids and actions, the market power of colluders, program goals, and variables relating to the national context.[97] This framework generated a number of comments suggesting minor modifications.

Large majorities (>80%) of the panel agreed that non-bidding stakeholders affect auction outcomes only indirectly; that ES auction cost-effectiveness depends heavily on the accuracy of biophysical models predicting how management alternatives influence ES levels; that academic auction innovations are not frequently adopted into practice; and that real-world auctions typically do not successfully account for seasonal uncertainty or produce spatially-coordinated outcomes. The failure to account for risk appears to be mainly attributable to limitations in the knowledge base and not necessarily a lack of adoption of accepted tools by policymakers. Whether or not the current knowledge base is sufficient to design auctions that can produce spatially coordinated outcomes or optimize across multiple objectives was controversial, but even skeptics were optimistic that research advancements would soon make such designs possible. The most controversial issue was related to distributional equity: although a strong majority agreed that real-world ES auctions do not promote distributional equity, the panel was perfectly divided about whether or not it would be possible to design an equity-promoting auction given the current knowledge base. Some qualitative comments indicated that it might be, while others implied that this objective would run counter to the primary purpose of using an auction in the first place.

Overall, this study seeks to offer a catalyst for further integrating a somewhat fragmented, but colorful and profoundly multidisciplinary, body of literature—and, perhaps, encourage the development of a coordinated research agenda for the field. The continued expansion of the PES literature and growing policy interest in promoting the development of circular bioeconomies is likely to present a range of new opportunities and challenges for the application of auction methods—particularly in contexts where funding is limited and cost-effective interventions that can involve stakeholders transparently are likely to be prioritized. This study suggests some priority areas for research and outreach, and suggests a need for the development and dissemination of evidence-based best-practice guidelines. By taking a proactive approach to addressing these areas, the field may be better positioned to contribute to sustainability-oriented policy initiatives through designs that account for context and deliver results in a cost-effective way.

[97] Opportunity cost heterogeneity is likely relevant as well, although it was not included in the proposed framework.

4. Study 3: Case Studies in NOBEL and SINCERE

4.1 Abstract

NOBEL and SINCERE are two international European research initiatives examining innovative models promoting the sustainable provision of ecosystem services (ES). This chapter applies lessons learned from Studies 1 and 2 to three case studies: a discriminatory price reverse auction in Denmark, a uniform first-rejected price reverse auction in Belgium, and an ECOSEL forward auction-style game in Portugal (Tóth et al. 2010). As of this writing, the case studies are in progress and at different stages of development. This chapter mainly aims to facilitate early cross-fertilization between NOBEL and SINCERE. The cases differ significantly in terms of the ES involved and bidding design, but all three emphasize engaging stakeholders at local and supranational levels and feature auction designs that have been carefully tailored to local contexts.

4.2 Introduction

This chapter opens with a short introduction to NOBEL and SINCERE. Next, it offers a snapshot of three case studies that are currently underway: a discriminatory reverse auction in Denmark, a first-rejected price reverse auction in Belgium[98], and an ECOSEL-style forward auction game in Portugal.[99] Data availability varied, and more rigorous analysis will be possible once the cases are complete and scientific articles have been published about each case. However, both NOBEL and SINCERE are carried out under the umbrella of research networks designed to facilitate collaborative learning and knowledge-sharing between diverse contexts as a driver of innovation. Thus, the ambition of this chapter is to provide a kind of progress report between the two projects regarding their respective auction experiments.

4.2.1 Research context: overview of NOBEL & SINCERE

NOBEL

The NOBEL research consortium is coordinated by the University of Natural Resources and Life Sciences (BOKU) and comprised of seven main partners: public universities and research organizations from Austria, France, Germany, Norway, Portugal, Spain, and Sweden. The project identifies three overarching objectives:

(i) develop business models and mechanisms to internalize the socio-economic value of forest ecosystems

(ii) combine public policy tools with business models for implementing payments for FES at multiple levels; and

(iii) demonstrate and compare alternative approaches for payments in case studies in Europe (NOBEL 2020).

As is typical of large projects seeking to address wicked problems like social and ecological trade-offs in land use planning, these objectives are formulated in a general way to encompass a large set of work projects spanning multiple disciplines. It may be useful to begin with a practical example of a potential vision to which the project might hope to contribute.

The capacity to manage forests efficiently to serve multiple functions represents a growing priority in an increasingly interdependent world. Initiatives like the MEA and TEEB helped to formalize ES provision as a global priority. However, trade-offs between ES are prevalent—e.g., thinning operations may provide fire protection, but at the cost of reducing the amount of carbon stored as biomass—and this problem is compounded by the fact that existing markets do not effectively capture the value of many ES. Rather than pushing for a single technical breakthrough, NOBEL's concept is to combine several distinct threads in forest science and natural resource

[98] The Belgian case study also features an additional experiment involving a discriminatory price auction, but limited information about this case was available.

[99] NOBEL also features a similar auction case in Spain, but due to the lack of data at this early stage, the preliminary analysis would closely parallel that presented for the Portuguese case, so it was excluded from this chapter.

management in an original way, then implement them in five pilot demonstrations. Perhaps NOBEL's most distinctive feature is its use of an ECOSEL-like auction format in the pilot demonstrations in Spain and Portugal.[100] As of this writing, both the Spanish and Portuguese pilot demonstrations are at an early stage of development, with stakeholder consultations underway to identify ES of interest and modelling potential. Thus, for simplicity this chapter only examines the Portuguese pilot.

SINCERE

SINCERE is a European Forest Institute (EFI)-coordinated project that launched in 2018. It features 23 partners, including public and private research organizations and university-affiliated environmental consulting firms (e.g. ETIFOR). The project includes 11 case studies in 9 countries (Spain, Russia, Peru, Denmark, Switzerland, Croatia, Italy, Finland, and Belgium). Like NOBEL, SINCERE is oriented toward facilitating innovation to foster more sustainable FES provision:

> SINCERE's main strategic goal is to advance innovation mechanisms (IM), including novel policies and business models, that support the provision of FES across Europe and beyond, and to align them with a coordinated and supportive policy framework in view of working towards a Europe-wide incentive system for FES (SINCERE 2020).

SINCERE places a strong emphasis on institutions and the project's connection to the policy process. The project identifies six supporting objectives:

- Provide an evidence base for innovations in FES through systematic reviews
- Build and run a Learning Architecture to facilitate learning between practitioners, policy makers, and academia
- Develop, implement, and analyze innovations for FES
- Synthesize knowledge gained across all innovation actions and from all involved disciplines for upscaling
- Work towards a coordinated European policy framework to support FES provision
- Disseminate knowledge on how to enhance FES (SINCERE 2020).

Where NOBEL articulates its work on more technical terms—attempting to address empirical, informational, and logistical barriers to ES-related business models and develop pilot demonstrations from the ground up—SINCERE conceptualizes itself more as a facilitator, with a stronger element of connecting nascent innovations. It self-consciously seeks to create a locus of discourse and channels for dialog and knowledge sharing between scientists and policymakers. Although there is significant overlap between the functional activities executed by each project, it is possible to think of NOBEL as engineered to generate an innovation (i.e., a product-oriented model), whereas SINCERE is arguably more concerned with enhancing the process by which innovations can be seeded, produced, developed, and scaled (i.e., a platform model). Consequently, SINCERE's case studies seem to comprise more varied and diverse business models than those in NOBEL, such as funeral forests, innovations in the commercialization of mushroom picking, and government-financed watershed PES. However, two case studies utilize reverse auctions and are presented below.

4.3 Case summaries

4.3.1 Case 1: Reverse auction in Belgium (SINCERE)

Setting

This case study will take place in Flanders, the most populous region of Belgium and one of the most densely populated in Europe, with a population density of 472 km^{-2} and urban areas accounting for nearly one-third of the regions land area (Landuyt et al. 2016; Rutten et al. 2019).[101] The use of reverse auctions as a subsidy scheme is not explicitly addressed by legal frameworks (SINCERE 2019). Forests are fragmented; roughly 70% of the forest area is privately owned, with the majority of owners maintaining relatively small landholdings (Sousa-Silva et al. 2016). In 1980, the responsibility for spatial land use planning was largely devolved from the federal to the regional scale,

[100] The examination of this unique auction format is a core focus of this thesis and is discussed in Study 4.
[101] The dominant land use is still agricultural (54%) (ibid.).

but supranational commitments (e.g. Natura 2000 directives) also influence management and complicate competing objectives (ibid.; Vandekerkhove 2013). Forest management regulations can be restrictive, but a variety of subsidy schemes for promoting ES provision are available (ibid.).

Multifunctional approaches to forest management in Flanders developed over the course of the last half-century and represent the most salient paradigm today. Prior to the 1970s, forests in the region were viewed primarily as sources of timber and game; hunting in particular continues to play an important role in how people relate to forests today:

> In Flanders, there are over 30,000 hunting license holders, and for many private forest owners, hunting is the most important reason why they own a forest. For owners who don't hunt themselves, the rent of hunting rights on their property can be an important source of income, often higher than the income from wood sales (p. 12).

Despite being absent from the region for 50 years prior to 2006, wild boar *Sus scrofa* (L.) is popularly viewed as a native game species in Flanders (Rutten et al. 2018). Over the last 15 years, growing population and an expanding range has had far-reaching consequences for forests, agriculture, and the relationship between humans and nature (Rutten et al. 2019). Boar damage to agricultural crops and land can impose major costs to individual farmers, and boars may participate in human-wildlife interactions, from car accidents to facilitating disease transmission (p. 2). Proximity to forests and scrub are a risk factor for boar damage to maize fields; sufficient hunting pressure can reduce the risk of damage (pp. 7-9).

Objectives

The Flemish pilot demonstrations will focus on two categories of FES-promoting activities:

> (1) habitat restoration and improvement in hunting areas, and
> (2) the creation of wild boar buffers between forests and agricultural lands (SINCERE 2019).

As discussed in the following section, criteria and implementation considerations were examined in a participatory setting with core stakeholders, but additional work is underway to operationalize these concerns and define specific management actions. Habitat restoration is not covered under existing subsidies in Flanders.

Auction design and development

The Flemish case aims to conduct a field test of two payment determination rules (uniform first-rejected vs. discriminatory price), and evaluate their performance relative to existing subsidy systems with a focus on feasibility, efficiency, and replicability (Therry 2018). The first-rejected price rule will be used for the wild boar buffer auction (with bids ranked by price per square meter), and a discriminatory price auction will be used for habitat restoration (Natuurinvest 2020). These two auctions are conducted in separate areas.

The scientific approach and auction design project is a result of a collaboration between the University of Leuven and Natuurinvest, a body that which "invests income generated by nature [...] on behalf of the Flemish Agency for Nature and Forests" (EUSTAFOR 2016). However, a participatory element is incorporated into the design and development process. A multi-actor group (MAG) meeting comprised of the auction team and representatives of key stakeholder groups was held in October 2018 in order to solicit input on the auction methods. In addition to introducing the reverse auction concept (which lacks dedicated regulatory framework in Flemish policymaking and is likely unfamiliar to many stakeholders), the MAG also enabled the project managers to target the mechanism to concerns that are salient in the local context: the selection of habitat restoration and wild boar buffers emerged from MAG discussions (SINCERE 2019). Thus meeting served a public outreach function to build early support by putting stakeholders in the role of rule-makers rather than rule-takers (Depres et al. 2008; Gupta & Dalei 2020).

For the wild boar buffer auction, participants were told that bids would be ranked by price per square meter and subject to restrictions defining the minimum and maximum buffer width, as well as minimum size requirements for the maize field protected and for the adjacent forest (Natuurinvest 2020). However, the length of a given site's buffer strip is fixed, since it is required to extend across the full length of contact between forest and field. Management restrictions are also included, such as prohibitions on the use of herbicides and pesticides to prevent damage to the forest. Spatial

considerations are only taken into account in the event of a tie for first rejected price. The agency reserved the right not to expend the entire budget. Interestingly, winners are also subject to reporting requirements, such as submitting monthly photos of the buffer and reporting on crop damages and hunting activities. Double-dipping with other subsidies is prohibited. Detailed information about the biodiversity auction could not be obtained.

Preliminary assessment

In this case, the targeted ES—wild boar risk reduction and game habitat—are to be enhanced through active measures. That is, the creation of buffer strips and the restoration and improvement of habitats does not occur with simple conservation set-asides, but must be achieved through specific management actions, so bids will be based not only on foregone revenue but estimations of costs to be incurred. This could entail higher compliance monitoring costs, since it is often easier to predict the effects of simply leaving a parcel alone than those associated with an intervention: capacity and technical skill vary from landowner to landowner (or contractor to contractor). Depending on how payments are disbursed, there may be a risk that some landowners receive funds and then fail to carry out the contracted action (moral hazard).

Policy conflicts and secondary effects of interventions can also reduce cost effectiveness. Existing subsidies may support wild boar protection measures, but do not support game habitat restoration and improvement. It is possible that management actions undertaken in pursuit of the latter objective could redound to the benefit of boars, resulting in population increases (or expanded range, if connectivity is considered in the habitat measures), conflicting with the objective of boar protection subsidies.[102] The two pilot tests appear to be targeted at different geographic areas within the region, but if preliminary results are favorable and they are scaled up, then there could be a direct conflict between their respective objectives.

The scale of individual participants should be considered in the context of a stakeholder analysis. If a forest owner typically receives revenue from the sale of hunting rights, then they may already engage in habitat management activities in the absence of government support, enabling them to submit very low bids and price out those whose lands are under greater threat or have more urgent restoration needs. Similarly, farmers who consider their fields at risk may already be willing to invest in boar control measures, if not necessarily buffers (e.g. electric fencing). If the auction schemes are expanded to encompass the same geographic areas, there is a possibility that larger landowners possessing both farms and forests used for hunting revenue could win contracts in both auctions.[103] In this case, the threat to their fields might be quite low if hunting pressure controls local boar populations effectively. In short, there are multiple pathways by which adverse selection undercut additionality or cost-effectiveness. However, the possibility of underbidding due to pricing in intrinsic motivations (potentially boosting budgetary cost-effectiveness) might also be interesting to explore through qualitative study.[104]

Mitigating the risk of adverse selection is likely to require detailed site assessments to establish a baseline and evaluate management actions, although such monitoring cannot identify actions that the landowner would have taken anyway. Assuming the bidding is truly competitive and transaction costs are not too high, the incentives inherent to the mechanism should limit this source of inefficiency, since landowners already planning an intervention would submit lower bids (and thus profit less from the information asymmetry regarding their intended future management than if they benefitted from a flat-rate scheme). However, some results have indicated that auctions may be less effective than other mechanisms: preferentially awarding contracts to the lowest bids might exacerbate the adverse selection problem (Arnold 2013).

For the first-rejected price auction to create wild boar buffers, the spread of submitted bids will provide interesting data: given the restrictions on size, cropping, and length, it is possible that

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[102] The auction is designed to support the creation of buffers around forests as well: the two stated goals are (1) to limit boars' negative impacts on forest biodiversity and (2) to protect crops (SINCERE 2018).

[103] This hypothetical critique simplifies a much more complex policy landscape to illustrate the issue of conflicting instruments. The risk of auctions creating unexpected interference with existing subsidy schemes is cited by the auction managers as one of the major challenges for the project.

[104] *see* e.g. Chan et al. (2017), Cooke & Corbo-Perkins (2018)

larger landowners will be in a position to submit much more competitive bids regardless of their planned interventions. First of all, they may exploit economies of scale and enjoy a more favorable ratio between buffer area and field area. The owner of a square 0.25 ha field (the smallest permitted size) with forest on three sides would need at least 600m^2 of buffer area (4m being the smallest permitted width), so buffer would occupy 24% of the total area. For a 1ha square field surrounded on three sides by forest, 1200m^2 of 4m-wide buffer would be needed, accounting for just 12% of the total land area. Larger landowners would also be likely to have more productive land at risk and higher capacity to implement the buffers, and thus be willing to accept lower subsidies.

4.3.2 Case 2: Reverse auction in Denmark (SINCERE)

Setting

This case is located in Central Jutland, Denmark. Nationally, agriculture accounts for two-thirds of the total land area, while forests account for less than 15% and open semi-natural areas just 10% (Müller, Bøcher, & Svenning 2015; Johannsen et al. 2019). Denmark's forests are mostly young and intensively managed, having been established through explicit afforestation initiatives over the course of the last century.[105] These initiatives encompass private landowners: although subsidies supporting afforestation (and municipal-level guidance for desirable locations) exist, private afforestation has been "extensive" even without direct financial support from the government (p. 16). In 2016, afforestation efforts less than thirty years old accounted for one-fifth of Denmark's forest area, and of these, only one-third benefitted from subsidy payments to private landowners (ibid.). Seventy percent of Denmark's forest area is owned by nearly 25,000 private landowners; roughly nine in ten have holdings smaller than 20ha, while private companies account for about 12% of the national forest area (Olsen & Jurgensen 2018; Johannsen et al. 2019, pp. 20-21). The remaining 30% of the national forest area is divided between state forests and ownership by other public bodies, with the proportion skewing slightly in favor of state ownership by land area (ibid.).

Biodiversity has been an explicit objective of forest legislation and management in Denmark for more than a century (pp. 17-18). The Danish government began to publish large-scale nature conservation guidelines for Natura 2000 in 2007; related management plans for the period beginning in 2016 emphasized public-private partnerships (Kamphorst et al. 2017). Central Jutland has several hotspots for recreational value and biodiversity, such as the Lake District (Odgaard et al. 2017). Public grant schemes to incentivize landowners to undertake biodiversity-conscious management are well-established; the state has pursued biodiversity conservation set-aside targets in part through grants designed to compensate landowners for foregone income associated with ceasing productive forestry operations on set-aside parcels (Thorsen et al. 2018).[106]

In light of the possibility that alternative approaches might improve landowner engagement and cost-effectiveness, reverse auctions are currently being explored as a contract allocation and price-setting mechanism. The Danish government has commissioned practical reports on reverse auction theory and practice, and is pursuing two reverse auction pilots (Thorsen et al. 2018; Lundhede et al. 2019). The primary effort is a Ministry of Environment-funded case, while the secondary experiment the SINCERE pilot. With a budget of roughly €65,000, the latter is conceptualized as a side experiment to the main case (Olsen & Jugensen 2018). As in Belgium, there are some challenges relating to the legal framework surrounding reverse auction schemes, so designing a scheme that is not overly burdensome in terms of its associated bureaucracy and red tape is a significant challenge.

[105] *Forest* as a land cover type is characterized by the FAO (2012) definition: minimum extent of 0.5ha, minimum tree height 5m, minimum canopy cover 10%, current or projected based on existing trees, agricultural or urban land uses excluded (Johannsen et al. 2019).

[106] The government launched a new biodiversity set-aside program launched in 2016. Since 2017, approximately 3,300ha of private forests have been set aside under a grant scheme; for reference, in 2018 almost 14,000ha of state forests were designated as set-asides, although the transition period for tapering down harvesting activities is several decades long (Lundhede et al. 2019).

Lundhede et al. (2019) suggest some changes to the Government Order related to the existing grant scheme in order to accommodate a reverse auction (p. 18).[107]

Objectives

With respect to ES, the Danish pilot targets biodiversity protection, encompassing both enhancement and conservation activities. However, the pilot also hopes to facilitate coordination between conservation efforts and serve a public communication/education function (e.g. raising stakeholder awareness of biodiversity issues and potential actions) (Olsen & Jurgensen 2018). Although not listed as an explicit objective, the auction design also suggests a clear interest in creating space for innovation, rather than seeking to promote strictly standardized interventions.[108]

Auction design and development

The design of the Danish pilot demonstration is notable in two regards: its use of a purpose-built online platform to facilitate bidding, and its solicitation of bids comprised of both a price and a landowner-formulated intervention proposal.

Through the online platform, landowners in eligible municipalities are given free rein to propose a set of biodiversity-promoting actions, outline their expected impacts, and identify the price they would be willing to accept to carry out these actions (Jurgensen & Olsen 2020).[109] Bidders may suggest indicators characterizing the status quo and the expected effects of their management actions. The bidding tool allows landowners to provide cadastral identifiers and select their parcels, making bids spatially explicit—an important step since certain actions might be either required or restricted depending on the land classification ("Biodiversitetsauktion" 2020). Within the Web GIS tool of the bidding platform, landowners can draw polygons to specify intervention areas within their parcels. The tool also contains functionalities allowing bidders to attach various files, including images, to illustrate both the current status of their land and the biodiversity actions they propose. These bids are then subjected to preliminary screening, and those which are judged to offer the best value for the proposed price are advanced to the next stage of consideration, which involves a site visit and evaluation (Olsen 2020). After the final selection is made, winners sign contracts and receive payment from the Danish Forest Owners Association (Dansk Skovforening).

Each contract contains provisions for subsequent site assessments to ensure compliance, seemingly on a case-by-case basis; since payments are made at the time of contract signing, winners are warned that non-compliance may result in legal efforts to reclaim the payment and associated costs (conditionality). For losers (and in order to mitigate the risk borne by landowners investing in high-quality bids no guarantee they will be accepted), the association promises that even rejected bids will receive feedback and a professional assessment, which landowners might use in future bids or subsidy applications. The provision of feedback also advances the public education goal of the pilot. The price submitted with the bid is binding and cannot be altered later ("Biodiversitetsauktion" 2020).

In order to develop the auction in a participatory way, the Danish case held a series of MAG meetings with key stakeholders at the University of Copenhagen (SINCERE 2020b). The first meeting explored ideas for innovative models to support ES in Denmark; the second set the course for pursuing a reverse auction for biodiversity; and by the time the third MAG meeting was held, provisional auction materials had already been developed and were available for evaluation, including the platform, supporting documents, and possible indicators. As in the Flemish case, the participatory nature of these meetings also served an outreach function; participants indicated that they would promote the scheme to other local forest owners.

[107] An interesting suggestion involves the inclusion of a 15-20 year "window of regret" in the case of offers that require preservation in perpetuity, defining conditions for owners to withdraw from the agreement. The goal is to improve participation, but conceptually invokes a problem that is the inverse of that of selecting bids under uncertainty described by Lewis and Polasky (2018).

[108] Design is discussed in the following subsection.

[109] During the bidding process, the platform prompts landowners to disclose payments they are already receiving to support desirable forest management actions in an effort to avoid double-dipping.

The auction managers also developed a catalog of ideas for possible conservation actions to assist landowners in bid design.[110] Actions were grouped into four broad categories: promoting down deadwood on different time horizons; promoting the diversity of woody plants; creating and preserving clearings and meadows; and creating and improving wetlands and other desirable hydrogeological features ("Inspirationskatalog" 2020). The catalog stressed that it only contained suggestions, and that landowners were free to propose other interventions.

After extending deadline and expanding the area of eligibility, the auctioneers ultimately received 25 bids from 17 owners, amounting to approximately three times the available budget (Olsen 2020; Jurgensen 2020; Jurgensen 2020, personal communication). A number of bids were based on catalog suggestions, but others were not (Thorsen 2020, personal communication). Given the small size of the experimental auction and the desire to emphasize competition and price efficiency rather than cooperation, spatial coordination was not considered in the bid evaluation process.

Preliminary assessment

With respect to probability of winning (a key factor determining the risk of successful collusion[111]), the Danish reverse auction case appears to have achieved good results. In this case, it seems likely that the principal had a wide assortment of options and that satisfactory proportion of bids will be rejected.[112] Expanding the eligible area is also likely to increase the social and geographic distance between participants. At this preliminary stage, this is suggestive (though certainly not demonstrative) of a situation where strategic dilemmas are likely to exist between bidders, generating efficient bids and incentivizing the disclosure of private opportunity cost information. Efficiency in this round may come at the cost of risking reduced participation in future auctions, however: landowners whose bids were rejected may see the effort invested in bid formulation and participation in the auction, potentially including paying consultants, as wasted.[113] If a minority of bids are accepted, then it is possible that a majority of participants could be more reluctant to participate in future auctions.[114]

Allowing participants to formulate their own management interventions in pursuit of a broadly-defined goal, and submit detailed information (including geographic data) about those bids using an online platform, is an interesting and intriguing approach. Insofar as the mechanism supports multiple activities under the broad banner of protecting or promoting biodiversity, it is reminiscent of combinatorial auction designs (Iftekhar et al. 2012; Schilizzi 2017). This depends to some extent on the bid selection protocol, and whether it evaluates synergies between multiple action, however.[115]

4.3.3 Case 3: Planned ECOSEL-style auction in Portugal (NOBEL)

Setting

Portugal is a biodiverse country with a high expected sensitivity to climate change (Pravalie et al. 2017; Malek et al. 2018; Rocha et al. 2020). It faces a number of land management challenges featuring multiple considerations and constraints, notably including interlinked issues surrounding land ownership fragmentation, the abandonment of rural lands (notably including management-reliant agroforestry systems like cork oak *montados*), and wildfire risks related to growing frequency and

[110] Stakeholders were able to provide input for the catalog during the participatory MAG process.

[111] see Study 2, Box 1: conceptual framework for determining minimum participation

[112] This would not be true if, for example, a very small number of bids were submitted with very high prices. The present study did not have access to sufficiently detailed data to make a more detailed evaluation, but a scientific article on the experiment is likely forthcoming.

[113] In this case, auction managers included provisions designed to discourage the participation of consultants: all bids had to be submitted by landowners, and all communication passed through landowners (Thorsen 2020, personal communication). Based on past experience and the nature of the bids, the managers believe that consultants did not contribute to the formulation of the vast majority of bids received.

[114] The auction designers judged it unlikely that rejected bidders would be too discouraged, since they work frequently with authorities and are accustomed to submitting proposals for subsidies with imperfect success rates (Thorsen 2020, personal communication).

[115] As of this writing, the bid selection protocol is still being determined. Although the key dimensions for evaluating the bids were defined in advance (e.g. spatial extent, price, etc.) and communicated to bidders, the open-proposal format precluded developing an a priori evaluation protocol (ibid.).

severity and an evolving wildland-urban interface (WUI) (Oliveira et al. 2017; Tonini et al. 2018; Van Der Zanden 2018). A large majority (>90%) of Portugal's forested areas are privately owned.

This pilot demonstration is set in Vale do Sousa, a rural forested area in northwestern Portugal that straddles the districts of Porto and Aveiro. The population density of Aveiro is about 248 inhabitants km^{-2}; Porto has an overall population density of 781 inhabitants km^{-2}, but this is mostly concentrated around the capital and declines to about half that value toward the interior where the study area is located (Pacheco, Claro, & Oliveira 2014). Relative to the other case studies considered in the present report, information about the setting for the Portuguese pilot is detailed due to a long history of research conducted in the area, which also has an interesting administrative history. Land ownership fragmentation contributed to a particularly devastating fire season in 2003: costly fuel treatments conducted by smallholders do not significantly reduce their vulnerability to extreme fires unless similar treatments are conducted by their neighbors on adjacent parcels, posing a collective action problem (Mendes 2005; Canadas, Novais, & Marques 2016; Canadas & Novais 2019). One policy response involved the creation of a new administrative tool enabling joint forest management areas (Zonas de Intervenção Florestal, ZIF) to "promote the integration of multiple owners' management plans to address wildfire prevention goals", with minimum area and participant thresholds (Borges et al. 2017, p. 51). The tool is intended to create a "large contiguous surface involving numerous owners" subject to a single management plan (Canadas et al. 2017, p. 179).

This case study takes place in one such joint management area, the 387-landowner 14,388ha ZIF in Vale do Sousa (ZIF_VS) (Borges et al. 2017; NOBEL 2020b).[116] Classified into nearly 2,000 stands, the majority of the area consists of either pure eucalypt stands (~2/3) or mixed eucalypt-maritime pine (~1/3) stands, with a small fraction of the area occupied by hardwoods (primarily chestnut) (Marques et al. 2017; Borges et al. 2017). Medium and large private holdings (>5ha), local parish property, and smallholders account for 60%, 35%, and 5% of the land area in ZIF_VS, respectively (Marto et al. 2018). Areas held by a single owner are often not contiguous: for instance, Marques et al. (2020) note that one owner held 36.4 ha fragmented across 50 separate blocks (p. 4).

The local landowners association (Associação Florestal de Vale do Sousa, AFVS) is responsible for developing management plans in the ZIF. To do so, it conducts stakeholder consultations with each ownership type, representatives from industries relevant to the local economy (e.g. furniture, timber), and other institutional stakeholders (e.g. state forest service, municipal governments, NGOs) (NOBEL 2020b). Currently, the most significant ES produced in ZIF_VS are eucalypt pulpwood, sawlogs (maritime pine, some hardwoods), and carbon storage. Previous research in the area found a strong interest among stakeholders in programs aimed at valuing nonmarket ES and supporting their provision through a PES scheme (Borges et al. 2017). In an actor analysis, Marques et al. (2020) find strong interest in water quality, soil erosion prevention, biodiversity, landscape aesthetics, environmental education, wood supply, and disturbance resistance (wildfire, pests and diseases) (p. 7).

Ecosystem services at stake

The Portuguese case study plans to consider baskets of market and non-market ES. Market ES include eucalyptus pulpwood and sawlogs (maritime pine, hardwood) (NOBEL 2020b). In addition to these provisioning ES, carbon storage and ending inventory volume are considered as regulating ES. Work is currently underway to include biodiversity and wildfire risk (for which indicators are already available) and recreation (for which a satisfactory indicator is needed).

Auction design and development

The pilot demonstration in ZIF_VS is still under development and the auction design has not been finalized as of this writing. However, the focus of the current effort has been to explore the application of an ECOSEL-style forward auction (Tóth et al. 2010; Roesch-McNally et al. 2016), likely under experimental conditions (the pilot will not seek to fully finance a management change by

[116] Technically, the study area is subdivided into two smaller ZIFs separated by the Douro River; for convenience, this administrative distinction is ignored in the present analysis (Marques, Juerges, & Borges 2020).

crowdfunding actual monetary contributions from stakeholders).[117] Biophysical models are available to estimate wood provision by stand type, wildfire occurrence, damage models for wildfire risk, and models for biodiversity (NOBEL 2020). Optimization models have also been developed to explore the trade-offs between these objectives, and may be expanded to incorporate recreation. Workshops have previously been held with stakeholders in ZIF_VS to explore trade-offs with interactive Pareto tools, providing a baseline level of familiarity with the concepts underlying bundle selection in an ECOSEL-style auction (Marques et al. 2019).

Preliminary assessment

The Portuguese pilot offers an interesting case study in which decisions must be made under conditions of risk and with reference to multiple objectives, and then carried out by a large number of actors in a coordinated way to achieve the desired result at the scale of the ZIF. It is also scientifically interesting given past research carried out at the case study location and the availability of detailed data regarding biophysical variables, actors and stakeholders, and trade-offs.

The ECOSEL approach is itself novel and largely untested. An application of the tool far from the context in which it was originally developed will be an interesting and challenging project, because the literature on the kind of auction-style subscription game it utilizes is virtually nonexistent beyond publications authored by those involved in the development of the tool itself. The evaluation of this case study will also depend on whether the auction ultimately uses ECOSEL as a valuation game in a laboratory experiment, or attempts to use it as the basis of a PES scheme. Even at the present stage, however, a number of interesting—and sometimes difficult—considerations relating to the auction design process itself can be identified. These considerations go beyond the scope of a preliminary reflection on the NOBEL auction case. The following chapter offers a theoretical critique of the ECOSEL approach and a more detailed analysis of considerations associated with its potential application in the Portuguese context.

4.4 Summary & Conclusion

These three cases illustrate very distinctive experimental approaches to applying auction methods to ES under the banner of two international research initiatives. Narloch et al. (2011) argue that participants' lack of involvement in mechanism design limits the procedural fairness of auctions. These three cases address that critique by placing a strong emphasis on the use of participatory methods and adopting a bottom-up approach to developing highly contextualized auctions that speak to local concerns and have the support of key stakeholder groups. In the SINCERE case studies, stakeholder engagement is most visibly achieved by using MAG meetings a starting point for auction design, allowing stakeholders to directly participate in identifying ES of interest and providing input into the mechanism design and selection processes. In the Portuguese case study, stakeholder consultations are required in order to select ES of interest to prioritize in developing Pareto frontiers for the auctions, since the inclusion of too many ES quickly complicates decision tasks and makes trade-offs difficult to visualize. These case studies also illustrate the philosophies underpinning the larger research initiatives to which they belong, which stress stakeholder interactions at multiple levels. Both projects invest heavily in efforts to integrate local stakeholders into the design of pilot demonstrations at an early stage, but also in coordination at the supra-national level in order to produce scientifically interesting designs and enable cross-fertilization. The present thesis was conceptualized with this philosophy in mind.

What about specific design decisions? The two SINCERE cases are the easiest to compare, since they both deal with reverse auctions. The use of a uniform first-reject price rule in the Belgian boar buffer auction may prove useful in scaling up subsidies over a larger geographic area: this design is generally considered to be incentive compatible, so the auction administrator pays an informational rent in order to obtain landowners' honest estimates of expected costs (Study 1, Study 2; Thorsen et al. 2018). This information could be used to inform future policy interventions or set prices in an open-enrollment scheme. The Danish case, by contrast, gives participants a remarkably wide latitude to

[117] The basic contours of the ECOSEL mechanism have been summarized in previous chapters, and the theoretical basis of the tool is interrogated below in the current chapter, so a more detailed discussion has been omitted here.

formulate their bids—so much so, in fact, that it is difficult to see how a uniform pricing rule could be applied. With so much heterogeneity in bid content, it would also probably not be very informative to elicit honest cost information. Thus, a discriminatory pricing rule is applied.

In this respect, despite its different format, the Portuguese case offers something of a middle ground. Like the Danish case, it will incorporate multiple objectives into the bidding process—but like the Belgian case, consistent pricing rules will be applied to allow direct comparisons between bundles. However, the differences between the SINCERE cases and the NOBEL case are substantial. The SINCERE cases represent a Pigouvian, government-financed PES scheme, whereas the Portuguese case aspires to a Coasean, user-financed design (albeit one with transaction costs subsidized by public bodies, such as the university providing optimization). Similarly, where the SINCERE pilots are designed to maximize the cost-effectiveness of each euro spent on ES supply, the NOBEL pilot is designed to maximize the profits accruing to ES providers (see Study 4).

Overall, these three cases involve novel applications of auctions in areas where they are not common, and they represent clear efforts to adapt auction research to practical demonstrations. In Study 2 of this thesis, Delphi respondents repeatedly stressed the need for more field trials to build the track record of ES auctions and familiarize the public and policymakers with their application. The pilot demonstrations discussed here make clear contributions to this goal.

5. Study 4: Theoretical critique of ECOSEL and case study application

5.1 Abstract

This chapter applies lessons learned in Studies 1-3 to a critique of the ECOSEL concept. The critique is based on three functions suggested by Tóth et al. (2010): that (1) ECOSEL is a cost-effective ecosystem services (ES) procurement tool which (2) provides information about ES values and (3) enables decentralized stakeholders to directly influence decision-making. I argue that (1) as a procurement tool, ECOSEL is designed to encourage cost-*in*effectiveness, (2) it is a poor valuation tool because it is not incentive compatible and does not provide a basis for quantifying social surplus, and (3) participatory decision-making methods that make purchasing power the sole determinant of influence risk legitimacy, equity, and inclusiveness problems. Next, ECOSEL is analyzed from the paradigm of public good games and participatory methods, respectively. Finally, a menu of possible design modifications is presented with reference to an in-progress pilot demonstration in Portugal. Overall, ECOSEL is credited as an innovative tool with interesting scientific and practical potential, but also one with serious risks that should be carefully considered prior to any large-scale application.

5.2 Introduction

The preceding chapters explore theoretical and empirical research surrounding ES auctions. This field is dominated by reverse auctions, with a handful of examples that illustrate the more familiar one-seller-many-buyers format. Study 3 offered a preliminary discussion of an in-progress NOBEL pilot study in Portugal which intends to apply the ECOSEL tool developed by Tóth et al. (2010). This tool has been briefly described above, but because it is unique and largely untested, a close critical examination is in order. This chapter presents such an examination.

In introducing ECOSEL, Tóth et al. (2010) stress at least three important features of the tool, which this chapter disputes as follows.

First, Tóth et al. present ECOSEL as a tool that can enable least-cost procurement of non-market ES by stimulating stakeholders to provide voluntary monetary contributions. In Section 5.3.1, I point out that ECOSEL only considers costs borne by the landowner, and argue that accounting for the cost of monetary contributions made by bidders renders the tool cost-ineffective.

Second, Tóth et al. present ECOSEL as a "decision tool" that can promote compromise solutions in the face of conflicting stakeholder preferences (p. 114). In Section 5.3.2, I raise practical and ethical objections to the idea of making purchasing power the basis of any conflict resolution approach—although I acknowledge that some of these objections are unavoidably ideological, and that this solution may be appealing when analyzed from a different ideological vantage.

Third, Tóth et al. suggest that ECOSEL might be able to tell us something about the values that individuals assign to ES (pp. 102-103, 114). In Section 5.3.3, I consider ECOSEL in relation to the basic theory underpinning two conceptually related valuation approaches—choice models (CM) and experimental auctions—and conclude that ECOSEL in its current form is likely to be an inferior valuation tool, at least in the absence of a serious effort to integrate the model with current valuation theory. However, efforts to modify ECOSEL to serve a valuation function may be warranted, considering the tool's many interesting parallels to these valuation approaches.

In Section 5.3.4, I attempt (with limited success) to better situate ECOSEL in relation to its true theoretical tradition, the public good game. In Section 5.3.5, I reimagine ECOSEL as a voting system. Finally, in Section 5.4, I consider several modifications to ECOSEL's structure that might address some of the objections raised in Sections 5.3.1-5. These suggestions are made with NOBEL's Portuguese pilot demonstration in mind, but also in the interest of advancing research around the tool more generally. They include profit caps, stakeholder pre-screening of bundles, quadratic voting, incorporating CM techniques, and hybridizing ECOSEL with the approach described by Chakrabarti et al. (2018) in the Bobolink Project.

5.3 Theoretical critique

5.3.1 ECOSEL as procurement mechanism (reverse auction analog)

Tóth et al. (2010) begin from an uncontroversial starting point: natural resources are chronically over-exploited and ES under-provisioned, and existing tools have not proved adequate to the task of creating incentives or correcting externalities to ensure that ES are provisioned at socially optimal levels. For Tóth et al., reverse auctions are limited by their reliance on a central purchasing authority. Thus, they conceptualize ECOSEL as a decentralized market process in which "any number of buyers" can "coordinate or compete in a bidding process for specific management plans that lead to desired bundles of ecosystem services" (p. 100). They go on to suggest that ECOSEL "produces ecosystem services at the lowest possible costs." (ibid.).

The kind of collaborative/competitive bidding process envisioned by Tóth et al. requires communication. ECOSEL achieves this through the Anglo-Dutch auction format, which is characterized by multiple rounds of open bidding (so that bids placed in subsequent rounds are informed by the aggregate allocations of all bidders in previous rounds) followed by a sealed final round designed to deter free riding (p. 101; Klemperer 2002; Azacis & Burguet 2008). Tóth et al. characterize the mechanism as follows:

> The auction component of ECOSEL can be thought of as a *competitive* multi-unit, multi-dimension public good subscription game with incomplete information. The competitive nature of the game [...] differentiates ECOSEL from other subscription games and brings it conceptually closer to auctions. Competition arises because the players likely prefer different outcomes and will bid [...] to avoid a loss of individual utility that might result from an undesired outcome such as intensive timber harvesting (p. 101). [118]

ECOSEL involves constructing a market with one seller (the landowner/association), several products (management plans corresponding to different levels of ES provision drawn from a Pareto frontier), and many sellers (bidders). To conceptualize ECOSEL as a market, it may be useful to begin from basic efficiency considerations. There are four commonly identified prerequisites for a market to achieve Pareto efficiency: (1) well-defined property rights and the possibility for buyers and sellers to transact freely; (2) agents act as competitive profit maximizers; (3) market prices are known by buyers and sellers; (4) there are no transaction costs (prices can change freely in response to competitive dynamics, and these changes do not consume resources). In the context of forest management, ECOSEL assumes an initial property rights allocation in which the landowner has the right to determine harvest levels. The auction mechanism, then, allows bidders—typically assumed to be community members or immediate stakeholders—to purchase partial harvesting rights from landowners. Its ambition is to serve as the Coasean, user-financed PES counterpart to reverse auctions, which are typically government-financed Pigouvian solutions. However, this is where the parallels to a Pareto-efficient market end.

Multiple rounds of bidding do not quite communicate market prices in this case. Instead, the initial bidding rounds have more similarity to voting system theory than aggregate market transactions: money allocated to each basket does not determine its level of production, but rather the probability that it will be produced at all (see 5.3.2) The products are discrete and exclusive—only one basket can win—so bidding is a zero-sum game with respect to baskets, but not bidders. Unlike traditional auctions, more than one bidder can win: everyone whose utility increases as the result of a given bundle being selected wins, whether they contributed to the transaction or not (free riding).

Reserve prices (the opportunity cost to the landowner associated with each ES basket) are determined *a priori* by the landowner in cooperation with a technical advisor (hereinafter consultant) responsible for constructing the optimization model to generate the Pareto frontier from which ES

[118] Apart from this characterization, Tóth et al. (2010) do not offer sustained engagement with the literature on public good games, but Rabotyagov et al. (2013) present a more detailed analysis. This section examines ECOSEL as an analog of reverse auctions, because the game is primarily framed as an auction by Tóth et al. (2010). A discussion of ECOSEL as a public good game is presented later in this chapter.

baskets are drawn.[119] Unlike bidders interested in a certain outcome, the landowner always has an available alternative and can walk away at any time: reserve prices are calculated based on expected revenues from implementing the financially optimal management plan, so the landowner will receive a return on his capital whether the auction succeeds or fails, and in this sense faces no risk apart from incidental costs associated with participating the auction itself. Thus, for the landowner, the auction is an opportunity to further increase profits.

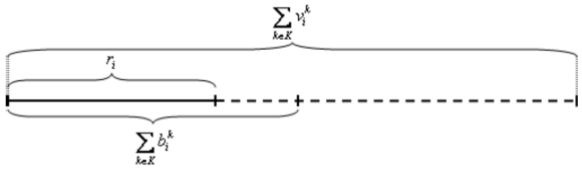
It is probably in the construction of efficiency that ECOSEL diverges most significantly from reverse auctions, because in ECOSEL it is the profit-maximizing bundle that wins (Rabotyagov et al. 2013). Consider how Tóth et al. (2010) characterize the social surplus *SS* for bundle i associated with a successful ECOSEL auction game (p. 103):

Equation 1

$$SS_i = \sum_{k \in K} \left(v_i^k - b_i^k\right) + \sum_{k \in K} \left(b_i^k - r_i\right) = \sum_{k \in K} \left(v_i^k - r_i\right) \qquad (1)$$

In this equation, I is the set of bundles i available in the auction where $i \in I$, K is the set of bidders k where $k \in K$, v_i^k denotes the utility of bundle i for bidder k, b_i^k denotes the final (sealed, binding) bid placed by bidder k on bundle i, and r_i is the reserve price (the landowner's opportunity cost of implementing a management plan to produce bundle i rather than the financially optimal plan) (p. 103). The following figure illustrates the simplified equation, where SS_i is calculated as the difference between the sum of bidders' utility from winning bid i and the reserve price[120]:

Figure 6: Illustration of Eq. 1[121]



Emphatically unlike reverse auctions, ECOSEL as proposed by Tóth et al. is unconcerned with the magnitude of $\sum_{k \in K} b_i^k - r_i$ (provided that it is greater than zero), and views the value $\sum_{k \in K} v_i^k - \sum_{k \in K} b_i^k$ as incidental and even uninteresting:

> The amount by which the total of bids exceeds the reserve price only affects the bidders' and the providers' respective shares in the benefits. The sum of the two shares, which is the social surplus, remains constant as long as the total value of the bids exceeds the reserve price (ibid.).

Dismissing these two arithmetic differences as outcomes of secondary interest is antithetical to the basic design constraints of Pigouvian PES in general, and especially reverse auctions. Reverse auctions typically involve a single purchaser who has been entrusted with spending public funds to secure public goods in a cost-effective way. The opportunity cost to the seller (corresponding to the reserve price r_i here) is typically private information; reverse auctions are a tool custom-built for the express purpose of accounting for it in order to minimize $\sum_{k \in K} b_i^k - r_i$ (in the case of reverse auctions, there is only one k in set K). Within a reverse auction paradigm, the dashed segment corresponding to $\sum_{k \in K} b_i^k - r_i$ in the figure above would be interpreted as the measure of *inefficiency* in the mechanism. It represents the amount by which the purchaser(s) overpaid for i relative to what they could have paid: r_i plus a small premium to cover uncertainty and transaction costs.

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[119] Whether or not reserve prices should be communicated to bidders is an open design question likely to be informed by practical experience as much as theoretical considerations (e.g. what is the probability of bids reaching the reserve price without a clear goal, when goal-setting is an integral component of most crowdfunding frameworks?)

[120] SS_i can be negative in an ongoing auction but not in a completed one: if the sum of bids does not at least meet the reserve price for any bundle, the auction fails and no transaction takes place.

[121] Image source: Tóth et al. 2010, p. 103.

It should be noted that this is not the case for all PES. There is no established, universally accepted rule for calculating the baseline for ES provider compensation, and in some cases it may be desirable to base compensation on the social surplus rather than the landowner's opportunity cost for this reason, much work in the field of environmental resource valuation is oriented toward quantifying the social surplus of non-market goods and services (Lederer 2011; Goldman-Benner 2012; Bingham 2020). However, in the case of reverse auctions—probably the tool to which ECOSEL is most closely analogous—it is standard to use landowner opportunity cost as the basis of compensation (Study 1, Study 2). The choice to implement a complex tool like a reverse auction is usually justified on the basis of their capacity to limit rent-seeking and set prices close to sellers' opportunity costs.[122]

Efficiency considerations: price discovery, collusion, transaction costs

Efficiency and cost-effectiveness in PES are closely related to social surplus and the opportunity cost of ES provision. In its current form, ECOSEL does not offer an obvious means of inferring the value of $\sum_{k\in K} v_i^k$ in Equation (1) above, except perhaps that it must, by definition, have $\sum_{k\in K} b_i^k - r_i$ as a lower bound. If this is the case, then it would not be straightforward to infer social surplus using data produced in the course of an ECOSEL-style auction.[123] However, the potential usefulness of ECOSEL *does* hinge on its ability to accurately evaluate opportunity costs prior to the auction itself and distribute benefits in a way that is viewed as fair by participants. This subsection examines some basic considerations relating to the potential efficiency of the mechanism. It is loosely based on major determinants of reverse auction efficiency identified in Study 1 and Study 2.

As suggested above, viewed from the perspective of a buyer aiming to minimize the payment for non-market ES, ECOSEL is designed to be cost-ineffective. The reason goes back to the fundamental distinction between forward and reverse formats: the former create competition between multiple buyers to make a purchase at the *highest* possible price; the latter create competition between multiple sellers to make a sale at the *lowest* possible price. Any discussion of the potential efficiency of ECOSEL must acknowledge at the outset that unlike most PES schemes, the tool is designed not to maximize bang-for-your-buck, but compensation to ES providers (and ES valuation as a corollary) (Rabotyagov et al. 2009).

Price discovery. Study 1 considered a number of reverse auction designs intended to induce landowners to reveal, or closely tether their bids to, private information: namely, their opportunity costs of implementing a non-financially-optimal management plan.

Box 2: Vickrey auctions create a strategic dilemma with price disclosure as a weakly dominant solution

Suppose that bidder *i*'s opportunity cost is c_i and, and *i* contemplates submitting a bid such that $b_i < c_i$. The value of the lowest bid b' submitted by any other bidder is unknown to *i* , so three outcomes are possible:

(1a) $b' < b_i , c_i$ (2a) $b_i < b' < c_i$ (3a) $b_i , c_i < b'$.

In scenarios (1a) and (3a), bidding c_i rather than b_i would not have changed the outcome: lose and win, respectively, receiving b' in the latter case. In scenario (2a), however, *i* wins, but the compensation *i* receives is less than *i*'s opportunity cost, which would have been avoided if *i* bid c_i rather than b_i. If *i* bids $b_i > c_i$, there are three possibilities:

(1b) $b' < b_i , c_i$ (2b) $b_i > b' > c_i$ (3b) $b_i , c_i < b'$.

In scenario (1b), *i* loses. In scenario (3b), *i* wins and receives b'. In scenario (2b), *i* loses, but would have won if *i* had bid c_i instead of b_i. Thus, *i* should bid c_i rather than another value b_i.

(Adapted by the author for reverse auctions from Levin 2004, p. 2)

One of the simplest and most intuitive variants is a sealed-bid auction employing the uniform first-rejected price rule: after bids are submitted and ranked, the auctioneer begins awarding contracts in ascending order until the budget is exhausted; winners are not paid their bid value, but that of the

[122] In the case of mechanisms using, e.g. uniform first rejected price rules, the intention may be to *reveal* the opportunity cost (price discovery), at the expense of paying some informational rent equivalent to the difference between the price of each winning bid and the price of the first rejected bid (Thorsen et al. 2018).

[123] This possibility is considered in the theoretical comparison with choice experiments below

first bid that was rejected (all winners receive at least as much as they bid, and probably more).[124] Does a seller participating in an ECOSEL auction also face a strategic dilemma in which the weakly dominant solution is to honestly reveal their opportunity costs, as in Box 2?

Interestingly, the answer is dependent the format of the auction: specifically, the disclosure of reserve prices (threshold costs). If reserve prices are *not* disclosed to bidders, then a similar logic applies: any attempt by the seller i to misrepresent their true opportunity cost c_i to set the reserve price at r_i where $c_i \neq r_i$ creates a potential outcome in which the sum of the bids b falls between them, that is, either (1) $c_i < b < r_i$ or (2) $c_i > b > r_i$ depending on whether c_i was inflated or deflated. In scenario (1), the seller could have received b (more than meeting his opportunity costs) but instead will receive nothing; in scenario (2), establishing an artificially low reserve price allowed the auction to succeed, but the seller will lose money implementing the winning management plan. In either case, the seller would have been better off being honest.

If reserve prices *are* disclosed to bidders, however, then this logic no longer applies. It is not a Vickrey auction because b' is no longer a random variable; a price signal has been sent. Disclosing the reserve price is akin to anchoring with an exorbitant initial ask in a bargaining process, bluffing in poker, or—perhaps more aptly—setting a public fundraising goal on a crowdfunding site and updating progress toward that goal in real time (Yang 2014; Pope et al. 2015; Kuo et al. 2018; Backus, Blake, & Tadelis 2019). In this case, the seller does not have a compelling incentive to be honest about their opportunity costs, and indeed, honesty is often counterproductive.

Tóth et al. (2010) explicitly conceptualize ECOSEL as a kind of crowdfunding; Rabotyagov et al. (2013) call it "a voluntary, decentralized market mechanism".[125] This invokes provision point mechanisms in public economics in that "goods will be provided only when the preset contribution level is reached" (Hu, Li, & Shi 2015, p. 332). At a glance, it seems to contradict findings from research in crowdfunding: the calculus involved in price- or goal-setting under these circumstances lies outside the scope of this thesis, but for the purposes of the present discussion, it is sufficient to note that it is far from trivial and only loosely tethered to actual cost (Burtch et al. 2016; Zvilchovsky, Danziger, & Steinhardt 2018; Dai & Zhang 2019; Chakraborty & Swinney 2020; Argo et al. 2020).

At a glance, there is clear trade-off implicit in deciding whether to disclose reserve prices to bidders. Disclosure removes a strategic disincentive for the seller to attempt to extract informational rents by inflating opportunity cost claims. Declining to disclose opens the door to scenarios in which auctions result in unexpected outcomes, including extremely discouraging failures: imagine a community coming together to learn the auction mechanism, spending months fundraising to preserve a local forest, and engaging in multiple bidding rounds, and taking pride in the amount of money raised—only to discover at the end that they failed to come anywhere close to meeting the reserve price, bidding has closed, and the harvest will take place as planned.[126] Without clear goals, crowdfunding is risky at best. Since ECOSEL's model is oriented toward generating the highest ES provision price regardless of landowner costs, it seems likely that reserve prices would be disclosed.

Feasibility of rent-seeking. So far, this discussion has only engaged with the question of whether a landowner, as a rational profit-maximizer, would *want* a reserve price to be set well above their true opportunity costs. Under the most likely design of the ECOSEL game, the answer is yes. But would it be *feasible* for a landowner to seek informational rents by inflating prices in practice?

Answering this question depends on the execution of a process that Tóth et al. (2010) and Rabotyagov et al. (2013) gloss over: the interaction between the consultant and the landowner to collect the data needed to build optimization models, generate the Pareto frontier, and select ES bundles to put up for auction.[127] If reserve prices will be disclosed (as seems likely), the perceived

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[124] Referring to the Vickrey format; forward auctions often say *second-price* in place of *first rejected price*.

[125] Rabotyagov et al. (2013) also suggest that lower reserve prices are desirable for landowners because they are more likely to attract bidders, but no support for this claim is offered.

[126] Or, alternatively, that they dramatically exceeded the reserve price: bidders may be willing to make monetary sacrifices to preserve a forest, but not to simply enrich the forest owner. There is a case to be made that an ethical imperative exists to immediately inform bidders when the reserve price has been met.

[127] Tóth et al. (2010) simply note that the landowner would provide growth and yield data to feed the optimization models.

legitimacy of (and thus level of participation in) the auction turns on the community's level of trust in the consultant's endorsement that reserve prices are reasonable.[128] Needless to say, if bidders perceive themselves as making painful monetary sacrifices for no reason other than padding the landowner's margins as a valued natural area is held hostage, the outcome is likely to be less than ideal.[129]

Either the consultant will rely on the landowner to contribute data for the optimization model, or not. If the landowner does provide data, then (assuming that the consultant is not interested in colluding) the landowner would need to deceive the consultant in order to inflate their opportunity costs. The risk to the landowner associated with providing false information is elevated if the model has more variables and if the landowner is less familiar with optimization methods. This is because the landowner can only manipulate input data, while reserve prices are based on optimization outputs, which can include counterintuitive results due to interacting variables or constraints (which is why models are needed in the first place).

For a landowner with competence in optimization, however, some simple modifications could be expected to produce higher reserve prices in most scenarios where the financially optimal prescription is to harvest more, sooner, and the landowner is seeking compensation for foregone or deferred timber revenue (assumed to be the base case for the ECOSEL approach). For instance, increasing the discount rate—which the landowner might do by claiming access to a higher alternative rate of return, or increased exposure to a source of risk—typically shortens the financially optimal rotation length, which would inflate the expected opportunity costs of delaying a harvest. Similarly, it is difficult to imagine a scenario in which inflating expected sales prices would not increase opportunity cost estimates; this might be done by claiming that the landowner expects to outperform average market prices because of the high quality of his sawlogs or access to a buyer with special requirements, for instance. It would be difficult to manipulate input data in order to produce a *specific* increase in reserve price, but imprecisely padding the figures at the optimization stage seems feasible.

What if the consultants conduct their own independent assessment and modeling, eliminating any opportunity for the landowner to inflate reserve prices at the optimization stage?[130] Even if technically possible (e.g. available and appropriately-calibrated growth-and-yield models, granular historical market price information, etc.), an independent assessment would significantly increase transaction costs and could reduce landowner willingness to participate. For the purposes of discussion, let us assume that these costs are not prohibitive. Landowners would still have an opportunity to inflate opportunity costs after the optimization stage. Possible justifications are plentiful: the model has underestimated my costs for compliance monitoring, conducting thinning operations is more expensive in this area, I expect to receive higher sales revenue, and so forth.[131]

In the face of sunk costs for assessment and modeling, the landowner would have leverage (presenting a take-it-or-leave-it ultimatum would likely not be a sustainable policy for ECOSEL consultants), although making adjustments to reserve prices *after* optimization might at least anchor them in reasonable territory. In any case, it is unlikely that reserve prices would be imported raw from the Pareto frontier: adjustments would have to be made for expected incidentals, and certification, inspection, monitoring, maintenance, and perhaps even an entirely subjective premium to cover the landowner's own risk disposition. Many of these could be independently verified (e.g. based on personal communications or private sales records), but would it be feasible—let alone worthwhile—for the consultant to function as an auditor and investigator in addition to a technical advisor?

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[128] In the case of the Portugal case study, the role of the consultant will be played by university faculty with a long history of research in the study area, so trust is likely to be high.

[129] Reserve prices for multiple baskets could also be met, in which case the driver of additional bidding would be groups' competing visions for the area under auction, not a big community rally around the bundle deemed most likely to win and save the forest (or save the sawmill, as the case may be).

[130] The concern raised in this paragraph is admittedly mostly academic. Even if opportunity costs could be rigorously determined in this manner, the fact that this is rarely—if ever—done in conservation procurement programs is an indication that expense and effort required to do so is likely prohibitive in practice. Once again, reverse auctions exist specifically to overcome this information asymmetry without performing such costly independent assessments.

[131] Prices are not binding until the auction, so landowners who massaged input data at the optimization stage and received an unsatisfactory output could also use this opportunity to make further adjustments.

Collusion, transaction costs, and policy interactions. In reverse auctions, collusion occurs when bidders (sellers) strategically coordinate offers to secure higher compensation, or underbid to win a contract (Study 1, Study 2).[132] A number of factors can elevate the risk of successful collusion, including scenarios where only a small number of offers will be rejected, a few closely-connected actors control a large share of the market, and so forth. There is some evidence that the use of uniform pricing and multiple rounds can increase the risk of collusion (ibid.; Schilizzi 2017; Banerjee et al. 2019). Collusion is considered undesirable for the principal because it involves interactions that occur outside the bounds of the auction game, which tend to undermine the efficiency of contract allocation.

ECOSEL, however, utilizes multiple bidding rounds specifically to enable to bidders (buyers) to coordinate, because its output is a winning basket, not a winning bidder. Since it is designed to maximize seller profits, overpayment is not considered problematic (Rabotyagov et al. 2013). So what might collusion look like in an ECOSEL auction?

As mentioned above, one possibility might involve cooperation between consultant and landowner to inflate opportunity cost estimates and thus establish artificial reserve prices—this would constitute a kind of out-of-bounds manipulation of the game itself, rather than a strategic behavior within it. Although it might raise questions about the legitimacy of the game, it would not necessarily produce an outcome that could not be achieved through its normal functioning, since reserve prices do not establish a target, but rather a minimum acceptable payment. Transaction costs in ECOSEL are likely to be quite high, if only because additional analyses are required (modelling, optimization).[133] Depending on implementation, an ECOSEL-based approach could shift the distribution of transaction costs: e.g., a public body might assume the costs of data collection, defining management alternatives, and optimization.[134] If individual bidding caps or eligibility requirements are imposed, then ineligible bids must be filtered out. Regardless, transaction costs borne by landowners will likely be bundled into the reserve price and passed onto bidders. In many cases, however, direct compliance monitoring costs could be relatively low after a successful ECOSEL auction. Pigouvian PES usually involve interactions between owners and a government agency that do not attract much public attention, but community involvement a successful ECOSEL auction would likely be high. Local stakeholders would have a vested interest in reporting violations, so social control could replace monitoring by state employees or contractors (e.g. Secco, Vidale, & Pettenella 2010; Gorriz-Mifused et al. 2017)

In ECOSEL, baskets are mutually exclusive but also non-excludable once purchased. In this incentive structure, the relevant consideration from an efficiency perspective is probably not collusion, but rather free riding. Free riding occurs when someone declines to make a contribution corresponding to the value they place on a bundle, because they expect to enjoy the benefits of the bundle whether they contribute or not. In a mock ECOSEL auction, Tóth et al. (2010) provided participants with real dollars that they could either keep or bid, and interpret the finding that 42%-65% of these dollars were used in auctions as evidence that free riding was low.[135]

Summary

ECOSEL uses an auction-like format designed to generate high prices for ES bundles that have been formulated so that trade-offs between component ES are Pareto efficient. However, as the basis of a user-financed PES scheme, ECOSEL has some characteristics that may be undesirable.

Lesson: Reserve prices result from negotiations between the landowner and consultant.

Lesson: The consultant's endorsement is likely to be the primary source of the reserve prices' legitimacy, so setting an obviously unreasonable price would be damaging to community trust and the auction's prospects for success.

Lesson: If reserve prices are not disclosed in the auction, landowners have an incentive to honestly communicate their opportunity costs. However, nondisclosure is likely to reduce the auction's probability of success.

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[132] Collusive underbidding may be more attractive under uniform pricing rules (Polasky et al. 2013).

[133] Recall that transaction costs are likely to be significantly influenced by the data provenance (e.g. how much is sourced from the landowner's own records, and the degree of scrutiny applied to it by the consultant).

[134] These costs typically lie with landowners in reverse auctions.

[135] Range reflects spending levels in different treatment groups (i.e. sessions with different rules).

Lesson: If reserve prices are disclosed, landowners have an incentive to inflate them to extract informational rents; as (potentially) the best-informed agent, landowners would enjoy a wide latitude to do so both before and after the optimization stage.

Lesson: Concerns about opportunity cost inflation are somewhat academic, insofar as ECOSEL is designed to generate high prices if used as the basis of a PES scheme. If cost-effectiveness is a primary concern, ECOSEL would not be a tool of choice in its current form.

5.3.2 ECOSEL as a decision tool: equity and ideology

Although the argument for choosing either social surplus or opportunity cost as the basis for calculating an ES payment can be pragmatic and context-sensitive, it can also be ideological. In the case of ECOSEL, it may be useful to probe the ideological presuppositions of the design premise:

> We also like to emphasize that ECOSEL is a voluntary mechanism that provides a platform for both potential sellers and potential buyers of [ES] to freely express their *intrinsic motivation*. It gives more freedom to individuals to influence forest management decisions on public or private lands via monetary contributions. [...] In contrast to regulations that can reward provisions or penalize non-provisions of [ES], it can be argued that ECOSEL is an intervention that *crowds in* motivation (p. 102).[136]

This series of claims deserves some scrutiny. Under certain circumstances and for certain stakeholders, they may be plausible, but it is easy to imagine scenarios where they are not. For wealthier stakeholders who belong to social networks with ready access to capital, a tool which enables the purchase of a desired landscape composition may well lead one to feel that their freedom has expanded. Less affluent stakeholders with limited disposable income, however, may feel more empowered by participatory management, stakeholder consultations, and a robust regulatory structure than by decision-making tools in which the extent to which one's voice is heard is directly proportional to the depth of one's pockets. It is easy to read the value claims made in support of ECOSEL, like the one quoted above, as appealing to a kind of *laissez-faire* logic where freedom and efficiency blossom as the regulatory scope recedes.

A rebuttal might point out that ECOSEL is intended to be used when these alternative methods are not available: after all, the tool assumes an initial property rights allocation in which management decisions rest entirely with the landowner, who may not by inclined to conduct any kind of stakeholder consultation in the absence of a monetary incentive. This logic, however, imposes a kind of pull-yourself-up-by-your-bootstraps expectation on stakeholders: if you want to influence management, nothing is stopping you from freely expressing your preference by setting out to build a coalition of donors to finance it; if your coalition is too small, then the failure is yours. If anything, this should lead to a crowding *out* of landowners' intrinsic motivation to produce non-market ES: ECOSEL is an opportunity for landowners to divest themselves of stewardship responsibility, because it is the stakeholders' job to compensate them for ES production.[137] Constructing monetary expenditure as free expression in this way also neglects the myriad structural factors that influence the ability of individuals and communities, including those with a real stake in management outcomes, to access capital—issues that the modern fields of social forestry and participatory governance are dedicated to grappling with.

The idea that an approach like ECOSEL could magnify the disproportionate sway of economically powerful interests over ES provision is not an academic complaint. In some NOBEL case areas, key stakeholders (e.g. forestry officials) ruled out conducting a non-experimental ECOSEL-style auction on the grounds that it would be perceived as unacceptable and contrary to local cultural values, potentially creating the impression of holding public goods hostage. Nor is it an

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[136] No justification for the claim that ECOSEL *crowds in* motivation is offered. Crowding out of intrinsic motivation to engage in conservation is a much-researched (and at times controversial) concern associated with PES (Moros et al. 2019; Akers & Yasué 2019).

[137] Tóth et al. (2010) suggest that stewardship-minded landowners could choose to subsidize the reserve prices to encourage participation. Of course, the notion of *crowding out* does not suggest that intrinsic motivations are eliminated entirely, but just that they are partially replaced by other motivations for stewardship.

exclusively European concern: worries regarding wealth dominating outcomes were also raised by stakeholders in qualitative research surrounding ECOSEL in the US:

> [ECOSEL] represented a conflict between local ownership and control with concerns about the potential for resources and outcomes to be effectively "bought" by better-financed outsiders [...] participants agreed that local stakeholders might not have the dollars to bid on management plans, thus creating the potential for corporate interests and other wealthy outsiders to influence decisions [...] there was an apprehensiveness [...] that big money was going to have the power to dictate what kinds of management plans won [...] (Roesch-McNally et al. 2016, pp. 327-28).

These are salient issues for prospective participants, but there is no obvious reason why they could not be addressed by introducing additional restrictions into the auction game. Tóth et al. (2010) test different formats in mock auctions. In one variant, all participating bidders were given the same amount of money to spend in the auction ($10). In another, participants represented organizations and were allocated funds proportional to the budgets of those organizations (pp. 109-10).

Box 3: Hypothetical application of ECOSEL in Brazil

Scenario. A landowner has recently obtained permission to begin intensive harvesting operations in a primary forest area adjacent to a reservation for an indigenous group, and decides to pursue an ECOSEL-style auction in hopes of raising funds to offset foregone income if a much lighter harvest is performed. The primary stakeholders (members of the indigenous group) do not have access to sufficient capital to meet the reserve price, so the landowner decides to collaborate with an NGO, which produces a viral marketing campaign. The campaign generates bids from around the world, meeting the reserve price for the most expensive basket (conserve everything) many times over. The landowner signs a private contract with the NGO prohibiting forestry activities in the parcel for a period of thirty years, and the total donations placed on the winning bid (less the auctioneer's fee) are transferred to the landowner's account. The landowner uses this money to purchase several tracts of land in the same general area, which are much larger than the first, and begins the process of securing permission to conduct harvesting activities there. The landowner also uses the original parcel to sell carbon credits, further increasing his profits. Due to compliance monitoring requirements, the indigenous group's access to the original parcel is significantly curtailed.

Analysis. In this scenario, the largest direct stakeholder category—the local indigenous group—is cut out of the decision process by the ECOSEL application. Although the mechanism technically succeeded, due to leakage, the social and environmental costs were higher than under the status quo scenario (negative additionality). Had the marketing campaign transferred money directly to the NGO or the indigenous group rather than the landowner, it may have been possible to purchase the original parcel while minimizing leakage. The landowner further increased his profits by double-dipping with a government-run offset scheme.

Placing a cap on the amount of money individuals can spend in the auction might be one way to partially alleviate concerns that the outcome could be "bought" by wealthy interests (although social network effects would still provide an advantage), but what about the fear that non-stakeholder bidders could tilt the outcome, as in Box 3 above?

Like caps on individual contributions, limiting the pool of potential donors is not exactly a crowdfunding best practice, and increases the risk that the reserve price is not met and the auction fails. This risk may be tolerable if it safeguards the legitimacy of the auction outcome, but determining eligibility in a way that is transparent and acceptable to the community is not a trivial task. Using the ECOSEL auction approach as a crowdfunding mechanism could require auction managers to make complex, murky, and potentially controversial trade-offs between participation, access to capital, and perceived legitimacy on a case-by-case basis. These issues are commonly encountered in any stakeholder consultation or participatory approach, but they may be made more acute by the competitive nature of the ECOSEL game.

Tóth et al. (2010) frame the basic idea of sending price signals in the course of a multi-round ECOSEL auction game as follows: it enables those with limited purchasing power "join forces with others to raise dollars [... to make an alternative succeed even if the reserve price is high]." (p. 112).

But if they can join forces, they can also be overwhelmed: the smaller the coalition, the easier it is to form—but the minimum membership required for a coalition to succeed is inversely proportional the purchasing power of its members. On the one hand, ECOSEL raises the possibility of a new funding stream that could conceivably allow stakeholders to influence land management and achieve outcomes that would otherwise be unavailable. On the other, there is a very simple reason that placing low-income stakeholders in bidding wars against wealthy interests is not a common approach to participatory decision-making: most people are unlikely to find it very fair.

Box 4: Hypothetical application of ECOSEL in France

Scenario. A timber company plans to harvest several dozen maritime pine stands near Cap Ferret, southwest of Bordeaux. Several stands are located near an affluent community, and others are situated along a roadway that receives large amounts of traffic during the tourist season. Activists raise awareness of the harvesting plan and it becomes a local controversy. Meetings between the company, local interest groups, tourist industry representatives, and the municipal government reveal persistent disagreements about the feasibility of alternatives, so ECOSEL consultants are hired. A Pareto frontier is generated and bundles are selected for bidding. A local sawmill makes an effective public appeal, arguing for the importance of the wood products industry for the local economy. In the end, the winning bid staggers harvests over the course of twenty years, during which time the company will harvest a few, more remote stands slightly before the financially optimal rotation. The company's reserve price is barely exceeded, so it is indifferent to the change in management plan at the time the contract is signed, but benefits from positive PR. Over the course of the next decade, timber prices significantly outperform forecasts, and the company benefits from having more standing volume than it would have under the status quo scenario. Meanwhile, the community avoids disruption to its recreational activities and the tourism industry protects the aesthetic value of the landscape from an abrupt disturbance.

Analysis. In this scenario, direct stakeholders were able form a coalition and use ECOSEL to influence forest management in a way that negotiations alone failed to achieve. It allowed a local community with shared interests to coordinate, make explicit trade-offs between multiple objectives, identify a compromise management plan, and generate the funds necessary to persuade the landowner to implement it.

The scenarios described in Boxes 3 and 4 above both use ECOSEL as combined decision-making and funding tool in PES schemes, which is the ambition suggested by Tóth et al. (2010) and Rabotyagov et al. (2013). The following subsections explore potential ECOSEL applications if the link between its funding and decentralized decision-making functions is weakened.

5.3.3 ECOSEL as a valuation tool: comparison to choice models

The previous sections offered a critique of ECOSEL's potential as a crowdfunding mechanism for PES, identifying several potentially undesirable characteristics relating to cost-effectiveness, equity, and inclusiveness. But ECOSEL has a number of interesting features as well, such as decision tasks involving trade-offs, a structured format for large numbers of stakeholders to form coalitions around efficient alternatives, and monetary sacrifice. Tóth et al. (2010) suggest that even if an auction fails, it can still offer "tangible, transaction-based data" to guide future interventions:

> [Even if this data] suggests little or no [WTP], it can be helpful to policymakers in identifying how much regulatory intervention is needed to promote these services to assure long-term social welfare (p. 114).

This section considers potential applications of this unique tool that do not involve using it primarily as a funding mechanism. Instead, it examines ECOSEL in relation to more traditional tools for soliciting preferences and inferring ES values—namely, stated preference methods, with an emphasis on choice experiments (CE).

ECOSEL and choice models

Valuation tools (techniques for making evidence-based inferences about the value that people place on non-market goods and services) might be employed prior to implementing a subsidy to set budgets or determine an amount of conservation that would maximize social surplus, for example.[138]

[138] As indicated in the section on ECOSEL's efficiency concerns above, ECOSEL does not offer an obvious means of inferring social surplus apart from establishing a lower bound, since social surplus does not depend on the value of bids themselves (as in Eq. 1).

The case of ECOSEL is different, because it adopts a forward auction-like format, requiring stakeholders to make trade-offs between different combinations of ES with price information. In this regard, there is a strong resonance with choice modelling (CM).

Although plenty of modifications exist, the central conceit of CM arguably rests on Lancaster's theory of value: that any good or service can be represented as a conglomerate (i.e. bundle or basket) of *attributes* which have different *levels* (Lancaster 1966; Louviere, Hensher, & Swait 2000; Nocella et al. 2012).[139] An attribute might be recreational trails, and its level might refer to the extent of those trails. If the level of an attribute changes, then the value of the good as a whole changes: adding 50km of new hiking trails might increase a valley's overall recreational value. Choice models are used to estimate the value of these changes in relative or absolute terms, enabling inferences regarding determinants of choice (Louviere et al. 2000; see e.g. Thiene et al. 2012, 2017). The marginal value of an attribute change is not endogenous to the good itself, but has to do with both individual preferences and the attributes that constitute that individual's alternatives:

> Suppose [...] that the consumer is assigned a specific discrete alternative. Given this alternative [and economic variables determining the budget constraint], the consumer will choose leisure and consumption levels of remaining goods to maximize utility subject to budget and time constraints. The level of utility attained is then a function of the attributes of the discrete alternative, observed consumer characteristics, a uniformly distributed random vector characterizing unobserved consumer characteristics, and the economic variables that determine the budget constraint (McFadden 2000, p. 338).

In *discrete choice experiments* (CE), agents are presented with a *choice set*, typically in the form of a matrix. Each row corresponds to an *attribute*, and each column to an *alternative*, with one alternative corresponding to the status quo, do-nothing option (Scarpa & Rose 2008; Riera & Signorello 2016; see e.g. Masiero et al. 2018).[140] The alternatives are differentiated by their attribute levels. Decisions like the number of alternatives to include in a choice set and whether to label alternatives generically (Option A, Option B) or descriptively (Conservation option, Recreation option) are design variables about which approximate but accepted practical guidelines are available, although research is ongoing (Riera & Signorello 2016, pp. 24-26). It is generally agreed that CE can produce welfare-consistent estimates of the marginal value of changing attribute levels and not just relative rankings, since actual values can be extrapolated based on the inclusion of the status quo option (Kangas, Horne, & Leskinen 2010; Ahtiainen et al. 2015).

Presented with a choice set, agents are asked to select one alternative—alternatives are *discrete*—requiring them to make trade-offs. This is called a *choice task.* It is generally not feasible to present respondents with every possible combination of attribute levels (complete factorial design), although this is preferred where possible: allowing the analyst to "investigate parameter estimates for the main effects on utility and for all the possible interactions between them" (Riera & Signorello 2016, p. 25). However, just four attributes, each with only four potential levels, generates 4^4 or 256 possible combinations; at three alternatives per choice task, respondents would be asked to perform a battery of dozens of tasks, and the number of realistic alternatives (as well as the number of attributes defining them) may be much higher in practice (Scarpa & Rose 2008; Bech, Kjaer & Lauridsen 2011; Lyu 2017). The cognitive burden posed by overly large questionnaires can fatigue respondents, introducing contradictory results and eroding the quality of the resulting data. For instance, respondents might use simplified decision rules (*choice heuristics*) which do not correspond to the basic assumptions underpinning the standard model that provides the basis for estimations:

> One of the heuristics that has been identified in the literature is the tendency to ignore one or more of the attributes describing the alternatives [attribute non-attendance, ANA.] [...] There is also growing evidence that, when ignored, ANA may lead to biased

[139] Marschak's (1960) application of Thurstone's law of comparative judgment into economic theory to propose the random utility maximization (RUM) model is another close contender (McFadden 2000).

[140] The row-column assignment in this example is arbitrary.

> coefficient estimates, and hence biased estimates of willingness to pay (Thiene, Franceschinis, & Scarpa 2019, pp. 835-56).

One approach to mitigating the problems associated with choice scenarios with a large number of attributes or excessively long questionnaires involves carefully constructing choice sets using experimental design theory (Scarpa & Rose 2008).[141] For instance, fractional factorial designs are commonly used to achieve orthogonality (no correlation between variables) (Riera & Signorello 2016). When the experimental design is too large, it may be possible to "block" the choice sets, so that each respondent only evaluates a defined subset of them, although this requires a much larger sample.[142] Thiene et al. (2019) offer a useful illustration of how reducing the number of attributes impacts the blocking of choice tasks into groups: with ten attributes, the efficient design consisted of 72 choice tasks blocked into 6 groups; with six attributes, 24 choice tasks were blocked into three groups; and with four attributes, only 12 choice tasks were produced, negating the need for blocking (p. 845). Note that determining and measuring experimental design efficiency and specificity are not trivial tasks, and although multiple algorithms have been proposed to facilitate design optimization, "there does not exist much theoretical guidance as to which method should be employed" in a given context (Scarpa & Rose 2008, pp. 267-68).

Preference- (rather than choice-) based methods may also be used in valuation, although the design and mode of inference differs somewhat. *Contingent ranking* is similar to CE, except that agents are asked to rank alternatives in order in preference rather than to make a single selection from a set of discrete alternatives (Riera et al. 2012; Salehnia et al. 2018). Thus, contingent ranking provides the researcher with an idea not only of the first-choice selection, but also of second- and third-ranked preferences. In *contingent rating*, choices are not discrete (Shoyama & Yamagata 2016; Riera & Signorello 2016).[143] Rather than side-by-side alternatives, agents are simply presented, one by one, with a sequence of alternatives, and asked to rate their preference for each (e.g. on a scale of 1-10). Each alternative is rated independently so no direct comparisons are made, and a null alternative is typically included "to ensure welfare consistent estimations" (p. 8).

As described by Tóth et al. (2010), ECOSEL combines elements of CE, contingent rating, and contingent ranking, if perhaps in a somewhat haphazard way. Setting aside for the moment the elements of communication, strategy, and collective decision-making, consider the structure of the decision to be made by an individual bidder in just the opening round. As in a choice experiment, participants face a menu of discrete ES bundles: Lancastrian goods composed of the same set of attributes and differentiable by the levels of those attributes. Each individual bidder faces a preference task is not unlike contingent rating: instead of selecting a value on an abstract numerical scale, a bidder can, if they choose, "rate" each alternative independently by placing a quantity of money proportionate to their relative preferences. Because the choices are discrete and only one will be selected, there is also a link to contingent ranking. The first round of ECOSEL bidding, at least under the conditions assumed here, thus resembles something of a hybrid between a choice- and preference-based contingent valuation method. The problem is that it is not incentive compatible: participants may not bid their true value at this stage for strategic reasons (e.g. sending a signal, observing other bids, attempting to free ride, etc.). The literature on experimental design may help guide bundle selection decisions, but only to a limited degree (e.g. blocking choice sets is unlikely to be feasible in an ECOSEL game).

Some studies have framed stated preference scenario prompts as auctions. Kim-Bakkegaard et al. (2017), for instance, conduct a contingent valuation (CV) experiment testing the effects of framing the task as a reverse auction. All participants were presented with a scenario involving the possibility

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[141] More advanced techniques may involve modelling sources of bias like ANA, as in Thiene et al. (2019). However, evidence-based practical guidance on the experimental design side, such as identifying the maximum number of choice sets agents can evaluate, is limited (Scarpa & Rose 2008; Rieri & Signorello 2016).

[142] Reiri & Signorello (2016) give the example of a fractional factorial design with 36 choice sets "blocked into 6 blocks with each respondent facing 6 choice sets" (p. 26).

[143] Some typologies draw a stronger contrast between these methods, noting that CE and contingent ranking involve making exclusive choices, whereas contingent rating is located in a separate "preference-based" subcategory of multi-attribute valuation methods (Merino-Castello 2003; Vega 2011; Asioli et al. 2016).

of being offered a voluntary contract in which they would receive a guaranteed payment for ceasing productive forestry activities on a parcel, subject to compliance monitoring. A control group completed a standard CV task in which they were asked to state the minimum payment that would persuade them to accept such a contract. In the treatment group, however, the problem was framed as a uniform first-rejected price reverse auction.[144]

In addition to describing the basic rules of this type of auction, the interviewer also explained how they translated into incentives[145]:

> The results of the split-sample test suggested that auction framing effectively reduced both mean and sample variance WTA. This lends support to the idea that auction framing was likely [...] incentive-compatible, and to the recommendation to build a credible context around the agent's answer that encourages truth-telling (p. 57).

To be clear, is a straightforward CV study with auction framing, whereas this section is primarily interested in the inverse—taking lessons from stated preference methods and applying them to the design of an ECOSEL-style game or the interpretation of such a game's results. This distinction is important: ultimately, stated preference methods like those used by Kim-Bakkegaard et al. (2017) rely on making inferences based on hypothetical scenarios and hypothetical responses.

ECOSEL and experimental auctions

The core methodological value claim associated with experimental auctions (EA) is that they consist of actual, non-hypothetical transactions, so WTP can be observed directly (Canavari et al. 2019).[146] As Corrigan et al. (2011) note, this has two major benefits:

> Conceptually, certain types of auctions are incentive compatible [...] Practically, the analyst receives bids from each person, which bypasses the need to formally specify a functional form for the utility function or [...] use econometric modelling to derive [WTP] (p. 97).

Efforts to theoretically integrate, and empirically compare, choice experiments and auctions have represented a niche area of research for roughly fifteen years, including some perplexing results like dramatically different valuations produced by CE and EA despite non-hypothetical incentive-compatible designs in both (Lusk & Schroeder 2006; Gracia et al. 2011; Su 2011; Grebitus et al. 2013). Lusk and Schroeder (2006) and Gracia et al. (2011) use the non-hypothetical real choice experiment (RCE) method, finding auction bids to be lower than valuations derived from RCE, while Su et al. (2011) find average auction bids to be significantly higher than WTP as calculated by CE.[147] Xie and Gao (2013) also find auctions to produce lower WTP than those found by CE or CV methods. Overall, however, results seem to be mixed.

Although the notion of simply observing transactions in an EA is appealing in its simplicity and directness, results obtained from EA are often complicated by a number of factors still under investigation, including cognitive ability, personality, sampling and representativeness, and emotions associated with game-like interactions in an experimental setting (e.g. desire to win or send a social signal) (Canavari et al. 2019). Debates surrounding the external validity of EA relative to other valuation techniques are ongoing.[148]

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[144] Vedel et al. (2015) point out that incentive compatibility "usually implies a design that involves avoiding the use of the information obtained about the specific agent to extort all possible rents." (p. 27).

[145] This explanation emphasized that underbidding would not affect the "cut-off price nor the probability of getting a contract, but would imply that agents would not cover their true costs should agents win a contract [... so] truth-telling is a weakly dominant strategy" (p. 53).

[146] For perhaps the seminal comprehensive treatment of EA in applied economics, see Lusk and Shogren (2017).

[147] For Lusk and Schroeder (2006), bids submitted in the fifth round of the auction were much closer to CE-estimated prices than those submitted in the first.

[148] It is important to emphasize at this juncture that despite the occasional use of phrases like "ECOSEL-style auction" in this thesis, the ECOSEL tool as described by Tóth et al. (2010) is *not* an experimental auction, but a competitive subscription public good game using elements of an auction format. Experimental auctions involve competition between bidders, not bundles: in an auction, among of a group of bidders, one submits a winning bid, which amounts to purchasing the product.

Most bundles in an ECOSEL-style game are hypothetical, but EA are limited to extant, non-hypothetical products.[149] Alfnes et al. (2006) try to close this gap by proposing a procedure for inferring expected EA results for hypothetical products using stated choice surveys.[150] The procedure involves carrying out an experimental auction involving non-hypothetical products, conducting a CE featuring same set of products plus an additional hypothetical one differing in some attribute. Values are estimated from CE data using standard modelling approaches; correlates associated with respondent demographics are estimated and then applied to auction participants; and a calibration function is used extrapolate auction results to the hypothetical product.

The use of multiple bidding rounds is central to the ECOSEL approach, but it is controversial in the case of experimental auctions. Corrigan et al. (2009) compare WTP estimates derived from a repeated non-hypothetical open-ended CE and a multi-round EA: value estimates from the former remained stable, but those from the latter grew >200% in five rounds (p. 837). These findings are consistent with previous results indicating that multi-round auctions in which winning bids from a previous round are disclosed tend to drive up bid values; whether this increase indicates bias or growing willingness to disclose one's true price is controversial, but multi-round experimental auctions may be falling out of favor among researchers (ibid.; Canavari et al. 2019).

The incentives in an ECOSEL game are different than those in an experimental auction, but the format much the same.[151] Even so, this is a case where the distinction between auctions and public goods subscription games matters, as the driver of bidding and bid increases in ECOSEL is related to achieving a goal with non-excludable benefits under game conditions rather than just honing in one's own valuation. In a multi-round experimental auction with price feedback, a bidder *B* compares their bid to the current top bids directly. If *B*'s bid is substantially higher than the second bid, *B* might safely reduce it in the next round to obtain the product at a lower price; if *B*'s bid is not winning, *B* risks not obtaining the benefits associated with the product, and may adjust their bid upward.[152] In ECOSEL, *B*'s bid amount is compared with an aggregate total, and *B* may enjoy the benefits of the product even if *B* does not bid at all (free riding).

Summary

The connection between EA and CM has been subject to extensive study, even if reasons for discrepancies between WTP elicited by these methods are not particularly well-understood yet. ECOSEL has clear parallels to both CM and EA. However, the structure of ECOSEL is not incentive compatible at any stage for either sellers or buyers, and its format contains a number of potential confounders connected to social signaling within its competitive/collaborative dynamics. It may be possible to use econometric approaches to make valuation inferences from ECOSEL data if bundles are selected with this in mind (e.g. using fractional factorial design) and if data is taken exclusively from the opening round of bidding, but these methods probably cannot be imported directly from CM or EA without substantial modifications to the ECOSEL procedure. Exploring this possibility would require focused experimental research. If rigorous ES valuation is the goal, ECOSEL is likely to be inferior to CM. Experimental auctions are not applicable valuation problems involving non-excludable public goods or hypothetical ES baskets.

5.3.4 ECOSEL as a public good game

Despite its formal similarity to auctions, ECOSEL technically resides in a different theoretical category, with its own rules and incentive structures. A more appropriate body of theory is probably that dedicated to public good games. Tóth et al. (2010, 2013) and Rabotyagov et al. (2013)

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[149] Revealed and stated preference methods are commonly used to evaluate hypothetical benefits.

[150] Experimental auctions also typically rely on a small group of participants, making representativeness an issue. The ECOSEL game can accommodate large numbers of participants—another way in which it resembles hypothetical stated preference methods more than most experimental auctions (ibid.).

[151] Corrigan et al. (2011) suggest that the relevant dynamic involves repeated bidding, not price feedback.

[152] Experimental auctions usually utilize excludable and non-hypothetical goods, but see e.g. Loureiro et al. (2012) for a discussion of experimental auctions applied to quasi-public goods (i.e. goods with some excludability issues whose cost of provision increases "less than proportionally to the number of individuals who benefit from it") (p. 8).

characterize ECOSEL as a voluntary public good game that is *competitive* and *discrete* (because bundles are mutually-exclusive units and participants compete to support their preferred bundle), with *refundable contributions* (provision point mechanism), in which bidders have heterogeneous preferences and each bidder has incomplete information about the preferences of the others.[153]

Rabotyagov et al. (2013) attempt to situate ECOSEL in relation to the literature on public good subscription games, but make clear that previous research on this topic is only partly extensible to ECOSEL: they report making decisions about basic ECOSEL variables like reserve price disclosure and bidder communication in the absence of "sufficient guidance" from the literature (p. 307). Nearly a decade later, a literature search performed for the present report failed to shed much additional light on how to analyze the unique features of ECOSEL from this theoretical perspective.[154]

Contribution games (which do not feature refunds for insufficient contributions) occasionally show a tendency by players to overpay for goods, which Barbieri and Malueg (2008) classify as a transfer to the collector. However, in the case of ECOSEL this behavior seems to be driven by the desire to ensure a winning bundle and thus may not be desired by players. Menezes et al. (2001) find that subscription games create less free riding with incomplete information than contribution games. Threshold uncertainty often increases individual contributions (though not necessarily participation) in subscription games; there may be some trade-offs associated with reserve price disclosure, contribution amount, and free riding (Caplan 2016). Haller (2014) notes that most economists consider the noncooperative equilibrium outcome of subscription games to be inefficient and to result in public good provision at levels lower than the optimum.

The applied example with perhaps the greatest relevance to the Portuguese pilot is the Bobolink Project, which (on the demand side) combines crowdfunding, a provision point mechanism, proportional rebates, and a solicitation framing designed to match donors' marginal payment to the marginal benefit they receive from an additional "unit" of the ES (here, bobolink habitat area) (Chakrabarti et al. 2019).[155] On the supply side, the funds raised using this approach then constitute the budget for a reverse auction to procure the ES using a uniform price rule. Like ECOSEL, this highly innovative strategy allows donors to express their intrinsic motivation to support ES provision, and trades off ES provision scenarios against financial cost. Unlike ECOSEL, it seeks to ensure that donors' contributions are used cost-effectively and links contribution levels to outcome levels.

Could features of these two models be combined to improve one another? Introducing trade-offs between multiple objectives—and thus a decision-making function—into the framework of Bobolink exposes it to the same criticisms regarding equity and legitimacy that have been raised about ECOSEL above: different groups assign different priorities to different objectives, so more complex decision environments risk creating conflicts in which actors with more purchasing power have a decisive advantage. Introducing a procurement auction into ECOSEL, however, might improve its budgetary cost-effectiveness. Achieving this without dramatically increasing transaction costs would be challenging, but separating fundraising from payment may be feasible. However, it would require significant revisions to the mechanism to accommodate a variable area under contract and multiple landowners, and to exclude financial variables from the initial set of Pareto frontiers.[156]

5.3.5 ECOSEL as a structured participatory approach

In a scenario where bids are capped and the auction is not designed with the primary purpose of generating funds, it may be worth asking how important the element of monetary sacrifice is for the decision-making process. If an auctioneer is willing to forgo this element, but wishes to retain a highly structured and formalized decision-making procedure, then another rich body of scholarship

[153] Because the Pareto frontier is continuous, the goods are constructed as discrete mainly for practical reasons related to assumed provision efficiency and transaction costs (Rabotyagov et al. 2013).

[154] Almost certainly a failing of the author rather than the literature.

[155] The solicitation framing is based on Lindahl pricing, an approach which "establishes one level of the good with many individualized prices, such that the sum of the marginal payments across individuals just equals the marginal cost of delivering the last unit" (p. 3).

[156] This possibility is considered in Section 5.4.6 below.

may provide guidance: voting methods theory. After all, strip away the crowdfunding component from ECOSEL, and what is left is an interactive DSS with a voting functionality.

Systematically linking the literature on voting methods to modify the ECOSEL platform lies outside the scope of this thesis, but a brief consideration of some possibilities may be useful. If participants are each provided an equal sum to bid by the auctioneer as in Tóth et al. (2010) then the mechanics of the auction are not substantially different from a *cumulative voting* system, with the small exception that one cannot pocket one's allocated voting "points" to spend elsewhere (Young 1950; Nguyen et al. 2016; Algaba 2019). In cumulative voting, each voter distributes a fixed number of points among options (henceforth *candidates* in this section) in whatever proportion they wish, and the winning candidate is the one that receives the highest overall score (ibid.). The aim is to allow voters to express intensity of preference (or, alternatively, ambivalence) between multiple options. Cumulative voting is probably the system that most closely resembles ECOSEL in its original form (assuming that fixed equal funds are assigned to each voter) but a diverse array of possible systems may be available depending on situational constraints and objectives.

For instance, in place of a fixed cap, a *quadratic voting* method could be used in which a participant can purchase n votes for the price $€n^2$ (Pacquit 2019).[157] A game-theoretic analysis suggests that each voter trades the marginal cost of an additional vote against their judgment of the probability "that the vote will be *pivotal* in swinging the election" (Lalley & Weyl 2018, pp. 34-35).[158] In the case of ECOSEL, funds raised in this manner could either go toward meeting the reserve price for the winning candidate, with excess funds less some profit buffer returned to voters according to a predetermined rule (see e.g. Posner & Weyl 2014; Quarfoot et al. 2017). However, this would require the principal to choose between (a) anonymous votes and (b) preserving the rule that funds allocated to losing bids are refunded. It should be stressed that while quadratic voting is considered here as a *more* egalitarian approach to soften the competitive dynamics of ECOSEL, in the voting methods literature it is subject to strong criticism on the grounds that communities are unlikely to view as legitimate outcomes of processes involving vote-buying (Ober 2017; Laurence & Sher 2017).

If the monetary element is removed entirely from ECOSEL, then *ranking* or *positional* methods may be conducted; these can be thought of as simplifications of cumulative voting. As the name implies, voters are asked to rank candidates in descending order of preference, with a fixed score being assigned to candidates at each rank.[159] If multiple rounds are used, then candidates may be successively eliminated according to some predefined rules: commonly, either the candidates with the lowest aggregate score or those who appear in the first position with the least frequency are eliminated (*Hare rule*) (Pacquit 2019).[160] In *approval voting*, each voter can cast a vote for each candidate they find satisfactory, allowing the system to capture ambivalence between options but not relative intensity of preference (ibid.; Brams & Fishburn 1978; Emerson 2013).

This subsection has focused on possible designs that preserve some aspect of the "bidding" element of ECOSEL, a highly structured game for making group decisions. If the goal is consultation, however, then ECOSEL-style games might be incorporated into participatory workshops aimed at identifying consensus options rather than making binding decisions. A good example of the latter is the workshops carried out by Marques et al. (2019), who used Pareto methods to select optimal bundles at the level of a forest owners association, then decomposed the problem to so subregions could choose how to meet their contribution to the overall target, allowing trade-offs to be made collaboratively and across levels with input from different stakeholder categories.

As with the ECOSEL base case, all of the approaches discussed in this section will have to contend, one way or another, with the issue of defining participant eligibility in a way that is acceptable to stakeholders and likely to result in a process that is perceived as fair, transparent, and

[157] The argument for setting the value of the exponent is primarily economic (ibid.).

[158] For Lalley and Weil (2018), voice credits can be either positive or negative—allowing voters to vote for or against a given candidate.

[159] Scoring rules can vary, but the Borda count is a common option—although strategic decision-making may come into play if partial voting is allowed (García-Lepresta & Martínez-Panero 2002; Emerson 2013)

[160] In the context of sequential scoring rules (rather than multiple rounds of voting or runoffs), the Hare rule is sometimes referred to as *single transferable vote* (Lepelley & Valognes 2003).

legitimate. There is both an art and a science to delineating stakeholder groups for consultations and deliberations, and these processes can be—and frequently are—controversial. For instance, a seemingly innocuous choice like requiring an equal number of representatives from farming and forestry to participate could meet resistance from conservationists or tourism on the grounds that it doubles the influence of agricultural actors. The use of voting methods might simplify these decisions by eliminating the need to stratify stakeholder groups; however, it would still be necessary to define the constituency in a manner that local communities and direct stakeholders view as legitimate.

5.4 Menu of potential design modifications

As noted in Study 3, the Portuguese pilot demonstration has several unique features that set it apart from many of the situations discussed in this chapter. For instance, the ECOSEL application will take place experimentally rather than as a full-fledged PES scheme. Many participants are already familiar with trade-offs and Pareto methods as a result of participation in previous workshops. Rather than a single landowner, the tool will be applied to an area featuring a large number of (primarily small) landholders organized in a forest owners' association. Thus, key actors are experienced in working together to develop and implement collective management plans, and there could be overlap between ES providers and bidders. If a reverse auction were to be held here, one might expect the risk of collusion to be high. In the case of ECOSEL, however, conflicts between stakeholders could be minor and consensus positions easily identified, lowering the stakes in any competition between bundles. Furthermore, the immediate area features many actors with the competence to critically evaluate reserve prices; combined with the researchers' long experience in this area, the risk of price inflation is also probably quite low. On the other hand, price heterogeneity may be high if decomposed to the level of individual landowners.

For these reasons, Vale do Sousa is probably a very safe setting to test the ECOSEL base case. Even if implemented as a PES scheme, overpayment would likely accrue to the benefit of small rural landowners as much as industrial actors or investors. However, these features are quite unique and unlikely to be reproduced in other settings. Thus, some possible risk-limiting modifications to the ECOSEL tool are proposed below.

5.4.1 Profit caps

ECOSEL is designed to maximize seller profits. This chapter has criticized that design as cost-ineffective. However, some overpayment might be tolerable to induce landowners to participate in the first place. ECOSEL's crowdfunding and decision-making functions could be partly disentangled by setting a cap on landowner profits. For instance, if contributions for the winning bundle exceed 150% of the reserve price, then the excess is refunded to bidders *pro rata* or transferred to a recipient (e.g. a charity) that has been selected in advance. This would give landowners an opportunity to make a profit while placing a lower bound on the cost-effectiveness of monetary contributions. This modification would be vulnerable to reserve price manipulation by landowners.

5.4.2 Stakeholder workshops for bundle pre-screening

Most of the critiques related to equity and legitimacy presented above envision scenarios where unrestricted bidding produces an outcome that is unacceptable to direct stakeholders.[161] In many cases, it may be possible to mitigate this risk by involving stakeholders in the bundle selection process. If only bundles that are more or less tolerable for everyone are put up for auction, then those with strong preferences but low purchasing power will not be excluded from the decision process, having provided their input at an earlier stage. On the other hand, this could turn the auction into a low-stakes affair in which ambivalent direct stakeholders do not find it necessary invest money or energy: a bidding war between those who want to save the local sawmill and those who want to save the forest could be much more exciting and stimulate larger contributions, albeit at the risk of leaving some groups extremely dissatisfied with the outcome.

[161] Tóth et al. (2010) give landowners "full control" over selecting which bundles to put up for auction (p. 102).

5.4.3 Quadratic voting

Quadratic voting could be implemented with minimal modifications to the ECOSEL mechanism. This approach offers a balance between the crowdfunding element of ECOSEL on the one hand and the risk that economically powerful groups could easily buy an outcome on the other. If it appears unlikely that the standard €n^2 for n votes pricing rule will generate sufficient funds, it could be modified and/or quadratic voting implemented as a soft bid cap: for instance, all participants can freely contribute up to €50, and additional votes are sold at a price of €n^2 per 5n votes. These rules and the procedure for handling excess funds could be set by stakeholders in a participatory process. However, this would at least modestly complicate efforts to use ECOSEL as a valuation tool.

5.4.5 Improving ECOSEL's valuation potential

There are numerous theoretical parallels between ECOSEL-style auction games and choice models. Can choice modelling techniques be used to enhance the scientific value of ECOSEL applications? In Tóth et al. (2010), with the exception of the "maximum revenue" bundle representing the status quo, the bundles to be put up for auction are selected *ad hoc* to satisfy the landowner's inclinations while providing a reasonable variety of alternatives for bidders.

CM techniques can provide a more statistically efficient approach to creating baskets. Using a fractional factorial approach, it would be possible to represent three levels of four attributes using 9 orthogonal alternatives selected from the set of Pareto-optimal solutions.[162] Nine side-by-side alternatives is admittedly not an ideal format for a CE from an experimental design perspective—the presentation may be confusing—but it is not an unimaginable departure from the five bundles put up for auction by Tóth et al. By selecting bundles in this way, it might be possible to make some inferences about determinants of choice or the marginal value of changes in ES levels given some individualized information about bidders (namely, their budgets and bids).[163] If there is an open bid in the first round of a multi-round auction, as in the ECOSEL base case, it will not be incentive compatible; a sealed initial round might be better suited for data collection. Even then, this modification would not produce an incentive-compatible valuation tool, but might introduce a degree of structure into bundle selection to facilitate some rough estimations of ES values.

Rather than attempting to adapt ECOSEL to serve a CM function, it might be scientifically interesting to simply introduce a CM exercise into the ECOSEL process. For instance, the auction itself could be preceded by a CE, which could provide marginal WTP estimates for component ES. This information could then be used to guide bundle selection and maximize the probability of the reserve price being met. The auction could then be viewed as a tool for testing these WTP estimates against observed stakeholder behavior and better characterize bidding behavior within the ECOSEL game. Meanwhile, the CE would serve a pedagogical function by familiarizing future participants with concepts like bundles, trade-offs, and Pareto maps.[164]

5.4.6 A Bobolink-ECOSEL hybrid

This design modification assumes the existence of an (ideally contiguous) area with multiple (>20) landowners, biophysical models associated with the ES under consideration, and sufficient data to run those models. The procedure would be as follows. First, select ES of interest through a stakeholder consultation. Second, optimize across entire area to construct the possibility frontier of efficient trade-offs, excluding financial variables. Third, select baskets and express them by unit area. Fourth, conduct an ECOSEL auction to generate funds. Fifth, having set the budget, use a uniform

[162] Recall that Tóth et al. (2010) uses just 3 attributes (sequestered carbon, old-forest habitat at the end of the planning period, and foregone timber revenues).

[163] In a true crowdfunding implementation aimed at generating the maximum possible revenue, bidder budgets would likely not be readily accessible, since requirements to provide demographic information like income would represent a serious barrier to participation while also being difficult to verify. In an experimental setting, however, participants may be given fixed sums to either bid or keep, as Tóth et al. (2010) do to evaluate free riding.

[164] In the case of the Portuguese pilot, workshops have already been conducted and expected participants are familiar with these concepts.

price procurement auction to place the largest area possible under management designed to produce the winning basket.

The advantage of this approach is that it would be expected to improve the cost-effectiveness of donations. The disadvantage is that without information on reserve prices, donors cannot trade off ES provision density against the total contracted area. In other words, an expensive bundle may win, leading to a small area under the desired management—but donors, had they been given the choice, may have preferred to place a larger area under less restrictive conditions. This could still be an improvement over the base case, where fundraising success increases landowner profits; in the hybrid version, higher funding translates into greater area under the desired management.[165]A possible adjustment would be to modify Chakrabarti et al.'s (2019) Lindahl-based pledge card to form a matrix with different bundles and different provision levels (i.e. use a CE-like format). At the cost of added complexity and cognitive burden, this would allow bidders to consider area as well.

A riskier alternative would be to reverse this sequence: conduct an initial uniform-price reverse auction for a low-cost intervention (e.g. heavy thinning rather than a full harvest, or conserving a few hectares of mature forest) to elicit opportunity cost information; use this information to extrapolate cost functions for different landowner profiles and cover types; and finally, carry out an ECOSEL-style auction with the reserve price set by the principal as a function of the total area. This would be a very deceptive approach that would only work once, since landowners would quickly learn to inflate their bids in the initial reverse auction in order to extract rents in the following, potentially much-better-funded ECOSEL auction.

5.4.7 ECOSEL inverted to set a development tax

Lewis and Polasky (2018) develop an ES auction mechanism involving spatial coordination under uncertainty. They also show that, per Coase (1960), the mechanism still functions if the property rights allocation is reversed: it can either be applied to evaluate bids in a reverse auction in which landowners compete for conservation contracts, or in a forward auction where developers compete for the right to develop (e.g. on public lands).

In principle, ECOSEL could be similarly inverted, although doing so would mean sacrificing many of its more unique elements. Because the principal (a public body) would not expect to profit from conducting a harvest, the Pareto frontier might not feature a financial variable at all. Instead of bundles, bidders would be free to select any point on this frontier, ensuring that their harvesting or development activities created an efficient trade-off between ES. The product would be non-hypothetical (the right to implement a specific plan), and only one bidder could win. Thus, inverse-ECOSEL would move out of the realm of public good games and plant itself firmly in auction theory. The issue of landowner rent-seeking through reserve price inflation would be eliminated. Unfortunately, this would neither engage stakeholders nor tell us very much about how societies value ES. Functionally, it would be similar to Lewis and Polasky (2018), with the main difference being that instead of using stochastic dynamic programming to optimize under uncertainty, inverse-ECOSEL would use multi-criteria methods optimize across multiple ES. Ultimately, the inversion would reduce ECOSEL to an LP-based bid-scoring tool.

5.5 Conclusion

This chapter critically analyzed ECOSEL from several different theoretical perspectives. In doing so, it contested three of the tool's core claims, arguing that it is not cost-effective as a procurement mechanism, that is inferior to existing tools for inferring ES values, and that applying it as a decision tool is risky due to possible equity and legitimacy problems. Despite these criticisms, the ECOSEL game features a number of interesting features that warrant further investigation.

To facilitate future research and potential pilot applications for ECOSEL, several design modifications were suggested in order to address these criticisms. In descending order of ease of

[165] In many cases there will be an upper bound on the area that can cost-effectively be procured, since site-specific characteristics determine the deviation from the winning bundle (and thus the cost of implementing it at a specific site). This is the reason for the reverse auction—landowners who can implement it cheaply will win bids—but there are additionality risks as well (see Studies 1 and 2).

implementation, these include: *profit caps* to ensure a minimum level of procurement cost-effectiveness; *bundle pre-screening* by stakeholders to reduce the risk of producing unacceptable outcomes; *quadratic voting* to balance crowdfunding needs against equity and fairness concerns; improving ECOSEL's valuation potential by using *CM techniques for bundle selection* or appending CE to the process; implementing a *Bobolink-ECOSEL hybrid* to link fundraising levels to outcomes; and *inverting* ECOSEL so that landowners bid for development rights.

6. Closing remarks

Over the coming decades, policymakers, foresters, and natural resource managers will be forced to make increasingly challenging choices to ensure the sustained provision of critical ES—and do it in decision environments characterized by scarce resources, competing claims, conflicting objectives, and pervasive uncertainty. As the destabilization of the natural systems that support human life accelerates, it is clear that dominant approaches to valuation and decision-making are inadequate. This thesis offers a detailed look at ecosystem services auctions, a subfield that has undergone comparatively rapid development despite halting adoption into policy and practice.

Auctions can be useful tools when efficiency and cost-effectiveness are overriding objectives, and where their achievement is hindered by asymmetric information. Much of the literature focuses on mechanism design (including advanced approaches integrating multiple objectives and risk), but recent work shows a gradual broadening of attention to encompass contextual considerations and equity issues—perhaps a result of ongoing integration with broader scholarship on PES. The Delphi survey underscored this issue, with panelists endorsing a conceptual framework for evaluating participation levels that emphasized factors related to the setting much more strongly than those related to the mechanism. The panel's insistence on the need for more, and more comprehensive, field trials reflects a shared recognition that while mechanism design may lie near the heart of the auction literature, the field continues to expand beyond it. Case studies from NOBEL and SINCERE further illustrate that the prioritization of context, appreciation of social dynamics and cultural values, interdisciplinary exchange, and the need for real-world field data continues to drive ES auction scholarship. Finally, the planned application of an ECOSEL-style approach in Portugal shows how innovations in auction theory can shed light on closely-related public good games and multicriteria allocation problems.

Taken together, the studies presented above represent four attempts to grapple with this rich and evolving body of literature, and each attempt is limited in its own way. For logistical reasons, the systematic review was restricted to a single database; the consultation was designed in with very little input from subject matter experts; the case studies examine pilots yet to produce final results; the analysis of ECOSEL does a better job of picking at problems than fleshing out solutions. These limitations introduce uncertainty into some of the results and arguments presented above, but certainty was not a primary objective of this project. The aim, rather, has been to take stock of an broad, interdisciplinary, and theoretically rich subfield in order to make a rough approximation of where it might be going and how we can get it there faster. For better or worse, resources are scarce, and we have to make decisions—so let us make them as explicitly and transparently as possible.

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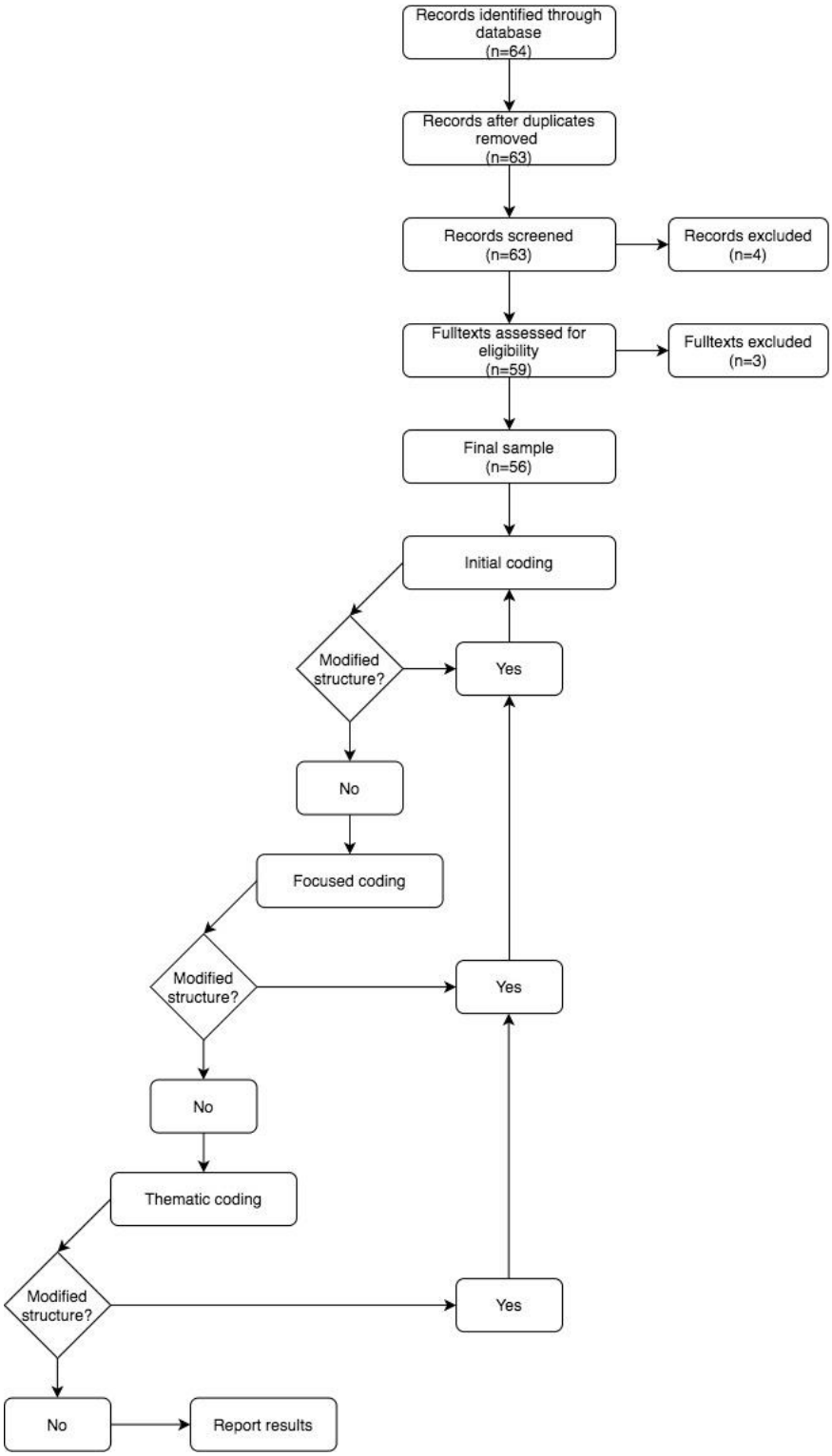
Appendix 1: Framework for systematic review



Appendix 2: Selected studies guiding the design of the Delphi study

Scolozzi et al. (2012) utilize the Delphi method to obtain estimations of ES potential for several land management units (relevant variables were identified using a focus group-based expert consultation prior to initiating the Delphi survey). Through a snowball sampling method, 46 experts were recruited and classified into two categories based on how they were identified (ether by referral or through publications), enabling the researchers to weight answers by level of expertise. The first Delphi round consisted of an email questionnaire that presented information (e.g. ES definitions and value tables) and a short series of questions that asked the respondent to (a) select ES they were experts in, (b) identify the most important variable from a list related to that ES, (c) estimate the minimum area required to provide that ES, and (d) estimate which previously defined land classes had the highest potential for providing it (p. 137). The second round questionnaire was more concise, because the winning variable for (b) was selected by consensus in the first round and presented to researchers along with achieved consensus about minimal thresholds. The stop criterion for the survey is not explicitly stated, but a third round was not considered necessary by the researchers.

Uthes and Matzdorf (2016) utilize a two-round online Delphi study to evaluate the expected impact of proposed agri-environmental interventions on a selection of public goods (e.g. biodiversity, aesthetic values, soil protection, etc.) on the supply side. Twenty-seven experts were evenly divided between generalists and those who specialized in an area directly related to one of the ES of interest; respondents were uniquely identifiable via personal access codes provided in recruitment emails (pp. 258-59). Responses on ES-specific items where the respondent's self-assessment of their expertise related to that item was low were excluded. In the first round, experts estimated impacts of interventions on each ES on a 3-point scale and additionally were asked to "provide reasons for their assessment" (p. 259).. The second round followed the same format as the first, but respondents were provided with both their previous response and the average response of the rest of the sample. Final results were analyzed descriptively and using distance metrics to provide a basis for assessing budget allocation for interventions across the selected ES. The contribution of the Delphi method to the overall study is interesting, as these results were coupled with demand-side research to provide inputs into an optimization model.

Rodríguez-Ortega, Olaizola, and Bernués (2018) apply the method in order to estimate how farmers' practices influence non-provisioning ES levels in the Mediterranean (p. 74). The consultation panel was selected to encompass two basic categories of expertise (academic experts and technicians), with the final sample consisting of 29 and 32 members in each group, respectively (p. 76).[166] The format for the first round consisted of an online questionnaire consisting of (a) description of the relevant agroecosystems, (b) personal data and topical knowledge self-assessment Likert items, (c) Likert items asking experts to estimate the ES impact of selected agricultural practices (ibid.). In the second round, experts were presented with the same items as in part (c) of the previous round, with the added information of global average scores and frequency distributions for each item; experts were asked to "rethink their individual responses compared to the global responses and to make modifications if appropriate" (ibid.). Finding that only half of respondents elected to change "one or a few" answers in the second round, the researchers determined that convergence had been achieved and decided not to carry out a third round.

Filyushkina et al. (2018) adopt an approach closely related to those described above: namely, adapting the Delphi method to estimate the expected impact of management alternatives on ES of interest. Potential participants were identified via literature review and through a snowball technique; the panel ultimately consisted of six experts. The questionnaire asked respondents to (a) characterize the impact of management alternatives on selected ES, (b) identify forest characteristics important for the ES, and (c) select from a set of graphics the algebraic functional form of the relationship between the identified characteristics and the selected ES (pp. 181-82). In the second round, respondents were presented with their previous answers, a space for revising them and a set of the most frequently identified relationships across the sample; additionally, item (b) was altered so that respondents were asked to qualitatively rate selected characteristics on a ten-point scale (ibid.). After two rounds, the

[166] The minimum number of category experts was established following Okoli and Pawlowski (2004); the overall approach considered the experience of Scolozzi et al. (2012).

researchers analyzed responses for "consensus and stability" and determined that given the minor changes between the two rounds, additional iterations would not be required (p. 183).

It should be noted that despite their close connection to the ES problem space, the Delphi applications reviewed above are all oriented to describing dynamics directly—that is, the focus is on providing inputs for management decision-making. This is in contrast to this thesis, which adopts a meta orientation and is interested in evaluating the applicability of tools for guiding management decision-making. Rather than forecasting human-environment interactions to make decisions, our objective here is to forecast how decision-making tools themselves might evolve either in their structure or their application moving forward. This approach is in some ways more in line with the original applications of the Delphi method, which sought to produce reasoned conjectures about complex dynamics surrounding technological changes.

Although this focused review failed to identify examples of the Delphi method being applied to evaluate the expected viability or impact of novel tools or as a basis for developing preliminary best-practice guidelines in the recent environmental management literature, this usage is fairly common in other disciplines. It may be useful to consider several such examples to better characterize the approach developed for the present project.

Emerging markets

The StarTree project was a large European research initiative targeting innovations in sustainable forest utilization and rural development, including emerging NWFP markets (Vidale, Da Re, & Pettenella 2015). The project's Scottish case study utilized a 2-round Delphi survey to explore the mushroom market; participants are informed at the outset that the process will require precisely 2 rounds (Dickson & Chapman 2012). The first round contained a series of Likert items in which respondents rated the accuracy of statements about the market structure (e.g. who regional wholesalers sell product to), items requesting numerical estimates (e.g. of the number of market actors in pre-defined categories and production volume figures in market segments), short-answer items asking respondents to rank regions by productivity, items asking respondents to forecast future production volume and trade flows on different timescales, and short answer items requesting the identification and ranking of driving and limiting factors for the industry. Interestingly, the version of the survey implemented in the second round does not merely re-present the same items with score summaries from the first round. Instead, it also uses findings about the market structure in order to interrogate respondents' perceptions about a series of normative statements about how the market might be improved, from changing property rights regimes to potential business models. In addition to inquiring about many facets of an emerging market—including those relating to specific subregions—the survey utilized a heterogeneous sample of experts. Consequently, the instructions for respondents emphatically request that any answers the respondent does not feel sure about should be left blank.

Ribeiro et al. (2014) apply the Delphi method in a slightly more technical context: namely, seeking to identify key issues and obstacles associated with the prospect of "large-scale commercialization of microalgae biodiesel and its incorporation into the fuel market" (p. 799). The process began with a "brainstorming session" by experts roughly akin to a focus group in order to come up with an initial set of issues that could provide the basis for questionnaire development. The initial panel of 55 experts was recruited from academia, government, business, and combinations thereof. After the brainstorming sections, two questionnaire rounds were performed:

> The 1st round questionnaire consisted of 50 statements. Those that did not reach an overall consensus (more than 66% agree or disagree) shaped the basis of the second round, which included open-ended fields for further explanations or suggestions. The second round focused on clarifying the answers of the first round (p. 801).

The inclusion of open-ended items in the second round is something of a departure from the standard practice of the other illustrative Delphi examples considered here, where open-ended items are typically available in the first round to generate lists or correct oversights in the initial item formulation process, which relies much more on the researcher's own judgments as a first step to soliciting expert input.

Winkler, Kiklinski, and Mosier (2015) modify the Delphi method, implementing a framework that is carried out online and in real time in order to explore how it might be applied to better understand decision processes in emerging markets, particularly those "coping with uncertainty and

equivocality" (pp. 1118-21). The survey is structured into single statements about market dynamics, forecasts, and limitations, which respondents are asked to rate according to three criteria (probability, impact, and desirability), immediately receiving feedback summarizing other participants' answers and being invited to revise that answer (p. 1122).[167] Relative to the StarTree example, the approach proposed by Winkler et al. (2015) is markedly more future forecast oriented.

Risk factors for novel systems

Huang et al. (2004) perform a Delphi study to identify risk factors in expensive environmental resource planning system development projects. The expert panel was recruited from an industry organization and completed online questionnaires to identify and rank major risk factors, which provided input to a second phase of analysis using the analytic hierarchy process (AHP). Hallowell and Gambatese (2010), in turn, offer a useful review of Delphi studies applied to construction engineering and management research. The surveyed studies analyzed risk, impact factors, and quality; as with Huang et al. (2004), one also used the Delphi findings as AHP inputs.

Best practice guidelines

Bond et al. (2015) used the Delphi method in order to propose guidelines for "people who work with or support those with mental health problems and financial difficulties" (p. 218). The study used five expert panels in each mental health and finance-associated professional category targeted with different criteria for inclusion in each. A systematic review provided the basis for a series of Likert items describing potential guidelines and spaces to suggest additional statements for review by the panel. After the first round, suggested statements were included and the option to add more was eliminated; rated statements received a designation of either *Endorsed* (if a large majority of respondents identified the practice as important), *Re-rate* (if a smaller majority identified the practice as important), or *Rejected* (if neither threshold was met). Three rounds were performed before convergence was achieved.[168] Hill et al. (2019) use a similar approach to develop guidelines for suicide-related crisis response. As above, a systematic review formed the basis for the development of a questionnaire featuring a long list of items that expert panels rated by importance, with consensus being achieved after three rounds.

Bain and Hanson (2020), in turn, applied a modified Delphi to developing guidelines for assessing certain stoma complications, engaging patients, and conducting follow-up assessments. The modifications to the process were drawn from the RAND Nominal Group Technique and designed to include larger sample and fast-track the time-consuming process to accelerate implementation of findings. First, an expert panel conducted the literature review and designed the questionnaire, which was then sent to a large sample for three iterations. After convergence was achieved a second expert review of guidelines was performed with a smaller panel before passing results on to a final stage for international confirmation and implementation planning.

Directions for future research

Kurubacek (2007) used the Delphi method a means of identifying and prioritizing potential directions for future research in the area of mobile learning technologies. A panel of seventy-two experts were recruited from listservs for online education workers to complete multiple rounds of online surveys. The first round questionnaire consisted of a series of Likert items with spaces for additional comments. In the second round, experts were presented with mean scores and asked to rate the accuracy of this average ranking on three-point qualitative scale, and additionally rate new items drawn from the comments as in the previous round. Means were adjusted based on second-round accuracy ratings, apart from which the third round followed the same format as the second. Fletcher-Johnson et al. (2011) utilize a panel of 38 experts across several phases (with academics being identified by publications) to identify research priorities in a healthcare field. In the first phase, panelists were provided with an initial questionnaire and asked if they would like to suggest additional questions. In the second, they rated these questions using a Likert scale. The third phase

[167] Note: The researchers here use Delphi in conjunction with several other methods (i.e. as just one component of a larger consultation strategy).

[168] This closely mirrors the protocol adopted by Bond et al. (2016), which used the Delphi method to develop guidelines for the assistance of individuals developing cognitive impairment or dementia.

narrowed down a list of topics identified in Phase 2 to identify the top five research priorities for the field.

Appendix 3: Delphi rating rank change after R1

Table A2: Most significant sources of development in ES auctions, ranked by importance (R2) and compared with ranking frequency after R1

Order change *emphasized*.

Final ranking	Item	Rank after R1
1	Policy developments	1
2	Technology	2
3	*Experimental results*	*4*
4	*Cross-functional synergies*	*3*
5	New applications in new contexts	5
6	Something else	6

Table Y presents the full results of the rating item questions. Importance score is included for illustration, but it is important to remember that this score was calculated in a fairly arbitrary basis and was only evaluated once by respondents; thus, it should be thought of as something of a fuzzy value. The relative rankings, by contrast, were produced twice: once through a content analysis of R1 responses, and then confirmed in the R2 slider questions. Nonetheless, the importance score was retained in order to reflect the relative degree of consolidation around certain topics.