Area Conditions and Positive Incentives: Engaging Local Communities to Protect Forests

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Tropical deforestation for agriculture causes alarming CO2 emissions and loss of biodiversity and ecosystem services. To prevent this, various governments and multinational commodity-buyers offer a positive incentive for locals conditional on no deforestation in a specified area. As an alternative to the area no-deforestation condition, we propose a weaker "regeneration condition": if forest is cleared on land in the specified area, locals prevent its economic use, enabling the forest to regenerate. With innovation in cooperative game theory, we characterize the best condition (area no-deforestation vs. area regeneration) and feasible incentives to prevent deforestation and to compensate each local for his missed economic opportunity. The regeneration condition is best in an area with the potential for entrants to engage in deforestation. Without entrants, if locals can cooperate, the area no-deforestation condition is best, and works with any incentive that is more valuable for locals collectively than deforestation. By surveying smallholder palm farmers in 58 villages of East Kalimantan, Indonesia, we fit our model with a price premium for palm fruit as the incentive, in each village as the area. A price premium is an imperfect incentive, having least value for a farmer with the least land and, correspondingly, high temptation to engage in deforestation. The Roundtable on Sustainable Palm Oil (RSPO) price premium is too low. Still, with a moderate price premium, our area regeneration condition prevents deforestation in most villages and is remarkably robust to deter potential entrants.

1. Introduction

Tropical forests hold 80% of the world's biodiversity, regulate freshwater, and provide other essential ecosystem services, yet are rapidly destroyed for agriculture, contributing 15% of humans' annual CO2 emissions (Pendrill et al. 2022, Feng et al. 2022). A hopeful prospect is that a local community, given a positive incentive, can prevent deforestation (FAO 2022). However, that might harm locals who would otherwise improve their livelihood through deforestation.

Governments, water funds, carbon offset providers, and conservation NGOs offer payments to individual landowners to forgo deforestation, and the Payment for Ecosystem Services (PES) literature, surveyed in Engel et al. (2016), describes these schemes and their common faults. One is distributional inequity: payment is provided only to a forest owner with a clear property right, in proportion to the amount of his forest that he chooses to preserve, enriching the wealthiest locals (Haas et al. 2019). A second is inefficient targeting of payments: Some individuals are paid for forest they would not have cleared, regardless, whereas, for other individuals, the offered payment is too low to motivate them to forgo deforestation (Jack and Jayachandran 2019). Li et al. (2022) recommend how to improve the PES contract for a forest owner with private information while highlighting the challenge of monitoring. A third is "leakage": displacement of deforestation, as an incentive to prevent deforestation in one location causes deforestation to occur elsewhere (Alix-Garcia et al.

2012, Delacote et al. 2016). A fourth is a failure to address illegal tropical deforestation, which is roughly half of all tropical deforestation and is commonly undertaken by impoverished locals (Lawson 2014, Wunder 2008). Kerr et al. (2014) calls for compensation for all locals - especially impoverished smallholders - to forgo deforestation.

Unilever, Nestle, Mars, Cargill, McDonald's, and many other firms are publicly committed to preventing deforestation in their supply chains, yet face problems of monitoring individual smallholders and traceability. A typical firm sources indirectly from many thousands of smallholders. Unilever and others have attempted to map each smallholder's land plots, verify that these weren't recently deforested, and provide a price premium and technical assistance to improve the smallholder's productivity (Lambin and Furumo 2023). However, a smallholder may sell produce from a nearby unmapped deforested plot under the disguise of improved productivity. Efforts to establish traceability by recording transactions, e.g., with blockchain, often fail due to the introduction of incorrect information at the origin (Babich and Hilary 2020). Unlike in testing for an adulterated input in a batch of agricultural produce, as studied by Mu et al. (2016), no test serves to detect input from a deforested plot. Yet EU regulation will soon require that, to sell in the EU, a firm must prove that its product contains no palm oil, coffee, cocoa, wood, soy, rubber, or beef raised on land deforested since 2020 (European Commission 2023). Depending on what will constitute proof, the regulation may harm smallholders by motivating firms to source from large producers (Reuters 2023, Guillot 2023).

Firms and governments now offer positive incentives conditional on *area no-deforestation.* The area can be a specified polygon containing forest and all farms associated with a farmers' cooperative, with training and financing for all the farmers as the incentive to prevent deforestation therein (Chocolonely 2020). Satellite remote sensing is used to monitor the specified polygon and detect, in almost real-time, any fire or other forest clearing activity (Lambin and Furumo 2023). The area can be the communal land of a village, with a payment to the community conditional on no deforestation in the area, as in Mexico's forested *ejidos* (Kaiser et al. 2023). Agarwal et al. (2022) and Santika et al. (2019) study how, in Thailand and Indonesia, respectively, indigenous and impoverished communities are granted *land-use rights* to preserve their community forests (though revoking land rights in the event of deforestation can prove problematic Kerr et al. 2014). The area can be a jurisdiction, such as the state of Sabah in Malaysia. Sabah's government and palm oil buyers aim to prevent deforestation in Sabah and enable all oil palm farmers therein to be paid a price premium (Ng et al. 2022).

In some intervention areas, but not others, the locals cooperate to share the benefits and coordinate actions to prevent deforestation. Literature on community-PES and community forestry commonly finds, in small areas with strong community ties, an association between cooperation and successful forest protection (Hayes et al. 2019). In contrast, in large jurisdictions, cooperation is difficult due to the large number of heterogeneous locals, resulting in inequities and exclusion of smallholders, and ongoing deforestation (von Essen and Lambin 2021).

Even a tight-knit community might fail to prevent deforestation due to *entry*. Examples arise in East and West Kalimantan, some of Indonesia's deforestation-prone regions, which are subdivided into rural villages (*desa*) (see Figure EC.1). Observing that locals within each village have strong social ties and ability to cooperate, Falcon et al. (2022) conducted a randomized controlled trial in offering payment to a village community conditional on no deforestation (no major forest clearing by fire) in the village for a year. This failed to prevent deforestation, which Falcon et al. (2022) partially attribute to forest clearing by "rogue" entrants. Related empirical literature shows a positive relationship between migrant entry and forest clearing for oil palm farms in Indonesia (Darmawan et al. 2016), cocoa in West Africa (Ruf et al. 2015) and cattle in the Amazon (Carr 2009).

To deter entrants from engaging in deforestation, we propose the *area regeneration* condition: either no deforestation occurs, or locals prevent production on the deforested land, enabling the forest to regenerate. We introduce the term "block" for the act of preventing production on deforested land, enabling the forest to regenerate. For example, Villadiego (2017) documents how locals block illegal oil palm farming in Sumatra. A positive incentive conditional on area regeneration could motivate locals to block any perpetrator that clears forest, and the threat of blocking could deter deforestation. In creating a deterrent to deforestation, our proposed scheme differs from today's common forest restoration programs (see Tedesco et al. 2023 for examples) that reward a landowner after the logging, farming, and degradation of primary forest on his land.

§2 presents our stylized model, with positive incentives for locals to meet a candidate condition. The three candidates are: area regeneration, area no-deforestation, and individual no-deforestation. With the latter, a local receives the incentive if and only if he does not engage in deforestation. Locals and potential entrants decide whether to engage in deforestation, locals observe any deforestation, then locals decide whether to block the perpetrators. We deliberately favor the individual no-deforestation condition by (unrealistically) assuming perfect, costless monitoring, yet find in §3 that with practical incentives an area condition outperforms the individual no-deforestation condition.

We characterize the best condition and the feasible set of incentives to prevent deforestation and to compensate each local for his lost economic opportunity. The results, summarized in §4, depend on whether or not locals can cooperate to coordinate their deforestation and blocking decisions and transfer utility[1]. With potential entrants, the area regeneration condition is best, and cooperation expands the feasible set of incentives to prevent deforestation. With cooperation and no potential entrants, the area no-deforestation condition is best. An incentive only needs to make locals better off *overall* than if they were to engage in deforestation, and locals prevent deforestation by compensating each local to forgo deforestation.

[1] In field research in rural Thailand and Indonesia, we observed that neighboring smallholders can share work, favors, food, and other goods; they have monetary and nonmonetary mechanisms to transfer utility.

In §5, based on our survey of smallholder palm farmers in 58 villages in East Kalimantan, we fit our model to evaluate the potential for a price premium for palm fruit conditional on area no-deforestation (or area regeneration) to prevent deforestation and achieve compensation. Like Falcon et al. (2022), we consider each village as the area because the smallholders we surveyed reported strong community ties and cooperation within their village. Though the price premium for palm fruit certified by the Roundtable on Sustainable Palm Oil (RSPO) is too low to prevent deforestation in all villages, at a moderate price premium, area conditions would prevent deforestation and achieve compensation in most villages. Surprisingly, the minimum price premium conditional on area regeneration that prevents deforestation, assuming no entrants, is robust enough to deter many potential entrants.

§6 draws conclusions to help interested parties (commodity buyers, governments, water funds, carbon offset providers, conservation NGOs, etc.) prevent deforestation and benefit locals.

A main contribution of the paper is to model strategic cooperation. The prior theoretical literature on forest protection by a local community assumes that only one coalition can exist (Zavalloni et al. 2019, Bareille et al. 2021). We propose the concept of a cooperative game in partition *correspondence* form and its Recursive Core. We apply this to predict how locals partition themselves into coalitions in anticipation of a *non*-cooperative game among the coalitions and potential entrants (the locals in a coalition cooperate to maximize net income for the coalition). The non-cooperative game has *multiple* equilibria, and locals anticipate the *correspondence* between the partition and *set* of equilibrium payoffs for coalitions in the partition. The premise of the Recursive Core is that when forming a coalition, the members assume that "residual locals" (those left out) will respond by forming coalitions to maximize their own net income. We derive by induction the Pessimistic Recursive Core, assuming locals have pessimistic beliefs regarding residual locals' partition and equilibrium strategies in the ensuing non-cooperative game. (The analogous Optimistic Recursive Core is a subset of the Pessimistic Recursive Core, so we conservatively conclude that an incentive and area condition prevent deforestation when all outcomes in the Pessimistic Recursive Core have no deforestation.) A game in partition *correspondence* form is a generalization of the game in partition *function* form as defined by Thrall and Lucas (1963), and our solution concept generalizes the Recursive Core defined by Kóczy (2007) for a game in partition function form. This methodological innovation allows us to analyze strategic cooperation in a setting with multiple non-cooperative equilibria.

In related operations management (OM) literature on cooperation, Fang and Cho (2020) model buyers' strategic cooperation in managing their common suppliers' social responsibility as a game in partition function form. The recursive core is a refinement of the core concept used by Fang and Cho. For cooperative games in which the payoff for a coalition does not depend on other coalitions (games in characteristic function form), Tian et al. 2019 use *farsighted* solution concepts similar in spirit to the recursive core (see Nagarajan and Sošić (2008) for a review). In modeling cooperation in assembly systems, Chen and Hall (2007) assume component suppliers form a single coalition and coordinate their production schedules. Qian and Olsen (2020, 2022) model how farmers coordinate their quality, quantity, and financial decisions through a cooperative and provide a survey of related literature on farmers' cooperatives. Boyabatli et al. (2021) provides insight in agricultural supply chain management, including for smallholders to cooperate in sharing knowledge and water.

Other OM literature analyzes non-cooperative games among farmers in low and middle-income countries, in which a farmer's choice of quantity Chintapalli and Tang (2022), Pay et al. (2022), technology adoption de Zegher et al. (2019), or quality Ayvaz-Çavdaroğlu et al. (2021), Mu et al. (2016), Levi et al. (2020) affects the income of neighboring farmers. The non-cooperative games in Mu et al. (2016), de Zegher et al. (2019), Pay et al. (2022) have multiple equilibria, so could be extended to model cooperation among farmers as a game in partition correspondence form.

On preventing deforestation, Orsdemir et al. (2019) show how a firm avoids sourcing illegal wood by purchasing a mill and log inputs and selling wood to competitors. McGahan and Pongeluppe (2023) show how a firm sources from indigenous forest communities, promoting sustainable agroforestry. Agrawal et al. (2022) analyze contract terms for offset credits, including for prevented deforestation.

Sunar and Swaminathan (2022) survey the literature on responsible operations and supply chain management, with a spotlight on agriculture.

Notation. We use bold letters to denote vectors and matrices. For a vector $\boldsymbol{x}$ with components indexed by some set N and for a subset $S \subseteq N$, we define the notation $x_S := \sum_{i\in S} x_i$, and we use the common game-theoretic notation $\boldsymbol{x}_{-i}$ for the vector obtained by removing component i from $\boldsymbol{x}$ and $(x_i, \boldsymbol{x}_{-i})$ for the vector where component i of $\boldsymbol{x}$ is replaced with a value x_i. A *partition* π of a set N is a set of mutually exclusive subsets whose union includes all the elements of N, i.e., $\bigcup_{S\in\pi} S = N$ and $S \cap H = \emptyset$ for all $S, H \in \pi$ with $S \neq H$. We denote the set of all partitions of a set N by Π_N.

2. Model Formulation

In an area containing forest, an interested party aims to prevent deforestation, and offers a positive incentive to each local $\ell \in \mathcal{L}$ to meet a specified forest protection condition.

Locals' Decisions: Each local $\ell \in \mathcal{L}$ ("he") decides whether to incur cost c_ℓ to convert forested land to an individually-profitable use ($d_\ell = 1$) or not ($d_\ell = 0$). If ℓ engages in deforestation, other locals observe that decision $d_\ell = 1$ and decide whether to incur a cost η to "block" ℓ, i.e., prevent ℓ from using land he deforested to generate income, so the forest regenerates. Similarly, the locals in $\mathcal{L}$ observe any new entrant that engages in deforestation in the area and decide whether to incur cost η to block that entrant. Each local $\ell \in \mathcal{L}$ derives income of $J_\ell\big(d_\ell \cdot (1 - b_\ell), \kappa_\ell\big)$ that depends on whether ℓ engages in deforestation, whether ℓ is blocked ($b_\ell = 1$) or not ($b_\ell = 0$), and whether ℓ receives the incentive $\kappa_\ell \in \{\text{yes}, \text{no}\}$. The incentive would increase a local's income

$$J_\ell(x, \text{yes}) \geq J_\ell(x, \text{no}), \forall\, x \in \{0, 1\}, \forall\, \ell \in \mathcal{L}, \tag{1}$$

while, absent any incentive or blocking, a local increases his net income by engaging in deforestation:

$$J_\ell(1,\text{no}) - c_\ell > J_\ell(0,\text{no}). \tag{2}$$

We use $\delta_\ell := \big(J_\ell(1,\text{no}) - c_\ell\big) - J_\ell(0,\text{no})$ to denote the value from engaging in deforestation, $\phi_\ell := J_\ell(0,\text{yes}) - J_\ell(0,\text{no})$ to denote the value of the incentive for a local who doesn't engage in deforestation, and $\Delta_\ell := \phi_\ell - \delta_\ell$ to denote the increase in net income from receiving the incentive rather than engaging in deforestation, for $\ell \in \mathcal{L}$. We say local ℓ *prefers the incentive* if $\Delta_\ell > 0$, whereas he *prefers deforestation* if $\Delta_\ell < 0$; more generally, a subset of locals $S \subseteq \mathcal{L}$ prefers the incentive if $\Delta_S > 0$, whereas that subset prefers deforestation if $\Delta_S < 0$. For brevity of exposition, we assume every local has a strict preference: $\Delta_\ell \neq 0$ for every $\ell \in \mathcal{L}$, and denote by $\mathcal{G} := \{\ell \in \mathcal{L} : \Delta_\ell > 0\}$ the set of all locals that prefer the incentive. We focus on the common circumstance that the incentive is imperfect; though some locals prefer the incentive, at least one local prefers deforestation:

$$\emptyset \neq \mathcal{G} \subset \mathcal{L}, \tag{3}$$

Entrants' Decisions: Let $\mathcal{E}$ represent the set of entrants, all of whom would individually profit from deforestation in the area. Each entrant $e \in \mathcal{E}$ decides whether to incur cost $c_e > 0$ to convert forested land to an individually-profitable use ($d_e = 1$) or not ($d_e = 0$), and derives income of $J_e\big(d_e \cdot (1 - b_e)\big)$, where $b_e \in \{0,1\}$ indicates whether locals block the entrant. Naturally, we assume that $J_e\big(1\big) > c_e$ for each $e \in \mathcal{E}$, meaning that an entrant could increase his net income by engaging in deforestation in the area if he isn't blocked. One should think of $\mathcal{E}$ as the *potential entrants* who might engage in deforestation in the area (enter by setting $d_e = 1$) though for brevity we write "entrant" rather than "potential entrants" throughout the paper.

Candidate Forest Protection Conditions: The interested party provides the incentive to locals if and only if they meet a specified condition, for which we consider three candidates:

1. *Individual Condition* $\mathbb{I}$: $\kappa_\ell = \text{yes}$ if and only if $d_\ell = 0$.
2. *Area No-Deforestation Condition* $\mathbb{N}$: $\kappa_\ell = \text{yes}$ if and only if $d_i = 0$ for all $i \in \mathcal{L} \cup \mathcal{E}$.
3. *Area Regeneration Condition* $\mathbb{R}$: $\kappa_\ell = \text{yes}$ if and only if $d_i \cdot (1 - b_i) = 0$ for all $i \in \mathcal{L} \cup \mathcal{E}$.

With the Individual Condition, whether a local receives the incentive only depends on his individual deforestation decision. Hence the optimization problems solved by the locals and entrants decouple and the equilibrium is simple: to maximize his net income, each local $\ell \in \mathcal{L}$ engages in deforestation ($d_\ell = 1$) if and only if $\Delta_\ell > 0$, each entrant $e \in \mathcal{E}$ engages in deforestation ($d_e = 1$), and no local blocks production on the deforested land (implying $b_i = 0$ for all $i \in \mathcal{L} \cup \mathcal{E}$).

In contrast, with either area condition, whether a local receives the incentive depends on the decisions of all the locals and entrants. For each area condition, we formalize and analyze locals' and entrants' equilibrium optimal decisions in the case that locals cannot coordinate decisions and transfer utility among themselves (the non-cooperative game in §3.2) and in the case that they can (the transferable utility cooperative game in §3.3). Entrants are individuals who do not coordinate decisions or transfer utility. Note that Area Regeneration $\mathbb{R}$ is a weaker condition than Area No-Deforestation $\mathbb{N}$: $\mathbb{R}$ is satisfied if $\mathbb{N}$ is satisfied or if every local and entrant that engaged in deforestation is blocked from generating income in the deforested land so that the forest regenerates.

Two Performance Criteria: To provide guidance to the interested party,

1. We say that a condition *prevents deforestation* if every equilibrium has no deforestation in the area, $d_i = 0$ for all $i \in \mathcal{L} \cup \mathcal{E}$.
2. We say that a condition *prevents deforestation with compensation* if it prevents deforestation and, in every equilibrium, the net income of each local $\ell \in \mathcal{L}$ exceeds his net income if he had engaged in deforestation, $J_\ell(1, \text{no}) - c_\ell$.

Because the interested party relies only on positive incentives (1), *preventing deforestation* weakly benefits each local $\ell \in \mathcal{L}$ in that his net income will be at least $J_\ell(0, \text{no})$, his status-quo income without the incentive and without engaging in deforestation. In comparison, preventing deforestation *with compensation* guarantees greater benefit for each local – full compensation for the lost opportunity to engage in deforestation. To emphasize that each local $\ell \in \mathcal{L}$ has net income greater than $J_\ell(1, \text{no}) - c_\ell$ in equilibrium under a given condition, we say that the condition *achieves compensation.*

2.1. Discussion of Modeling Assumptions

Deforestation: Parameter δ_ℓ is local ℓ's value from his *optimal* extent of deforestation. §5 estimates δ_ℓ's for heterogeneous smallholders using an operational model, field survey and data envelope analysis.

Imperfect Incentive: §3 takes as given the *imperfect* incentive the interested party offers to locals. The incentive could be the RSPO price premium, for example, or legal recognition of a smallholder's right to his existing farm. In both examples, a local with a smaller farm tends to have $\phi_\ell < \delta_\ell$ because the value of the incentive ϕ_ℓ is smaller with the smaller farm, whereas the value of deforestation δ_ℓ to expand the farm is larger. Kaiser et al. (2023) documents barriers to targeting a perfect incentive to each individual so, in practice, an offered incentive is insufficient for some individuals to forgo deforestation. Hence we assume in §3 that $\phi_\ell < \delta_\ell$ for at least one local, represented by $\mathcal{G} \subset \mathcal{L}$ in (3).

§4 relaxes assumption 3 and provides guidance for selecting an incentive and condition $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$.

Blocking: In reality, the means and cost of blocking depend on characteristics of the area.

In many a deforestation-prone area, the perpetrators of deforestation lack the heavy machinery required for logging and instead light fire to clear forest (Tyukavina et al. 2018, van Wees et al. 2021). In such an area, blocking could occur by locals putting out the fire and motivating the perpetrator to relinquish the forest land. Falcon et al. (2022) document that villagers in Indonesia formed fire brigades in response to an incentive to prevent any major clearing of forest in their village.

An area's cost of blocking (η in our model) can be lowered by training locals to stop forest-clearing activity and an alert system with remote sensing to quickly detect and direct locals to the specific location of any forest-clearing activity, as Slough et al. (2021) did for 39 community forest areas in the Peruvian Amazon. Quick response facilitates blocking – putting out a fire is easier while the fire is small; motivating a perpetrator to relinquish forest land may be easier before he grows a crop.

The means and cost of blocking depend on an area's governance and property rights. Blocking illegal deforestation is easy for a local who simply reports it to the police to stop the perpetrator from using the deforested land; this would be represented in our model by small η, the reporting cost. The blocking cost is higher in an area without such government enforcement. In an area with weak property rights and logging machinery, Engel et al. (2006) describe how locals block logging by damaging or stealing the perpetrator's machinery, burning the perpetrator's camp, or blocking roads to prevent transport of logs out of the forest. An area with strong individual property rights to forested land, such that a local could not be blocked from deforesting his own property and no entrant could seize and deforest a local's property, would have $\eta = \infty$ in our model (and $\mathcal{E} = \emptyset$).

Our model has constant blocking cost η as an area parameter. Needed for analytic tractability, this lets us see how the magnitude of the blocking cost affects the regeneration condition's performance.

3. Analysis of Equilibrium Decisions Under Each Area Condition

The overarching purpose of this section is to determine when and how the incentive to meet a specified area condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$ prevents deforestation and achieves compensation, respectively.

In §3.1, we analyze how deforestation and blocking decisions depend on the partition of locals into coalitions. A *coalition* $S \subseteq \mathcal{L}$ is a set of locals who coordinate their deforestation and blocking decisions to maximize their aggregate net income. Each $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$ induces a non-cooperative game, with net income for each entrant and coalition depending on others' decisions.

In §3.2 and §3.3 we apply the results of §3.1. In §3.2 the locals do not coordinate, so the partition is $\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$ in which each local is a singleton. In §3.3, the locals are able to coordinate and transfer utility within a coalition, and we analyze how they partition themselves into coalitions in anticipation of the non-cooperative game of deforestation and blocking.

3.1. Non-cooperative Game of Deforestation and Blocking

For a specified area condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$ and partition $\pi \in \Pi_{\mathcal{L}}$ of locals, the non-cooperative game occurs in two stages. In the first stage, each coalition $S \in \pi$ chooses whether to engage in deforestation (set $d_S = 1$) or not (set $d_S = 0$), and all locals follow their respective coalition's decision, i.e., $d_\ell = d_S$ for every $\ell \in S$ and every $S \in \pi$. Simultaneously, each entrant chooses whether or not to engage in deforestation, $d_e \in \{0, 1\}$. We use $\mathbf{d} \in \{0, 1\}^{|\pi|+|\mathcal{E}|}$ to denote the deforestation decisions of all coalitions and entrants. In the second stage, having observed which individuals engaged in deforestation

($d_i = 1, \forall i \in \mathcal{L} \cup \mathcal{E}$), each coalition $S \in \pi$ chooses which of those individuals to block from deriving economic benefit from their deforested land. We represent the blocking decisions by $\mathbf{B} \in \{0,1\}^{|\pi| \times |\mathcal{L} \cup \mathcal{E}|}$ with $\mathbf{B}_{Si} = 1$ indicating that coalition S blocks individual $i \in \mathcal{L} \cup \mathcal{E}$, and $\max_{S \in \pi} \mathbf{B}_{Si} = 1$ indicating that individual i is blocked from using deforested land.

The locals receive the incentive if the deforestation and blocking decisions comply with the specified area condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$, as indicated by

$$\kappa^{\mathbb{N}}(\mathbf{d}, \mathbf{B}) = \begin{cases} \text{yes} & \text{if } \sum_{S \in \pi} d_S + \sum_{e \in \mathcal{E}} d_e = 0, \\ \text{no} & \text{otherwise.} \end{cases} \tag{4}$$

$$\kappa^{\mathbb{R}}(\mathbf{d}, \mathbf{B}) = \begin{cases} \text{yes} & \text{if } \sum_{S \in \pi} \sum_{\ell \in S} d_S \cdot \left(1 - \max_{H \in \pi} \mathbf{B}_{H\ell}\right) + \sum_{e \in \mathcal{E}} d_e \cdot \left(1 - \max_{H \in \pi} \mathbf{B}_{He}\right) = 0, \\ \text{no} & \text{otherwise,} \end{cases} \tag{5}$$

A subgame-perfect equilibrium is a set of deforestation decisions $\mathbf{d}^*$ and blocking decisions $\mathbf{B}^*(\mathbf{d})$ for $\mathbf{d} \in \{0,1\}^{|\pi|+|\mathcal{E}|}$ that satisfy, for each $S \in \pi$ and $e \in \mathcal{E}$:

$$\mathbf{B}^*_S(\mathbf{d}) \in \operatorname*{arg\,max}_{\mathbf{B}_S \in \{0,1\}^{|\mathcal{L} \cup \mathcal{E}|}} \left(\sum_{\ell \in S} \left[J_\ell \Big(d_S \cdot \big(1 - \max_{H \in \pi} \mathbf{B}^*_{H\ell}(\mathbf{d})\big), \kappa^{\mathbb{C}}\big(\mathbf{d}, \mathbf{B}_S, \mathbf{B}^*_{-S}(\mathbf{d})\big) \Big) \right] - \eta \cdot \sum_{i \in \mathcal{L} \cup \mathcal{E}} \mathbf{B}_{Si} \right) \tag{6}$$

$$d^*_e \in \operatorname*{arg\,max}_{d_e \in \{0,1\}} \left(J_e \Big(d_e \cdot \big(1 - \max_{S \in \pi} \mathbf{B}^*_{Se}(d_e, \mathbf{d}^*_{-e})\big) \Big) - c_e \cdot d_e \right) \tag{7}$$

$$d^*_S \in \operatorname*{arg\,max}_{d_S \in \{0,1\}} \left(\sum_{\ell \in S} \left[J_\ell \Big(d_S \cdot \big(1 - \max_{H \in \pi} \mathbf{B}^*_{H\ell}(d_S, \mathbf{d}^*_{-S})\big), \kappa^{\mathbb{C}}\big(\pi, d_S, \mathbf{d}^*_{-S}, \mathbf{B}^*(d_S, \mathbf{d}^*_{-S})\big) \Big) - c_\ell \cdot d_S - \eta \cdot \sum_{i \in \mathcal{L} \cup \mathcal{E}} \mathbf{B}^*_{Si} \right] \right). \tag{8}$$

We use $\mathcal{Q}(\pi, \mathbb{C})$ to denote the set of all subgame-perfect equilibria, i.e., all $(\mathbf{d}^*, \mathbf{B}^*(\mathbf{d}))$, that satisfy (8)-(6) for partition $\pi \in \Pi_{\mathcal{L}}$ and forest protection condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$.

Our first result establishes that in equilibrium, either no individual engages in deforestation or all individuals engage in deforestation, then none are blocked.

Lemma 1. *For every partition $\pi \in \Pi_{\mathcal{L}}$ and condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$, $\mathcal{Q}(\pi, \mathbb{C})$ is non-empty, and any subgame-perfect equilibrium in $\mathcal{Q}(\pi, \mathbb{C})$ has $\mathbf{B}^*(\mathbf{d}^*) = \mathbf{0}$ and either $\mathbf{d}^* = \mathbf{1}$ or $\mathbf{d}^* = \mathbf{0}$.*

We use the terms *deforestation equilibrium* to refer to a subgame-perfect equilibrium with $\mathbf{d}^* = \mathbf{1}$, *no-deforestation equilibrium* to refer to a subgame-perfect equilibrium with $\mathbf{d}^* = \mathbf{0}$, and *equilibrium indicator* for $\mathbf{d}^*$. Only the two extreme types of equilibrium exist because each coalition and entrant are more inclined to engage in deforestation when others do so. With $\mathbb{N}$, deforestation by any coalition or entrant prevents all the others from earning the incentive, so their best response is to engage in deforestation, too. With $\mathbb{R}$, deforestation by more individuals raises the total cost for a coalition to earn the incentive by blocking all of them, which favors the coalition also engaging in deforestation.

The next result identifies when each of the two types of equilibrium exists. $T(\pi, \mathbb{C})$ represents the types of equilibria in $\mathcal{Q}(\pi, \mathbb{C})$: $T(\pi, \mathbb{C}) = \{\mathbf{0}\}$ for only no-deforestation equilibria, $T(\pi, \mathbb{C}) = \{\mathbf{1}\}$ for only deforestation equilibria, and $T(\pi, \mathbb{C}) = \{\mathbf{0}, \mathbf{1}\}$ for both types.

Lemma 2. *Consider a partition* $\pi \in \Pi_{\mathcal{L}}$*. With the area no-deforestation condition* $\mathbb{N}$*,*

$$T(\pi, \mathbb{N}) = \begin{cases} \{\mathbf{0}\} & \text{if } \pi = \{\mathcal{L}\}, \Delta_{\mathcal{L}} > 0, \text{and } \mathcal{E} = \emptyset \\ \{\mathbf{1}\} & \text{if } \Delta_S < 0 \text{ for some coalition } S \text{ in } \pi \text{ or } \mathcal{E} \neq \emptyset \\ \{\mathbf{0}, \mathbf{1}\} & \text{otherwise.} \end{cases}$$

With the area regeneration condition $\mathbb{R}$*, there exist thresholds* $\eta_1(\pi), \eta_2(\pi)$ *so that* $\eta_1(\pi) \leq \eta_2(\pi)$ *and*

$$T(\pi, \mathbb{R}) = \begin{cases} \{\mathbf{0}\} & \text{if } \eta < \eta_1(\pi) \\ \{\mathbf{1}\} & \text{if } \eta > \eta_2(\pi) \\ \{\mathbf{0}, \mathbf{1}\} & \text{otherwise.} \end{cases}$$

With $\mathbb{N}$, deforestation equilibria exist unless the locals form the grand coalition ($\pi = \{\mathcal{L}\}$), prefer the incentive ($\Delta_{\mathcal{L}} > 0$), and face no entrants. Only deforestation equilibria exist when a coalition prefers deforestation ($\Delta_S < 0$) or there are entrants; there is no credible threat of blocking to deter them ($\mathbf{B}^*(\mathbf{d}) = \mathbf{0}$) and deforestation is the best response from all other parties.

With $\mathbb{R}$, a credible threat of blocking can sustain no-deforestation equilibria. Consider:

$$\eta_1(\pi) := \sup\{\eta : \exists S \in \pi \text{ with } \Delta_S > \eta\,(|\mathcal{L} \setminus S| + |\mathcal{E}|)\} \tag{9a}$$

$$\eta_2(\pi) := \inf\left\{\eta : \sum_{S \in \pi : \Delta_S > 0} \left\lfloor \frac{\Delta_S}{\eta} \right\rfloor < \max\left\{\max_{H \in \pi : \Delta_H < 0} |H|\,, \mathbf{1}_{\mathcal{E} \neq \emptyset}\right\}\right\}. \tag{9b}$$

When $\eta < \eta_1(\pi)$, some coalition of locals $S \in \pi$ could profitably block all other locals $\mathcal{L} \setminus S$ and entrants $\mathcal{E}$ from using deforested land. Given that credible threat of blocking, no individual would engage in deforestation. When $\eta > \eta_2(\pi)$, some entrant or coalition $H \in \pi$ that prefers deforestation ($\Delta_H < 0$) will engage in deforestation, knowing that coalitions that prefer the incentive ($S \in \pi$ with $\Delta_S > 0$) won't block use of that deforested land. The term $\sum_{S \in \pi : \Delta_S > 0} \lfloor \frac{\Delta_S}{\eta} \rfloor$ is the maximum number of locals or entrants that the coalitions that prefer the incentive would block; the floor operator $\lfloor \cdot \rfloor$ is used because utility transfer occurs only within coalitions, not across coalitions. When $\eta \in [\eta_1(\pi), \eta_2(\pi)]$, deforestation and no-deforestation equilibria exist because no single coalition could profitably block all other individuals, whereas two or more coalitions jointly could.

The thresholds $\eta_1(\pi)$ and $\eta_2(\pi)$ decrease with the number of entrants. In other words, with more entrants, the blocking cost η must be lower to guarantee a (unique) no-deforestation equilibrium.

The thresholds $\eta_1(\pi)$ and $\eta_2(\pi)$ depend on the partition π. If locals are in the grand coalition ($\pi = \{\mathcal{L}\}$), prefer the incentive ($\Delta_{\mathcal{L}} > 0$) and face no entrants then $\eta_1(\pi) = \eta_2(\pi) = +\infty$: only no-deforestation equilibria exist irrespective of the blocking cost. Similarly, with any partition of locals into coalitions that all prefer the incentive ($\Delta_S > 0$ for all $S \in \pi$) and no entrants, $\eta_2(\pi) = +\infty$: no-deforestation equilibria exist irrespective of the blocking cost. With any partition of locals into coalitions that all prefer deforestation ($\Delta_S < 0, \forall S \in \pi$), $\eta_1(\pi) = \eta_2(\pi) = -\infty$: only deforestation equilibria exist, irrespective of the blocking cost. Except in the aforementioned cases, $\eta_1(\pi)$ and $\eta_2(\pi)$ are strictly positive and finite, i.e., the types of equilibria depend on the blocking cost.

Importantly for §3.3 (how locals partition themselves into coalitions), the partition affects whether or not deforestation occurs and the resulting net income for each coalition. Moreover, Lemma 2 implies that given a partition and condition, the resulting net income may not be unique.

A *Partition Correspondence* $V : \Pi_{\mathcal{L}} \to 2^{\mathrm{R}^{\pi}}$ evaluated at partition π and condition $\mathbb{C}$ is the set of characteristic functions that assign the net income for each coalition $S \in \pi$ in the associated subgame-perfect equilibrium for $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$:

$$V(\pi; \mathbb{C}) = \Big\{ w_{\pi}^{q} : \pi \to \mathrm{R} \text{ for all } q \in \mathcal{Q}(\pi, \mathbb{C}) \Big\}, \tag{10}$$

where the characteristic functions w_{π}^{q} for condition $\mathbb{C}$ and equilibrium $q = (\mathbf{d}^*, \mathbf{B}^*(\mathbf{d})) \in \mathcal{Q}(\pi, \mathbb{C})$ are:

$$w_{\pi}^{q}(S; \mathbb{C}) := \sum_{\ell \in S} J_{\ell}\Big(\mathbf{d}_S^* \cdot \big(1 - \max_{H \in \pi} \mathbf{B}_{H\ell}^*(\mathbf{d}^*)\big), \kappa^{\mathbb{C}}\big(\mathbf{d}^*, \mathbf{B}^*(\mathbf{d}^*)\big)\Big) - \eta \cdot \sum_{i \in \mathcal{L} \cup \mathcal{E}} \mathbf{B}_{Si}^*. \tag{11}$$

Lemma 1 implies that the value of these characteristic functions depends only on S and whether $(\mathbf{d}^*, \mathbf{B}^*(\mathbf{d}))$ is a deforestation equilibrium or no-deforestation equilibrium:

$$w_{\pi}^{q}(S; \mathbb{C}) := w(S, \pi; \mathbf{d}^*) := w(S; \mathbf{d}^*) = \begin{cases} \sum_{\ell \in S} J_{\ell}\big(0, \text{yes}\big) & \text{if } \mathbf{d}^* = \mathbf{0} \\ \sum_{\ell \in S} \big[J_{\ell}(1, \text{no}) - c_{\ell}\big] & \text{if } \mathbf{d}^* = \mathbf{1}, \end{cases} \tag{12}$$

We subsequently use notations $w(S; \mathbf{d}^*)$ and $w(S, \pi; \mathbf{d}^*)$ with the understanding that $\mathbf{d}^* \in T(\pi, \mathbb{C})$.

3.2. Without Coordination and Utility Transfer

Locals and entrants engage in the non-cooperative game of deforestation and blocking with each individual maximizing his own net income (partition $\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$), for which Lemma 2 implies:

Corollary 1. *Without coordination and utility transfer, the area no-deforestation condition* $\mathbb{N}$ *does not prevent deforestation, whereas the area regeneration condition* $\mathbb{R}$ *prevents deforestation if*

$$\eta \le \eta_1^{\mathrm{NC}} := \frac{\max_{g \in \mathcal{G}} \Delta_g}{|\mathcal{L}| - 1 + |\mathcal{E}|}, \tag{13}$$

albeit without achieving compensation.

Our conservative performance criteria (to prevent deforestation, to achieve compliance) require that *all* equilibria have the desired performance. The area no deforestation condition cannot prevent deforestation because $\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$ so deforestation equilibria exist; with one individual engaging in deforestation, deforestation is the best response of all others. The area regeneration condition $\mathbb{R}$ prevents deforestation when the blocking cost is sufficiently low (or equivalently, the incentive is sufficiently strong) that one local $g \in \mathcal{G}$ is motivated to block all other locals $\mathcal{L} \setminus \{g\}$ and all entrants from using deforested land, a credible threat of blocking, so only no-deforestation equilibria exist.

The advantage of the area regeneration condition $\mathbb{R}$ over the area no-deforestation condition $\mathbb{N}$ would be even greater if we were optimistic that the interested party could induce a no-deforestation equilibrium when both equilibrium types exist. From Lemma 2, a no-deforestation equilibrium exists with $\mathbb{R}$ when the blocking cost satisfies $\eta \le \max_{\ell\in\mathcal{L}} \Delta_\ell$, which is weaker than requirement (13) in that the incentive need only motivate a local to block *one* individual, not all the other locals and entrants as in (13). In contrast, under the area no-deforestation condition $\mathbb{N}$, with any entrant or with a local who prefers deforestation (as assumed in 3), only deforestation equilibria exist.

3.3. With Coordination and Utility Transfer

Consider a TU cooperative game in partition correspondence form: $(\mathcal{L}, V)$, where V is the partition correspondence defined in (10). Offered the incentive to meet condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$, the locals $\ell \in \mathcal{L}$ form coalitions and may transfer utility within each coalition. The locals know that with partition $\pi \in \Pi_{\mathcal{L}}$, the net income for each coalition $S \in \pi$ is $w(S, \mathbf{d}^*)$ for some $\mathbf{d}^* \in T(\pi, \mathbb{C})$, with $w(S, \mathbf{d}^*)$ and $T(\pi, \mathbb{C})$ specified in (12) and Lemma 2 of §3.1. An *outcome* of this game is a triple: a partition $\pi \in \Pi_{\mathcal{L}}$, equilibrium indicator $\mathbf{d}^* \in T(\pi)$, and allocation of net income to each local $\{a_\ell\}_{\ell\in\mathcal{L}}$ with $\sum_{\ell\in S} a_\ell = w(S, \mathbf{d}^*)$ for every $S \in \pi$.

To predict which outcomes could occur, we extend Kóczy's *Pessimistic Recursive Core* solution concept to games in partition correspondence form. The premise of the recursive core is that locals who form a coalition anticipate that locals left out of that coalition will act so as to maximize their own net income, engaging in a smaller, "residual TU cooperative game." Through recursion over residual games, one solves for the recursive core: the set of outcomes at which no set of locals would expect to achieve higher net income by forming different coalitions. If the core outcome of a residual game *or the characteristic functions* are not unique, we assume locals who form a coalition have *pessimistic* beliefs about how the rest will act.

Definition 1 (Residual TU Cooperative Game). Consider a subset of locals $R \subseteq \mathcal{L}$ and a fixed partition $\pi_{\mathcal{L}\setminus R} \in \Pi_{\mathcal{L}\setminus R}$ of the other locals. In response to $\pi_{\mathcal{L}\setminus R}$, the locals in R face a *residual TU cooperative game* in partition correspondence form: the sub-partition $\pi_R \in \Pi_R$ formed by the locals in R together with the sub-partition of the other locals $\pi_{\mathcal{L}\setminus R}$ and the associated equilibrium indicator $\mathbf{d}^* \in T(\pi_R \cup \pi_{\mathcal{L}\setminus R})$ determine the net income $w\big(S, \pi_R \cup \pi_{\mathcal{L}\setminus R}; \mathbf{d}^*\big)$ for the locals in each coalition $S \in \pi_R$. An *outcome for the residual game* is a partition $\pi_R \in \Pi_R$, equilibrium indicator $\mathbf{d}^* \in T(\pi_R \cup \pi_{\mathcal{L}\setminus R})$, and allocation $\{a_\ell\}_{\ell\in R}$ with $\sum_{\ell\in S} a_\ell = w\big(S, \pi_R \cup \pi_{\mathcal{L}\setminus R}; \mathbf{d}^*\big)$ for every $S \in \pi_R$.

Definition 2 (Pessimistic Recursive Core). Suppose that for an integer $k \in [1, |\mathcal{L}|-1]$, the core $C(R; \pi_{\mathcal{L}\setminus R})$ is defined for every residual game in which a set of locals $R \subset \mathcal{L}$ with $|R| \in [1, k]$ respond to a partition of the other locals $\pi_{\mathcal{L}\setminus R} \in \Pi_{\mathcal{L}\setminus R}$. For $k = 1$, the residual game has a single local $R = \{\ell\}$ and the core $C(\{\ell\}; \pi_{\mathcal{L}\setminus\{\ell\}})$ is the set of triples of partition, equilibrium indicator, and allocations of the form $\big(\{\{\ell\}\}, \mathbf{d}^*, a_\ell\big)$ with $a_\ell = w\big(\{\ell\}, \{\{\ell\}\}; \mathbf{d}^*\big)$ and $\mathbf{d}^* \in T(\{\{\ell\}\} \cup \pi_{\mathcal{L}\setminus\{\ell\}})$. For a residual game with $|R| = k+1$, the core $C(R; \pi_{\mathcal{L}\setminus R})$ is the set of *un-dominated* outcomes, where an outcome with allocation $\{a_\ell\}_{\ell\in R}$ and partition π_R is *dominated* if there exists a coalition $H \subseteq R$ forming partition $\pi_H \in \Pi_H$ so that

$$w\big(S, \sigma_{R\setminus H} \cup \pi_H \cup \pi_{\mathcal{L}\setminus R}; \hat{\mathbf{d}}^*\big) > \textstyle\sum_{\ell\in S} a_\ell \tag{14}$$

for **every** coalition $S \in \pi_H$, **every** sub-partition $\sigma_{R\setminus H} \in \Pi_{R\setminus H}$ and **every** equilibrium indicator $\hat{\mathbf{d}}^*$ and real values $\{\theta_\ell\}_{\ell\in R\setminus H}$ satisfying:

$$\begin{cases} \big(\sigma_{R\setminus H}, \hat{\mathbf{d}}^*, \{\theta_\ell\}_{\ell\in R\setminus H}\big) \in C(R\setminus H; \pi_H \cup \pi_{\mathcal{L}\setminus R}) & \text{if } H \subset R \text{ and } C(R\setminus H; \pi_H \cup \pi_{\mathcal{L}\setminus R}) \neq \emptyset \\ \hat{\mathbf{d}}^* \in T(\sigma_{R\setminus H} \cup \pi_H \cup \pi_{\mathcal{L}\setminus R}) & \text{otherwise.} \end{cases} \tag{15}$$

The pessimistic recursive core of the TU cooperative game among all locals is then given by $C(\mathcal{L};\emptyset)$.

Notice how the definition of dominated outcome represents *pessimism* (that locals that form a coalition anticipate their *worst-case* net income when the residual locals act to maximize their own net income). For coalition H to deviate, it should be able to form some new partition π_H in which every coalition $S \in \pi_H$ has strictly greater net income than in the starting outcome (per 14) under *every* plausible configuration that could emerge in the residual game played by the remaining locals in $R \setminus H$, i.e., any core outcome (if that residual game has a non-empty core) or any possible equilibrium outcome otherwise (per 15).

The alternative to pessimism is optimism (locals that form a coalition anticipate their best-case net income when residual locals act to maximize their own net income). The EC formulates the optimistic recursive core and, in Proposition 6, shows that this is a subset of the pessimistic recursive core. Our performance criteria require that *only* outcomes with the desired performance are in the recursive core. Therefore, we conservatively assume pessimism. If the performance criteria are met with pessimistic locals, they would also be met with optimistic locals.

For brevity, we subsequently use "core" to refer to the pessimistic recursive core.

A condition $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$ prevents deforestation if the core only contains "No-Deforestation Outcomes", and it achieves compensation if the core only contains "Compensation Outcomes":

Definition 3. A *Deforestation Outcome* is an outcome with a deforestation equilibrium $\mathbf{d}^* = \mathbf{1}$. A *No-Deforestation Outcome* is an outcome with a no-deforestation type of equilibrium $\mathbf{d}^* = \mathbf{0}$ that allocates $a_\ell \geq \min\big(J_\ell(0,\text{yes}),\, J_\ell(1,\text{no}) - c_\ell\big)$ to every local $\ell \in \mathcal{L}$; it is a

$$\textit{Compensation Outcome} \text{ if } a_\ell \geq J_\ell(1,\text{no}) - c_\ell, \text{ for all } \ell \in \mathcal{L}\setminus\mathcal{G}, \tag{16a}$$

$$\textit{Blocking-Threat Outcome} \text{ if } a_\ell = J_\ell(0,\text{yes}), \text{ for all } \ell \in \mathcal{L}\setminus\mathcal{G}, \tag{16b}$$

$$\textit{Partial Compensation Outcome} \text{ if } a_\ell < J_\ell(1,\text{no}) - c_\ell \text{ and } a_h > J_h(0,\text{yes}) \text{ for some } \ell, h \in \mathcal{L}\setminus\mathcal{G}. \tag{16c}$$

In a No-Deforestation Outcome, all locals are better off than in the status quo. A local who prefers the incentive $\ell \in \mathcal{G}$ is allocated at least the net income that he could have earned with deforestation

$J_\ell(1,\text{no}) - c_\ell$, whereas a local who prefers deforestation $\ell \in \mathcal{L} \setminus \mathcal{G}$ has at least his net income with the incentive and no deforestation $J_\ell(0,\text{yes})$. Hence, every local who prefers the incentive is strictly better off than in the status quo with no deforestation and no incentive, and a local who prefers deforestation is also strictly better off than in the status quo if the incentive is strictly positive $\big(J_\ell(0,\text{yes}) > J_\ell(0,\text{no})\big)$. In a "Compensation" Outcome, all locals are allocated at least their net income under deforestation $J_\ell(1,\text{no}) - c_\ell$, being compensated for not deforesting. In a "Blocking-Threat" Outcome, deforestation is prevented through the threat of being blocked, so locals that prefer deforestation are allocated exactly their net incomes with the incentive and no deforestation. In a "Partial Compensation" Outcome, only some of the locals that prefer deforestation are being compensated, while the others do not deforest due to the threat of being blocked. Theorems 1 and 2 show that Compensation, Blocking-Threat, and Partial Compensation are the only types of No-Deforestation Outcome that can be in the core.

Theorem 1 characterizes the core under the area no-deforestation condition $\mathbb{N}$.

THEOREM 1. *Assume* $\mathbb{N}$. *If* $\Delta_\mathcal{L} > 0$ *and* $\mathcal{E} = \emptyset$*, the core is the set of all Compensation Outcomes. If* $\Delta_\mathcal{L} < 0$ *or* $\mathcal{E} \neq \emptyset$*, the core is the set of all Deforestation Outcomes.*

Theorem 1 shows that the area no-deforestation condition prevents deforestation with compensation when the locals collectively prefer the incentive ($\Delta_\mathcal{L} > 0$) and there are no entrants ($\mathcal{E} = \emptyset$). Due to $\mathcal{G} \neq \mathcal{L}$, this requires utility transfer. To induce a no-deforestation equilibrium $\mathbf{d}^* = \mathbf{0}$, locals who prefer the incentive must transfer utility to the locals within their coalition who prefer deforestation (locals $S \cap \mathcal{G}$ transfer utility to $S \cap (\mathcal{L} \setminus \mathcal{G})$ in every coalition $S \in \pi$) so every local is fully compensated for his missed deforestation opportunity and thus motivated to set $d_\ell = 0$. This compensation mechanism is effective exactly when the local community prefers the incentive ($\Delta_\mathcal{L} > 0$) and faces no entrants ($\mathcal{E} = \emptyset$). When utility transfer cannot compensate all individuals who prefer deforestation, either because $\Delta_\mathcal{L} < 0$ or there are entrants, a Deforestation Outcome occurs. As $\mathbb{N}$ produces no credible threat of blocking, the only No-Deforestation Outcomes are Compensation ones.

Theorem 2 characterizes the core under the area regeneration condition $\mathbb{R}$. While reading statements (a-h) for the case that locals collectively prefer the incentive ($\Delta_\mathcal{L} > 0$), consider Figure 3.1. It illustrates how the types of outcome in the core vary with the magnitude of the blocking cost η and (unless η is small) vary with the potential for entry. Statements (a-b) address cases of low blocking cost; Statements (c-e) and the top panel of Figure 3.1 focus on the case without entrants; Statements (f-h) and the bottom panel focus on the case with entrants.

THEOREM 2. *Assume* $\mathbb{R}$. *If* $\Delta_\mathcal{L} > 0$*, there exist thresholds* $\eta_1^{\text{TU}} \leq \eta_2^{\text{TU}} \leq \eta_3^{\text{TU}} \leq \eta_4^{\text{TU}}$ *such that*

(a) If $\eta \leq \eta_1^{\text{TU}}$*, the core is the set of Blocking-Threat Outcomes;*

(b) *If* $\eta_1^{\mathrm{TU}} < \eta < \eta_2^{\mathrm{TU}}$*, the core contains only Blocking-Threat Outcomes and (if* $\eta > \min_{S\subseteq\mathcal{L}:\Delta_S<0} \frac{\Delta_{\mathcal{L}\setminus S}}{|S|}$*) it may be empty;*

(c) *If* $\mathcal{E} = \emptyset$ *and* $\eta_2^{\mathrm{TU}} < \eta < \eta_3^{\mathrm{TU}}$*, the core contains only Partial Compensation Outcomes, and it may be empty;*

(d) *If* $\mathcal{E} = \emptyset$ *and* $\eta_3^{\mathrm{TU}} < \eta \le \Delta_{\mathcal{G}}$*, the core contains all Compensation Outcomes, may contain Partial Compensation Outcomes, and does not contain a Blocking Threat or Deforestation Outcome;*

(e) *If* $\mathcal{E} = \emptyset$ *and* $\eta > \Delta_{\mathcal{G}}$*, the core is the set of Compensation Outcomes;*

(f) *If* $\mathcal{E} \neq \emptyset$ *and* $\eta_2^{\mathrm{TU}} < \eta < \eta_3^{\mathrm{TU}}$ *the core may contain Partial Compensation Outcomes, may (if* $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$*) contain Blocking Threat Outcomes, and (if* $\eta > \min_{S\subseteq\mathcal{L}:\Delta_S<0} \frac{\Delta_{\mathcal{L}\setminus S}}{|S|}$*) may be empty; it does not contain any Compensation or Deforestation Outcome;*

(g) *If* $\mathcal{E} \neq \emptyset$ *and* $\eta_3^{\mathrm{TU}} < \eta < \eta_4^{\mathrm{TU}}$*, the core contains all Compensation Outcomes, may contain Partial Compensation Outcomes, may (if* $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$*) contain Blocking-Threat Outcomes, and does not contain any Deforestation Outcome;*

(h) *If* $\mathcal{E} \neq \emptyset$ *and* $\eta_4^{\mathrm{TU}} < \eta < \Delta_{\mathcal{G}}$*, the core contains Deforestation Outcomes, may (if* $\eta < \Delta_{\mathcal{L}}$*) contain Compensation Outcomes, may (if* $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$*) contain Blocking-Threat Outcomes, and may contain Partial Compensation Outcomes.*

(i) *If* $\mathcal{E} \neq \emptyset$ *and* $\eta > \Delta_{\mathcal{G}}$*, the core is the set of Deforestation Outcomes.*

If $\Delta_{\mathcal{L}} < 0$*, the core contains only Deforestation Outcomes and may be empty.*

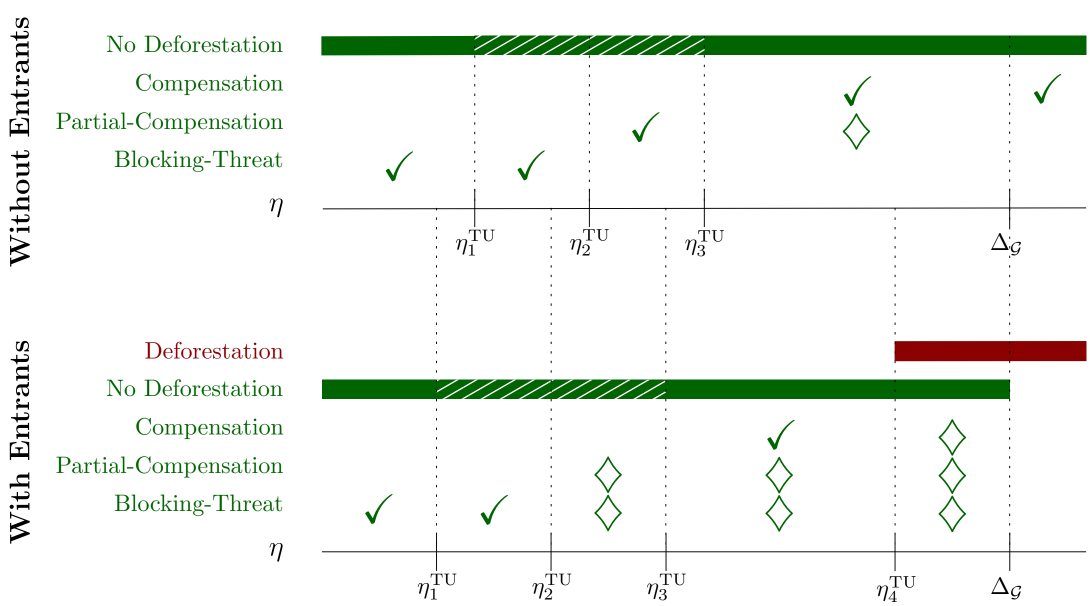

Figure 3.1 Types of outcome in the core under the regeneration condition $\mathbb{R}$, when locals collectively prefer to protect the forest ($\Delta_{\mathcal{L}} > 0$), as a function of the blocking cost η. A solid bar indicates that the core is nonempty. Slashed grey/green indicates that the core may be empty and contains only No-Deforestation Outcomes. A "✓" indicates that a particular welfare type (Compensation vs. Partial-Compensation vs. Blocking-Threat) of No-Deforestation Outcome is in the core, whereas a "◇" indicates that the particular welfare type *can* be in the core.

Theorem 2 shows that the area regeneration condition $\mathbb{R}$ can prevent deforestation when locals collectively prefer the incentive ($\Delta_{\mathcal{L}} > 0$). Let us focus on the case $\Delta_{\mathcal{L}} > 0$ and, to understand the various mechanisms by which $\mathbb{R}$ prevents deforestation, consider the expressions for the thresholds:

$$\eta_1^{\mathrm{TU}} := \min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S| + |\mathcal{E}|}, \quad \eta_2^{\mathrm{TU}} := \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G}| + |\mathcal{E}|}, \quad \eta_3^{\mathrm{TU}} := \max_{S \subset \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S| + |\mathcal{E}|}, \quad \eta_4^{\mathrm{TU}} := \max_{S \subseteq \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S| + |\mathcal{E}|}.$$

Without entrants ($\mathcal{E} = \emptyset$), the area regeneration condition prevents deforestation. When the blocking cost is sufficiently low ($\eta < \eta_2^{\mathrm{TU}}$), the credible threat of blocking prevents deforestation: any outcome with deforestation or involving utility transfer from locals in $\mathcal{G}$ who prefer the incentive would be dominated by all such locals forming a coalition $\mathcal{G}$, which would strictly increase their net income and create a credible threat of blocking all other locals $\mathcal{L} \setminus \mathcal{G}$; hence only Blocking-Threat Outcomes are in the core. As the blocking cost exceeds η_2^{TU}, the locals in $\mathcal{G}$ can no longer profitably block a coalition $\mathcal{L} \setminus \mathcal{G}$, so locals in $\mathcal{G}$ must transfer utility to some locals in $\mathcal{L} \setminus \mathcal{G}$ to attract them into a coalition with a credible blocking threat, which leads to Partial Compensation Outcomes. As the blocking cost exceeds η_3^{TU}, no coalition S could be formed that could profitably block all the other locals $\mathcal{L} \setminus S$, which leads to all Compensation Outcomes appearing in the core, and possibly some Partial Compensation Outcomes. When the blocking cost is so high that blocking could never occur ($\eta > \Delta_{\mathcal{G}}$), condition $\mathbb{R}$ is equivalent to $\mathbb{N}$, and the core is the set of Compensation Outcomes.

The case with entrants ($\mathcal{E} \neq \emptyset$) has several similarities to the case without entrants. As discussed above, the core only contains Blocking-Threat Outcomes if the blocking cost is sufficiently low ($\eta < \eta_2^{\mathrm{TU}}$); at larger blocking cost values, the core continues to contain Blocking-Threat Outcomes provided the locals who prefer the incentive have a credible threat of blocking all other locals ($\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G}|}$), and it also includes outcomes with some degree of compensation: Partial Compensation Outcomes again emerge if η exceeds η_2^{TU} and Compensation Outcomes emerge if η exceeds η_3^{TU}. However, the values of η_1^{TU}, η_2^{TU}, and η_3^{TU} decrease with the number of entrants, which signifies that each of these different regimes occurs at lower levels of the blocking cost η. One can see this shift in η_1^{TU}, η_2^{TU}, and η_3^{TU} from the case without entrants to the case with entrants in Figure 3.1.

The important difference is that with entrants, deforestation can occur even though the local community prefers the incentive ($\Delta_{\mathcal{L}} > 0$), as illustrated in Figure 3.1. When the blocking cost exceeds η_4^{TU}, the core contains Deforestation Outcomes because no coalition of locals can profitably block the remaining locals and entrants from engaging in deforestation. For $\eta \in (\eta_4^{\mathrm{TU}}, \Delta_{\mathcal{G}})$, Deforestation Outcomes co-exist in the core with No-Deforestation Outcomes, and the Deforestation Outcomes are maintained by locals who prefer deforestation ($\mathcal{L} \setminus \mathcal{G}$) transferring sufficient utility to locals who prefer the incentive to induce them to engage in deforestation. Those transfers cease for $\eta > \Delta_{\mathcal{G}}$ because blocking would never occur, so the core contains only Deforestation Outcomes.

Another difference is that the regeneration condition $\mathbb{R}$ can prevent deforestation with compensation only without entrants. However, with entrants and without entrants, at moderate levels of the blocking cost, the core with $\mathbb{R}$ contains Compensation Outcomes and another type of No-Deforestation Outcome. In that case, the regeneration condition $\mathbb{R}$ does not achieve compensation because, by our conservative definition, that would require having only Compensation Outcomes.

With the regeneration condition $\mathbb{R}$, the core may be empty (locals may fail to coordinate and transfer utility). When the local community collectively prefers the incentive ($\Delta_{\mathcal{L}} > 0$), the core may be empty *only* if $\eta \in (\eta_1^{\text{TU}}, \eta_3^{\text{TU}})$. At those intermediate levels of blocking cost, a No-Deforestation Outcome may be dominated by a Deforestation Outcome wherein a group of locals $B \subseteq \mathcal{L} \setminus \mathcal{G}$ who prefer deforestation transfer utility to locals $B' \subseteq \mathcal{G}$ to induce them to join coalition $B \cup B'$ that collectively prefers deforestation ($\Delta_{B\cup B'} < 0$) and could not be blocked by the residual locals $\mathcal{L} \setminus (B \cup B')$. However, the core cannot contain a Deforestation Outcome because it would be dominated by the entire community of locals forming the grand coalition $\mathcal{L}$ and protecting the forest, which would improve the community's collective net income.

When the local community collectively prefers deforestation ($\Delta_{\mathcal{L}} < 0$), area regeneration condition $\mathbb{R}$ cannot prevent deforestation: any core outcome is a Deforestation Outcome. However, the core may be empty. Consider an example with no entrants and three locals $\mathcal{L} = \{f, g, h\}$; g prefers the incentive ($\Delta_g > 0$); the other two prefer deforestation, to the extent that $\Delta_g + \Delta_f < 0$ and $\Delta_g + \Delta_h < 0$, meaning that either f or h could transfer enough utility to induce g to participate in deforestation rather than block others' production. In this case, f would refuse to join a coalition to transfer utility to g, hoping to free-ride on h doing so (and the same would be true for h). Thus, despite having $\Delta_{\mathcal{L}} < 0$, the locals might not engage in deforestation.

The following corollary to Theorems 1 and 2 summarizes the performance of the area conditions.

Corollary 2. *With coordination and utility transfer, area conditions* $\mathbb{N}$ *and* $\mathbb{R}$ *prevent deforestation* <u>*only*</u> *if locals collectively prefer the incentive* ($\Delta_{\mathcal{L}} > 0$)*, in which case: (a.) Without entrants,* $\mathbb{N}$ *and* $\mathbb{R}$ *prevent deforestation;* $\mathbb{N}$ *achieves compensation and* $\mathbb{R}$ *achieves compensation if* $\eta > \Delta_{\mathcal{G}}$*; (b.) With entrants,* $\mathbb{N}$ *cannot prevent deforestation, whereas* $\mathbb{R}$ *prevents deforestation if* $\eta < \eta_4^{\text{TU}}$*.*

Corollaries 1 and 2 show that $\mathbb{R}$ is better than $\mathbb{N}$ to prevent deforestation. However, in the more limited case that $\mathbb{N}$ also prevents deforestation (with coordination and utility transfer, no entrants, and locals that collectively prefer the incentive) $\mathbb{N}$ is better for achieving compensation. Assuming locals collectively prefer the incentive, $\mathbb{R}$ prevents deforestation at higher levels of the blocking cost with coordination and utility transfer than without: $\eta_1^{\text{NC}} \leq \eta_2^{\text{TU}}$ and the inequality is strict if $|\mathcal{G}| > 1$.

4. Selecting an Incentive and a Forest Protection Condition

This section provides guidance on how to select an incentive and a forest protection condition $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$ to prevent deforestation and to achieve compensation, respectively. For each of those two purposes, we recommend the best among the three candidate conditions and the corresponding feasible set of incentives to use. The best condition is one with the largest feasible set of incentives; in most cases, this exists and is unique. We relax assumption (3) to allow for incentives with

$$\phi_\ell \geq \delta_\ell \text{ for every } \ell \in \mathcal{L}, \tag{17}$$

and remind the reader that δ_ℓ denotes the value to local ℓ of engaging in deforestation, and ϕ_ℓ denotes the value of the incentive to local ℓ if he doesn't engage in deforestation. Figure 4.2 summarizes our recommendations. One could use Figure 4.2 to check whether a candidate non-monetary incentive (e.g., land tenure) or practical financial incentive (e.g., RSPO price premium) will work. We also derive the idiosyncratic payment to each local $\ell \in \mathcal{L}$ that would minimize the total payment $\sum_{\ell\in\mathcal{L}} \phi_\ell$ required to prevent deforestation and achieve compensation, respectively. (Admittedly, implementing that idiosyncratic payment to each local may be prohibitively difficult.) The best forest protection condition and feasible set of incentives (and hence the minimum total payment) depend on the potential for entry and whether locals can coordinate and transfer utility, so we will discuss each of the four scenarios in turn. The EC provides formal statements (Propositions 1-4) of all results in this section, and their proofs, leveraging Corollary 1 and Theorems 1 and 2.

		Without Coordination & TU	**With Coordination & TU**
Without Entrants	Prevent Deforestation	$\mathbb{R}$ with $\phi_\ell > \delta_\ell + \eta\cdot(\lvert\mathcal{L}\rvert - 1)$ for some $\ell\in\mathcal{L}$ or $\mathbb{I}$ with $\phi_\ell > \delta_\ell$ for all $\ell \in \mathcal{L}$	$\mathbb{N}$ or $\mathbb{R}$ with $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$
Without Entrants	and Achieve Compensation	$\mathbb{I}$ with $\phi_\ell > \delta_\ell$ for all $\ell \in \mathcal{L}$	$\mathbb{N}$ with $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$
With Entrants	Prevent Deforestation	$\mathbb{R}$ with $\phi_\ell > \delta_\ell + \eta\cdot(\lvert\mathcal{L}\rvert - 1 + \lvert\mathcal{E}\rvert)$ for some $\ell\in\mathcal{L}$	$\mathbb{R}$ with $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$ and $\sum_{\ell\in H}\phi_\ell > \sum_{\ell\in H}\delta_\ell + \eta\cdot(\lvert\mathcal{L}\rvert - \lvert H\rvert + \lvert\mathcal{E}\rvert)$ for some $H \subseteq \mathcal{L}$
With Entrants	and Achieve Compensation	$\mathbb{R}$ with $\phi_\ell > \delta_\ell$ for all $\ell\in\mathcal{L}$ and $\phi_\ell > \delta_\ell + \eta\cdot(\lvert\mathcal{L}\rvert - 1 + \lvert\mathcal{E}\rvert)$ for some $\ell\in\mathcal{L}$	$\mathbb{R}$ with $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$, $\phi_\ell > \delta_\ell$ for all $\ell \in \mathcal{L}$, and $\sum_{\ell\in H}\phi_\ell > \sum_{\ell\in H}\delta_\ell + \eta\cdot(\lvert\mathcal{L}\rvert - \lvert H\rvert + \lvert\mathcal{E}\rvert)$ for some $H \subseteq \mathcal{L}$

Figure 4.2 Recommended forest protection condition $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$ and corresponding feasible set of incentives. Each inequality has a distinct color to highlight the similarities and differences among the feasible sets of incentives.

Without Coordination and Utility Transfer Among Locals, and Without Entrants, to prevent deforestation, one should offer an incentive conditional on area regeneration $\mathbb{R}$ with

$$\phi_\ell > \delta_\ell + \eta \cdot (\lvert\mathcal{L}\rvert - 1) \text{ for at least one } \ell \in \mathcal{L} \tag{18}$$

or offer an incentive conditional on $\mathbb{I}$ with

$$\phi_\ell > \delta_\ell \text{ for every } \ell \in \mathcal{L}. \tag{19}$$

The area regeneration condition $\mathbb{R}$ prevents deforestation with the minimum total payment unless the blocking cost is so large that $\eta > (\sum_{\ell\in\mathcal{L}} \delta_\ell - \min_{\ell\in\mathcal{L}} \delta_\ell)/(|\mathcal{L}|-1)$. With $\mathbb{R}$, the minimum total payment is $\min_{\ell\in\mathcal{L}} \delta_\ell + \eta\cdot(|\mathcal{L}|-1)$. That total payment must go to just one local ℓ who would benefit least from deforestation and zero payment to the others. Unfortunately, that is worst for distributive justice, especially in the common circumstance that the local who would benefit least from deforestation is the wealthiest. With $\mathbb{I}$, the minimum total payment is just above $\sum_{\ell\in\mathcal{L}} \delta_\ell$.

With $\mathbb{I}$, an incentive with (19) would prevent deforestation with compensation. The minimum total payment to achieve compensation is the same as to prevent deforestation, just above $\sum_{\ell\in\mathcal{L}} \delta_\ell$. However, (19) requires a *perfect* incentive that directly compensates every local to forgo deforestation. An easier approach might be to promote cooperation, for example, by dividing the area so that locals in each sub-area can coordinate and transfer utility among themselves and applying $\mathbb{R}$ or $\mathbb{N}$.

Without coordination, $\mathbb{N}$ cannot prevent deforestation.

Without Coordination and Utility Transfer Among Locals, and With Entrants, to prevent deforestation, one should offer an incentive conditional on area regeneration $\mathbb{R}$ with

$$\phi_\ell > \delta_\ell + \eta\cdot(|\mathcal{L}|-1+|\mathcal{E}|) \text{ for at least one } \ell\in\mathcal{L}. \tag{20}$$

The minimum total payment to prevent deforestation with $\mathbb{R}$ is $\min_{\ell\in\mathcal{L}} \delta_\ell + \eta\cdot(|\mathcal{L}|-1+|\mathcal{E}|)$, and that total payment must go to just one local ℓ who would benefit least from deforestation.

To prevent deforestation with compensation, one should offer an incentive conditional on area regeneration $\mathbb{R}$ that satisfies (20) and (19). Paying $\phi_j = \delta_j + \eta\cdot(|\mathcal{L}|-1+|\mathcal{E}|)$ to one (arbitrarily chosen) local j and paying $\phi_\ell = \delta_\ell$ to each other local $\ell\in\mathcal{L}\setminus\{j\}$ would minimize the total payment.

With entrants, the other conditions $\mathbb{I}$ and $\mathbb{N}$ cannot prevent deforestation.

With Coordination and Utility Transfer Among Locals, and Without Entrants, to prevent deforestation, one should offer an incentive with

$$\textstyle\sum_{\ell\in\mathcal{L}} \phi_\ell > \sum_{\ell\in\mathcal{L}} \delta_\ell. \tag{21}$$

and use area no-deforestation condition $\mathbb{N}$ or area regeneration condition $\mathbb{R}$. An incentive conditional on $\mathbb{I}$ must satisfy (19) to prevent deforestation, which is stronger than (21), so $\mathbb{N}$ and $\mathbb{R}$ are best.

To achieve compensation, $\mathbb{N}$ is the unique best condition. An incentive with (21) conditional on $\mathbb{N}$ will prevent deforestation with compensation. Indeed, with no entrants, the locals' ability to transfer utility enables $\mathbb{N}$ to prevent deforestation *and* promote distributive justice, as $\mathbb{N}$ incentivizes locals to transfer utility so that every local is compensated for not engaging in deforestation. The feasible set of incentives is strictly smaller with $\mathbb{R}$ than $\mathbb{N}$, and is strictly smaller with $\mathbb{I}$ than $\mathbb{R}$. An incentive conditional on $\mathbb{R}$ prevents deforestation with compensation if and only if (21) and (19) hold or (21) and $\sum_{\ell\in\mathcal{G}}\phi_\ell < \eta + \sum_{\ell\in\mathcal{G}}\delta_\ell$ hold. An incentive conditional on $\mathbb{I}$ prevents deforestation with compensation if and only if (19) holds.

The minimum total payment to prevent deforestation or to prevent deforestation with compensation is just above $\sum_{\ell\in\mathcal{L}}\delta_\ell$. Remarkably, this is achieved with $\mathbb{N}$ and any payments that satisfy (21). Recall, for comparison, that when locals are unable to transfer utility, the minimum total payment to prevent deforestation would be $\min_{\ell\in\mathcal{L}}\delta_\ell + \eta\cdot(|\mathcal{L}|-1)$ and the minimum total payment to achieve compensation would be $\sum_{\ell\in\mathcal{L}}\delta_\ell + \eta\cdot(|\mathcal{L}|-1)$. We conclude that utility transfer reduces the cost to the interested party to achieve compensation, and it also reduces the cost to prevent deforestation if and only if the blocking cost is sufficiently large: $\eta > (\sum_{\ell\in\mathcal{L}}\delta_\ell - \min_{\ell\in\mathcal{L}}\delta_\ell)/(|\mathcal{L}|-1)$.

With Coordination and Utility Transfer Among Locals, and With Entrants, to prevent deforestation, one should offer an incentive conditional on area regeneration $\mathbb{R}$ with

$$\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell \tag{22a}$$

$$\sum_{i\in H}\phi_i > \sum_{i\in H}\delta_i + \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|) \text{ for some } H\subseteq\mathcal{L}. \tag{22b}$$

In such a case, Falcon et al. (2022) conducted an RCT in offering payment to a village community conditional on no major forest clearing by fire in the village for a year. This failed, which Falcon et al. attribute to forest clearing by entrants and insufficient payment to the local community. However, with blocking interpreted as locals putting out fires quickly, preventing a major clearing, and allowing the forest to regenerate, Equation (22b) suggests that the intervention might have failed because η, the cost of blocking, was prohibitively high. Providing locals with a fire-alert system could reduce the cost of blocking and make the intervention successful.

The minimum total payment to prevent deforestation is $\max\left(\sum_{\ell\in\mathcal{L}}\delta_\ell, \sum_{\ell\in H}\delta_\ell + \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)\right)$ and is achieved with a payment of $\sum_{\ell\in H}\phi_\ell = \sum_{\ell\in H}\delta_\ell + \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)$ to the locals in H and an arbitrary split of any remaining payment $\left(\sum_{\ell\in\mathcal{L}\setminus H}\delta_\ell - \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)\right)^+$ among all locals; the set H includes all locals with values from deforestation strictly less than the blocking cost η (when such locals exist) or a local with the lowest value from engaging in deforestation otherwise, i.e., $H := \{\ell\in\mathcal{L} : \delta_\ell < \eta\} \cup \{i\}$ for some $i \in \arg\min_{\ell\in\mathcal{L}}\delta_\ell$. This favors locals with low value from engaging in deforestation and so performs poorly from a distributional justice perspective. The potential for entry increases the minimum total payment to prevent deforestation, for sufficiently high η, by $(\eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|) - \sum_{\ell\in\mathcal{L}\setminus H}\delta_\ell)^+$. Like in the case without entrants, utility transfer reduces the cost to prevent deforestation if and only if the blocking cost is sufficiently large, and the threshold decreases with $|\mathcal{E}|$. Utility transfer reduces the cost to prevent deforestation if $|\mathcal{E}|$ is sufficiently large.

To prevent deforestation with compensation, one should offer an incentive conditional on area regeneration $\mathbb{R}$ with (22a), (22b), and (19). The minimum total payment to achieve compensation is $\sum_{\ell\in\mathcal{L}}\delta_\ell + \eta\cdot|\mathcal{E}|$ and requires paying at least $\phi_\ell = \delta_\ell$ to each local, with the additional amount $\eta\cdot|\mathcal{E}|$ distributed arbitrarily among the locals. The potential for entry strictly increases the minimum payment to prevent deforestation with compensation by $\eta\cdot|\mathcal{E}|$, the cost for locals to block all entrants.

5. Illustration in Indonesia

East Kalimantan, Indonesia, has extensive forests at risk of conversion to oil palm farms. In 58 villages therein (mapped in Figure EC.1) we surveyed smallholder palm farmers in order to evaluate the potential for a price premium for palm fruit conditional on $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$ to prevent deforestation and achieve compensation, respectively. In §5.1, we calibrate our model for each of the 58 villages. In §5.2 we consider the case without entrants ($\mathcal{E} = \emptyset$) because $\mathbb{I}$ and $\mathbb{N}$ are useful only in that case. In §5.3, we find that the area regeneration requirement $\mathbb{R}$ is highly robust to deter entrants.

5.1. Model Calibration

A local ℓ is a palm farmer. Recall that his value from engaging in deforestation is $\delta_\ell := J_\ell(1, \text{no}) - c_\ell - J_\ell(0, \text{no})$ and from the incentive is $\phi_\ell := J_\ell(0, \text{yes}) - J_\ell(0, \text{no})$, wherein $J_\ell(0, \text{no})$ represents his status quo income, $J_\ell(0, \text{yes})$ his income with no deforestation and the incentive, and $J_\ell(1, \text{no}) - c_\ell$ his net income with deforestation. We calibrate those model parameters for each ℓ to be representative of one of the 391 idiosyncratic palm farmers in our survey, distributed in 58 villages (with the number of farmers $|\mathcal{L}|$ ranging from 35 to 295). Importantly, we apply robust Data Envelope Analysis (DEA) to over- rather than under-estimate each farmer's idiosyncratic value with deforestation δ_ℓ, in order to be conservative in predicting that an incentive and condition would prevent deforestation.

The Table in Figure 5.3 describes and assigns notation for data we use from our survey. We use plot-level data because half of surveyed farmers have more than one plot, and tree ages, production yields, and (in some cases) selling prices and production costs differ among a farmer's plots. Production is measured in metric tons of fresh fruit bunches (tFFB). Farmers generally reported their significant production costs as those for harvest labor and transport of fruit from the plot to the mill for sale. Half of the surveyed farmers did not report an interest rate to borrow money, so we substitute the median reported interest rate for β_ℓ; we use an analogous procedure in the few cases that the price, transport cost, or harvest cost is missing for a plot.

Lastly, we assume that any farmer can convert forest to a new plot by incurring cost $c^{\text{def}} = 375$ USD per hectare, comprised of the costs to clear forest by fire (5 USD/ha per Falcon et al. 2022) and to plant saplings (2.96 USD/sapling and 125 saplings per hectare per our survey).

Palm fruit production varies with tree age (years elapsed since planting) as shown in Figure 5.3: production is zero for two years after planting, peaks after eight years, and declines thereafter.

Status Quo Income from Existing Plots. Our estimate of net cash flow for farmer ℓ from existing plot $i \in \mathcal{P}_\ell$ in a future year when the trees reach age $a \geq a_{\ell,i}$ and with fruit price p is

$$I^e_\ell(i, a, p) = (p - h_{\ell,i} - \tau_{\ell,i}) \cdot q_{\ell,i} \cdot y_a / y_{a_{\ell,i}}, \text{ for any } a \geq a_{\ell,i}. \tag{23}$$

Here, $y_a/y_{a_{\ell,i}}$ accounts for the predictable variation in fruit production with the age of the trees. Our estimate of the farmer's status-quo income without deforestation and without the incentive is

$$J_\ell(0, \text{no}) = \textstyle\sum_{t=1}^{T} (1 + \beta_\ell)^{-t} \sum_{i \in \mathcal{P}_\ell} I^e_\ell(i, a_{\ell,i} + t, p_{\ell,i}). \tag{24}$$

Definition	Mean	Range
plot area $A_{\ell,i}$ (hectares)	2	0.3-17.5
tree age $a_{\ell,i}$ (years)	9.9	1-40
production $q_{\ell,i}$ (tFFB/year)	41.3	0.5-480
price $p_{\ell,i}$ (USD/tFFB)	90	51-129
transport cost $\tau_{\ell,i}$ (USD/tFFB)	11.8	1-29.6
harvest cost $h_{\ell,i}$ (USD/tFFB)	16	0.2-29.6
interest rate β_ℓ (% /year)	16.5	2.6-102

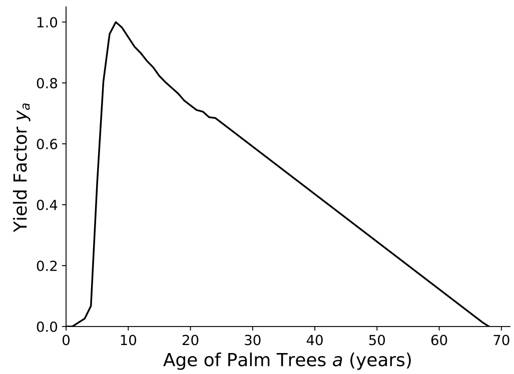

Figure 5.3 Data by Plot and Farmer (Left): The 391 survey participants produce palm fruit on 683 separate plots: $i \in \mathcal{P}_\ell$ indicates that plot i is among farmer ℓ's plots. Yield Multiplier (Right): The attainable yield for oil palm in Indonesia as a function of tree age a is taken from Hoffmann et al. (2014) for tree ages a of 1-25 years and linearly extrapolated for the later years. Yield multiplier y_a is the attainable yield divided by the maximum attainable yield that occurs at age 8 years. In other words, yield multiplier y_a is the attainable yield normalized to take values between zero and (at age 8 years) one.

We assume that a farmer discounts cash flows according to his interest rate to borrow money and uses a finite planning horizon T. All results in this section are for $T = 20$ years, and §EC.3.3 shows that (due to discounting) the results exhibit remarkably little variation with any choice of planning horizon larger than T=15. We assume a farmer's expected future prices and costs are the same as those he reported in the survey. This is not an unreasonable representation of information available to a smallholder farmer and could even be justified in a stochastic model with a martingale structure.

Income from Existing Plots with the Incentive. The incentive is a *price premium* p^* per tFBB, so farmer ℓ's estimated income without deforestation and with the incentive is

$$J_\ell(0,\text{yes}) = \sum_{t=1}^{T}(1+\beta_\ell)^{-t}\sum_{i\in\mathcal{P}_\ell} I_\ell^e(i, a_{\ell,i}+t, p_{\ell,i}+p^*), \tag{25}$$

and his value from the incentive is

$$\phi_\ell(p^*) = J_\ell(0,\text{yes}) - J_\ell(0,\text{no}) = p^*\cdot\sum_{t=1}^{T}(1+\beta_\ell)^{-t}\sum_{i\in\mathcal{P}_\ell} q_{\ell,i}\cdot y_{(a_{\ell,i}+t)}/y_{a_{\ell,i}}. \tag{26}$$

The maximum RSPO price premium contemporaneous with our survey is 30 USD/tFFB.

Income with Deforestation. We conservatively (over) estimate the area of forest x_ℓ that farmer ℓ would convert to palm farm, and his resulting net income $J_\ell(1,\text{no}) - c_\ell$.

The first step is to estimate an efficient production frontier $u(A)$: maximum annual production quantity of palm fruit for a farmer with *total* land area A and trees at peak productive age 8 years. Scaling up the production quantity $q_{\ell,i}$ reported by farmer ℓ (for trees aged $a_{\ell,i}$) by a factor $y_8/y_{a_{\ell,i}} = 1/y_{a_{\ell,i}} \geq 1$, we estimate the *total peak production quantity* that farmer ℓ could have produced on all his existing plots if the trees were at the peak productive age:

$$\hat{q}_\ell := \sum_{i\in\mathcal{P}_\ell} q_{\ell,i}/y_{a_{\ell,i}}. \tag{27}$$

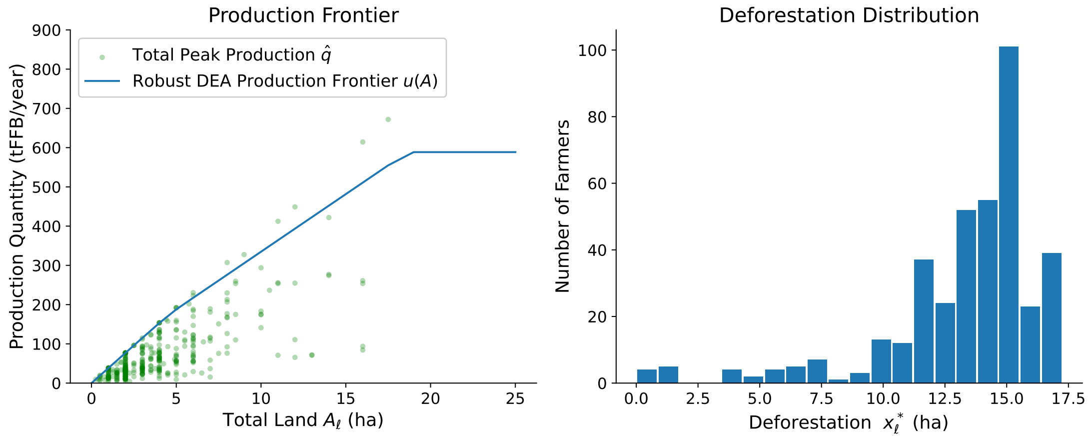

Figure 5.4 (Left) Scatter plot of each farmer's total peak production quantity $\hat{q}_\ell$ and total land $A_\ell = \sum_{i\in\mathcal{P}_\ell} A_{\ell,i}$, with $u(A)$, the robust efficient production frontier of these points estimated using m-estimator DEA. (Right) Histogram of a farmer's estimated optimal area to deforest x^*; the leftmost bar is for $x^* = 0$.

Each point in Figure 5.4 (left) plots a farmer's total peak production quantity $\hat{q}_\ell$ and total land $A_\ell = \sum_{i\in\mathcal{P}_\ell} A_{\ell,i}$. Estimated efficient production frontier $u(A)$ is the robust concave envelope of those points (blue line) calculated by m-estimator robust DEA, as detailed in §EC.3.1.

Second, we use that efficient production frontier to (over) estimate the net income that farmer ℓ could generate by deforesting a plot of area x_ℓ. The estimated annual production quantity for farmer ℓ from the deforested plot of area x_ℓ with trees at peak productive age is:

$$\hat{q}^{\text{def}}_\ell(x_\ell) := u\Big(\sum_{i\in\mathcal{P}_\ell} A_{\ell,i} + x_\ell\Big) - u\Big(\sum_{i\in\mathcal{P}_\ell} A_{\ell,i}\Big), \tag{28}$$

and with trees of arbitrary age a it is $\hat{q}^{\text{def}}_\ell(x_\ell)\cdot y_a$. Hence, in the a^{th} year after deforesting the land and planting seedlings, the estimated net cash flow from the new plot is:

$$I^d_\ell(x_\ell, a) = (\overline{p}_\ell - \underline{h}_\ell - \underline{\tau}_\ell)\cdot \hat{q}^{\text{def}}_\ell(x_\ell)\cdot y_a, \text{ for any } a \geq 0, \tag{29}$$

where $\overline{p}_\ell := \max_{i\in\mathcal{P}_\ell} p_{\ell,i}$, $\underline{h}_\ell := \min_{i\in\mathcal{P}_\ell} h_{\ell,i}$, and $\underline{\tau}_\ell := \min_{i\in\mathcal{P}_\ell} \tau_{\ell,i}$ denote the largest price obtained and lowest costs incurred by farmer ℓ on his existing plots, respectively.

At last, we (over) estimate the net income for ℓ with deforestation and without the incentive by

$$J_\ell(1,\text{no}) - c_\ell = \max_{x_\ell\geq 0}\left\{\sum_{t=1}^T (1+\beta_\ell)^{-t}\left[\sum_{i\in\mathcal{P}_\ell} I^e_\ell(i, a_{\ell,i}+t, p_{\ell,i}) + I^d_\ell(x_\ell, t)\right] - c^{\text{def}}\cdot x_\ell\right\}, \tag{30}$$

and the value from deforestation δ_ℓ as,

$$\delta_\ell = J_\ell(1,\text{no}) - c_\ell - J_\ell(0,\text{no}) = \sum_{t=1}^T (1+\beta_\ell)^{-t} I^d_\ell(x^*_\ell, t) - c^{\text{def}}\cdot x^*_\ell, \tag{31}$$

where $c^{\text{def}} = 375$ USD/hectare is the cost to clear forest and plant seedlings. With x^*_ℓ denoting the solution to (30), Figure 5.4 (right) shows the distribution of x^*_ℓ among farmers. Nearly all (387 out of 391) farmers would benefit from some deforestation. None would deforest more than 20 hectares.

Blocking Cost. We consider the range $\eta \in (0, 3000]$ USD. The upper bound 3000 USD is the cost to use bulldozers and excavators to clear 20 hectares of light forest (Falcon et al. 2022). Lower blocking cost could be achieved, for instance, by cutting palm seedlings with a chainsaw (Villadiego 2017).

5.2. Performance of a Price Premium Conditional on $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$, Without Entrants

Figure 5.5 illustrates the *mismatch* inherent in a price premium incentive to prevent deforestation: the largest value from the incentive goes to farmers with the least value from deforestation, whereas farmers with the least land and largest value from deforestation gain the least value from the incentive. Due to mismatch and insufficient magnitude of RSPO price premium $p^* = 30$ USD/tFFB, at that price premium, 94% of the farmers prefer deforestation (have $\Delta_\ell = \phi_\ell - \delta_\ell < 0$).

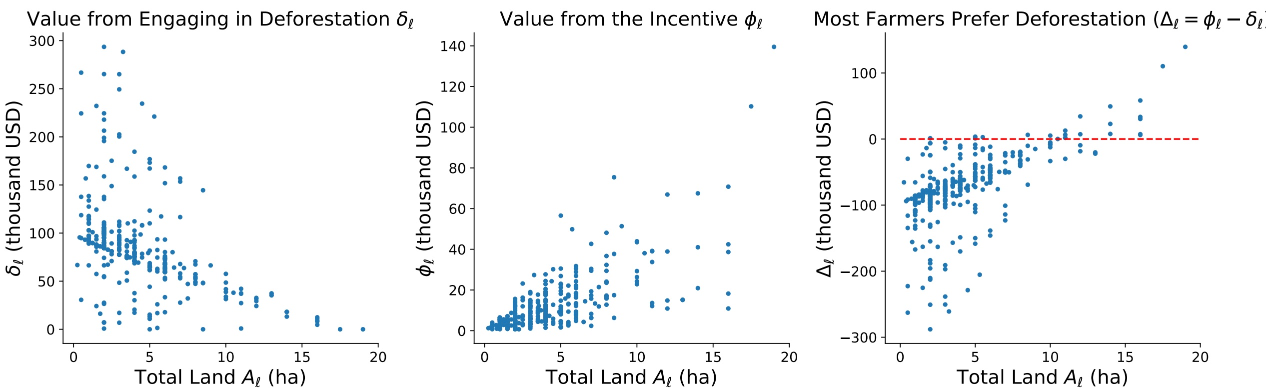

Figure 5.5 Scatter plots of a farmer's value δ_ℓ from engaging in deforestation, value ϕ_ℓ from a price premium $p^* = 30$ USD/tFFB, and preference for deforestation Δ_ℓ as a function of the farmer's total land A_ℓ.

We apply the area no-deforestation condition $\mathbb{N}$ and area regeneration condition $\mathbb{R}$ at a village level. In each of the 58 villages, all palm farmers in the village get the price premium on all their production if and only if the specified condition holds for that village. For each of those villages, §EC.3.2 reports the number of households in the village that are palm farmers, estimated from Indonesia census data, and we set $|\mathcal{L}|$ for the village to that number. We assume that the surveyed farmers from each village are representative of the other farmers in their village and replicate their model parameters to characterize the set of farmers $\ell \in \mathcal{L}$ in the village.

With RSPO price premium $p^* = 30$ USD/tFFB, only area regeneration condition $\mathbb{R}$ can possibly prevent deforestation. In each of the 58 villages, farmers collectively prefer deforestation ($\Delta_{\mathcal{L}} < 0$) so $\mathbb{R}$ can prevent deforestation in a village *only* if the farmers cannot coordinate and transfer utility. In that case, $\mathbb{R}$ prevents deforestation in 23 villages if the blocking cost $\eta \leq 10$ USD, in only one village at $\eta = 500$ USD, and in none for $\eta \geq 1,060$ USD.

What is the minimum uniform price premium that would prevent deforestation and achieve compensation, respectively, in *all* 58 villages? From (26) the value of the incentive $\phi_\ell(p^*)$ to each farmer ℓ increases linearly with the price premium p^*. Depending on the condition $\mathbb{C} \in \{\mathbb{I}, \mathbb{N}, \mathbb{R}\}$ and the setting, we determine the minimum value of p^* that satisfies the necessary requirements in (18), (19) or (21), respectively, for all villages. Figure 5.6 shows the minimum uniform price premium for each condition and setting (except $\mathbb{N}$ in the setting without coordination and TU, where $\mathbb{N}$ cannot prevent deforestation). The minimum uniform price premium to prevent deforestation is much lower for area regeneration condition $\mathbb{R}$ (and $\mathbb{N}$ with coordination and TU) than for individual condition $\mathbb{I}$. For $\mathbb{R}$ it is lower with coordination and TU than without, if and only if the blocking cost η exceeds 630 USD. As in §4, TU reduces the cost to an interested party to prevent deforestation if and only if the blocking cost is sufficiently large. For $\mathbb{R}$ without coordination and TU, the minimum uniform price premium to prevent deforestation increases with η, from 471 USD/tFFB at η=1 USD to 2496 USD/tFFB at η=3000 USD. For $\mathbb{R}$ with coordination and TU, the minimum uniform price premium is invariant with η. To achieve compensation, the minimum uniform price premium is the same for $\mathbb{R}$ and $\mathbb{I}$, and (assuming coordination and TU) much lower for $\mathbb{N}$.

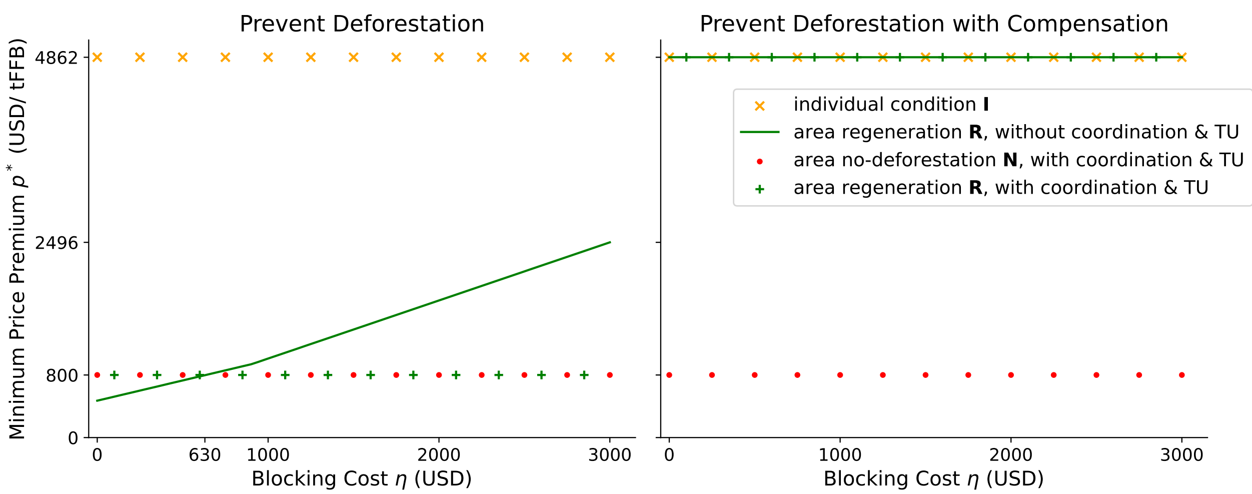

Figure 5.6 Minimum uniform price premium to prevent deforestation (left) and achieve compensation (right) in all villages.

The village-specific minimum price premium to prevent deforestation and achieve compensation, respectively, differ among villages. See Figure 5.7 and Figure 5.8. If farmers can transfer utility, a price premium below 250 USD prevents deforestation (with $\mathbb{R}$) and achieves compensation (with $\mathbb{N}$) in most villages. That is less than a third of the 800 USD/tFFB uniform price premium needed to prevent deforestation in all villages. This suggests that using area-specific incentives in adjacent areas could reduce the cost to prevent deforestation and achieve compensation in this region.

5.3. Entrants Deterred: Robustness of Area Regeneration Condition $\mathbb{R}$

Without coordination and TU, if a price premium p^* conditional on $\mathbb{R}$ prevents deforestation with no entrants ($\mathcal{E}=\emptyset$), it also prevents deforestation with up to

$$M := \left\lfloor \max_{\ell\in\mathcal{L}} (\phi_\ell(p^*) - \delta_\ell)/\eta \right\rfloor + 1 - |\mathcal{L}| \tag{32}$$

entrants. In other words, M is the maximum number of (potential) entrants deterred. Expression (32) for M holds whether or not the price premium achieves compensation. With coordination and TU, if a price premium p^* conditional on $\mathbb{R}$ would prevent deforestation with no entrants ($\mathcal{E}=\emptyset$), it would also prevent deforestation with up to

$$M_{TU} := \left\lfloor \sum_{\ell\in H} \Big(\phi_\ell(p^*) - \delta_\ell\Big)/\eta \right\rfloor - |\mathcal{L}| + |H| \text{ with } H = \{\ell \in \mathcal{L} : \phi_\ell(p^*) > \delta_\ell - \eta\} \tag{33}$$

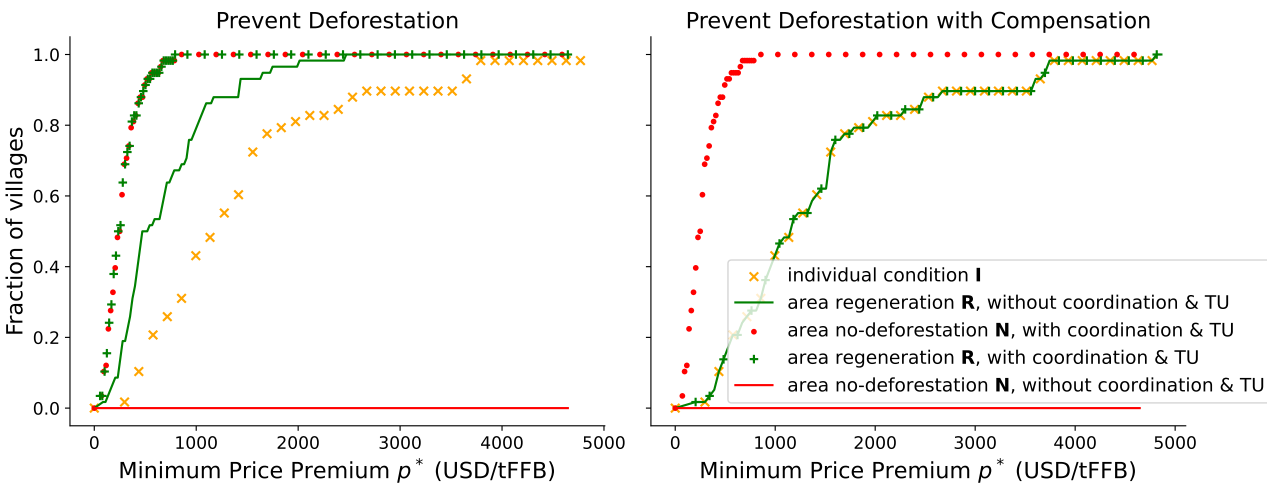

Figure 5.7 Fraction of villages in which a condition prevents deforestation (left) and achieves compensation (right) as a function of the price premium. For $\mathbb{R}$, this is at $\eta = 3,000$ USD; the fraction of villages would be higher at lower blocking cost.

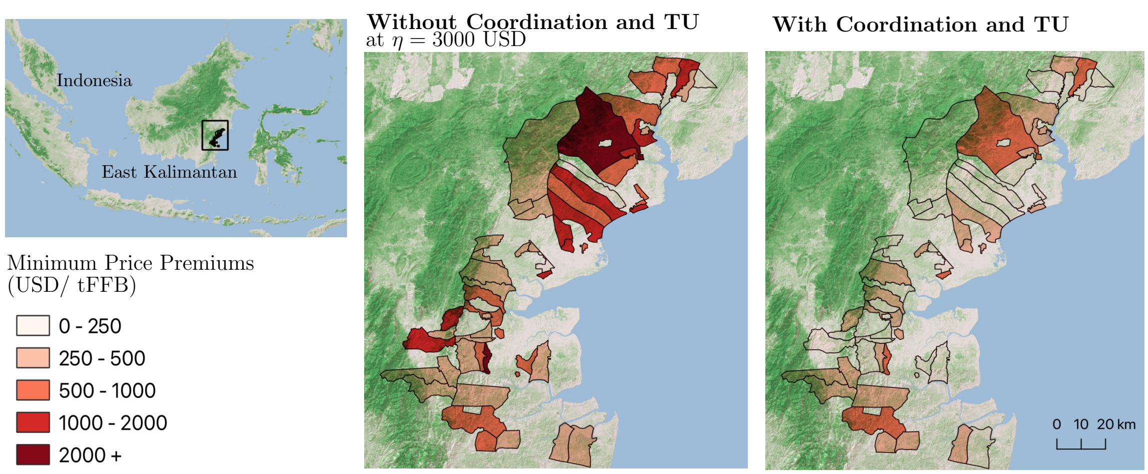

Figure 5.8 Minimum price premium to prevent deforestation and, with $\mathbb{N}$, coordination and TU, achieve compensation.

entrants; if it achieves compensation, it would prevent deforestation with compensation with up to

$$\bar{M}_{TU} := \left\lfloor \sum_{\ell \in \mathcal{L}} \left(\phi_\ell(p^*) - \delta_\ell \right) / \eta \right\rfloor \geq M_{TU} \tag{34}$$

entrants. The maximum number of entrants deterred (M, M_{TU} or $\bar{M}_{TU}$ depending on the setting) grows infinitely large as the blocking cost η decreases towards zero, decreases with the blocking cost η, and increases with the price premium p^*.

The maximum number of entrants deterred is remarkably *large*, even with the *minimum* price premium assuming no entrants $\mathcal{E} = \emptyset$. In Table 5.1, "uniform p^*" refers to the minimum uniform price premium conditional on $\mathbb{R}$ that prevents deforestation and achieves compensation, respectively, in *all* 58 villages, assuming $\mathcal{E} = \emptyset$. See Figure 5.6 for the exact values. Analogously, "village-specific p^*" refers to each village's minimum price premium conditional on $\mathbb{R}$ to prevent deforestation and achieve compensation, respectively, assuming $\mathcal{E} = \emptyset$. Only in the setting without coordination and TU, to calculate the minimum price premium conditional on $\mathbb{R}$ that prevents deforestation requires an assumption about the blocking cost η; we assume $\eta = 3000$ USD ensuring the price premium prevents deforestation for all $\eta \in (0, 3000]$. For each village, we calculate the maximum number of entrants deterred (M, M_{TU} or $\bar{M}_{TU}$ depending on the setting) at blocking cost values $\eta = 1000$ and $\eta = 3000$. The table shows the range over all villages in each setting. Achieving compensation or using a uniform price premium for all villages requires a higher price premium, which increases the maximum number of entrants deterred. Without coordination and TU, the maximum number of entrants deterred M is large except in the boundary case with blocking cost $\eta = 3000$ USD[2]. Coordination and TU significantly reduce the minimum price premium but nevertheless increase the maximum number of entrants deterred at the minimum price premium. Indeed, M_{TU} and $\bar{M}_{TU}$ are very large in all settings and all villages; the village with the least farmers (only 35 farmers) consistently has the least M_{TU} and $\bar{M}_{TU}$, and yet even with maximum blocking cost η=3,000 USD and the village-specific minimum price that prevents deforestation assuming no entrants, that small village deters up to $M_{TU} = 194$ entrants, over five times the number of farmers in the village!

How does coordination and TU make the performance of a price premium conditional on $\mathbb{R}$ so highly robust to potential entrants? With coordination and TU, a price premium conditional on $\mathbb{R}$ must be large enough that

$$\sum_{\ell \in \mathcal{L}} (\phi_\ell(p^*) - \delta_\ell) > 0 \tag{35}$$

to prevent deforestation. In each of the 58 villages, at the village-specific minimum price premium to prevent deforestation (determined by 35), the subset of farmers $H = \{\ell \in \mathcal{L} : \phi_\ell(p^*) > \delta_\ell - \eta\}$ have large $\sum_{\ell \in H} (\phi_\ell(p^*) - \delta_\ell)$ and hence a credible threat to block all the other farmers plus a large number of potential entrants, even at the maximum blocking cost $\eta = 3000$ USD. This entry deterrence rests on the heterogeneity of the farmers. Additionally, for any price premium that satisfies (35), coordination and utility transfer enables farmers to deter more entrants: M_{TU} and $\bar{M}_{TU}$ are greater than M. Without coordination and TU, blocking of entrants would have to be done by just one farmer with the greatest $\phi_\ell(p^*) - \delta_\ell$, whereas through coordination and utility transfer, farmers can pool their resources to block, which deters more entrants. This echoes the observation in §4 that TU reduces the cost to prevent deforestation when the number of entrants is large.

We conclude that – especially when farmers are able to coordinate and transfer utility– the performance of a price premium under area regeneration condition $\mathbb{R}$ is robust to entry.

[2] Even in this boundary case, M can be considerable. With the uniform p^*, M is large except for the one village whose village-specific minimum price premium to prevent deforestation exactly equals that uniform p^*. With village-specific p^*, M is large with price premiums that achieve compensation, except in the 13 villages where these prices match the corresponding minimum price premiums needed to prevent deforestation with no entrants.

		Prevent Deforestation		Achieve Compensation	
		$\eta = 1,000$	$\eta = 3,000$	$\eta = 1,000$	$\eta = 3,000$
Uniform p^*	Without TU	338 - 11,453	0 - 3,716	869 - 22,479	212 - 7,406
	With TU	2,744 - 264,362	905 - 88,120	27,775 - 1,707,419	9,258 - 569,139
Village-specific p^*	Without TU	68 - 588	0 - 0	131 - 7,957	0 - 2,550
	With TU	626 - 15,261	194 - 4,918	2,470 - 357,614	823 - 119,204

Table 5.1 Range among villages of the maximum number of entrants deterred, with the minimum price premium calculated assuming no entrants $\mathcal{E} = \emptyset$ and, in the setting without TU, a blocking cost of 3000 USD.

6. Conclusions: Reasons and Guidelines to Use Area Conditions

Area conditions can work with imperfect individual incentives. Practical incentives such as a price premium or land tenure are imperfect: the value they provide to an individual increases with his landholding, whereas an individual with less land may benefit more from engaging in deforestation. With an incentive that is insufficient for some individuals to forgo deforestation, an area condition can potentially prevent deforestation and promote distributional justice.

Area conditions can be implemented with less information and less effort than individual conditions require. Imagine a village with forest and hundreds of smallholder farmers. Preventing deforestation in the village with individual conditions requires gathering information about each individual's idiosyncratic value from deforestation, targeting an adequate incentive to each individual, and monitoring each individual. Those difficulties scale up as interested parties aim to prevent deforestation in supply sheds and jurisdictions with millions of smallholders. In contrast, implementing our proposed area conditions may only require information about the aggregated value of deforestation to the local smallholders overall, providing an overall adequate incentive, and satellite remote monitoring for deforestation in the area. In contrast to individual conditions, an area condition enables a greater range of easy-to-implement incentives to be effective. Figure 4.2 fully characterizes the range of incentives that are effective with our proposed area conditions.

If locals can coordinate and transfer utility and there are no potential entrants, we recommend providing an incentive conditional on no deforestation in the area $\mathbb{N}$, especially to promote distributive justice. The incentive need only be large enough that the locals, collectively, are better off with no deforestation in the area. Then, the incentive conditional on $\mathbb{N}$ prevents deforestation with compensation, as locals who prefer the incentive transfer utility to those who otherwise would prefer deforestation so that each local becomes better off than with deforestation. Insofar as the poorest locals with the least landholdings have the most to gain from deforestation, compensating each local for not engaging in deforestation promotes distributive justice. Support for community education and activities could help locals cooperate and transfer utility to thus prevent deforestation with compensation in their area. The caveat with the area no deforestation condition is that if an entrant were to burn forest in the area, the locals would lose their incentive, and the scheme would fail.

With potential entrants, especially in regions prone to illegal deforestation, we recommend an area regeneration condition $\mathbb{R}$: if deforestation occurs on any land in the area, economic use is blocked and forest regenerates on that land. If such blocking is not too costly, a positive incentive conditional on area regeneration $\mathbb{R}$ prevents deforestation. If locals cannot transfer utility, this is true even if the locals collectively would be better off with deforestation, and few prefer the incentive to deforestation. In contrast, if locals can transfer utility, the incentive should be generous enough to make them collectively better off than with deforestation (lest they coordinate on deforestation). The ability to transfer utility helps locals coordinate blocking so that an incentive conditional on area regeneration prevents deforestation at even higher blocking costs and with more potential entrants than if locals could not transfer utility. Indeed, in the Indonesian context, we found that if locals can coordinate and transfer utility among themselves, then a price premium conditional on area regeneration is highly robust to deter potential entrants; that robustness occurs even with the minimal price premium that barely makes the local community better off than with deforestation.

To complement the area regeneration condition $\mathbb{R}$, consider supporting locals with technology, equipment, and training to immediately detect and halt any fire or other forest-clearing activity, as a cheap means of blocking. This could mitigate the widespread tragedy that even more forest is cleared (often by escaped fire) than actually farmed (Pendrill et al. 2022). The Falcon et al. (2022) experiment should be replicated with such support.

To prevent deforestation with compensation, if locals can coordinate and there are potential entrants, we recommend a sufficiently generous and well-targeted incentive to compensate each local to forgo deforestation, conditional on area regeneration $\mathbb{R}$. Compensation could be achieved with an incentive conditional on $\mathbb{R}$ that is *not* well-targeted, but only at moderate levels of the blocking cost, with intervention to promote benefit-sharing among locals.

Though our analysis takes the area as given, the results suggest guidelines for choosing the area(s) to apply an area condition. The first is to choose an area wherein the locals can coordinate and transfer utility, such as a village in Indonesia. Prior initiatives to prevent deforestation in such a small area caused leakage, whereas in a larger area, the many locals therein are unable to coordinate. That tension motivates a second guideline: to mitigate leakage, choose multiple adjacent areas and implement an area condition within each. Third, choose multiple adjacent areas to cover a jurisdiction and engage the government therein to prevent entrants to the jurisdiction from engaging in deforestation (enabling use of the area no deforestation condition $\mathbb{N}$) or to support blocking (complementing the area regeneration condition $\mathbb{R}$).

In implementing the new regulation to prevent tropical deforestation (European Commission 2023), the EU should embrace a role for area conditions. In principle, a firm could comply with the EU regulation by tracing its commodity input to an area that meets the area regeneration condition retroactive to 2020, i.e., in which no production occurs on land deforested since 2020.

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E-companion to Area Conditions and Positive Incentives: Engaging Locals to Protect Forests

EC.1. Proofs of results in §3

Before proving Lemmas 1 and 2, we state and prove Lemma EC.1, where we show that $\mathcal{Q}(\pi,\mathbb{C})$ is not empty, for $\mathbb{C}\in\{\mathbb{N},\mathbb{R}\}$.

LEMMA EC.1. *For the cooperative game with transferable utility, consider a partition $\pi_{\mathcal{L}}\in\Pi_{\mathcal{L}}$. Under the Area No-Deforestation condition $\mathbb{N}$, if $\pi_{\mathcal{L}}=\{\mathcal{L}\}$, $\mathcal{E}=\emptyset$, and $\Delta_{\mathcal{L}}>0$, then $\mathcal{Q}(\pi,\mathbb{N})$ contains a no-deforestation equilibrium ($\mathbf{d}^*=\mathbf{0}$); otherwise, $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{N})$ contains a deforestation equilibrium ($\mathbf{d}^*=\mathbf{1}$). Under the Area Regeneration condition $\mathbb{R}$, if*

$$\eta<\eta_1(\pi_{\mathcal{L}})=\sup\{\eta:\exists S\in\pi \text{ with } \Delta_S>\eta\,|\mathcal{L}\setminus S\cup\mathcal{E}|\},$$

the set of equilibria, $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{R})$ contains a no-deforestation equilibrium ($\mathbf{d}^*=\mathbf{0}$); otherwise, $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{R})$ contains a deforestation equilibrium ($\mathbf{d}^*=\mathbf{1}$). Note that this result does not require Assumption 3.

Proof of Lemma EC.1. Under $\mathbb{N}$, we will consider four cases. First, if $\pi_{\mathcal{L}}=\{\mathcal{L}\}$, $\mathcal{E}=\emptyset$, and $\Delta_{\mathcal{L}}>0$, then there are only two options, either $d^*_{\mathcal{L}}=1$, or $d^*_{\mathcal{L}}=0$. Because $\Delta_{\mathcal{L}}>0$, the optimal decision in (8) is $d^*_{\mathcal{L}}=0$, resulting in a no-deforestation equilibrium. Second, if $\pi_{\mathcal{L}}=\{\mathcal{L}\}$ and $\mathcal{E}\neq\emptyset$, then, because under $\mathbb{N}$ the reward does not depend on any blocking decisions (4), every entrant $e\in\mathcal{E}$ would choose $d^*_e=1$, according to (7). But then $\kappa^{\mathbb{N}}(\pi,\mathbf{d}^*)=\text{no}$, and the deforestation equilibrium with $d^*_{\mathcal{L}}=1$ is in $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{N})$. Third, if $\pi_{\mathcal{L}}=\{\mathcal{L}\}$, $\mathcal{E}=\emptyset$ and $\Delta_{\mathcal{L}}\leq 0$, the solution to the maximization in (8) must include $d^*_{\mathcal{L}}=1$, and $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{N})$ includes a deforestation equilibria. Finally, if $\pi\neq\{\mathcal{L}\}$, then there are at least two coalitions S_1, and S_2, in $\pi_{\mathcal{L}}$. Hence, if we consider a deforestation equilibrium, with $d^*_{S_1}=1$, and $d^*_{S_2}=1$, we can see that $\kappa^{\mathbb{N}}(\pi_{\mathcal{L}},\mathbf{d}^*)=\text{no}$, and no unilateral deviation of any $S\in\pi$ can change this, which implies that, absent any reward, each coalition will engage in deforestation and therefore, $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{N})$ contains a deforestation equilibrium.

Under $\mathbb{R}$, if $\eta<\eta_1(\pi)$, then there exists $S\in\pi$ such that $\Delta_S>\eta|\mathcal{L}\setminus S\cup\mathcal{E}|\geq 0$. Thus, a no-deforestation equilibrium $(\mathbf{d}^*,\mathbf{B}^*)$ must be in $\mathcal{Q}(\pi_{\mathcal{L}},\mathbb{R})$ because in such an equilibrium, if any coalition S' or entrant e unilaterally deviates and sets $d_{S'}=1$, then coalition S would block all individuals that deviated in the second stage.

On the other hand, if $\eta\geq\eta_1(\pi_{\mathcal{L}})$, no coalition S exists so that $\Delta_S>\eta|\mathcal{L}\setminus S\cup\mathcal{E}|$. We consider two (sub)cases, the first with $|\pi_{\mathcal{L}}|=1$ and the second with $|\pi_{\mathcal{L}}|\geq 2|$.

First, if $\pi_{\mathcal{L}}=\{\mathcal{L}\}$, then $\eta\geq\eta_1(\pi_{\mathcal{L}})$ implies that $\Delta_{\mathcal{L}}\leq\eta|\mathcal{E}|$ or equivalently

$$\sum_{\ell\in\mathcal{L}}J(0,\text{yes})-\eta|\mathcal{E}|\leq\sum_{\ell\in\mathcal{L}}J(1,\text{no}).$$

Therefore, the coalition $\mathcal{L}$ could not strictly profit by blocking all entrants in $\mathcal{E}$ in the second stage of the game, leaving $\kappa^{\mathbb{R}}(\{\mathcal{L}\}, \mathbf{d}^*, \mathbf{B}^*) = \text{no}$. Therefore, $\mathbf{B}^*_{\mathcal{L}i} = 0$ is an optimal solution in (6) for each $i \in \mathcal{L} \cup \mathcal{E}$, conditional on $d^*_{\mathcal{L}} = 1$ and $d^*_e = 1$ for each $e \in \mathcal{E}$, which in turn implies that these deforestation decisions are optimal in (8)-(7) respectively, which proves that this deforestation equilibrium is in $\mathcal{Q}(\{\mathcal{L}\}, \mathbb{R})$.

Assume now that $\eta \geq \eta_1(\pi)$ and $|\pi_{\mathcal{L}}| \geq 2$. Let S_1, and S_2 be two coalitions in $\pi_{\mathcal{L}}$. Consider a deforestation equilibrium, where $d^*_S = 1$, $d^*_e = 1$, and $\mathbf{B}^*_{Si} = 0$, for every $S \in \pi$, $i \in \mathcal{L} \cup \mathcal{E}$, and $e \in \mathcal{E}$. In this case, $\kappa^{\mathbb{R}}(\pi_{\mathcal{L}}, \mathbf{d}^*, \mathbf{B}^*) = \text{no}$, and there is no profitable deviation of any one coalition that can change this: for instance, coalition S_1 would not change its second stage blocking decision because $\eta \geq \eta_1(\pi_{\mathcal{L}})$ implies that it would not be strictly profitable to block all other individuals in $\mathcal{L} \setminus S_1 \cup \mathcal{E}$, and the compliance indicator would not change even if $\mathbf{d}_{S_1} = 0$ because there are at least two coalitions, and $\mathbf{d}^*_{S_2} = 1$. Therefore, this deforestation equilibrium must be in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{R})$. □

Proof of Lemma 1. By Lemma EC.1, we know that $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{C}) \neq \emptyset$ for $\mathbb{C} \in \{\mathbb{N}, \mathbb{R}\}$ and any partition $\pi_{\mathcal{L}} \in \Pi_{\mathcal{L}}$. Hence, we must only prove that any equilibrium in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{C})$ is either a deforestation equilibrium or a no-deforestation equilibrium.

If $|\pi_{\mathcal{L}}| = 1$, then the result is immediate by the definition of the game, as the single coalition in $\pi_{\mathcal{L}}$ can only choose $\mathbf{d}^*_{\mathcal{L}} = 1$ or $\mathbf{d}^*_{\mathcal{L}} = 0$, corresponding to a deforestation equilibrium and no-deforestation equilibrium respectively. Thus, we consider below only the case with $|\pi_{\mathcal{L}}| \geq 2$.

We first show the result for the Area No-Deforestation condition $\mathbb{N}$. Assume by contradiction that there exists an equilibrium such that $d^*_{S_1} = 1$ and $d^*_{S_2} = 0$, for $S_1 \neq S_2$, and both $S_1, S_2 \in \pi_{\mathcal{L}}$. By definition, $\kappa^{\mathbb{N}}(\pi_{\mathcal{L}}, \mathbf{d}^*, \mathbf{B}^*) = \text{no}$, as there is at least one coalition that engages in deforestation (and blocking decisions do not matter with $\mathbb{N}$). But without rewards, it is always optimal to engage in deforestation by (2), so it is a profitable deviation for S_2 to set $d^*_{S_2} = 1$. Therefore, no equilibrium can exist in $\mathcal{Q}(\pi_{\mathcal{L}})$ with $\mathbf{d}^*_{S_1} = 0$ and $\mathbf{d}^*_{S_2} = 1$.

We now show the result for the Area Regeneration condition $\mathbb{R}$. Assume by contradiction that there exists an equilibrium such that $d^*_{S_1} = 1$ and $d^*_{S_2} = 0$, for $S_1 \neq S_2$, and both $S_1, S_2 \in \pi_{\mathcal{L}}$. Consider then the second stage blocking decisions; there are two possible scenarios, either all locals in S_1 that engage in deforestation are blocked in the second stage (i.e., $\max_{H \neq S_1} \mathbf{B}_{H\ell} = 1$, for every $\ell \in S_2$), or at least one local in S_2 is not blocked (i.e., $\max_{H \neq S_1} \mathbf{B}_{H\ell} = 0$, for some $\ell \in S_2$). In the former case, coalition S_2 has a profitable deviation by changing $d^*_{S_2} = 0$ and not incurring the deforestation costs $\sum_{\ell \in S_2} c_\ell$. In the latter case, $\kappa^{\mathbb{R}}(\pi_{\mathcal{L}}, \mathbf{d}^*, \mathbf{B}^*) = \text{no}$, as at least one local from S_2 is engaging in deforestation and not being blocked by any other coalition. Hence, S_1 has a profitable deviation by either changing $\mathbf{B}_{S_2 f} = 1$ for the unblocked local $\ell \in S_2$ (depending on the magnitude of the blocking cost η) or setting $d^*_{S_1} = 1$. In all cases, there is a profitable deviation, and therefore every equilibrium must either be a deforestation equilibrium or a no-deforestation equilibrium. Note we do not use assumption 3 to prove these results, and therefore they hold even if $\mathcal{L} = \mathcal{G}$. □

Proof of Lemma 2. We begin by showing the results under the Area No-Deforestation condition $\mathbb{N}$. We have shown in Lemma 1 that $T(\pi_{\mathcal{L}})$ can take only values $\{\mathbf{0}\}$, $\{\mathbf{1}\}$, or $\{\mathbf{0},\mathbf{1}\}$, so we only need to prove that a) $T(\pi_{\mathcal{L}}) = \{\mathbf{0}\}$ if and only if $\pi_{\mathcal{L}} = \{\mathcal{L}\}$, $\Delta_{\mathcal{L}} > 0$, and $\mathcal{E} = \emptyset$, and b) $T(\pi_{\mathcal{L}}) = \{\mathbf{1}\}$ if and only if $\Delta_S < 0$ for some $S \in \pi_{\mathcal{L}}$ or $\mathcal{E} \neq \emptyset$.

Lemma EC.1 implies that $T(\pi_{\mathcal{L}}) = \{\mathbf{0}\}$ (i.e., *only* no-deforestation equilibria) can occur only if $\pi_{\mathcal{L}} = \{\mathcal{L}\}$, $\Delta_{\mathcal{L}} > 0$, and $\mathcal{E} = \emptyset$. Conversely, if $\pi_{\mathcal{L}} = \{\mathcal{L}\}$, $\Delta_{\mathcal{L}} > 0$, and $\mathcal{E} = \emptyset$, then $d^*_{\mathcal{L}} = 0$ is the unique solution to (8) by definition of $\Delta_{\mathcal{L}}$, which implies that $T(\pi_{\mathcal{L}}) = \{\mathbf{0}\}$.

If $\Delta_S < 0$ for some $S \in \pi_{\mathcal{L}}$ or $\mathcal{E} \neq \emptyset$, then $d^*_S = 1$ or $d^*_e = 1$ (for all $e \in \mathcal{E}$) for *any* equilibrium in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{N})$, as these are the only solution to (8) and (7), respectively. But then, Lemma 1 implies $T(\pi_{\mathcal{L}}) = \{1\}$. Conversely, if $\Delta_S \geq 0$ for all $S \in \pi_{\mathcal{L}}$ and $\mathcal{E} = \emptyset$, then any no-deforestation equilibrium will be in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{N})$, because when $\kappa^{\mathbb{N}}(\pi_{\mathcal{L}}, \mathbf{d}^*) = \text{yes}$, then $d^*_S = 0$ is the only solution to (8), which implies that no coalition would want to deviate from a no-deforestation equilibrium if they all prefer not to deforest. Therefore, $T(\pi_{\mathcal{L}}) = \{\mathbf{1}\}$ if and only if $\Delta_S < 0$ for some $S \in \pi_{\mathcal{L}}$ or $\mathcal{E} \neq \emptyset$.

Under the Area Regeneration condition $\mathbb{R}$, we showed in Lemma EC.1 that if $\eta < \eta_1(\pi_{\mathcal{L}}) = \sup\{\eta : \exists S \in \pi \text{ with } \Delta_S > \eta\, |\mathcal{L} \setminus S \cup \mathcal{E}|\}$, then $\mathbf{0} \in T(\pi_{\mathcal{L}})$; and if $\eta \geq \eta_1(\pi_{\mathcal{L}})$, then $\mathbf{1} \in T(\pi_{\mathcal{L}})$. Because

$$\eta_1(\pi_{\mathcal{L}}) \leq \eta_2(\pi_{\mathcal{L}}) := \inf\left\{\eta : \sum_{S \in \pi : \Delta_S > 0} \left\lfloor \frac{\Delta_S}{\eta} \right\rfloor < \max\left\{\max_{H \in \pi : \Delta_H < 0} |H|\,, \mathbf{1}_{\mathcal{E} \neq \emptyset}\right\}\right\},$$

we need only to show that $\eta < \eta_1(\pi_{\mathcal{L}})$ implies $\mathbf{1} \notin T(\pi_{\mathcal{L}})$ and that $\eta > \eta_2(\pi_{\mathcal{L}})$ implies $\mathbf{0} \notin T(\pi_{\mathcal{L}})$.

To see that $\eta < \eta_1(\pi_{\mathcal{L}})$ implies $\mathbf{1} \notin T(\pi_{\mathcal{L}})$, assume by contradiction that $\mathbf{1} \in T(\pi_{\mathcal{L}})$. If $\eta < \eta_1(\pi_{\mathcal{L}})$, there exists a coalition $S \in \pi_{\mathcal{L}}$, such that $\Delta_S > \eta |\mathcal{L} \setminus S \cup \mathcal{E}|$. Thus, given any deforestation equilibrium, S will have a profitable deviation of setting $d_S = 0$, and $\mathbf{B}_{Si} = 1$, for every $i \in \mathcal{L} \setminus S \cup \mathcal{E}$, blocking all locals outside of S that deforest and all entrants in $\mathcal{E}$. This implies that there cannot be a deforestation equilibrium in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{R})$.

To see that $\eta > \eta_2(\pi_{\mathcal{L}})$ implies $\mathbf{0} \notin T(\pi_{\mathcal{L}})$, assume by contradiction that $\mathbf{0} \in T(\pi_{\mathcal{L}})$. As η is finite, it follows from the definition of $\eta_2(\pi_{\mathcal{L}})$ that either (i) there exists some coalition $H \in \pi_{\mathcal{L}}$ with $\Delta_H < 0$ or (ii) $\Delta_H \geq 0$ for all $H \in \pi_{\mathcal{L}}$ but $\mathcal{E} \neq 0$ and $\eta > \max_{H \in \pi} \Delta_H$. In case (i), consider $H \in \arg\max_{S' \in \pi_{\mathcal{L}} : \Delta_{S'} < 0} |S|$. In any no-deforestation equilibrium, H could deviate by setting $d_H = 1$ and because $\eta > \eta_2(\pi_{\mathcal{L}})$, the locals in H cannot be blocked by the coalitions $S \in \pi_{\mathcal{L}}$ with $\Delta_S \geq 0$. In case (ii), η is so high that no single entrant can be blocked by any coalition $H \in \pi_{\mathcal{L}}$. Thus, any entrant $e \in \mathcal{E}$ could profit by deviating and setting $d_e = 1$. It follows in both cases that there cannot be a no-deforestation equilibrium in $\mathcal{Q}(\pi_{\mathcal{L}}, \mathbb{R})$ if $\eta > \eta_2(\pi_{\mathcal{L}})$. Note we do not use assumption 3 to prove these results, and therefore they hold even if $\mathcal{L} = \mathcal{G}$. □

To prove our subsequent results, we define the following set:

$$A(R;\pi_{\mathcal{L}\setminus R}) = \begin{cases} \bigcup_{\left(\pi_R,(\mathbf{d}^*,\mathbf{B}^*),\{a_\ell\}_{\ell\in R}\right)\in C(R;\pi_{\mathcal{L}\setminus R})} T(\pi_R \cup \pi_{\mathcal{L}\setminus R}) & \text{if } C(R;\pi_{\mathcal{L}\setminus R}) \neq \emptyset \\ T(\pi_R \cup \pi_{\mathcal{L}\setminus R}) & \text{otherwise.} \end{cases} \quad \text{(EC.1)}$$

To understand the construction, consider the definition of the core and specifically (EC.1). The set in (EC.1) contains all the deforestation decisions $\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}$ that could be encountered in the residual game played by locals in R when all the other locals form a partition $\pi_{\mathcal{L}\setminus R}$, specifically, all the Deforestation Outcomes encountered in core outcomes of that residual game if the core is nonempty, or all Deforestation Outcomes arising in equilibria of any non-cooperative games between locals in R (and the other locals organized as $\pi_{\mathcal{L}\setminus R}$) if that core is empty. The notation $\underline{A}(\cdot)$ highlights that this set contains all the plausible Assumptions that a deviating coalition $S \in \pi_{\mathcal{L}\setminus R}$ should make regarding outcomes in the residual game played by R. Because the deforestation decisions $\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}$ suffices for purposes of calculating the welfare of any coalition S, per (12), the set $A(R;\pi_{\mathcal{L}\setminus R})$ provides a very concise summary of the information needed when determining whether a deviation is profitable or not (and whether an outcome is dominated).

Proof of Theorem 1. First consider the case where $\Delta_{\mathcal{L}} > 0$ and $\mathcal{E} = \emptyset$. Under the Area No-Deforestation condition $\mathbb{N}$, no outcome that violates (16a) could be in the core because it would have at least one local ℓ with $a_\ell < J_\ell(1,\text{no}) - c_\ell$ for whom the outcome is dominated by local ℓ who forms the singleton coalition $\{\ell\}$. In the case $\Delta_\ell < 0$, Lemma 2 implies that for every partition $\pi_{\mathcal{L}\setminus f}$ of the residual locals $\mathcal{L}\setminus f$, $T(\{\{\ell\}\} \cup \pi_{\mathcal{L}\setminus f}) = \{\mathbf{1}\}$ which yields strictly greater welfare $J_\ell(1,\text{no}) - c_\ell > a_\ell$ for the local ℓ. In the case that $\Delta_\ell \geq 0$ by forming the singleton coalition $\{\ell\}$, local ℓ will gain strictly greater welfare regardless of whether or not deforestation occurs because

$$J_\ell(0,\text{yes}) \geq J_\ell(1,\text{no}) - c_\ell > a_\ell.$$

If $\Delta_{\mathcal{L}} > 0$ and $\mathcal{E} = \emptyset$ no outcome with deforestation $\mathbf{d}^* = \mathbf{1}$ could be in the core because it would be dominated by locals $\ell \in \mathcal{L}$ who form the grand coalition $\{\mathcal{L}\}$ and maximize their aggregate welfare without deforestation $\mathbf{d}^* = \mathbf{0}$, as $\{\mathbf{0}\} = T(\{\mathcal{L}\})$ by Lemma 2. This implies that when $\Delta_{\mathcal{L}} > 0$ and $\mathcal{E} = \emptyset$, the core may only contain Compensation Outcomes.

To see that the core contains all Compensation Outcomes, we show that any outcome with partition $\pi_{\mathcal{L}}$, $\mathbf{d}^* = \mathbf{0}$, and allocations $a_\ell > J_\ell(1,\text{no}) - c_\ell$, for all $\ell \in \mathcal{L}$, such that $\mathbf{0} \in T(\pi_{\mathcal{L}})$, must be in the core. For this, we show that no set $S \subseteq \mathcal{L}$ would deviate from such an outcome. The whole set $S = \mathcal{L}$ would not deviate, as $\Delta_{\mathcal{L}} > 0$ implies that $\sum_{\ell\in\mathcal{L}} a_\ell = w(\mathcal{L},\mathbf{0}) > w(\mathcal{L},\mathbf{1})$. Moreover, no subset $S \subset \mathcal{L}$ would deviate and form partition $\pi_S \in \Pi_S$, as Lemma 2 implies that $\mathbf{1} \in T(\pi_S \cup \pi_{\mathcal{L}\setminus S})$, for any partition

$\pi_{\mathcal{L}\setminus S}$, which in turn implies that $\mathbf{1} \in A(\mathcal{L} \setminus S; \pi_S)$. But then under pessimism, any (sub)coalition $S_i \in \pi_S$ would not prefer to deforest:

$$\sum_{\ell \in S_i} a_\ell \geq \sum_{\ell \in S_i} (J_\ell(1, \text{no}) - c_\ell) = w(S_i, \mathbf{1}).$$

This proves that there would be no deviation from the Compensation Outcome we considered, and therefore the core contains all Compensation Outcomes and only Compensation Outcomes.

Finally, we consider the case of $\Delta_{\mathcal{L}} < 0$ or $\mathcal{E} \neq \emptyset$. Lemma 2 implies that if $\Delta_{\mathcal{L}} < 0$ then $T(\pi_{\mathcal{L}}) = \{\mathbf{1}\}$ for every partition $\pi_{\mathcal{L}}$ of $\mathcal{L}$. Therefore, the core is the set of outcomes $(\pi_{\mathcal{L}}, \mathbf{d}^*, \{a_\ell\}_{\ell \in \mathcal{L}})$ with $\mathbf{d}^* = \mathbf{1}$, any feasible partition $\pi_{\mathcal{L}} \in \Pi_{\mathcal{L}}$, and allocation $a_\ell = J_\ell(1, \text{no}) - c_\ell$, for all $\ell \in \mathcal{L}$. Any outcome with a different allocation must have $a_\ell < J_\ell(1, \text{no}) - c_\ell$ for at least one local ℓ and would be dominated by the local forming the singleton coalition $\{\ell\}$, by which local ℓ would have guaranteed the welfare of $J_\ell(1, \text{no}) - c_\ell$. We conclude that the core is exactly the set of Deforestation Outcomes. □

We now prove Theorem 2. For this, we divided the proof into a series of lemmas stated and proven below the Theorem.

Proof of Theorem 2. We prove each statement in the theorem by combining the above-mentioned lemmas.

(a) If $\eta \leq \eta_1^{\text{TU}}$, because $\eta_1^{\text{TU}} \leq \eta_3^{\text{TU}}$, and $\Delta_{\mathcal{L}} > 0$, Lemma EC.3 and Lemma EC.4 imply that there are only No-Deforestation Outcomes in the core. Additionally, Lemma EC.8 and Lemma EC.9 imply that the core contains all Blocking-Threat Outcomes.

(b) If $\eta_1^{\text{TU}} < \eta < \eta_2^{\text{TU}}$, as in the previous case, Lemma EC.3 and Lemma EC.4 imply that there are only No-Deforestation Outcomes in the core. Lemma EC.9, on the other hand, implies that there can only be Blocking-Threat Outcomes in the core, while Lemma EC.8 and Lemma EC.19 combined show that the core may be empty if $\eta > \min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L}\setminus S}}{|S|}$.

(c) If $\mathcal{E} = \emptyset$ and $\eta_2^{\text{TU}} < \eta < \eta_3^{\text{TU}}$, Lemma EC.11 and Lemma EC.17 imply the core cannot contain any Blocking-Threat or Compensation Outcomes, while Lemma EC.13 shows that the core may contain Partial Compensation Outcomes. Additionally, Lemma EC.3 implies that the core can only contain No-Deforestation Outcomes, which implies that the core can only contain Partial Compensation Outcomes. Finally, Lemma EC.20 shows that the core could be empty.

(d) If $\mathcal{E} = \emptyset$ and $\eta_3^{\text{TU}} < \eta \leq \Delta_{\mathcal{G}}$, Lemma EC.15 implies the core contains all Compensation Outcomes, Lemma EC.12 implies the core may contain Partial Compensation Outcomes, and Lemma EC.11 implies the core cannot contain Blocking-Threat Outcomes. Finally, Lemma EC.3 shows the core can only contain No-Deforestation Outcomes.

(e) If $\mathcal{E} = \emptyset$ and $\eta > \Delta_{\mathcal{G}}$, Lemma EC.3 implies the core may contain only No-Deforestation Outcomes, while Lemma EC.16 implies all No-Deforestation Outcomes must be Compensation Outcomes. Finally, Lemma EC.15 implies the core contains all Compensation Outcomes.

(f) If $\mathcal{E} \neq \emptyset$ and $\eta_2^{\mathrm{TU}} < \eta < \eta_3^{\mathrm{TU}}$, Lemma EC.17 implies the core cannot contain any Compensation Outcomes. Lemma EC.13 implies the core may contain Partial Compensation Outcomes, while Lemmas EC.9 and EC.10 imply that if η satisfies as well $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$, then the core may contain Blocking-Threat Outcomes. Moreover, Lemma EC.4 implies that the core can only contain No-Deforestation Outcomes. Finally, Lemma EC.21 shows that the core may be empty.

(g) If $\mathcal{E} \neq \emptyset$ and $\eta_3^{\mathrm{TU}} < \eta < \eta_4^{\mathrm{TU}}$, then $\eta < \frac{\Delta_{\mathcal{L}}}{|\mathcal{E}|} \leq \Delta_{\mathcal{L}}$, which, by Lemma EC.15 implies that the core must contain all Compensation Outcomes. Moreover, Lemma EC.12 shows the core may contain Partial Compensation Outcomes, and Lemmas EC.9 and EC.10 imply that if $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$ it may contain Blocking-Threat Outcomes. Finally, Lemma EC.4 shows that the core can only contain No-Deforestation Outcomes.

(h) If $\mathcal{E} \neq \emptyset$ and $\eta_4^{\mathrm{TU}} < \eta < \Delta_{\mathcal{G}}$, Lemma EC.6 implies the core contains Deforestation Outcomes. Lemmas EC.12 and Lemma EC.18 imply that if $\eta < \Delta_{\mathcal{L}}$ it may contain Compensation Outcomes, and Lemmas EC.9 and EC.10 imply the core may contain Blocking-Threat Outcomes as long as $\eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$). Finally, Lemma EC.14 implies the core may contain Partial Compensation Outcomes.

(i) If $\mathcal{E} \neq \emptyset$ and $\eta > \Delta_{\mathcal{G}}$, Lemmas EC.16 and EC.18 imply the core does not contain No-Deforestation Outcomes, while Lemma EC.6 implies the core always contains Deforestation Outcomes, which implies that the core contains only Deforestation Outcomes.

If $\Delta_{\mathcal{L}} < 0$, then the core may only contain Deforestation Outcomes. To see this, notice that $\Delta_{\mathcal{L}} < 0$ implies that $\eta > \eta_2(\{\mathcal{L}\})$, for any $\eta > 0$, where $\eta_2(\cdot)$ is defined in (9b), which, by Lemma 2 implies that $T(\{\mathcal{L}\}) = \{\mathbf{1}\}$. Moreover, $\Delta_{\mathcal{L}} < 0$ implies that the grand coalition prefers deforestation ($w(\mathcal{L};\mathbf{1}) > w(\mathcal{L};\mathbf{0})$). These two observations combined show that any No-Deforestation Outcomes ($\mathbf{d}^* = \mathbf{0}$) would be dominated by the grand coalition $\{\mathcal{L}\}$ deviating towards deforestation, which implies that the core may only contain Deforestation Outcomes ($\mathbf{d}^* = \mathbf{1}$). Finally, Lemma EC.22 implies that the core may be empty when $\Delta_{\mathcal{L}} < 0$, which completes the proof of the theorem. □

LEMMA EC.2. *Consider the cooperative game with transferable utility defined in §3.3. Every outcome in the core with allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$ must satisfy:*

$$a_g \geq J_g(1, no) - c_g \text{ for all } g \in \mathcal{G} \tag{EC.2a}$$

$$a_\ell \geq J_\ell(0, yes) \text{ for all } \ell \in \mathcal{L} \setminus \mathcal{G}. \tag{EC.2b}$$

Proof of Lemma EC.2. We show the following generalization of both requirements (EC.2a) and (EC.2b):

$$a_\ell \geq \min\{J_\ell(0,\mathrm{yes}), J_\ell(1,\mathrm{no}) - c_\ell\} \text{ for all } \ell \in \mathcal{L},$$

for every outcome in the core with allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$.

Assume by contradiction that there is an outcome in the core with a local $\ell \in \mathcal{L}$, that receives allocation $a_\ell < \min\{J_\ell(0,\text{yes}), J_\ell(1,\text{no}) - c_\ell\}$. Then, local ℓ can deviate and form a coalition $\{\ell\}$. And, by our assumption, $a_\ell < w(\{\ell\}, \mathbf{d}^*)$, for every $\mathbf{d}^* \in \{\mathbf{0}, \mathbf{1}\}$, so the outcome is dominated and cannot be in the core. □

Lemma EC.3. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_\mathcal{L} > 0$ *and* $\mathcal{E} = \emptyset$*, then the core contains only No-Deforestation Outcomes.*

Proof of Lemma EC.3. Assume by contradiction that the core contains a Deforestation Outcome ($\mathbf{d}^* = \mathbf{1}$). But then, the trivial deviation of $\mathcal{L}$ forming the grand coalition dominates this outcome:

$$\sum_{\ell \in \mathcal{L}} a_\ell = \sum_{\ell \in \mathcal{L}} J(1, N) < w(\mathcal{L}, \mathbf{0}) = \sum_{\ell \in \mathcal{L}} J(0, Y). \tag{EC.3}$$

Where the inequality is due to $\Delta_\mathcal{L} > 0$. Finally, because $\Delta_\mathcal{L} > 0$ and $\mathcal{E} = \emptyset$, $\eta_1(\{\mathcal{L}\}) = \infty$, and by Lemma 2, $T(\{\mathcal{L}\}) = \{\mathbf{0}\}$, for any η, proving that the deviation is profitable for all equilibria. And therefore, the core cannot contain Deforestation Outcomes. □

Lemma EC.4. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_\mathcal{L} > 0$*,* $\mathcal{E} \neq \emptyset$*, and* $\eta < \eta_4^{\text{TU}} := \max_{S \subseteq \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S \cup \mathcal{E}|}$*, the core contains only No-Deforestation Outcomes. Note that this result does not require Assumption 3.*

Proof of Lemma EC.4. We show that every Deforestation Outcome ($\mathbf{d}^* = \mathbf{1}$) is dominated. The assumption on the value of η implies that there exists a coalition $S \subseteq \mathcal{L}$ such that

$$\Delta_S > \eta |\mathcal{L} \setminus S \cup \mathcal{E}| \geq 0, \tag{EC.4}$$

where the second inequality follows because $\Delta_\mathcal{L} > 0$. Moreover, because including in S the locals in $\mathcal{G} \setminus S$ only expands Δ_S and reduces $|\mathcal{L} \setminus S \cup \mathcal{E}|$ in (EC.4), we consider a S that also satisfies $\mathcal{G} \subseteq S$.

Consider then any Deforestation Outcome ($\mathbf{d}^* = \mathbf{1}$). We show that the coalition S satisfying (EC.4) and $\mathcal{G} \subseteq S$ could profitably deviate towards a No-Deforestation Outcome. Because $\mathcal{G} \subseteq S$, Lemma EC.2 implies that $\sum_{\ell \in \mathcal{L} \setminus S} a_\ell \geq \sum_{\ell \in \mathcal{L} \setminus S} J_\ell(0, \text{yes})$. Moreover, $\Delta_\mathcal{L} > 0$ and the outcome being a Deforestation Outcome imply that:

$$\sum_{\ell \in S} a_\ell + \sum_{\ell \in \mathcal{L} \setminus S} a_\ell = \sum_{\ell \in \mathcal{L}} \big(J_\ell(1, \text{no}) - c_\ell\big) < \sum_{\ell \in \mathcal{L}} J_\ell(0, \text{yes}) = \sum_{\ell \in S} J_\ell(0, \text{yes}) + \sum_{\ell \in \mathcal{L} \setminus S} J_\ell(0, \text{yes}).$$

Therefore, $\sum_{\ell \in S} a_\ell < \sum_{\ell \in S} J_\ell(0, \text{yes})$. But then, consider any partition of $\mathcal{L} \setminus S$, $\pi_{\mathcal{L} \setminus S} \in \Pi_{\mathcal{L} \setminus S}$. Condition (EC.4) implies that $\eta < \eta_1(\pi_{\mathcal{L} \setminus S} \cup \{S\})$, which by Lemma 2 (which does not require Assumption 3) implies that $\{\mathbf{0}\} = T(\pi_{\mathcal{L} \setminus S} \cup \{S\})$. Because this holds for every partition of the remaining locals $\mathcal{L} \setminus S$, then $\{\mathbf{0}\} = A(\mathcal{L}\setminus S;\{S\})$, as defined in (EC.1). Finally, this implies that $\sum_{\ell\in S} a_\ell < w(S;\mathbf{d}^*)$ for every $\mathbf{d}^* \in A(\mathcal{L}\setminus S;\{S\})$, proving that the Deforestation Outcome is dominated by coalition S deviating and guaranteeing higher welfare with a No-Deforestation Outcome. □

Lemma EC.5. *If the core $C(\mathcal{L};\emptyset)$ contains a No-Deforestation Outcome ($\mathbf{d}^*=\mathbf{0}$), with allocations $\{a_\ell\}_{\ell\in\mathcal{L}}$, then it must contain all No-Deforestation Outcomes with the same allocation.*

Proof of Lemma EC.5. Notice that we need only prove that if the core contains a No-Deforestation Outcome with a given allocation, it must contain any other No-Deforestation Outcome with the same allocation for every feasible partition.

To see this, assume that we have an outcome with partition $\pi_{\mathcal{L}}$, $\mathbf{d}^*=\mathbf{0}$, and allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$. Consider then any partition $\sigma_{\mathcal{L}}$ that satisfies:

$$\sum_{\ell\in S} a_\ell = w(S,\mathbf{0}),\ \text{for every } S\in\sigma_{\mathcal{L}}. \tag{EC.5}$$

We show that the outcome with partition $\sigma_{\mathcal{L}}$, $\mathbf{d}^*=\mathbf{0}$ and allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$ is in the core. To see this, assume by contradiction that a set $S\subseteq\mathcal{L}$ could deviate and form partition $\hat{\pi}_S\in\Pi_S$. This means that for each $S_i\in\hat{\pi}_S$,

$$\sum_{\ell\in S_i} a_\ell < w(S_i,\mathbf{d}^*),\ \text{for every } \mathbf{d}^*\in A(\mathcal{L}\setminus S;\hat{\pi}_S).$$

But then, this same set S with partition $\hat{\pi}_S$ constitutes a deviation from the original outcome with partition $\pi_{\mathcal{L}}$, which contradicts the premise that the outcome is in the core. □

Lemma EC.6. *Consider the Area Regeneration condition $\mathbb{R}$ in the cooperative game with transferable utility defined in §3.3. If $\Delta_{\mathcal{L}}>0$, $\mathcal{E}\neq\emptyset$, and $\eta\geq\max_{S\subseteq\mathcal{L}}\frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$, then the core always contains Deforestation Outcomes. Note that this result does not require Assumption 3.*

Proof of Lemma EC.6. Consider any Deforestation Outcome, with $a_\ell = J_\ell(1,\text{no})-c_\ell$, for all $\ell\in\mathcal{L}$, and $\mathbf{d}^*=\mathbf{1}$. We will show that this outcome must be in the core. Assume by contradiction that a subset $H\subseteq\mathcal{L}$ can profitably deviate and form partition π_H.

First, we analyze the case where $H=\mathcal{L}$. In this case,

$$\eta_1(\{\{\mathcal{L}\}\}) := \frac{\Delta_{\mathcal{L}}}{|\mathcal{E}|} \leq \max_{S\subseteq\mathcal{L}}\frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}\leq\eta.$$

Hence, by Lemma 2 (which does not require Assumption 3, $\mathbf{1}\in T(\pi_H)=A(\emptyset,\pi_H)$), so $H=\mathcal{L}$ would not strictly benefit by deviating.

If $H\subset\mathcal{L}$, then Lemma EC.7 (that does not require Assumption 3) implies that $\mathbf{1}\in A(\mathcal{L}\setminus H,\pi_H)$. So any coalition $S\in\pi_H$ must satisfy

$$\sum_{\ell\in S} a_\ell < \min_{\mathbf{d}^*\in A(\mathcal{L}\setminus H,\pi_H)} w(S;\mathbf{d}^*) \leq w(S;\mathbf{1}) := \sum_{\ell\in S}\big(J_\ell(1,\text{no})-c_\ell\big)$$

where the strict inequality comes from π_H being a profitable deviation and the second inequality follows from $\mathbf{1} \in A(\mathcal{L} \setminus H, \pi_H)$. This provides the contradiction and completes the proof. $\square$

LEMMA EC.7. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta \geq \eta_3^{\text{TU}} := \max_{S \subset \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S \cup \mathcal{E}|}$*, then for every residual game with* $|R| \leq |\mathcal{L}| - 1$ *and any partition* $\pi_{\mathcal{L}\setminus R}$ *of the remaining locals, we have* $\mathbf{1} \in A(R; \pi_{\mathcal{L}\setminus R})$*. Note that this result does not require Assumption 3.*

Proof of Lemma EC.7. We proceed by induction in the size of the residual set $|R| = k$. We first prove the base case $k = 1$: that the core for a residual game with one local $R = \{h\}$ for $h \in \mathcal{L}$ and any partition $\pi_{\mathcal{L}\setminus\{h\}} \in \Pi_{\mathcal{L}\setminus\{h\}}$ of the other locals contains a Deforestation Outcome.

We claim that in this case, our standing assumption on η implies that $\eta \geq \eta_1(\{\{h\}, \pi_{\mathcal{L}\setminus\{h\}}\})$, for any partition $\pi_{\mathcal{L}\setminus\{h\}}$. This follows directly from the definition of $\eta_1(\cdot)$ in (9a), because we have:

$$\forall \pi \in \Pi_{\mathcal{L}} \setminus \{\mathcal{L}\}, \quad \eta \geq \max_{S \subset \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S \cup \mathcal{E}|} \geq \sup\Big\{\eta : \exists S \in \pi : \Delta_S > \eta |\mathcal{L} \setminus S \cup \mathcal{E}|\Big\} := \eta_1(\pi). \tag{EC.6}$$

Therefore, according to Lemma 2 (which does not require Assumption 3), $\mathbf{1} \in T(\{\{h\}, \pi_{\mathcal{L}\setminus\{h\}}\})$, so the core of the residual game $C(\{h\}; \pi_{\mathcal{L}\setminus\{h\}})$ contains the Deforestation Outcome $(\pi_h = \{\{h\}\}, \mathbf{d}^* = \mathbf{1}, a_h = J_h(1, \text{no}) - c_h)$.

Having just established our claim for $k = 1$, assume by induction that for an integer $k \in [1, |\mathcal{L}| - 2]$, every residual game with $|R| \leq k$ locals has

$$\mathbf{1} \in A(R; \pi_{\mathcal{L}\setminus R}). \tag{EC.7}$$

We prove the inductive assumption for a residual game with $|R| = k + 1$. Our assumption $k \leq |\mathcal{L}| - 2$ implies that $\mathcal{L} \setminus R$ is nonempty, so by (EC.6) we have again that $\eta \geq \eta_1(\{\pi_R, \pi_{\mathcal{L}\setminus R}\})$ for any partitions π_R and $\pi_{\mathcal{L}\setminus R}$, and therefore according to Lemma 2, $\mathbf{1} \in T(\{\pi_R, \pi_{\mathcal{L}\setminus R}\})$. Hence,

$$\pi_R = \{R\}, \ \mathbf{d}^* = \mathbf{1}, \ a_\ell = J_\ell(1, \text{no}) - c_\ell, \forall \ell \in R \tag{EC.8}$$

is an outcome of the residual game. That outcome is un-dominated under pessimism because for any coalition $S \subset R$, partition $\pi_S \in \Pi_S$ and (sub)coalition $S_i \in \pi_S$,

$$\min_{\mathbf{d}^* \in A(R\setminus S; \pi_S \cup \pi_{\mathcal{L}\setminus R})} w(S_i; \mathbf{d}^*) \leq w(S_i; \mathbf{1}) = \sum_{\ell \in S_i} J_\ell(1, \text{no}) - c_\ell = \sum_{\ell \in S_i} a_\ell \tag{EC.9}$$

wherein the inequality follows from the inductive assumption (because the residual set $R \setminus S$ has size at most $k - 1$), the first equality from (12), and the second equality from (EC.8). Hence the outcome (EC.8) is in the core for the residual game, which completes our inductive proof. $\square$

LEMMA EC.8. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta < \min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S|}$*, then the core contains every Blocking-Threat Outcome.*

Proof of Lemma EC.8. We first claim that

$$\eta < \min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S|} \tag{EC.10}$$

implies that for any residual game for a set of locals $R \subseteq \mathcal{L}$, $R \neq \emptyset$, and any feasible partition $\pi_{\mathcal{L} \setminus R}$ of the other locals that satisfies

$$\Delta_S < 0 \text{ for every } S \in \pi_{\mathcal{L} \setminus R}, \tag{EC.11}$$

the core contains the outcomes:

$$\pi_R = \{\mathcal{G} \cap R, \{\ell\}_{\ell \in R \setminus \mathcal{G}}\} \tag{EC.12a}$$

$$\mathbf{d}^* = \mathbf{0} \tag{EC.12b}$$

$$a_\ell = J_\ell(0, \text{yes}) \text{ for all } \ell \in R. \tag{EC.12c}$$

We prove the claim by induction on the number of residual locals, $|R|$. To verify the inductive assumption for $|R| = 1$, consider a residual game with one local $R = \{h\}$ and a partition of the other locals $\pi_{\mathcal{L} \setminus R}$ that satisfies (EC.11). This implies that $\Delta_{\mathcal{L} \setminus \{h\}} = \sum_{S \in \pi_{\mathcal{L} \setminus R}} \Delta_S < 0$. Because $\Delta_{\mathcal{L}} > 0$, this implies that $h \in \mathcal{G}$, and therefore (EC.10) implies:

$$\eta < \frac{\Delta_R}{|\mathcal{L} \setminus R|} \leq \Delta_R \cdot \left[\max\left(1, \max_{S \in \pi_{\mathcal{L} \setminus R}: \Delta_S < 0} |S|\right)\right]^{-1} := \eta_2(\{R\} \cup \pi_{\mathcal{L} \setminus R}).$$

Therefore, by Lemma 2, $\mathbf{0} \in T(\{h\} \cup \pi_{\mathcal{L} \setminus \{h\}})$, which implies that the core contains the outcome $\left(\{h\}, 0, a_h = J_h(0, \text{yes})\right)$, which is (EC.12a)-(EC.12c) for this residual game with $R = \{h\}$.

To complete the inductive proof, assume that the claim holds for any residual game with $|R| \leq k$ for some integer $k \in [1, |\mathcal{L}| - 1]$, and consider a residual game with $|R| = k + 1$ residual locals and a feasible partition of the other locals $\pi_{\mathcal{L} \setminus R}$ for which (EC.11) holds. The outcome (EC.12a)-(EC.12c) is a valid outcome of the residual game because (EC.10) and (EC.11) imply that $R \cap \mathcal{G}$ is nonempty and

$$\eta < \frac{\Delta_{R \cap \mathcal{G}}}{|\mathcal{L} \setminus (R \cap \mathcal{G})|} \leq \Delta_{R \cap \mathcal{G}} \cdot \left[\max\left(1, \max_{S \in \pi_{\mathcal{L} \setminus R}: \Delta_S < 0} |S|\right)\right]^{-1} := \eta_2(\{\{R \cap \mathcal{G}\}, \{\ell\}_{\ell \in R \setminus \mathcal{G}}\} \cup \pi_{\mathcal{L} \setminus R}),$$

where the first inequality comes from $\Delta_{\mathcal{L} \setminus (R \cap \mathcal{G})} = \sum_{S \in \pi_{\mathcal{L} \setminus R}} \Delta_S + \sum_{\ell \in R \setminus \mathcal{G}} \Delta_\ell < 0$ combined with (EC.10) and the second one follows from the definition of $\eta_2(\cdot)$ in (9b). Lemma 2 then implies that $\mathbf{0} \in T(\{\{R/\mathcal{G}\}, \{\ell\}_{\ell \in R \setminus \mathcal{G}}\} \cup \pi_{\mathcal{L} \setminus R})$, so the outcome (EC.12a)-(EC.12c) is valid. To see that this outcome is undominated, consider a group of locals $S \subseteq R$ that forms partition $\pi_S \in \Pi_S$. We distinguish two mutually exclusive and exhaustive cases. In Case 1, there exists a (sub)coalition $S_i \in \pi_S$ such that $\Delta_{S_i} \geq 0$. For this (sub)coalition, (12) implies that

$$w(S_i;\mathbf{d}^*) \leq \sum_{\ell \in S_i} J_\ell(0,\text{yes}) = \sum_{\ell \in S_i} a_\ell, \text{ for all } \mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}.$$

Therefore, our initial outcome with allocation (EC.12c) cannot be dominated by coalition $S \subseteq R$ forming partition $\pi_S \in \Pi_S$ that satisfies $\Delta_{S_i} \geq 0$ for some $S_i \in \pi_S$. In Case 2, there is no (sub)coalition $S_i \in \pi_S$ with $\Delta_{S_i} \geq 0$, which with (EC.11) implies that:

$$\Delta_S < 0, \text{ for every coalition } S \in \pi_{\mathcal{L}\setminus R} \cup \pi_S. \tag{EC.13}$$

Therefore, $\Delta_{\mathcal{L}} > 0$ and (EC.13) imply $\Delta_{R\setminus S} > 0$, while $S \neq \emptyset$ and $|R| = k+1$ imply that $|R \setminus S| \leq k$, so our inductive assumption applies to the residual game played by locals $R \setminus S$ when the other locals form a partition $\pi_{\mathcal{L}\setminus R} \cup \pi_S$. This implies that $\mathbf{0} \in A(R\setminus S; \pi_{\mathcal{L}\setminus R} \cup \pi_S)$ and thus:

$$\min_{\mathbf{d}^* \in A(R\setminus S;\pi_{\mathcal{L}\setminus R}\cup\pi_S)} w(S_i;\mathbf{d}^*) \leq w(S_i;\mathbf{0}) = \sum_{\ell \in S_i} J_\ell(0,\text{yes}) = \sum_{\ell \in S_i} a_\ell, \text{ for every (sub)coalition } S_i \in \pi_S.$$

Therefore, an outcome with allocation (EC.12c) is not dominated by coalition $S \subseteq R$ forming partition $\pi_S \in \Pi_S$ under pessimism in Case 2, which completes the inductive proof of our claim.

As the special case of the claim for the residual game with $R = \mathcal{L}$, we have established that if (EC.10) holds, then the core contains the outcome with $\pi = \big\{\{\mathcal{G}\}, \{\ell\}_{\ell \in \mathcal{L}\setminus\mathcal{G}}\big\}$, $\mathbf{d}^* = \mathbf{0}$ and $a_\ell = J_\ell(0,\text{yes})$ for $\ell \in \mathcal{L}$. Moreover, by Lemma EC.5, because the core contains one Blocking-Threat Outcome, every Blocking-Threat Outcome must be in the core, which concludes the proof. □

Lemma EC.9. *Consider the Area Regeneration condition $\mathbb{R}$ in the cooperative game with transferable utility defined in §3.3. If $\Delta_{\mathcal{L}} > 0$ and $\eta < \eta_2^{\text{TU}} := \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}\cup\mathcal{E}|}$, then any outcome in the core must be a Blocking-Threat Outcome.*

Proof of Lemma EC.9. We prove that any core outcome has $\mathbf{d}^* = \mathbf{0}$ and $a_\ell = J_\ell(0,\text{yes})$ for $\ell \in \mathcal{L}\setminus\mathcal{G}$, by showing that any outcome that does not satisfy those conditions must be dominated. Any outcome with $a_\ell < J_\ell(0,\text{yes})$ for some $\ell \in \mathcal{L}\setminus\mathcal{G}$ cannot be in the core by Lemma EC.2. Thus, the allocations to locals in $\mathcal{L}\setminus\mathcal{G}$ must satisfy

$$\sum_{\ell \in \mathcal{L}\setminus\mathcal{G}} a_\ell \geq \sum_{\ell \in \mathcal{L}\setminus\mathcal{G}} J_\ell(0,\text{yes}). \tag{EC.14}$$

To derive a contradiction, assume there exists $\ell \in \mathcal{L}\setminus\mathcal{G}$ with $a_\ell > J_\ell(0,\text{yes})$, which implies:

$$\begin{aligned}\sum_{g\in\mathcal{G}} a_g &\leq \max\Big\{\sum_{i\in\mathcal{L}}\big(J_i(1,\text{no}) - c_i\big),\ \sum_{i\in\mathcal{L}} J_i(0,\text{yes})\Big\} - \sum_{\ell\in\mathcal{L}\setminus\mathcal{G}} a_\ell \\ &\leq \sum_{i\in\mathcal{L}} J_i(0,\text{yes}) - \sum_{\ell\in\mathcal{L}\setminus\mathcal{G}} a_\ell\end{aligned}$$

$$= \sum_{g \in \mathcal{G}} J_g(0, \text{yes}) + \sum_{\ell \in \mathcal{L} \setminus \mathcal{G}} J_\ell(0, \text{yes}) - \sum_{\ell \in \mathcal{L} \setminus \mathcal{G}} a_\ell$$
$$< \sum_{g \in \mathcal{G}} J_g(0, \text{yes}), \tag{EC.15}$$

where the first inequality follows by (12) (because any outcome either has $\mathbf{d}^* = \mathbf{0}$ or $\mathbf{d}^* = \mathbf{1}$), the second inequality follows because $\Delta_{\mathcal{L}} > 0$, and the last inequality is implied by our assumption. We claim that an outcome satisfying (EC.15) cannot be in the core because it is dominated by the locals in $\mathcal{G}$ forming a coalition that can prevent deforestation and can achieve an aggregate welfare of $\sum_{g \in \mathcal{G}} J_g(0, \text{yes})$. To see that the latter is a valid outcome, consider any partition $\pi_{\mathcal{L} \setminus \mathcal{G}}$ of the other locals and note that our standing assumption $\eta < \eta_2^{\text{TU}}$ implies:

$$\eta_1(\{\mathcal{G}\} \cup \pi_{\mathcal{L} \setminus \mathcal{G}}) > \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G} \cup \mathcal{E}|} = \eta_2^{\text{TU}} > \eta, \tag{EC.16}$$

where the first inequality follows directly from the definition of $\eta_1(\pi)$ in (9a). Thus, Lemma 2 and (EC.16) imply that $T(\{\mathcal{G}\} \cup \pi_{\mathcal{L} \setminus \mathcal{G}}) = \{\mathbf{0}\}$, so any outcome involving the coalition $\mathcal{G}$ must satisfy $\mathbf{d}^* = \mathbf{0}$ and a welfare of $w(\mathcal{G}; \mathbf{0}) = \sum_{g \in \mathcal{G}} J_g(0, \text{yes})$ for coalition $\mathcal{G}$, which completes the contradiction. Therefore, every residual core outcome under the premises of the Lemma must involve $\mathbf{d}^* = \mathbf{0}$ and $a_\ell = J_\ell(0, \text{yes})$ for every $\ell \in \mathcal{L} \setminus \mathcal{G}$, proving the result. □

LEMMA EC.10. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta \in \left(\min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S|}, \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G}|} \right)$*, then the core may contain Blocking-Threat Outcomes.*

Proof of Lemma EC.10. To prove the Lemma, we consider first the following instance with $|\mathcal{E}| \neq \emptyset$ and $\mathcal{L} = \{\ell, g, h\}$ satisfying:

$$\Delta_g > \Delta_\ell > 0, \quad \Delta_h < 0, \quad \Delta_\ell + \Delta_h < 0, \quad \Delta_g + \Delta_h > 0, \quad \Delta_{\mathcal{L}} > 0, \tag{EC.17}$$

and $\min_{S \subseteq \mathcal{L}: \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S|} = \frac{\Delta_g}{2} < \eta < \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G}|} = \Delta_g + \Delta_\ell$. We show that the Blocking-Threat Outcome with no-deforestation ($\mathbf{d}^* = \mathbf{0}$), locals forming the coalition $\pi_{\mathcal{L}} = \{\{\ell, g\}, \{h\}\}$, and allocations

$$a_\ell = J_\ell(0, \text{yes}) - \Delta_h, \quad a_g = J_g(0, \text{yes}) + \Delta_h, \quad a_h = J_h(0, \text{yes}), \tag{EC.18}$$

is in the core. First, notice that the outcome is a Blocking-Threat Outcome, as h is allocated $J_h(0, \text{yes})$. We will consider all possible deviations to show that it is in the core.

Local g would not deviate and form partition $\{g\}$, because $\eta > \frac{\Delta_g}{2}$ and $\Delta_\ell + \Delta_h < 0$ imply that $\{\ell, h\}$ could deforest and not be blocked. In particular, because $\eta_2(\{\{g\}, \{\ell, h\}\}) = \frac{\Delta_g}{2}$, then $\eta > \frac{\Delta_g}{2}$ implies by Lemma 2 that $T(\{\{g\}, \{\ell, h\}\}) = \{\mathbf{1}\}$, which in turn implies that $\mathbf{1} \in A(\{\ell, h\}; \{\{g\}\})$. Finally, because $\Delta_g + \Delta_h > 0$ by (EC.17), $a_g = J_g(0, \text{yes}) + \Delta_h > J_g(1, \text{no}) - c_g = w(\{g\}; \mathbf{1})$, which implies that under pessimism, g would not deviate.

Local ℓ would not deviate and form partition $\{\ell\}$ because

$$a_\ell > J_\ell(0,\text{yes}) > J_\ell(1,\text{no}) - c_\ell \geq \min_{\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}} w(\{\ell\};\mathbf{d}^*),$$

where the first inequality is due to $\Delta_h < 0$ and the second due to $\Delta_\ell > 0$.

Local h would not deviate as a singleton $\{h\}$ because $\eta < \Delta_\ell + \Delta_g$ implies $\eta < \eta_2(\{\{\ell,g\},\{h\}\})$, so Lemma 2 implies $\mathbf{0} \in T(\{\{\ell,g\},\{h\}\}) \subseteq A(\{\ell,g\};\{\{h\}\}$ and thus $a_h \geq \min_{\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}} w(\{h\};\mathbf{d}^*)$.

Locals g and ℓ together are already receiving their maximum allocation $w(\{\ell,g\};\mathbf{0})$, as $\Delta_\ell + \Delta_g > 0$, and therefore would not deviate and form a coalition $\{\ell,g\}$. For the same reason, locals g and h would not deviate, as $\Delta_g + \Delta_h > 0$.

Locals ℓ and h would not deviate because,

$$a_\ell + a_h = J_\ell(0,\text{yes}) - \Delta_h + J_h(0,\text{yes}) = J_\ell(0,\text{yes}) + J_h(1,\text{no}) - c_h,$$

and hence, $\Delta_h < 0$ implies that $a_\ell + a_h > J_\ell(0,\text{yes}) + J_h(0,\text{yes})$, while $\Delta_\ell > 0$ implies that

$$a_\ell + a_h > J_\ell(1,\text{no}) - c_\ell + J_h(1,\text{no}) - c_h.$$

This proves that $a_\ell + a_g > w(\{\ell,g\};\mathbf{d}^*)$, for every $\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}$, and therefore $\{\ell,h\}$ would not deviate together.

Finally, the grand coalition $\{\ell,g,h\}$ would not deviate because $\Delta_{\mathcal{L}} > 0$ implies

$$a_\ell + a_g + a_h = w(\mathcal{L};\mathbf{0}) > w(\mathcal{L};\mathbf{1}).$$

We have shown then that this instance contains a Blocking-Threat Outcome in the core. Notice that we did not use the fact that there are entrants ($\mathcal{E} \neq \emptyset$). This is because $\eta < \Delta_\ell + \Delta_g$ implies that the coalition $\{\ell,g\}$ can block either h or any individual entry, which leads to $\eta < \eta_2(\{\{\ell,g\},\{h\}\})$, regardless of how many entrants there are in $\mathcal{E}$. Therefore, the same example works with $\mathcal{E} = \emptyset$ or with an arbitrary number of entrants. □

Lemma EC.11. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta > \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$, *then the core contains no Blocking-Threat Outcomes.*

Proof of Lemma EC.11. Assume by contradiction that the core contains a Blocking-Threat outcome, i.e., $\mathbf{d}^* = \mathbf{0}$ and allocation a_ℓ that satisfies $a_\ell = J_\ell(0,Y)$ for every $\ell \in \mathcal{L} \setminus \mathcal{G}$. We claim that this outcome is dominated by the locals in $\mathcal{L} \setminus \mathcal{G}$ forming a coalition and deriving strictly larger welfare. In that case, because $\eta > \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}|}$, any partition $\pi_{\mathcal{G}}$ of the locals in $\mathcal{G}$ would satisfy

$$\eta_2(\pi_{\mathcal{G}} \cup \{\mathcal{L} \setminus \mathcal{G}\}) \leq \frac{\Delta_{\mathcal{G}}}{|\mathcal{L} \setminus \mathcal{G}|} < \eta,$$

which follows from the definition of $\eta_2(\cdot)$ in (9b). Lemma 2 would imply that $T(\pi_{\mathcal{G}} \cup \{\mathcal{L}\setminus\mathcal{G}\}) = \{\mathbf{1}\}$, so any outcome involving the coalition $\{\mathcal{L}\setminus\mathcal{G}\}$ would have $\mathbf{d}^* = \mathbf{1}$ and a welfare for that coalition of

$$w(\mathcal{L}\setminus\mathcal{G}, \pi_{\mathcal{G}} \cup \{\mathcal{L}\setminus\mathcal{G}\}, 1) = \sum_{\ell\in\mathcal{L}\setminus\mathcal{G}} \big(J_\ell(1,N) - c_\ell\big) > \sum_{\ell\in\mathcal{L}\setminus\mathcal{G}} J_\ell(0,Y) = \sum_{\ell\in\mathcal{L}\setminus\mathcal{G}} a_\ell,$$

providing that the Blocking-Threat outcome would be dominated. □

Lemma EC.12. *Consider the Area Regeneration condition $\mathbb{R}$ in the cooperative game with transferable utility defined in §3.3. If $\Delta_{\mathcal{L}} > 0$ and $\eta \in \big(\eta_3^{\mathrm{TU}} := \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}, \Delta_{\mathcal{G}}\cdot\mathbf{1}_{\mathcal{E}=\emptyset} + \Delta_{\mathcal{L}}\cdot\mathbf{1}_{\mathcal{E}\neq\emptyset}\big)$, the core may contain Partial Compensation Outcomes.*

Proof of Lemma EC.12. Consider an example with $\mathcal{L} = \{\ell, g, h\}$ so that:

$$\Delta_g > 0,\ \Delta_\ell < 0,\ \Delta_h < 0,\ \Delta_{\mathcal{L}} > 0. \tag{EC.19}$$

We will show that the core $C(\mathcal{L};\emptyset)$ contains outcomes with $\pi_{\mathcal{L}} = \{\{\mathcal{L}\}\}$, $\mathbf{d}^* = \mathbf{0}$, and allocation $\{a_i\}_{i\in\mathcal{L}}$ satisfying:

$$a_h = J_h(1,\text{no}) - c_h + \epsilon \tag{EC.20a}$$
$$a_g = J_g(0,\text{yes}) - (J_\ell(0,\text{yes}) - a_\ell) - (J_h(0,\text{yes}) - a_h) + \epsilon \geq J_g(1,\text{no}) - c_g + \epsilon \tag{EC.20b}$$
$$a_\ell = J_\ell(1,\text{no}) - c_\ell - \epsilon \tag{EC.20c}$$
$$a_\ell \geq J_\ell(0,\text{yes}). \tag{EC.20d}$$

for some $\epsilon > 0$. Note first that an outcome satisfying (EC.20a)-(EC.20d) is feasible due to (EC.19). We prove that it belongs to the core by checking that it is not dominated, i.e., no subset $S\subseteq\mathcal{L}$ could profitably deviate.

First, consider the case with $\mathcal{E} = \emptyset$. The conditions in the Lemma imply that η satisfies:

$$\max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|} < \eta < \Delta_{\mathcal{G}} = \Delta_g. \tag{EC.21}$$

The locals in $\{h,\ell\}$ would not deviate together, as

$$a_h + a_\ell \geq J_h(1,\text{no}) - c_h + J_\ell(1,\text{no}) - c_\ell \geq w(\{h,f\},\mathbf{d}^*),$$

for $\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}$. Here, the first inequality comes from (EC.20a) and (EC.20c), and the second from $\ell, g \in \mathcal{L}\setminus\mathcal{G}$.

Neither h nor ℓ could profitably deviate as singletons. Local h would not deviate due to (EC.20a). To verify this for ℓ, we show that there is a No-Deforestation Outcome in $C(\{h,g\};\{\ell\})$, which by (EC.20d) implies that ℓ would not deviate under pessimism. To that end, we claim that the residual outcome $\pi_{\{h,g\}} = \{\{h\},\{g\}\}$, $\mathbf{d}^* = \mathbf{0}$, and $a_i = J_i(0,\text{yes})$, for $i\in\mathcal{L}$ is an outcome of the residual game played by $\{g,h\}$ when ℓ deviates. $\eta < \Delta_{\mathcal{G}}$ implies that $\eta < \eta_3\big(\{\{h\},\{g\},\{\ell\}\}\big)$, and therefore Lemma 2 implies that $\mathbf{0} \in T(\{\{h\},\{g\},\{\ell\}\})$. Thus $\mathbf{0} \in A(\{h\};\{g\},\{\ell\})$, so g could not profitably deviate from the residual outcome under pessimism, which in turn proves that ℓ would not deviate under pessimism from the outcome (EC.20a)-(EC.20d).

Lastly, to see that local g would not unilaterally deviate or form a coalition with ℓ or h to deviate, consider any $S \subset \mathcal{L}$ with $g \in S$. Because $\eta > \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$ implies that $\eta > \eta_1(\{\mathcal{L}\setminus S, S\})$ in this case, Lemma 2 implies that $\mathbf{1} \in A(\mathcal{L}\setminus S;\{S\})$. But then, because any such S satisfies

$$\sum_{i\in S} a_i \geq \sum_{i\in S}\big(J_i(1,\text{no}) - c_i\big)$$

from (EC.20a)-(EC.20c), the coalition S would not strictly benefit from deviating under pessimism.

To conclude the proof, consider the same instance as above but with one entrant, $|\mathcal{E}| = 1$. We claim that the outcome in (EC.20a)-(EC.20c) is in the core $C(\mathcal{L};\emptyset)$ provided that $\max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|} < \eta < \Delta_{\mathcal{L}}$. The requirement $\eta < \Delta_{\mathcal{L}}$ is sufficient for $\{\ell,g,h\}$ to credibly threaten to block $e \in \mathcal{E}$ from producing and it also implies that $\eta < \Delta_{\mathcal{G}}$ holds, so the rest of the proof proceeds exactly as above. □

Lemma EC.13. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta \in \big(\frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}\cup\mathcal{E}|} + \epsilon, \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}\big)$*, for any* $0 < \epsilon < \frac{\Delta_{\mathcal{G}}}{(2+|\mathcal{E}|)^2}$ *then the core may contain Partial Compensation Outcomes.*

Proof of Lemma EC.13. Consider an instance with arbitrary $\mathcal{E}$ and $\mathcal{L} = \{\ell, g, h\}$ satisfying:

$$\Delta_g > 0, \quad \Delta_\ell = \frac{-\Delta_g}{2} + \epsilon < \Delta_h = -\epsilon < 0, \quad \Delta_{\mathcal{L}} > 0. \tag{EC.22}$$

These conditions imply that $\frac{\Delta_g+\Delta_\ell}{1+|\mathcal{E}|} = \frac{\Delta_g}{2+2|\mathcal{E}|} + \frac{\epsilon}{1+|\mathcal{E}|} \leq \frac{\Delta_g}{2+|\mathcal{E}|} + \epsilon < \frac{\Delta_g+\Delta_h}{1+|\mathcal{E}|} = \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup|\mathcal{E}||}$, so by our assumptions on η we have:

$$\frac{\Delta_\ell+\Delta_g}{1+|\mathcal{E}|} \leq \frac{\Delta_g}{2+|\mathcal{E}|} + \epsilon < \eta < \frac{\Delta_g+\Delta_h}{1+|\mathcal{E}|}. \tag{EC.23}$$

We prove that the core contains the Partial Compensation Outcome:

$$\pi_{\mathcal{L}} = \{\{\ell\},\{g,h\}\},\ \mathbf{d}^* = \mathbf{0},\ a_\ell = J_\ell(0,\text{yes}),\ a_h = J_h(1,\text{no}) - c_h - \Delta_\ell,$$
$$a_g = J_g(0,\text{yes}) - (a_h - J_h(0,\text{yes})) = J_g(0,\text{yes}) + \Delta_h + \Delta_\ell.$$

Notice that this is a Partial Compensation Outcome because $\Delta_\ell < 0$ implies that $a_h > J_h(1,\text{no}) - c_h$ and $a_\ell < J_\ell(1,\text{no}) - c_\ell$. Moreover, (EC.23) implies $\eta < \frac{\Delta_g+\Delta_h}{1+|\mathcal{E}|}$ and thus $\eta < \eta_2(\{\{\ell\},\{g,h\}\}) = \Delta_g + \Delta_h$, so Lemma 2 implies that $\mathbf{0} \in T(\{\{\ell\},\{g,h\}\})$. We show that this outcome belongs to the core by proving that no deviation is profitable.

Local h would not deviate as a singleton because $a_h > w(\{h\},\mathbf{d}^*)$, for every $\mathbf{d}^* \in \{\mathbf{0},\mathbf{1}\}$.

Local ℓ would not deviate as a singleton because $\mathbf{0}\in T(\{\{g,h\},\{\ell\}\})\subseteq A(\{g,h\};\{\{\ell\}\})$, and thus $a_\ell = J_\ell(0,\text{yes}) \geq \min_{\mathbf{d}^*\in A(\{g,h\};\{\{\ell\}\})} w(\{\ell\};\mathbf{d}^*)$, so ℓ would not deviate under pessimism.

To see why g would not deviate as a singleton, note that ℓ cannot block by himself all other locals (and potentially any entrants). In particular, (EC.23) implies that $\eta > \frac{\Delta_g}{2+|\mathcal{E}|} = \eta_1(\{\{g\},\{\ell,h\}\})$, so Lemma 2 implies that $\mathbf{1}\in T(\{\{g\},\{\ell,h\}\})\subseteq A(\{\ell,h\};\{\{g\}\})$; local g's allocation thus satisfies

$$\begin{aligned} a_g &= J_g(0,\text{yes}) + \Delta_h + \Delta_\ell \\ &= J_g(1,\text{no}) - c_g + \Delta_{\mathcal{L}} \\ &> \min_{\mathbf{d}^*\in A(\{\ell,h\};\{\{g\}\})} w(\{g\};\mathbf{d}^*), \end{aligned}$$

where the last inequality follows because $\Delta_{\mathcal{L}} > 0$ and $1\in A(\{\ell,h\};\{\{g\}\})$. Therefore, local g would not deviate under pessimism.

Locals ℓ and h would not deviate as $\{\ell,h\}$ because their current allocation already satisfies:

$$a_\ell + a_h = J_\ell(1,\text{no}) - c_\ell + \Delta_\ell + J_h(1,\text{no}) - c_h - \Delta_\ell \geq w(\{\ell,h\};\mathbf{d}^*), \text{ for every } \mathbf{d}^*\in\{\mathbf{0},\mathbf{1}\},$$

where the inequality follows because $\Delta_\ell + \Delta_h < 0$.

To prove that locals ℓ and g would also not deviate as $\{\ell,g\}$, note that (EC.23) implies that $\eta > \frac{\Delta_\ell+\Delta_g}{1+|\mathcal{E}|} := \eta_1(\{\{\ell,g\},\{h\}\})$, Therefore, Lemma 2 implies that $\mathbf{1}\in T(\{\{h\},\{\ell,g\}\})\subseteq A(\{h\};\{\{\ell,g\}\})$, so the allocations for ℓ and g satisfy:

$$\begin{aligned} a_\ell + a_g &= J_\ell(0,\text{yes}) + J_g(0,\text{yes}) + \Delta_h + \Delta_\ell \\ &= J_\ell(1,\text{no}) - c_\ell + J_g(1,\text{no}) - c_g + 2\Delta_\ell + \Delta_h + \Delta_g \\ &= \sum_{i\in\{\ell,g\}} (J_i(1,\text{no}) - c_i) + \epsilon \\ &\geq \min_{\mathbf{d}^*\in A(\{h\};\{\{\ell,g\}\})} w(\{\ell,g\};\mathbf{d}^*), \end{aligned}$$

where the last inequality follows because $\epsilon > 0$ and $\mathbf{1}\in A(\{h\};\{\{\ell,g\}\})$. Therefore, ℓ and g would not deviate together.

Finally, the two subsets $\{g,h\}$ and $\{\ell,g,h\}$ would not deviate because for every such subset S we have $\sum_{i\in S} a_i = \sum_{i\in S} J_i(0,\text{yes})$ and $\Delta_S > 0$, so their current allocations cannot be improved.

This proves that no subset would deviate, so the Partial Compensation Outcome is in the core. □

Lemma EC.14. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$*,* $\mathcal{E}\neq\emptyset$*, and* $\eta \in \left(\max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}, \Delta_{\mathcal{G}}\right)$*, then the core may contain Partial Compensation Outcomes.*

Proof of Lemma EC.14. We consider an instance with $\mathcal{L} = \{\ell, g\}$ and $|\mathcal{E}| = 1$ satisfying the conditions:

$$\Delta_g > 0, \quad \Delta_\ell < 0, \quad \Delta_{\mathcal{L}} > 0.$$

Let η satisfy $\max_{S \subset \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S \cup \mathcal{E}|} = \frac{\Delta_g}{2} < \eta < \Delta_{\mathcal{G}} = \Delta_g$. We show that the core contains the Partial Compensation Outcome with $\pi_{\mathcal{L}} = \{\mathcal{L}\}$, no deforestation ($\mathbf{d}^* = \mathbf{0}$), and the allocation

$$a_\ell = J_\ell(0, \text{yes}) + \epsilon, \quad a_g = J_g(0, \text{yes}) - \epsilon,$$

for $0 < \epsilon < -\Delta_\ell$. Notice first that this is a Partial Compensation Outcome, as ℓ satisfies both conditions in (16a). To show that it is in the core, we consider all possible deviations.

We first consider the deviation of local ℓ. Because $\eta < \Delta_g = \eta_2(\{\{\ell\}, \{g\}\})$, Lemma 2 implies $\mathbf{0} \in T(\{\{\ell\}, \{g\}\}) \subseteq A(\{g\}; \{\{\ell\}\})$ and therefore $a_\ell > w(\{\ell\}; \mathbf{0}) \geq \min_{\mathbf{d}^* \in A(\{g\}; \{\{\ell\}\})} w(\{\ell\}; \mathbf{d}^*)$, so ℓ would not deviate under pessimism.

Local g would not deviate either. To see this, notice that $\eta > \frac{\Delta_g}{2} = \eta_1(\{\{g\}, \{\ell\}\})$, so Lemma 2 implies that $\mathbf{1} \in T(\{\{g\}, \{\ell\}\}) \subseteq A(\{\ell\}; \{\{g\}\})$. As $a_g = J(0, \text{yes}) - \epsilon$ and $\epsilon < -\Delta_\ell < \Delta_g$, then $a_g > w(\{g\}, \mathbf{1}) \geq \min_{\mathbf{d}^* \in A(\{\ell\}; \{\{g\}\})} w(\{g\}; \mathbf{d}^*)$ holds, so g would not deviate under pessimism.

Lastly, ℓ, g would not deviate together because $\Delta_{\mathcal{L}} > 0$ implies $a_\ell + a_g \geq w(\mathcal{L}, \mathbf{d}^*)$, for all $\mathbf{d}^* \in \{\mathbf{0}, \mathbf{1}\}$. $\square$

Lemma EC.15. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$, $\eta > \eta_3^{\text{TU}} := \max_{S \subset \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S \cup \mathcal{E}|}$ *and* $\eta < \mathbf{1}_{\mathcal{E} \neq \emptyset} \cdot \Delta_{\mathcal{L}} + \mathbf{1}_{\mathcal{E} = \emptyset} \cdot \infty$, *then the core contains the set of Compensation Outcomes.*

Proof of Lemma EC.15. Consider any Compensation Outcome, which satisfies by definition

$$a_\ell \geq J_\ell(1, \text{no}) - c_\ell, \text{ for all } \ell \in \mathcal{L}.$$

Using Lemma EC.7, we will show that this outcome is in the core. Note that $\eta < \eta_2(\{\mathcal{L}\}) = \mathbf{1}_{\mathcal{E} \neq \emptyset} \cdot \Delta_{\mathcal{L}} + \mathbf{1}_{\mathcal{E} = \emptyset} \cdot \infty$, which by Lemma 2 implies that $\mathbf{0} \in T(\{\mathcal{L}\})$. We proceed then to show that this outcome is un-dominated.

First, note that the grand coalition $\{\mathcal{L}\}$ can never profitably deviate from any No-Deforestation Outcome (and thus also from a Compensation Outcome) when $\Delta_{\mathcal{L}} > 0$, because any No-Deforestation Outcome already provides the largest possible welfare for $\mathcal{L}$, namely $\sum_{\ell \in \mathcal{L}} J_\ell(0, \text{yes})$.

Now, consider any coalition $S \subset \mathcal{L}$ that forms partition $\pi_S \in \Pi_S$. We show that this configuration cannot dominate the Compensation Outcome. For any such coalition S, we have $|\mathcal{L} \setminus S| \in [1, |\mathcal{L}| - 1]$, and by Lemma EC.7, we have $\mathbf{1} \in A(\mathcal{L} \setminus S; \pi_S)$. Hence, for any (sub)coalition $S_i \in \pi_S$,

$$\min_{\mathbf{d}^* \in A(\mathcal{L} \setminus S; \pi_S)} w(S_i; \mathbf{d}^*) \leq w(S_i; \mathbf{1}) = \sum_{\ell \in S} \big(J_\ell(1, \text{no}) - c_\ell\big) \leq \sum_{\ell \in S} a_\ell.$$

Therefore, the coalition S with partition π_S cannot derive a strictly larger welfare under pessimism, proving that the Compensation Outcome is un-dominated and must belong to the core. $\square$

LEMMA EC.16. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta > \Delta_{\mathcal{G}}$*, then any No-Deforestation Outcome in the core must be a Compensation Outcome.*

Proof of Lemma EC.16. Assume by contradiction that there is a No-Deforestation Outcome in the core such that $a_\ell < J_\ell(1, \text{no}) - c_\ell$, for some $\ell \in \mathcal{L} \setminus \mathcal{G}$. Then, ℓ can deviate towards a deforestation equilibrium all by himself. This is because, for any partition of the remaining locals $\pi_{\mathcal{L}\setminus\{\ell\}}$,

$$\eta_2(\pi_{\mathcal{L}\setminus\{\ell\}} \cup \{\{\ell\}\}) \leq \Delta_{\mathcal{G}} < \eta,$$

which, by Lemma 2, implies that $\{\mathbf{1}\} = T(\pi_{\mathcal{L}\setminus\{\ell\}} \cup \{\{\ell\}\})$ and thus $\{\mathbf{1}\} = A(\mathcal{L} \setminus \{\ell\}; \{\{\ell\}\})$ and

$$w(\{\ell\}; \mathbf{d}^*) > a_\ell, \text{ for every } \mathbf{d}^* \in A(\mathcal{L} \setminus \{\ell\}; \{\{\ell\}\}).$$

This proves that $\{\ell\}$ can deviate and improve his allocation, and therefore, every $\ell \in \mathcal{L} \setminus \mathcal{G}$ must have an allocation that satisfies

$$a_\ell \geq J_\ell(1, \text{no}) - c_\ell. \qquad \square$$

LEMMA EC.17. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta < \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$*, then the core contains no Compensation Outcomes.*

Proof of Lemma EC.17. Assume by contradiction that there is a Compensation Outcome in the core. The allocations $\{a\}_{\ell\in\mathcal{L}}$ should then satisfy $a_\ell \geq J_\ell(1, \text{no}) - c_\ell$, for all $\ell \in \mathcal{L} \setminus \mathcal{G}$. We prove that this outcome is dominated.

First, we observe that because $\eta < \max_{S\subset\mathcal{L}} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$, then there must exist $S \subset \mathcal{L}$, such that

$$\Delta_S > \eta|\mathcal{L} \setminus S \cup \mathcal{E}|. \tag{EC.24}$$

Without loss of generality, we can assume $\mathcal{G} \subseteq S$, and therefore $\mathcal{L} \setminus S \subseteq \mathcal{L} \setminus \mathcal{G}$. We will show that S can deviate from the Compensation Outcome.

For any partition $\pi_{\mathcal{L}\setminus S} \in \Pi_{\mathcal{L}\setminus S}$, equation (EC.24) implies that $\eta \leq \eta_1(\{S\} \cup \pi_{\mathcal{L}\setminus S})$, which by Lemma 2 implies that $T(\{S\} \cup \pi_{\mathcal{L}\setminus S}) = \{\mathbf{0}\}$. Because this holds for every partition $\pi_{\mathcal{L}\setminus S}$, then $A(\mathcal{L} \setminus S; \{S\}) = \{\mathbf{0}\}$, where $A(\cdot;\cdot)$ is defined in (EC.1).

Because the Compensation Outcome is a No-Deforestation Outcome, we know that

$$\sum_{\ell\in S} a_\ell + \sum_{\ell\in\mathcal{L}\setminus S} a_\ell = w(\mathcal{L}; \mathbf{0}).$$

But then,

$$\begin{aligned}\sum_{\ell\in S} a_\ell &= w(\mathcal{L};\mathbf{0}) - \sum_{\ell\in\mathcal{L}\setminus S} a_\ell \\ &\le w(\mathcal{L};\mathbf{0}) - \sum_{\ell\in\mathcal{L}\setminus S} \big(J_\ell(1,\text{no}) - c_\ell\big) \\ &= w(S;\mathbf{0}) + \Delta_{\mathcal{L}\setminus S} \\ &< w(S;\mathbf{0}),\end{aligned}$$

where the first inequality comes from the outcome being a Compensation Outcome, and the second (strict) inequality comes from $\mathcal{L}\setminus S \subseteq \mathcal{L}\setminus\mathcal{G}$, which implies that $\Delta_{\mathcal{L}\setminus S} < 0$. But then, we have shown that $\sum_{\ell\in S} a_\ell < w(S;\mathbf{d}^*)$, for every $\mathbf{d}^* \in A(\mathcal{L}\setminus S;\{S\})$, which completes the proof that the Compensation Outcome is dominated. □

Lemma EC.18. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$, $\mathcal{E} \neq \emptyset$, *and* $\eta > \Delta_{\mathcal{L}}$, *then the core does not contain any Compensation Outcomes.*

Proof of Lemma EC.18. Assume by contradiction that the core contains a Compensation Outcome, i.e., $\mathbf{d}^* = \mathbf{0}$ some partition $\pi_{\mathcal{L}}$ and allocations $\{a_\ell\}_{\ell\in\mathcal{L}}$ with $a_\ell \ge J_\ell(1,\text{no}) - c_\ell$, for every $\ell \in \mathcal{L}\setminus\mathcal{G}$.

We claim that $\Delta_S \ge 0$, for every $S \in \pi_{\mathcal{L}}$. Otherwise, if some coalition $S \in \pi_{\mathcal{L}}$ had $\Delta_S < 0$, then the locals in $S\cap\mathcal{G}$ would have to have allocations satisfying:

$$\begin{aligned}\sum_{g\in S\cap\mathcal{G}} a_g &= \sum_{g\in S\cap\mathcal{G}} J_g(0,\text{yes}) + \sum_{\ell\in S\setminus\mathcal{G}} J_\ell(0,\text{yes}) - \sum_{\ell\in S\setminus\mathcal{G}} a_\ell \\ &< \sum_{g\in S\cap\mathcal{G}} (J_g(1,\text{no}) - c_g) + \sum_{\ell\in S\setminus\mathcal{G}} (J_\ell(1,\text{no}) - c_\ell) - \sum_{\ell\in S\setminus\mathcal{G}} a_\ell \\ &\le \sum_{g\in S\cap\mathcal{G}} (J_g(1,\text{no}) - c_g),\end{aligned}$$

where the first inequality follows from $\Delta_S < 0$ and the second follows from the definition of a Compensation Outcome. The latter result would contradict Lemma EC.2, proving our claim.

As every coalition S satisfies $\Delta_S \ge 0$ and $\sum_{S\in\pi_{\mathcal{L}}} \Delta_S = \Delta_{\mathcal{L}} > 0$, then $\Delta_S \le \Delta_{\mathcal{L}}$, for every $S \in \pi_{\mathcal{L}}$. But then, any entrant could deviate from this No-Deforestation Outcome and not be blocked by any coalition S; specifically, $\eta > \Delta_{\mathcal{L}} \ge \Delta_S$ and $\mathcal{E} \neq \emptyset$ imply $\eta_2(\pi_{\mathcal{L}}) = \max_{S\in\pi_{\mathcal{L}}} \Delta_S < \eta$ and thus Lemma 2 implies that $\{\mathbf{1}\} = T(\pi_{\mathcal{L}})$. This proves that the Compensation Outcome cannot be in the core. □

Lemma EC.19. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$ *and* $\eta \in \big(\min_{S\subseteq\mathcal{L}:\Delta_S<0} \frac{\Delta_{\mathcal{L}\setminus S}}{|S|},\ \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}\cup\mathcal{E}|}\big)$, *then the core may be empty.*

Proof of Lemma EC.19. Consider the following example with $\mathcal{L} = \{\ell, g, h\}$, $\mathcal{E} = \{e\}$, and:

$$\Delta_\ell = \Delta_g > 0, \quad \Delta_h < 0, \quad \Delta_{\mathcal{L}} > 0, \tag{EC.25a}$$

$$\Delta_h + \Delta_g < 0, \quad \Delta_h + \Delta_\ell < 0. \tag{EC.25b}$$

Finally, consider η such that:

$$\min_{S \subseteq \mathcal{L}, \Delta_S < 0} \frac{\Delta_{\mathcal{L} \setminus S}}{|S|} := \frac{\Delta_\ell}{2} = \frac{\Delta_g}{2} < \eta < \frac{\Delta_\ell + \Delta_g}{2} = \Delta_\ell = \Delta_g. \tag{EC.26}$$

Let us assume by contradiction that there is an outcome in $C(\mathcal{L}; \emptyset)$, with allocations $\{a_\ell, a_g, a_h\}$. We show that these allocations would have to satisfy the following infeasible system of inequalities:

$$a_\ell + a_g + a_h = J_\ell(0, \text{yes}) + J_g(0, \text{yes}) + J_h(0, \text{yes}) \tag{EC.27a}$$

$$a_\ell + a_g \geq J_\ell(0, \text{yes}) + J_g(0, \text{yes}) \tag{EC.27b}$$

$$a_h \geq J_h(0, \text{yes}) \tag{EC.27c}$$

$$a_\ell + a_h \geq J_\ell(1, \text{no}) - c_\ell + J_h(1, \text{no}) - c_h \tag{EC.27d}$$

$$a_g + a_h \geq J_g(1, \text{no}) - c_g + J_h(1, \text{no}) - c_h. \tag{EC.27e}$$

First, we show that the above system is indeed infeasible. For this, note that (EC.27a)-(EC.27c) imply that $a_h = J_h(0, \text{yes})$. This, together with (EC.27d)-(EC.27e) and (EC.25b), implies that $a_\ell > J_\ell(0, \text{yes})$ and $a_g > J_g(0, \text{yes})$. So we get $a_\ell > J_\ell(0, \text{yes})$, $a_g > J_g(0, \text{yes})$, and $a_h = J_h(0, \text{yes})$, contradicting (EC.27a).

The equality in (EC.27a) comes from Lemma EC.4, which applies because $\eta < \eta_2^{\text{TU}} \leq \eta_3^{\text{TU}}$, and states that all outcomes in the core should be No-Deforestation Outcomes. Thus, the sum of all allocations should be equal to $w(\mathcal{L}, \mathbf{0}) = J_\ell(0, \text{yes}) + J_g(0, \text{yes}) + J_h(0, \text{yes})$.

The inequality (EC.27b) comes from the plausible deviation of ℓ and g, where they cooperate to block any production by h. This applies because in our case

$$\eta_1(\{\{\ell, g\}, \{h\}\}) = \Delta_g, \tag{EC.28}$$

which together with (EC.26) implies that $\eta < \eta_1(\{\{\ell, g\}, \{h\}\})$, which by Lemma 2 implies that $T(\{\{h\}, \{\ell, g\}\}) = A(\{h\}; \{\{\ell, g\}\}) = \{\mathbf{0}\}$. This in turn implies that if ℓ and g were to form the coalition $\{\ell, g\}$, they could block h and ensure a No-Deforestation Outcome where they would get welfare $J_\ell(0, \text{yes}) + J_g(0, \text{yes})$, so $a_\ell + a_g$ must satisfy (EC.27b).

The inequality (EC.27c) comes from Lemma EC.2 and $h \in \mathcal{L} \setminus \mathcal{G}$.

The two inequalities (EC.27d)-(EC.27e) come from two plausible deviations of $\{\ell, h\}$ and $\{g, h\}$, respectively. Because ℓ and g are symmetric in our example, we show this for $\{\ell, h\}$. We have that

$$\eta_3\big(\{\{g\}, \{\ell, h\}\}\big) = \frac{\Delta_g}{2}, \tag{EC.29}$$

which together with (EC.26) implies that $\eta > \eta_2(\{\{g\},\{\ell,h\}\})$, which by Lemma 2 implies that $\{\mathbf{1}\} = T(\{\{g\},\{\ell,h\}\}) = A(\{g\};\{\{\ell,h\}\})$, which implies that $\{\ell,h\}$ could deviate to a Deforestation Outcome. A symmetric argument for $\{g,h\}$ implies that any outcome in the core $C(\mathcal{L};\emptyset)$ must satisfy (EC.27d)-(EC.27e), which proves the lemma for the case when $\mathcal{E} \neq \emptyset$.

Finally, we note that the same instance but with $\mathcal{E} = \emptyset$ would also lead to an empty core, as long as η satisfies:

$$\min_{S\subseteq\mathcal{L},\Delta_S<0} \frac{\Delta_{\mathcal{L}\setminus S}}{|S|} := \frac{\Delta_\ell}{2} = \frac{\Delta_g}{2} < \eta < \Delta_{\mathcal{G}} = 2\Delta_\ell = 2\Delta_g.$$

The proof is identical to the one above, except that $\eta_1(\{\{\ell,g\},\{h\}\})$ takes value $\Delta_{\mathcal{G}}$ in (EC.28). □

Lemma EC.20. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$*,* $\mathcal{E} = \emptyset$*, and* $\eta_2^{\mathrm{TU}} := \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}\cup\mathcal{E}|} < \eta < \eta_3^{\mathrm{TU}} := \max_{S\subset\mathcal{L},\Delta_S>0} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$*, then the core may be empty.*

Proof of Lemma EC.20. We consider an instance with $\mathcal{L} = \{\ell,g,h\}$ satisfying the conditions:

$$\Delta_{\mathcal{L}} > 0, \quad \Delta_g > 0, \quad \Delta_\ell = \Delta_h < 0, \quad \Delta_{\{g,\ell\}} = \Delta_{\{g,h\}} > \frac{\Delta_g}{2}.$$

Under these conditions, $\eta_2^{\mathrm{TU}} := \frac{\Delta_g}{2} < \eta_3^{\mathrm{TU}} := \Delta_{\{g,\ell\}}$. Assume the core contains an outcome with allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$. We prove that this allocation has to satisfy the following infeasible system:

$$a_\ell + a_g + a_h = J_\ell(0,\mathrm{yes}) + J_g(0,\mathrm{yes}) + J_h(0,\mathrm{yes}) \tag{EC.30a}$$
$$a_\ell + a_g \geq J_\ell(0,\mathrm{yes}) + J_g(0,\mathrm{yes}) \tag{EC.30b}$$
$$a_g + a_h \geq J_g(0,\mathrm{yes}) + J_h(0,\mathrm{yes}) \tag{EC.30c}$$
$$a_\ell + a_h \geq J_\ell(1,\mathrm{no}) - c_\ell + J_h(1,\mathrm{no}) - c_h. \tag{EC.30d}$$

First, we show that the system is indeed infeasible. Equations (EC.30a)-(EC.30c) imply that $a_h \leq J_h(0,\mathrm{yes})$ and $a_\ell \leq J_\ell(0,\mathrm{yes})$, which together with (EC.30d) imply that $J_\ell(1,\mathrm{no}) - c_\ell + J_h(1,\mathrm{no}) - c_h \leq a_\ell + a_h \leq J_\ell(0,\mathrm{yes}) + J_h(0,\mathrm{yes})$, which leads to a contradiction because $\Delta_\ell < 0$ and $\Delta_h < 0$.

We now prove that the system is implied by requirements that all core outcomes must satisfy. Lemma EC.4 and $\eta < \eta_3^{\mathrm{TU}}$ imply that only No-Deforestation Outcomes are in the core, so (EC.30a) holds.

Inequalities (EC.30b)-(EC.30c) must hold, because if not, either $\{\ell,g\}$ or $\{h,g\}$ could profitably deviate. To see this, assume $a_\ell + a_g < J_\ell(0,\mathrm{yes}) + J_g(0,\mathrm{yes})$. Because $\eta < \Delta_{\{\ell,g\}} = \eta_1(\{\{\ell,g\},\{h\}\})$ holds, Lemma 2 implies that $\{\mathbf{0}\} = T(\{\{h\},\{\ell,g\}\}) = A(\{h\};\{\{\ell,g\}\})$. Hence, the deviation would guarantee $\{\ell,g\}$ a welfare of $J_\ell(0,\mathrm{yes}) + J_g(0,\mathrm{yes})$, which dominates the starting outcome. An analogous argument also works for $\{h,g\}$.

Lastly, inequality (EC.30d) must hold because otherwise coalition $\{\ell, h\}$ could deviate towards a deforestation equilibrium. Because $\frac{\Delta_g}{2} = \eta_2(\{\{g\},\{\ell,h\}\}) < \eta$, Lemma 2 implies that $\{\mathbf{1}\} = T(\{\{g\},\{\ell,h\}\}) = A(\{g\};\{\{\ell,h\}\})$, so $\{\ell,h\}$ could derive a cumulative welfare of $\sum_{i\in\{\ell,h\}}(J_i(1,\text{no}) - c_i)$ by deviating, so any allocation in the core must satisfy (EC.30d). □

Lemma EC.21. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. If* $\Delta_{\mathcal{L}} > 0$*,* $\mathcal{E} \neq \emptyset$*, and* $\eta_2^{\text{TU}} := \frac{\Delta_{\mathcal{G}}}{|\mathcal{L}\setminus\mathcal{G}\cup\mathcal{E}|} < \eta < \eta_3^{\text{TU}} := \max_{S\subset\mathcal{L},\Delta_S>0} \frac{\Delta_S}{|\mathcal{L}\setminus S\cup\mathcal{E}|}$*, then the core may be empty.*

Proof of Lemma EC.21. Consider an instance with $\mathcal{E} = \{e\}$ and $\mathcal{L} = \{\ell, g_1, g_2, h\}$ satisfying:

$$\Delta_{\mathcal{L}} > 0, \quad \Delta_{g_1} = \Delta_{g_2} := \Delta_g > 0, \quad \Delta_\ell = \Delta_h < 0, \quad \Delta_g + \Delta_\ell > 0, \quad \Delta_g + \Delta_\ell + \Delta_h < 0.$$

Under these conditions, $\eta_2^{\text{TU}} := \frac{2\Delta_g}{3} < \eta_3^{\text{TU}} := \frac{2\Delta_g + \Delta_\ell}{2}$. Assume the core contains an outcome with allocation $\{a_\ell\}_{\ell\in\mathcal{L}}$. We prove that this allocation has to satisfy the following infeasible system:

$$\sum_{i\in\mathcal{L}} a_i = \sum_{i\in\mathcal{L}} J_i(0,\text{yes}) \tag{EC.31a}$$

$$\sum_{i\in\mathcal{L}\setminus\{x\}} a_i \geq \sum_{i\in\mathcal{L}\setminus\{x\}} J_i(0,\text{yes}), \forall x \in \{\ell, h\}. \tag{EC.31b}$$

$$\sum_{i\in\mathcal{L}\setminus\{g\}} a_i \geq \sum_{i\in\mathcal{L}\setminus\{g\}} \big(J_i(1,\text{no}) - c_i\big), \forall g \in \{g_1, g_2\}. \tag{EC.31c}$$

First, we show that the system is infeasible. (EC.31a) and (EC.31b) imply that $a_\ell \leq J_\ell(0,\text{yes})$ and $a_h \leq J_h(0,\text{yes})$, which then implies that:

$$\begin{aligned}\forall g \in \{g_1, g_2\}, \quad a_g &\geq \sum_{i\in\{g,\ell,h\}} \big(J_i(1,\text{no}) - c_i\big) - \sum_{i\in\mathcal{L}\setminus\{\ell,h\}} a_i \\ &> \sum_{i\in\{g,\ell,h\}} J_i(0,\text{yes}) - \sum_{i\in\{\ell,h\}} a_i \\ &\geq J_g(0,\text{yes}),\end{aligned}$$

where the first inequality follows directly from (EC.31c), the second (strict) inequality follows because $\Delta_{\{g,\ell,h\}} < 0, \forall g \in \{g_1, g_2\}$ from (EC.1), and the last inequality follows because $a_x \leq J_x(0,\text{yes}), \forall x \in \{\ell, g\}$. But then, this implies that $\sum_{i\in\mathcal{L}} a_i > \sum_{i\in\mathcal{L}} J_i(0,\text{yes})$, which contradicts (EC.31a).

We now prove that the system is implied by requirements that all core outcomes must satisfy.

Lemma EC.4 and $\eta < \eta_3^{\text{TU}}$ imply that only outcomes with $\mathbf{d}^* = \mathbf{0}$ are in the core, so (EC.31a) holds.

Inequalities (EC.31b) must hold because otherwise, either $\{g_1, g_2, \ell\}$ or $\{g_1, g_2, h\}$ could profitably deviate. To see this, assume for instance that $\sum_{i\in\{g_1,g_2,\ell\}} a_i < \sum_{i\in\{g_1,g_2,\ell\}} J_i(0,\text{yes})$. Because $\eta_1(\{\{g_1,g_2,\ell\},\{h\}\}) = \Delta_g + \frac{\Delta_\ell}{2} = \eta_3^{\text{TU}} > \eta$ holds, Lemma 2 implies that $\{\mathbf{0}\} = T(\{\{h\},\{g_1,g_2,\ell\}\}) = A(\{h\};\{\{g_1,g_2,\ell\}\})$. Hence, the deviation would guarantee $\{g_1, g_2, \ell\}$ a welfare of $\sum_{i\in\{g_1,g_2,\ell\}} J_i(0,\text{yes})$, which would dominate the starting outcome. An analogous argument also works for $\{g_1, g_2, h\}$.

Lastly, inequalities (EC.31c) must hold because otherwise either $\{g_1,\ell,h\}$ or $\{g_2,\ell,h\}$ could profitably deviate towards a deforestation equilibrium. To see this for instance for $\{g_1,\ell,h\}$, note that $\eta_2(\{\{g_1,\ell,h\},\{g_2\}\}) = \frac{\Delta_g}{3}$ because $\Delta_{\{g_1,\ell,h\}} < 0$ by (EC.1), so $< \eta$ holds in this case, so Lemma 2 would imply that $\{\mathbf{1}\} = T(\{\{g_2\},\{g_1,\ell,h\}\}) = A(\{g_2\};\{\{g_1,\ell,h\}\})$, so $\{g_1,\ell,h\}$ could derive a cumulative welfare of $\sum_{i\in\{g_1,\ell,h\}}(J_i(1,\text{no}) - c_i)$ by deviating, so any allocation in the core must satisfy (EC.31c). An analogous argument holds for $\{g_2,\ell,h\}$. □

Lemma EC.22. *Consider the Area Regeneration condition* $\mathbb{R}$ *in the cooperative game with transferable utility defined in §3.3. The core may be empty if* $\Delta_{\mathcal{L}} < 0$.

Proof of Lemma EC.22. Consider an example with three locals $\mathcal{L} = \{\ell, g, h\}$ and no entrants ($\mathcal{E} = \emptyset$) in which exactly one local g prefers the incentive ($\mathcal{G} = \{g\}$), the other two locals prefer deforestation to the extent that:

$$\Delta_g + \Delta_\ell < 0, \;\; \Delta_g + \Delta_h < 0, \tag{EC.32}$$

and the cost of blocking is sufficiently low that

$$\eta < \Delta_g/2. \tag{EC.33}$$

The core cannot contain an outcome with a partition in which the local g forms a singleton coalition because (EC.33) and Lemma 2 imply that for any partition of the other two locals $\pi_{\{\ell,h\}} \in \Pi_{\{\ell,h\}}$, $T(\{\{\{g\}\} \cup \pi_{\{\ell,h\}}) = \{\mathbf{0}\}$, so any such outcome must have an allocation that satisfies

$$\sum_{\ell\in\mathcal{L}} a_\ell = \sum_{\ell\in\mathcal{L}} J_\ell(A_\ell, 0, \text{yes}),$$

and would therefore be dominated by the formation of the grand coalition $\{\mathcal{L}\}$. Observe that (EC.32) implies $T(\{\mathcal{L}\}) = \{\mathbf{1}\}$ which guarantees strictly higher aggregate welfare of $\sum_{\ell\in\mathcal{L}}(J_\ell(1,\text{no}) - c_\ell)$.

If a local $h \in \mathcal{L}\setminus\mathcal{G}$ forms a singleton coalition, we claim that the core $C(\mathcal{L}\setminus\{h\};\{\{h\}\})$ for the residual game for locals $R = \mathcal{L}\setminus\{h\}$ is non-empty and contains all outcomes that satisfy

$$\pi_R = \{R\} \tag{EC.34}$$

$$\mathbf{d}^* = \mathbf{1} \tag{EC.35}$$

$$\sum_{\ell\in R} a_\ell = \sum_{\ell\in R}\left[J_\ell(1,\text{no}) - c_\ell\right] \tag{EC.36}$$

$$a_\ell \geq J_\ell(0,\text{yes}) \;\; \text{for all } \ell \in R. \tag{EC.37}$$

We distinguish two cases, depending on whether the outcomes in $C(R;\{\{h\}\})$ involve the grand coalition $\{R\}$ or the partition of singletons (this is exhaustive since $|R| = 2$). For any outcomes corresponding to the grand coalition $\{R\}$, Lemma 2, (EC.32) and $h \in \mathcal{L}\setminus\mathcal{G}$ imply that $T(\{\{R\}\} \cup$

$\{\{h\}\}) = \{\mathbf{1}\}$, and therefore (EC.35) and (EC.36) hold. These outcomes are undominated if and only if they satisfy (EC.37); this follows since the only possible deviations from R are by a (sub)coalition consisting of one local, leading to a game with singleton coalitions and $a_\ell = J_\ell(0, \text{yes})$ for all $\ell \in R$, due to (EC.33) and $g \in R$. Finally, (EC.32) also implies that the set of allocations satisfying (EC.36)-(EC.37) is nonempty. The argument above also shows that all the outcomes corresponding to the partition of singletons are dominated: these outcomes have $a_\ell = J_\ell(0, \text{yes})$ for all $\ell \in R$ and are dominated by outcomes that satisfy (EC.37) with a strict inequality for every $\ell \in R$, which exist in view of (EC.32). □

EC.1.1. Proofs for the Results In §4

In this section, we maintain Assumption 1 (which implies $\phi_\ell \geq 0$ for every $\ell \in \mathcal{L}$), but we relax some of the other working assumptions in §2. Specifically, Assumption 3 is relaxed to allow for $\mathcal{G} = \mathcal{L}$. Additionally, when characterizing the idiosyncratic payments $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that minimize the total payment $\sum_{\ell\in\mathcal{L}} \phi_\ell$, we also relax the requirement that either $\phi_\ell > \delta_\ell$ or $\phi_\ell < \delta_\ell$ to allow for $\phi_\ell = \delta_\ell$ (to obtain closed sets and the existence of optimal solutions in the optimization problems).

PROPOSITION 1. Consider the setting without coordination and utility transfer in §3.2 and without entrants ($\mathcal{E} = \emptyset$), and any incentive satisfying $\phi_\ell \geq 0$ for every $\ell \in \mathcal{L}$.

(i) The incentives that guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\max_{\ell\in\mathcal{L}} (\phi_\ell - \delta_\ell) > \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|). \tag{EC.38}$$

(ii) The incentives that minimize the total payment $\sum_{\ell\in\mathcal{L}} \phi_\ell$ and guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\phi_i = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|), \text{ for some } i \in \arg\min_{\ell\in\mathcal{L}} \{\delta_\ell\} \tag{EC.39a}$$

$$\phi_\ell = 0, \text{ for all } \ell \in \mathcal{L} \setminus \{i\}. \tag{EC.39b}$$

(iii) The incentives that guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation with compensation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\text{(EC.38) and } \phi_\ell > \delta_\ell \text{ for all } \ell \in \mathcal{L}. \tag{EC.40}$$

(iv) The incentives that minimize the total payment $\sum_{\ell\in\mathcal{L}} \phi_\ell$ and guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation with compensation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\phi_i = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|), \text{ for some } i \in \mathcal{L} \tag{EC.41a}$$

$$\phi_\ell = \delta_\ell, \text{ for all } \ell \in \mathcal{L} \setminus \{i\}. \tag{EC.41b}$$

(v) The incentives that guarantee that the individual condition $\mathbb{I}$ *prevents deforestation* (and *achieves compensation*) are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\phi_\ell > \delta_\ell \text{ for all } \ell \in \mathcal{L}. \tag{EC.42}$$

(vi) The infimum of the total payment to *prevent deforestation with compensation* under the individual condition $\mathbb{I}$ is $\sum_{\ell\in\mathcal{L}} \delta_\ell$.

(vii) No incentive can prevent deforestation with the area no-deforestation condition $\mathbb{N}$.

Proof. (i) By Lemma 2, under $\mathbb{R}$, when locals cannot transfer utility ($\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$), the set of equilibria $\mathcal{Q}(\pi, \mathbb{R})$ contains only no-deforestation equilibria $T(\pi) = \{\mathbf{0}\}$ if and only if $\eta < \eta_1(\pi) = \max_{g\in\mathcal{G}} \frac{\Delta_g}{|\mathcal{L}|-1+|\mathcal{E}|} = \max_{\ell\in\mathcal{L}} \frac{\Delta_\ell}{|\mathcal{L}|-1+|\mathcal{E}|}$. Notice that this result does not require Assumption 3. Rewriting this condition in terms of the incentives, we obtain (EC.38).

(ii) Consider the problem of minimizing the monetary cost to the interested party while preventing deforestation (and allowing for $\phi_\ell = \delta_\ell$):

$$\begin{array}{ll} \min\limits_{\{\phi_\ell\}_{\ell\in\mathcal{L}}} & \sum_{\ell\in\mathcal{L}} \phi_\ell \\ \text{subject to} & \phi_\ell \ge 0, \text{ for all } \ell \in \mathcal{L} \\ & \max_{\ell\in\mathcal{L}}(\phi_\ell - \delta_\ell) \ge \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|), \end{array} \tag{EC.43}$$

Any optimal solution $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ will satisfy that $\max_{\ell\in\mathcal{L}}(\phi_\ell - \delta_\ell) = \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$, as otherwise the objective could be lowered by lowering the ϕ_i for every $i \in \arg\max_{\ell\in\mathcal{L}}(\phi_\ell - \delta_\ell)$. Moreover, any optimal solution must satisfy $\phi_i = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$ for some $i \in \mathcal{L}$ and $\phi_j = 0$ for all other $j \ne i$. This is because if $\phi_i = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$ and $\phi_\ell > 0$ for any other $\ell \ne i$, the objective could be lowered by taking $\phi_\ell = 0$. Moreover, because in any optimal solution $\sum_{\ell\in\mathcal{L}} \phi_\ell = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$ for some $i \in \mathcal{L}$, then $i \in \arg\min_{\ell\in\mathcal{L}} \delta_\ell$. This shows that any optimal solution for problem (EC.43) must satisfy (EC.39a)-(EC.39b). In turn, because any solution satisfying (EC.39a)-(EC.39b) is feasible for (EC.43) and achieves the same objective as an optimal solution, it must also be optimal.

(iii) Without utility transfer, the only way to prevent deforestation with compensation is to satisfy (EC.38) and also $\Delta_\ell > 0$ (or equivalently, $\phi_\ell > \delta_\ell$) for every $\ell \in \mathcal{L}$, which proves the result.

(iv) Consider the problem of minimizing the monetary cost to the interested party while preventing deforestation with compensation (and allowing for $\phi_\ell = \delta_\ell$):

$$\begin{array}{lll} \min\limits_{\{\phi_\ell\}_{\ell\in\mathcal{L}}} & \sum_{\ell\in\mathcal{L}} \phi_\ell & \\ \text{subject to} & \phi_\ell \ge 0, & \text{for all } \ell \in \mathcal{L} \\ & \max_{\ell\in\mathcal{L}}(\phi_\ell - \delta_\ell) \ge \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|) & \\ & \phi_\ell \ge \delta_\ell & \text{for all } \ell \in \mathcal{L}. \end{array} \tag{EC.44}$$

Based on arguments that parallel those in the proof of (ii), it can be readily seen that any optimal solution $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ satisfies $\max_{\ell\in\mathcal{L}}(\phi_\ell - \delta_\ell) = \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$ and that $\phi_i = \delta_i + \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$ for a single (but arbitrarily chosen) $i \in \mathcal{L}$ and $\phi_\ell = \delta_\ell$ for all other $\ell \ne i$.

(v) As discussed in §2, $\mathbb{I}$, prevents deforestation with compensation if and only if $\Delta_\ell > 0$, or equivalently, $\phi_\ell > \delta_\ell$, for all $\ell \in \mathcal{L}$, and $\mathcal{E} = \emptyset$.

(vi) The result is immediate as $\mathbb{I}$ prevents deforestation (and prevents deforestation with compensation, respectively) if and only if (EC.42) holds.

(vii) Corollary 1 implies that $\mathbb{N}$ cannot prevent deforestation if $\mathcal{G} \subset \mathcal{L}$ or if $\mathcal{E} \neq \emptyset$. We then show that a deforestation equilibrium exists even if $\mathcal{G} = \mathcal{L}$ and $\mathcal{E} = \emptyset$. To see this, consider the decisions $\mathbf{d} = \mathbf{1}$ and $\mathbf{B}(\mathbf{d}) \equiv \mathbf{0}$. These must be an equilibrium in $\mathcal{Q}(\pi, \mathbb{N})$ for $\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$, because $\kappa^{\mathbb{N}}(\mathbf{d}, \mathbf{B}) = \text{no}$, and no unilateral deviation of any local $\ell \in \mathcal{L}$ can change this. Therefore, no local would deviate from this deforestation equilibrium even if $\phi_\ell > \delta_\ell$ for every $\ell \in \mathcal{L}$. □

Proposition 2. Consider the setting without coordination and utility transfer in §3.2 and with entrants ($\mathcal{E} \neq \emptyset$), and any incentive satisfying $\phi_\ell \geq 0$ for every $\ell \in \mathcal{L}$.

(i) The incentives that guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell \in \mathcal{L}}$ that satisfy (EC.38).

(ii) The incentives that minimize the total payment $\sum_{\ell \in \mathcal{L}} \phi_\ell$ and guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell \in \mathcal{L}}$ that satisfy (EC.39a)-(EC.39b).

(iii) The incentives that guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation with compensation* are all the $\{\phi_\ell\}_{\ell \in \mathcal{L}}$ that satisfy (EC.38)-(EC.40).

(iv) The incentives that minimize the total payment $\sum_{\ell \in \mathcal{L}} \phi_\ell$ and guarantee that the area regeneration condition $\mathbb{R}$ *prevents deforestation with compensation* are the $\{\phi_\ell\}_{\ell \in \mathcal{L}}$ that satisfy (EC.41a)-(EC.41b).

(v) No incentive can prevent deforestation with the area no-deforestation condition $\mathbb{N}$ or with the individual condition $\mathbb{I}$, even if $\mathcal{L} = \mathcal{G}$.

Proof. (i) - (iv) The proofs of these results are identical to those in Proposition 1 (i)-(iv), which do not depend on the presence of entrants.

(v) Corollary 1 implies that $\mathbb{N}$ cannot prevent deforestation if $\mathcal{G} \subset \mathcal{L}$ or if $\mathcal{E} \neq \emptyset$. Finally, as shown in §2, the individual condition fails to prevent deforestation if $\mathcal{E} \neq \emptyset$. □

Proposition 3. Consider the setting with coordination and utility transfer from §3.3 and without entrants ($\mathcal{E} = \emptyset$), and any incentive satisfying $\phi_\ell \geq 0$ for every $\ell \in \mathcal{L}$.

(i) The incentives that guarantee that the no-deforestation condition $\mathbb{N}$ *prevents deforestation* (and *achieves compensation*, respectively) are all the $\{\phi_\ell\}_{\ell \in \mathcal{L}}$ that satisfy:

$$\sum_{\ell \in \mathcal{L}} \phi_\ell > \sum_{\ell \in \mathcal{L}} \delta_\ell. \tag{EC.45}$$

(ii) The infimum total payment to *prevent deforestation with compensation* under the area no-deforestation condition $\mathbb{N}$ is $\sum_{\ell \in \mathcal{L}} \delta_\ell$.

(iii) The incentives that guarantee that the regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy (EC.45).

(iv) The incentives that guarantee that the regeneration condition $\mathbb{R}$ *prevents deforestation with compensation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\begin{cases} \sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell \text{ and } \sum_{\ell\in\mathcal{G}}\phi_\ell < \eta + \sum_{\ell\in\mathcal{G}}\delta_\ell, \text{ where } \mathcal{G}=\{\ell\in\mathcal{L}:\phi_\ell>\delta_\ell\}, & \text{if } \exists \ell\in\mathcal{L}:\phi_\ell<\delta_\ell \\ \sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell \text{ and } \phi_\ell>\delta_\ell \text{ for all } \ell\in\mathcal{L} & \text{otherwise.} \end{cases} \tag{EC.46}$$

(v) The incentives that guarantee that the individual condition $\mathbb{I}$ *prevents deforestation* (and *achieves compensation*, respectively) are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy $\phi_\ell > \delta_\ell$, for all $\ell\in\mathcal{L}$.

Proof. (i) If $\mathcal{L}\neq\mathcal{G}$, by Theorem 1, the core with $\mathbb{N}$ only contains Compensation Outcomes if and only if $\Delta_\mathcal{L}>0$ and $\mathcal{E}=\emptyset$, which is equivalent to $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$ in this setting.

We show that the core contains only Compensation Outcomes if $\mathcal{L}=\mathcal{G}$. First, we note that the core contains only No-Deforestation Outcomes. This follows because $\mathcal{L}=\mathcal{G}$ implies $\Delta_\mathcal{L}>0$, so Lemma 2 implies that $\mathbf{0}\in A(\emptyset,\{\mathcal{L}\})$ and the grand coalition would always profitably deviate from any Deforestation Outcome. Second, we show that any No-Deforestation Outcome in the core must satisfy $a_\ell \geq J_\ell(1,\text{no})-c_\ell$, for all $\ell\in\mathcal{L}$. Assume to reach a contradiction that $a_i<J_i(1,\text{no})-c_i$; but then, $\{i\}$ would deviate because $w(\{i\},\mathbf{d})>a_i$ for any $\mathbf{d}\in\{\mathbf{0},\mathbf{1}\}$ (because $\Delta_i>0$). This shows that the core contains only Compensation Outcomes if $\mathcal{L}=\mathcal{G}$.

(ii) The proof is immediate from (i): a set of minimizing incentives can be obtained by considering $\phi_\ell=\delta_\ell+\epsilon$ in the limit as $\epsilon\to 0$.

(iii) If $\mathcal{L}\neq\mathcal{G}$, then, by Theorem 2 (a)-(e), the area regeneration condition $\mathbb{R}$ prevents deforestation if and only if $\Delta_\mathcal{L}>0$, or equivalently $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$. On the other hand, if $\mathcal{L}=\mathcal{G}$, then the core can only contain No-Deforestation Outcomes, as any Deforestation Outcome would be dominated by a deviation of the grand coalition $\mathcal{L}$. Finally, $\mathcal{L}=\mathcal{G}$ implies that $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$, and therefore, in both cases, $\mathbb{R}$ prevents deforestation if and only if $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$.

(iv) If $\mathcal{G}\neq\mathcal{L}$ (or equivalently, there exists $\ell\in\mathcal{L}$ such that $\phi_\ell<\delta_\ell$), by Theorem 2, when $\mathcal{E}=\emptyset$, the core contains only Compensation Outcomes under $\mathbb{R}$ if and only if $\Delta_\mathcal{L}>0$ and $\eta>\Delta_\mathcal{G}$, where $\mathcal{G}=\{\ell\in\mathcal{L}:\Delta_\ell>0\}$. Rewriting these two conditions in terms of the incentives ϕ_ℓ, we obtain $\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell$ and $\sum_{\ell\in\mathcal{G}}\phi_\ell > \sum_{\ell\in\mathcal{G}}\delta_\ell+\eta$. On the other hand, if $\mathcal{L}=\mathcal{G}$, then, as shown in (iii), the regeneration condition $\mathbb{R}$ prevents deforestation, and therefore, as $\phi_\ell>\delta_\ell$, for all $\ell\in\mathcal{L}$, it prevents deforestation with compensation as well.

(v) The proof is identical to the proof of Proposition 1 (v). □

Proposition 4. Consider the setting with coordination and utility transfer in §3.3 and with entrants ($\mathcal{E}\neq\emptyset$), and any incentive satisfying $\phi_\ell\geq 0$ for every $\ell\in\mathcal{L}$.

(i) The incentives that guarantee that the regeneration condition $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell \tag{EC.47a}$$

$$\sum_{i\in H}\phi_i > \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)+\sum_{i\in H}\delta_i,\ \text{ for some } H\subseteq\mathcal{L}. \tag{EC.47b}$$

(ii) The incentives that minimize the total payment $\sum_{\ell\in\mathcal{L}}\phi_\ell$ and guarantee that $\mathbb{R}$ *prevents deforestation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\sum_{i\in S}\phi_i > \eta\cdot(|\mathcal{L}|-|S|+|\mathcal{E}|)+\sum_{i\in S}\delta_i,\ \text{ for some } S\subseteq\mathcal{L}, \tag{EC.48a}$$

$$\sum_{\ell\in\mathcal{L}}\phi_\ell = \max\Big\{\eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)+\big(\sum_{i\in H}\delta_i\big),\sum_{\ell\in\mathcal{L}}\delta_\ell\Big\},\ \text{ for } H=\{\ell\in\mathcal{L}:\delta_\ell<\eta\}\cup\{i\} \text{ for some } i\in\arg\min_{j\in\ell}\delta_j. \tag{EC.48b}$$

(iii) The incentives that guarantee that $\mathbb{R}$ *prevents deforestation with compensation* are all the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\phi_\ell\ge\delta_\ell,\ \text{ for all } \ell\in\mathcal{L}, \tag{EC.49a}$$

$$\sum_{\ell\in\mathcal{L}}\phi_\ell > \sum_{\ell\in\mathcal{L}}\delta_\ell \tag{EC.49b}$$

$$\sum_{i\in H}\phi_i > \eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)+\sum_{i\in H}\delta_i,\ \text{ for some } H\subseteq\mathcal{L}. \tag{EC.49c}$$

(iv) The incentives that minimize the total payment $\sum_{\ell\in\mathcal{L}}\phi_\ell$ and guarantee that $\mathbb{R}$ *prevents deforestation with compensation* are the $\{\phi_\ell\}_{\ell\in\mathcal{L}}$ that satisfy:

$$\phi_\ell\ge\delta_\ell,\ \text{ for all } \ell\in\mathcal{L}, \tag{EC.50a}$$

$$\sum_{\ell\in\mathcal{L}}\phi_\ell = \sum_{\ell\in\mathcal{L}}\delta_\ell+\eta\cdot|\mathcal{E}|. \tag{EC.50b}$$

Proof. (i) Notice that Lemma EC.4 and EC.6 do not require Assumption 3, and together imply that under the area regeneration condition $\mathbb{R}$, the core contains only No-Deforestation Outcomes if and only if $\eta<\eta_4^{\mathrm{TU}}=\max_{S\subseteq\mathcal{L}}\frac{\Delta_S}{|\mathcal{L}\setminus S|+|\mathcal{E}|}$ and $\Delta_{\mathcal{L}}>0$. It is immediate to see then that these two conditions are equivalent to (EC.47a)-(EC.47b).

ii) By part (i), the problem of minimizing the monetary cost to the interested party while preventing deforestation can be written as:

$$\begin{array}{lll}\min\limits_{\{\phi_\ell\}_{\ell\in\mathcal{L}}} & \sum_{\ell\in\mathcal{L}}\phi_\ell & \\ \text{subject to} & \phi_\ell\ge 0, & \text{for all } \ell\in\mathcal{L} \\ & \sum_{\ell\in\mathcal{L}}\phi_\ell\ge\sum_{\ell\in\mathcal{L}}\delta_\ell & \\ & \sum_{i\in H}\phi_i\ge\eta\cdot(|\mathcal{L}|-|H|+|\mathcal{E}|)+\sum_{i\in H}\delta_i, & \text{for some } H\subseteq\mathcal{L}.\end{array} \tag{EC.51}$$

First, we show that any optimal solution to (EC.51) satisfies conditions (EC.48a)-(EC.48b). Clearly, (EC.48a) must hold, as the optimal solution must be feasible. To see that (EC.48b) must hold, consider that the minimum value of $\eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) + \big(\sum_{i \in H} \delta_i\big)$ over $H \subseteq \mathcal{L}$ is achieved at $H = \{\ell \in \mathcal{L} : \delta_\ell < \eta\}$, if there exists any $\ell \in \mathcal{L}$, such that $\delta_\ell < \eta$, and $H = \{\ell\}$ for any $\ell \in \arg\min_{i \in \mathcal{L}} \delta_i$ otherwise. This implies that $\sum_{j \in \mathcal{L}} \phi_j \geq \sum_{i \in H} \phi_i \geq \eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) + \big(\sum_{i \in H} \delta_i\big)$. This, together with the fact that $\sum_{\ell \in \mathcal{L}} \phi_\ell \geq \sum_{\ell \in \mathcal{L}} \delta_\ell$, implies that

$$\sum_{\ell \in \mathcal{L}} \phi_\ell \geq \max\Big\{\eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) + \big(\sum_{i \in H} \delta_i\big), \sum_{\ell \in \mathcal{L}} \delta_\ell\Big\}.$$

To show that the optimal value must be exactly this maximum, we can observe that setting

$$\sum_{i \in H} \phi_i = \max\Big\{\eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) + \big(\sum_{i \in H} \delta_i\big), \sum_{\ell \in \mathcal{L}} \delta_\ell\Big\},$$

and $\phi_j = 0$, for any $j \in \mathcal{L} \setminus H$, is always a feasible solution to (EC.51) that achieves the desired objective. Therefore, any optimal solution must satisfy (EC.48a)-(EC.48b). Vice-versa, any solution that satisfies these conditions is feasible and achieves the optimal objective value in (EC.51), so it must be optimal.

iii) Theorem 2 implies that when $\mathcal{E} \neq \emptyset$, condition $\mathbb{R}$ cannot prevent deforestation with compensation if $\mathcal{G} \neq \mathcal{L}$ (Assumption 3 holds) or $\Delta_{\mathcal{L}} \leq 0$[3]. Additionally, Lemma EC.6 implies that the core under $\mathbb{R}$ contains Deforestation Outcomes if $\eta \geq \eta_4^{\mathrm{TU}} = \max_{S \subseteq \mathcal{L}} \frac{\Delta_S}{|\mathcal{L} \setminus S| + |\mathcal{E}|}$ (even if $\mathcal{G} = \mathcal{L}$ holds). Therefore, if the incentive prevents deforestation with compensation under $\mathbb{R}$, it must satisfy that $\mathcal{L} = \mathcal{G}$, $\Delta_{\mathcal{L}} > 0$, and $\eta < \eta_4^{\mathrm{TU}}$. These three conditions are equivalent to (EC.49a)-(EC.49c).

We only need to show then that (EC.49a)-(EC.49c) imply that $\mathbb{R}$ prevents deforestation with compensation. By Lemma EC.4, which holds even if Assumption 3 does not, (EC.49b) and (EC.49c) imply that the core contains only No-Deforestation Outcomes. But then, because (EC.49a) implies that $\mathcal{L} = \mathcal{G}$, we have $a_\ell \geq \min\{J_\ell(0, \text{yes}), J(1, \text{no}) - c_\ell\} = J(1, \text{no}) - c_\ell$, for every $\ell \in \mathcal{L}$ and any allocation $\{a_\ell\}_{\ell \in \mathcal{L}}$ of any outcome in the core. Therefore, the core contains only No-Deforestation Outcomes that satisfy $a_\ell \geq J(1, \text{no}) - c_\ell$, which implies that $\mathbb{R}$ prevents deforestation with compensation.

iv) By part iii), the problem of minimizing the monetary cost to the interested party while preventing deforestation with compensation (and allowing for $\phi_\ell = \delta_\ell$) can be written as:

$$\begin{array}{lll}
\min\limits_{\{\phi_\ell\}_{\ell \in \mathcal{L}}} & \sum_{\ell \in \mathcal{L}} \phi_\ell & \\
\text{subject to} & \phi_\ell \geq \delta_\ell, & \text{for all } \ell \in \mathcal{L} \\
& \sum_{\ell \in \mathcal{L}} \phi_\ell > \sum_{\ell \in \mathcal{L}} \delta_\ell & \\
& \sum_{i \in H} \phi_i \geq \eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) + \sum_{i \in H} \delta_i, & \text{for some } H \subseteq \mathcal{L}.
\end{array} \tag{EC.52}$$

First, we show that the optimal objective value in (EC.52) is exactly $\sum_{\ell \in \mathcal{L}} \phi_\ell = \sum_{\ell \in \mathcal{L}} \delta_\ell + \eta \cdot |\mathcal{E}|$. Combining (EC.49a) and (EC.49c), we obtain that $\sum_{\ell \in \mathcal{L}} \phi_\ell \geq \sum_{\ell \in \mathcal{L}} \delta_\ell + \eta \cdot (|\mathcal{L}| - |H| + |\mathcal{E}|) \geq \eta \cdot |\mathcal{E}|$,

[3] Note that Lemmas EC.6 and EC.17 can be readily extended to show that when $\Delta_{\mathcal{L}} = 0$ and $\mathcal{E} \neq \emptyset$, condition $\mathbb{R}$ cannot prevent deforestation with compensation.

where $H \subseteq \mathcal{L}$ is some subset of locals. We provide a feasible solution that exactly obtains this objective value. For this, consider $\phi_j = \delta_j + \eta \cdot |\mathcal{E}|$ for some $j \in \mathcal{L}$, and $\phi_i = \delta_i$, for all $i \in \mathcal{L}$, $i \neq j$. By construction, $\sum_{\ell\in\mathcal{L}} \phi_\ell = \sum_{\ell\in\mathcal{L}} \delta_\ell + \eta \cdot |\mathcal{E}|$. This distribution is feasible for (EC.52). We have shown then that the optimal objective value for (EC.52) is $\sum_{\ell\in\mathcal{L}} \phi_\ell = \sum_{\ell\in\mathcal{L}} \delta_\ell + \eta \cdot |\mathcal{E}|$, which implies that (EC.50b) must hold for any optimal solution. Requirement (EC.50a) must hold as well, as it is required for $\mathbb{R}$ to prevent deforestation with compensation, as shown in (iii).

Finally, any set of incentives that satisfy (EC.50a) and (EC.50b) is readily feasible in problem (EC.52) (taking $H = \mathcal{L}$ for (EC.49c)), which also implies that these are optimal. □

EC.1.2. Results for the Instance Obtained by Scaling the Number of Locals

PROPOSITION 5. Consider a problem instance characterized by $\mathcal{L} = \{1, 2, \dots, |\mathcal{L}|\}$, $\mathcal{E} = \{1, 2, \dots, |\mathcal{E}|\}$ and a given $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$. For a positive integer k, consider a new problem instance obtained by duplicating the original instance k times, that is, where the set of locals is $\tilde{\mathcal{L}} := \{1, 2, \dots, k \cdot |\mathcal{L}|\}$, the set of entrants is $\tilde{\mathcal{E}} := \{1, 2, \dots, k \cdot |\mathcal{E}|\}$, and $\tilde{\Delta}_i = \Delta_{1+((i-1) \bmod |\mathcal{L}|)}$ for all $i \in \tilde{\mathcal{L}}$.

(i) The individual condition $\mathbb{I}$ *prevents deforestation* (*and achieves compensation*, respectively) for the problem instance with $\mathcal{L}$, $\mathcal{E}$ and $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ if and only if it prevents deforestation (*and achieves compensation*, respectively) for the problem instance with $\tilde{\mathcal{L}}$, $\tilde{\mathcal{E}}$ and $\{\tilde{\Delta}_i\}_{i\in\tilde{\mathcal{L}}}$.

(ii) If locals cannot coordinate and transfer utility, the area regeneration condition $\mathbb{R}$ *prevents deforestation* (and *achieves compensation*, respectively) for the problem instance with $\mathcal{L}$, $\mathcal{E}$, $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ and a blocking cost of η if and only if it prevents deforestation (*and achieves compensation*, respectively) for the problem instance with $\tilde{\mathcal{L}}$, $\tilde{\mathcal{E}}$ and $\{\tilde{\Delta}_i\}_{i\in\tilde{\mathcal{L}}}$ and a blocking cost of $\eta \cdot \frac{|\mathcal{L}|-1+|\mathcal{E}|}{|\mathcal{L}|\cdot k-1+|\mathcal{E}|\cdot k}$.

(iii) If locals can coordinate and transfer utility, the area no-deforestation condition $\mathbb{N}$ *prevents deforestation* (and *achieves compensation*, respectively) for the problem instance with $\mathcal{L}$, $\mathcal{E}$, $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ if and only if it prevents deforestation (*and achieves compensation*, respectively) for the problem instance with $\tilde{\mathcal{L}}$, $\tilde{\mathcal{E}}$ and $\{\tilde{\Delta}_i\}_{i\in\tilde{\mathcal{L}}}$.

(iv) If locals can transfer utility, the area regeneration condition $\mathbb{R}$ *prevents deforestation* (and *achieves compensation*, respectively) for the problem instance with $\mathcal{L}$, $\mathcal{E}$, $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ and a blocking cost of η if and only if it prevents deforestation (*and achieves compensation*, respectively) for the problem instance with $\tilde{\mathcal{L}}$, $\tilde{\mathcal{E}}$ and $\{\tilde{\Delta}_i\}_{i\in\tilde{\mathcal{L}}}$ and a blocking cost of η.

Proof: (i) As discussed in §2, the individual condition $\mathbb{I}$ prevents deforestation (and also *achieves compensation*) if and only if $\Delta_\ell > 0, \forall\, \ell \in \mathcal{L}$ and $\mathcal{E} = \emptyset$, which holds if and only if $\Delta_{\ell^i} > 0, \forall\, \ell^i \in \tilde{\mathcal{L}}$ and $\tilde{\mathcal{E}} = \emptyset$.

(ii) By Lemma 2, under $\mathbb{R}$ and when locals cannot transfer utility, the set of equilibria $\mathcal{Q}(\pi, \mathbb{R})$ (with partition $\pi = \{\{\ell\} : \ell \in \mathcal{L}\}$) contains only no-deforestation equilibria $T(\pi) = \{\mathbf{0}\}$ if and only if $\eta < \eta_1(\pi) = \max_{g\in\mathcal{G}} \frac{\Delta_g}{|\mathcal{L}|-1+|\mathcal{E}|} = \max_{\ell\in\mathcal{L}} \frac{\Delta_\ell}{|\mathcal{L}|-1+|\mathcal{E}|}$, which holds if and only if $\max_{\ell\in\mathcal{L}} \Delta_\ell > \eta \cdot (|\mathcal{L}| - 1 + |\mathcal{E}|)$, or equivalently, $\max_{\ell\in\mathcal{L}} \Delta_\ell > \eta\frac{|\mathcal{L}|-1+|\mathcal{E}|}{|\mathcal{L}|\cdot k-1+|\mathcal{E}|\cdot k}\cdot(|\mathcal{L}|\cdot k-1+|\mathcal{E}|\cdot k)$. The latter holds if and only in the problem instance with $\tilde{\mathcal{L}}$, $\tilde{\mathcal{E}}$ and $\{\tilde{\Delta}_i\}_{i\in\tilde{\mathcal{L}}}$ and in the case without cooperation and utility transfer under $\mathbb{R}$, the set of equilibria $\mathcal{Q}(\tilde{\pi},\mathbb{R})$ (with partition $\tilde{\pi}=\{\{i\}:i\in\tilde{\mathcal{L}}\}$) contains only no-deforestation equilibria for the blocking cost $\eta\cdot\frac{|\mathcal{L}|-1+|\mathcal{E}|}{|\mathcal{L}|\cdot k-1+|\mathcal{E}|\cdot k}$.

(iii) If locals can transfer utility, by Theorem 1, $\mathbb{N}$ prevents deforestation (and achieves compensation, respectively) in the problem instance with $\mathcal{L}$, $\mathcal{E}$, $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ if and only if $\mathcal{E}=\emptyset$ and $\Delta_{\mathcal{L}}>0$, which occurs if and only if $\tilde{\mathcal{E}}=\emptyset$ and $\tilde{\Delta}_{\tilde{\mathcal{L}}}>0$, which gives the desired result.

(iv) If locals can transfer utility, by Theorem 2, $\mathbb{R}$ prevents deforestation in the problem instance with $\mathcal{L}$, $\mathcal{E}$, $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ if and only if $\eta<\eta_4^{\mathrm{TU}}=\max_{S\subseteq\mathcal{L}}\frac{\Delta_S}{|\mathcal{L}|-|S|+|\mathcal{E}|}$, or equivalently,

$$\Delta_S > \eta\cdot(|\mathcal{L}|-|S|+|\mathcal{E}|) \text{ for some } S\subseteq\mathcal{L}. \tag{EC.53}$$

Similarly, $\mathbb{R}$ prevents deforestation for the instance with $\tilde{\mathcal{L}},\tilde{\mathcal{E}},\tilde{\Delta}$ if and only if

$$\tilde{\Delta}_{\tilde{S}} > \eta\cdot(|\tilde{\mathcal{L}}|-|\tilde{S}|+|\tilde{\mathcal{E}}|) \text{ for some } \tilde{S}\subseteq\tilde{\mathcal{L}}. \tag{EC.54}$$

We will show that (EC.53) and (EC.54) are equivalent. That (EC.53) implies (EC.54) is immediate, simply by taking the set $\tilde{S}=\{\ell+n\cdot|\mathcal{L}|:\ell\in S,\, n\in\{0,\dots,k-1\}\}\subseteq\tilde{\mathcal{L}}$. To show that (EC.54) implies (EC.53), we first argue that if (EC.54) holds for some $\tilde{S}\subseteq\tilde{\mathcal{L}}$, it must hold for $\tilde{H}=\{\ell+n\cdot|\mathcal{L}|:\ell\in H,\, n\in\{0,\dots,k-1\}\}$ where $H=\{\ell\in\mathcal{L}:\Delta_\ell>-\eta\}$. From this, it is immediate that H must satisfy (EC.53).

Assume $\tilde{S}\not\subseteq\tilde{H}$, consider then $f\in\tilde{S}\setminus\tilde{H}$. We have that $\Delta_{\tilde{S}\setminus\{f\}}>\eta\cdot(|\tilde{\mathcal{L}}|-|\tilde{S}|+|\tilde{\mathcal{E}}|)-\Delta_f\ge\eta\cdot(|\tilde{\mathcal{L}}|-|\tilde{S}\setminus\{f\}|+|\tilde{\mathcal{E}}|)$, where the last inequality comes from $f\notin\tilde{H}$, which implies that $-\Delta_f\ge\eta$. But then, $\tilde{S}\setminus f$ satisfies (EC.54) as well. We can thus assume that $\tilde{S}\subseteq\tilde{H}$.

If $\tilde{S}\subset\tilde{H}$, consider $f\in\tilde{H}\setminus\tilde{S}$. Because $f\in\tilde{H}$ and $\tilde{S}$ satisfies (EC.54), then $\Delta_{\tilde{S}}+\Delta_f>\eta\cdot(|\tilde{\mathcal{L}}|-|\tilde{S}|+|\tilde{\mathcal{E}}|)+\Delta_f>\eta\cdot(|\tilde{\mathcal{L}}|-|\tilde{S}\cup\{f\}|+|\tilde{\mathcal{E}}|)$. Therefore, any $f\in\tilde{H}\setminus\tilde{S}$ can be included and (EC.54) would still hold, showing that $\tilde{H}$ must satisfy (EC.54).

Finally, by Proposition 4, $\mathbb{R}$ would prevent deforestation with compensation for the instance with $\mathcal{L}$, $\mathcal{E}$ and $\{\Delta_\ell\}_{\ell\in\mathcal{L}}$ if and only if (EC.53) holds and $\Delta_\ell>0$ for every $\ell\in\mathcal{L}$, which is equivalent to (EC.54) and $\tilde{\Delta}_i>0$, for every $i\in\tilde{\mathcal{L}}$, implying the desired result. □

EC.2. Modeling Extensions

EC.2.1. Optimistic Recursive Core

Next, we define the *optimistic* recursive core and show that any outcome in the optimistic recursive core must also be in the pessimistic recursive core. This implies that if the forest is protected and locals are better off in all pessimistic recursive core outcomes, then the same is true in all optimistic recursive core outcomes.

Definition EC.1 (Optimistic Recursive Core). Suppose that for an integer $k \in [1, |\mathcal{L}|-1]$, the *optimistic* core $C_o(R; \pi_{\mathcal{L}\setminus R})$ is defined for every residual game in which a set of locals $R \subset \mathcal{L}$ with $|R| \in [1, k]$ responds to a partition of the other locals $\pi_{\mathcal{L}\setminus R} \in \Pi_{\mathcal{L}\setminus R}$. For $k=1$, the residual game has a single local $R = \{\ell\}$ and the core $C_o(\{\ell\}; \pi_{\mathcal{L}\setminus\{\ell\}})$ is the set of triples of partition, equilibrium decisions, and allocations $\big(\{\{\ell\}\}, (\mathbf{d}^*, \mathbf{B}^*), a_\ell\big)$ with $a_\ell = w\big(\{\ell\}, \{\{\ell\}\}, (\mathbf{d}^*, \mathbf{B}^*)\big)$ and $(\mathbf{d}^*, \mathbf{B}^*) \in \mathcal{Q}(\{\{\ell\}\} \cup \pi_{\mathcal{L}\setminus\{\ell\}})$. For a residual game with $|R| = k+1$, the core $C_o(R; \pi_{\mathcal{L}\setminus R})$ is the set of *undominated* outcomes, where an outcome with allocation $\{a_\ell\}_{\ell \in R}$ and partition π_R is *dominated* if there exists a coalition $H \subseteq R$ that forms partition $\pi_H \in \Pi_H$, and there exist also a (sub)partition $\pi^*_{R\setminus H}$ and equilibrium decisions $(\mathbf{d'}^*, \mathbf{B'}^*)$ where

$$w\big(S, \pi_H \cup \pi_{\mathcal{L}\setminus R} \cup \pi'_{R\setminus H}, (\mathbf{d'}^*, \mathbf{B'}^*)\big) > \sum_{\ell \in S} a_\ell$$

for **every** coalition $S \in \pi_H$ and the (sub)partition $\pi^*_{R\setminus H}$ and equilibrium decisions $(\mathbf{d'}^*, \mathbf{B'}^*)$ satisfy:

$$\begin{cases} \big(\pi'_{R\setminus H}, (\mathbf{d'}^*, \mathbf{B'}^*), \{a_\ell\}_{\ell \in R\setminus H}\big) \in C_o(R\setminus H; \pi_H \cup \pi_{\mathcal{L}\setminus R}) & \text{if } H \subset R \text{ and } C_o(R\setminus H; \pi_H \cup \pi_{\mathcal{L}\setminus R}) \neq \emptyset \\ \pi'_{R\setminus H} \in \Pi_{R\setminus H} \text{ and } (\mathbf{d'}^*, \mathbf{B'}^*) \in \mathcal{Q}(\pi_H \cup \pi_{\mathcal{L}\setminus R} \cup \pi'_{R\setminus H}) & \text{if } H \subset R \text{ and } C_o(R\setminus H; \pi_H \cup \pi_{\mathcal{L}\setminus R}) = \emptyset. \\ (\mathbf{d'}^*, \mathbf{B'}^*) \in \mathcal{Q}(\pi_H \cup \pi_{\mathcal{L}\setminus R} \cup \pi'_{R\setminus H}) & \text{if } H = R \end{cases}$$

The recursive core of the TU cooperative game among all locals is $C_o(\mathcal{L}; \emptyset)$.

Notice that the optimistic core $C_o(\mathcal{L}; \emptyset)$ differs from the pessimistic core defined in (2) only in the notion of dominance: While in a pessimistic core a coalition set would have to be better off in all outcomes of the remaining locals $(R \setminus H)$, in the optimistic core, deviating coalitions need only be better off for one feasible outcome. It is then immediate by the definition that any optimistic outcome would also be pessimistic, as any dominated outcome in the pessimistic sense would have to be dominated in the optimistic sense. Our next proposition shows this rigorously using the recursive definitions of both core concepts.

Proposition 6. Given any cooperative game with transfer of utilities as defined in § 2, the optimistic core $C_o(\mathcal{L}; \emptyset)$ must be included in the pessimistic core $C(\mathcal{L}; \emptyset)$, defined in (2).

Proof of Proposition 6.

We will prove that for every $R \subseteq \mathcal{L}$, and partition $\pi_{\mathcal{L}\setminus R}$, $C_o(R; \pi_{\mathcal{L}\setminus R}) \subseteq C(R; \pi_{\mathcal{L}\setminus R})$, which, taking $R = \mathcal{L}$, implies the proposition. We then proceed by induction in $|R|$. For $|R| = 1$, note that $C_o(R; \pi_{\mathcal{L}\setminus R}) = C(R; \pi_{\mathcal{L}\setminus R})$, because both definitions coincide when the residual game is of size 1.

Thus, our inductive assumption is that $C_o(R; \pi_{\mathcal{L}\setminus R}) \subseteq C(R; \pi_{\mathcal{L}\setminus R})$, for any set $R \subseteq \mathcal{L}$ and (sub)partition $\pi_{\mathcal{L}\setminus R}$, such that $|R| \leq k$.

Let $R \subseteq \mathcal{L}$ such that $|R| = k+1$. Assume by contradiction that there is an outcome in $C_o(R; \pi_{\mathcal{L}\setminus R})$ that is not in $C(R; \pi_{\mathcal{L}\setminus R})$, for some (sub)partition $\pi_{\mathcal{L}\setminus R}$, with allocation $\{a^*_\ell\}_{\ell \in \mathcal{L}}$. But this implies that this outcome must be *dominated* according to the pessimistic definition in (2), which implies that there exists a coalition $H \subseteq R$ that forms the partition $\pi_H \in \Pi_H$ that would prefer to deviate from all the outcomes of the remaining locals in $R \setminus H$. But, because $|R \setminus H| \leq k$, the inductive assumption implies that H must also have a positive deviation under the optimistic definition. This leads to a contradiction, as the outcome being in $C_o(R;\pi_{\mathcal{L}\setminus R}$ implied that it was undominated under the optimistic definition. Therefore, we have proved the case for $|R|=k+1$ and the proposition. □

EC.2.2. Result with farmers that would not deforest absent the incentive

We assume in §2 that all farmers would deforest absent the incentive ($\delta_\ell > 0$, for all $\ell \in \mathcal{L}$). In this section, we generalize our main results for the case where $\delta_\ell < 0$ for some $\ell \in \mathcal{L}$. We assume that $\delta_\ell > 0$ for at least one $\ell \in \mathcal{L}$ (i.e., there is at least one local that would deforest). The proofs are identical to the ones presented above.

Proposition 7. Without coordination and utility transfer, the area no-deforestation condition $\mathbb{N}$ prevent deforestation only if $\mathcal{L} = \mathcal{G}$, whereas the area regeneration condition $\mathbb{R}$ prevents deforestation if

$$\eta < \frac{\max g \in \mathcal{G}\Delta_g}{|\{\ell \in \mathcal{L} : \delta_\ell > 0\}| - 1 + |\mathcal{E}|},$$

albeit without achieving compensation.

Proposition 8. With coordination and utility transfer, the area conditions $\mathbb{N}$ and $\mathbb{R}$ prevent deforestation only if locals prefer the incentive ($\mathcal{L} > 0$), in which case: (a) Without entrants, $\mathbb{N}$ and $\mathbb{R}$ prevent deforestation; $\mathbb{N}$ achieves compensation and $\mathbb{R}$ achieves compensation if $\eta > \sum_{\ell \in \mathcal{L}:\delta_\ell > 0 \text{ and } \Delta_\ell > 0} \Delta_\ell$; (b) With entrants, $\mathbb{N}$ cannot prevent deforestation, whereas $\mathbb{R}$ prevents deforestation if $\eta < \max_{S \subseteq \{\ell \in \mathcal{L}:\delta_\ell > 0\}} \frac{\Delta_S}{|\{\ell \in \mathcal{L}:\delta_\ell > 0\} \setminus S| + |\mathcal{E}|}$.

EC.3. Details on Illustration in Indonesia

Our full survey consists of data from 420 farmers in 60 villages, out of which we use a subset of from 391 farmers from 58 villages in two regencies of East Kalimantan, Indonesia. This constitutes all farmers in our survey with total land less than 20 ha and all villages with at least two observations. In Figure EC.1 shows all villages in East Kalimantan, as well as those in the survey data.

We use the farmer and plot level data specified in Figure 5.3 for each farmer (left). Figure EC.2 shows the distributions of the data collected. We deal with missing prices, costs, and interest rate values for each farmer by considering the median over the available data. Finally, because some farmers reported overly optimistic production values in our survey, we limit their maximum production quantities using the maximum attainable yields for palm trees in Indonesia (as a function of the age of the trees) according to Hoffmann et al. (2014).

EC.3.1. Data Envelope Analysis

In order to obtain the production frontier while systematically accounting for outliers, we use m-estimator Data Envelope Analysis defined by Aragon et al. (2005). We obtain the production frontier

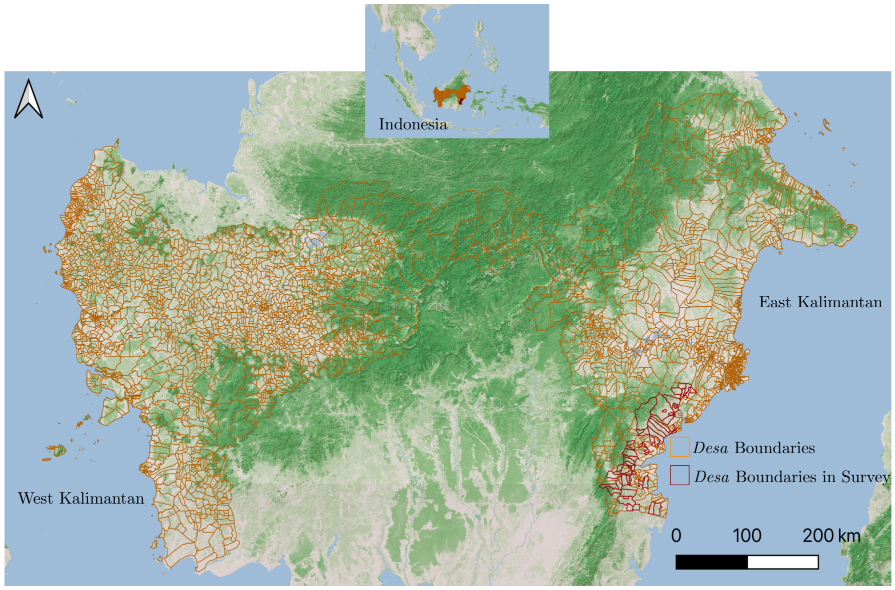

Figure EC.1 Map of East and West Kalimantan, Indonesia, showing the divisions into all rural villages (*desa*) in orange, and those in the survey in red. Darker shades of green denote more forest cover.

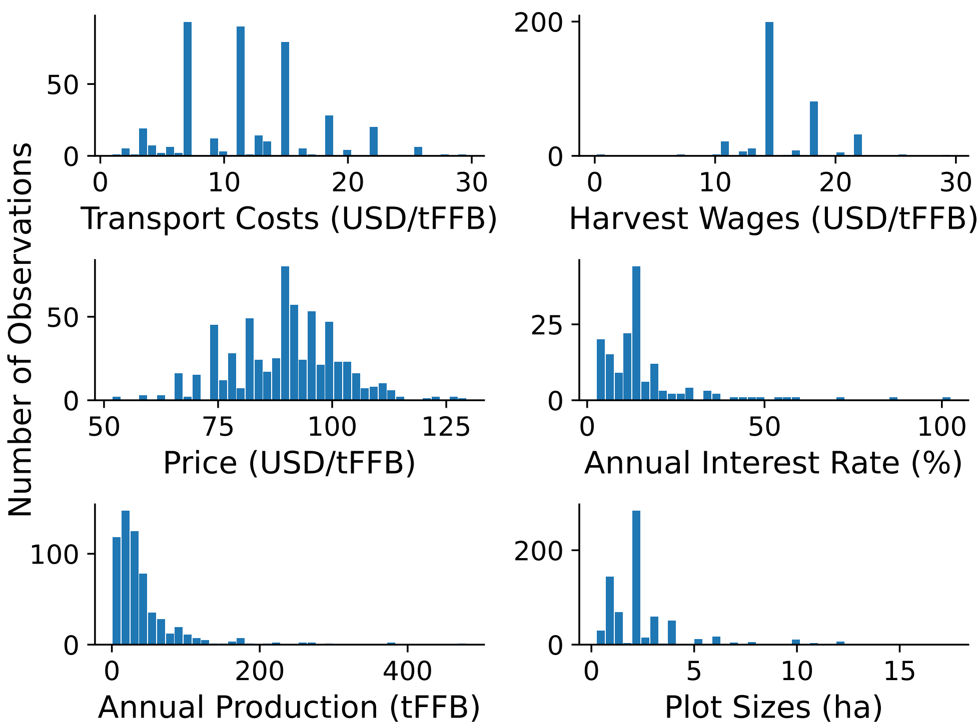

Figure EC.2 Distributions of key parameters in our data set. Each observation corresponds to a particular farmer and plot except the interest rates, where each observation corresponds to a specific farmer.

$u(A)$ by applying Algorithm 1 to the set of points $\{(A_\ell, \hat{q}_\ell) : \ell \in \cup_j \mathcal{L}_j\}$, where $\cup_j \mathcal{L}_j$ is the union of all the villages in the data-set.

Algorithm 1 Production Frontier $u(x)$

Require: $x \geq 0$, $\{(A_\ell, \bar{v}_\ell) : \ell \in \mathcal{L}\}$

procedure U(x)
  for $A \in \cup_{\ell \in \cup_j \mathcal{L}_j} A_\ell$ **do**
    for $b = 1$ to B **do**
      $\{q_b^1, ..., q_b^m\} \leftarrow$ A random sample with replacement of size m from $\{\bar{v}_\ell : A_\ell \leq A\}$
      $h_b(A) \leftarrow \max\{q_b^1, ..., q_b^m\}$
    end for
    $h(A) \leftarrow \frac{1}{B} \sum_{b=1}^{B} h_b(A)$
  end for
  $\{(A, \hat{h}(A))\} \leftarrow$ convex hull of $\{(A, h(A)) : A \in \cup_{\ell \in \cup_j \mathcal{L}_j} A_\ell\}$
  if $x \leq \max_{\ell \in \cup_j \mathcal{L}_j} A_\ell$ **then**
    $u(x) \leftarrow$ linear interpolation of $\{(A, \hat{h}(A))\}$ at x
  else
    $u(x) \leftarrow u(\max_{\ell \in \cup_j \mathcal{L}_j} A_\ell)$
  end if
end procedure

The procedure for obtaining the production frontier $u(x)$, for any $x \geq 0$ detailed in Algorithm 1 works in three parts: a) first, it obtains the expected value of the DEA frontier defined by a sub-sample of m points with total area $A_\ell \leq x$. It uses a Monte-Carlo simulation, sampling B times and taking the average. We set $B = 500$, and $m = 150$. b) Because the sampling procedure in (a) need not produce a concave function, this step computes the convex hull of the points obtained. c) Finally, a linear interpolation of the points in the convex hull leads to the value of $u(x)$. We assume the production would be constant for any x larger than the maximum total land registered in our data set.

EC.3.2. Additional Data Sources

We estimate the total number of palm farmers in each village $|\mathcal{L}|$ by multiplying the average number of households that farm palm fruit in East Kalimantan, 38% according to BPS, Indonesia (2013), by the number of households in each village, which we estimate by dividing the available population data for each district by the number of villages in the district and then dividing this population by 5.12, the average household size in East Kalimantan according to BPS, Indonesia (2010). Table EC.1 shows these estimates for each district.

District	District Population (people)	Number of Villages	Village Population (people)	Village Households	Palm Farmers $\|\mathcal{L}\|$
Tanah Grogot	63,311	16	3,957	773	295
Waru	15,643	4	3,911	764	292
Penajam	66,983	23	2,912	569	217
Batu Sopang	22,540	9	2,504	489	187
Babulu	29,434	12	2,453	479	183
Sepaku	30,863	15	2,058	402	154
Pasir Belengkong	23,543	15	1,570	307	117
Kuaro	23,934	13	1,841	360	137
Long Ikis	36,701	26	1,412	276	105
Tanjung Harapan	7,720	7	1,103	215	82
Batu Engau	11,662	13	897	175	67
Muara Samu	4,221	9	469	92	35

Table EC.1 District and village information, including the estimated number of palm farmers $|\mathcal{L}|$.

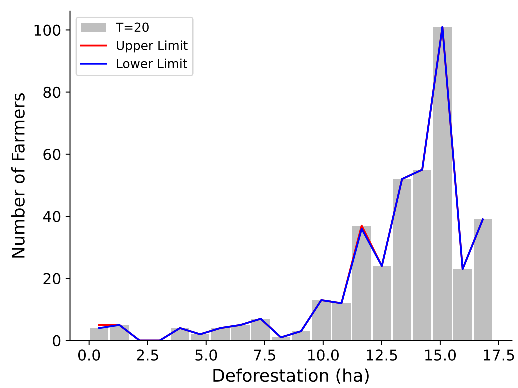

Figure EC.3 Histogram of the estimated optimal area to deforest x^* at $T = 20$ years, with upper limit (lower limit) showing the maximum (minimum) number of farmers in each bucket for $T \in [15, 60]$ years.

To generate the maps in Figure 5.8, we combined global data on forest canopy cover from Potapov et al. (2021) with the village boundaries extracted from the sub-national administrative boundaries from Indonesia from OCHA (2020).

EC.3.3. Robustness with respect to the planning horizon T

Due to the heavy discounting, the results presented in §5 present very little variation for any price T above 15 years. We computed all our results with $T \in [15, 60]$ years to show this. Figure EC.3 shows that the deforestation distribution would remain almost identical for any T in that range. While Figures EC.4 and EC.5 show that the uniform and village-specific minimum prices would also change very little. The most meaningful change is that of the uniform minimum price that would prevent deforestation with compensation in all 58 villages under the individual incentive, which changes between $4,456$ USD/tFFB considering $T = 15$ years and $5,193$ USD/tFFB considering $T = 60$ years.

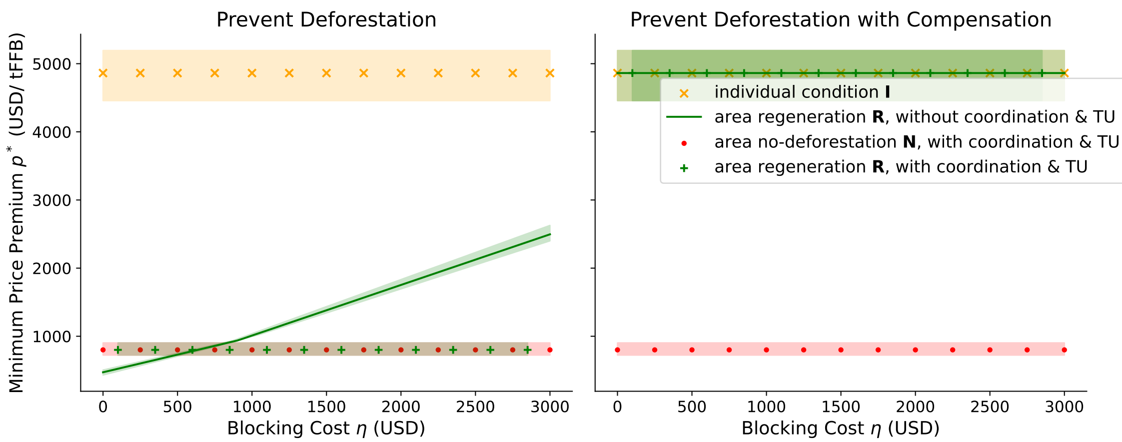

Figure EC.4 Minimum price premium p^* that would prevent deforestation (left) and achieve compensation (right) in all villages, for $T = 20$ years, together shaded areas showing the variation for $T \in [15, 60]$ years.

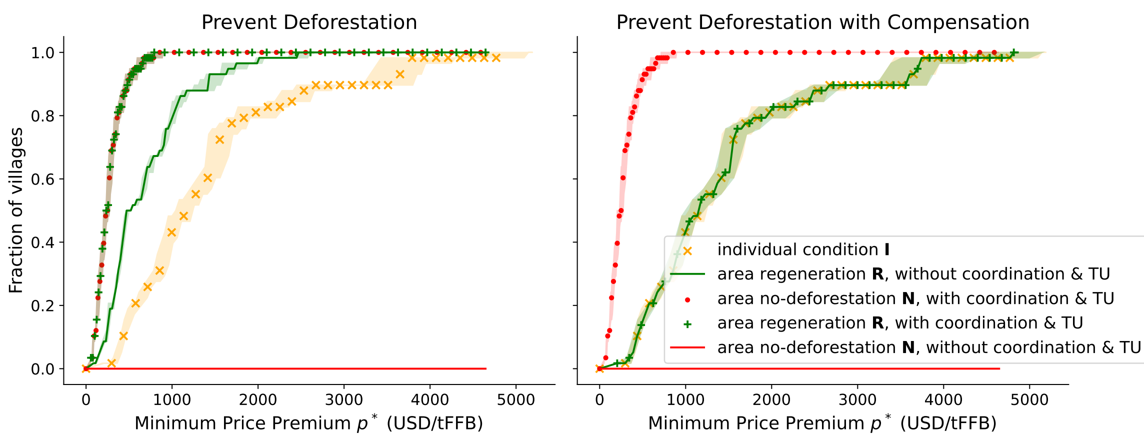

Figure EC.5 Fraction of villages in which each condition prevents deforestation (left) and achieves compensation (right) as a function of the price premium p^*, considering $\eta = 3,000$ USD and $T = 20$ years. The shaded areas show the variation of these curves for $T \in [15, 60]$ years.

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