Contesting an International Environmental Agreement*

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Abstract

International environmental agreements (IEAs) often condition entry into force on ratification by a minimum number of countries, yet deep environmental commitments frequently face strong domestic political resistance. We study how IEA breadth, through minimum ratification thresholds (MRTs), and depth are jointly determined when domestic ratification incentives are endogenous. In our model, lobbying by pro- and anti-environmental interest groups shape domestic ratification outcomes, and lobbying incentives depend on expectations about ratification in other countries. MRTs affect domestic political incentives by altering the pivotality of a country's ratification for entry-into-force and the extent that global emissions externalities are internalized. Thus, deeper agreements optimally feature lower MRTs: governments relax breadth requirements to offset endogenous domestic political resistance to more ambitious environmental commitments. Our analysis provides a political-economy foundation for the breadth–depth trade-off and offers a novel perspective on free riding that operates through domestic political effort rather than participation or enforcement mechanisms.

Keywords. International environmental agreements; Minimum ratification thresholds; Contest; Ratification; Lobbying; Domestic political economy; Breadth–depth trade-off; Free riding

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1 Introduction

International environmental agreements (IEAs) frequently condition entry into force on domestic political ratification by a minimum number of signatory countries. For example, the Kyoto Protocol required ratification by at least 55 countries representing 55 percent of global emissions, while other environmental treaties impose supermajority or critical-mass requirements to ensure effectiveness and legitimacy. At the same time, IEAs with ambitious environmental commitments—such as deep emissions reductions—often face strong domestic political resistance, because they impose substantial costs on domestic industries and require legislative approval.[1] Governments negotiating IEAs must therefore balance ambitious global action against the risk that agreements fail to be ratified and never enter into force.

Minimum ratification thresholds (MRTs) specify the minimum number of countries that must ratify an agreement domestically before it enters into force and are a central feature of IEAs. A growing body of work treats MRTs as institutional constraints or enforcement devices that support cooperation by ensuring agreements enter into force only when participation is sufficiently broad (e.g., Black et al. 1993; Carraro et al. 2009; Weikard et al. 2015). This perspective connects MRTs to a broader IEA literature on coalition formation, which emphasizes how incentives to free ride limit participation in IEAs (e.g., Carraro and Siniscalco 1993; Barrett 1994, 2001; McGinty 2007). It also relates to work highlighting the breadth–depth trade-off, whereby broader agreements tend to feature weaker commitments, while deeper agreements attract fewer participants (Diamantoudi and Sartzetakis 2006; Rubio and Ulph 2007; Finus and Maus 2008). In all of these models, countries' participation decisions depend on the payoff consequences of being inside or outside the agreement, rather than on the domestic political processes that determine whether agreements are ratified in the first place.

More recent work argues that further progress in the IEA literature requires integrating institutional design with domestic political economy considerations (e.g., Tavoni and Winkler 2021). In this spirit, a growing strand of the literature shows that domestic political opposition can substantially limit the ambition of environmental commitments, even when deeper commitments would be welfare improving (e.g., Oates and Portney 2003; Marchiori et al. 2017; Battaglini and Harstad 2020). In particular, Marchiori et al. (2017) model how lobbying by domestic interest groups constrains the depth of IEAs. However, this literature abstracts from MRTs and, more generally, from how domestic political incentives interact with the breadth of IEAs.

Most closely related to our paper, Köke and Lange (2017) incorporate domestic ratification uncertainty into the design of IEAs and show that ratification risk can lead governments to choose shallower and narrower agreements in order to increase the likelihood of entry into force. In their framework, however, ratification uncertainty arises from stochastic preference realizations of a pivotal domestic actor and is independent of political effort or lobbying incentives. As a result,

[1] Domestic political resistance to international environmental commitments is well documented (e.g., Putnam 1988; Aklin and Urpelainen 2013; Keohane and Oppenheimer 2016).

ratification risk does not respond to IEA design itself. The existing literature therefore lacks a framework in which institutional design choices—such as MRTs—feed back into the domestic political incentives that determine whether agreements are ratified.

Motivated by this gap, we study the optimal design of IEAs when domestic ratification incentives are endogenous to political effort and interact strategically across countries. Building on the parallel contest framework of Cole et al. (2021), we model domestic ratification as the outcome of lobbying contests between pro- and anti-environmental interest groups in each signatory country. MRTs then shape not only whether an agreement enters into force mechanically, but also the political incentives that determine ratification probabilities. This feedback between institutional design and domestic politics generates a depth–breadth trade-off that does not arise in models where ratification uncertainty reflects exogenous preference shocks rather than endogenous political behavior.[2]

In our framework, domestic ratification is determined by a political contest between pro- and anti-IEA interest groups within each signatory country. Lobbying effort is costly and influences ratification probabilistically, but the return to lobbying in any one country depends on expectations about ratification outcomes elsewhere. When a country's ratification is unlikely to be pivotal for entry into force, domestic lobbying incentives are weak; when ratification is pivotal, lobbying effort intensifies. We combine this political structure with an economic environment in which anti-IEA interests benefit only from their own country's emissions and face increasing marginal costs of emissions abatement, while pro-IEA interests value global emissions reductions and enjoy constant marginal benefits from such reductions. As a result, deeper agreements reduce the probability of ratification by strengthening domestic opposition, whereas broader agreements—implemented through stricter MRTs—raise ratification probabilities by increasing pivotality and the extent to which global emissions externalities are internalized. Through this channel, institutional design choices directly reshape domestic political incentives rather than just determining the mechanical feasibility of entry into force.

These political incentives translate directly into the classic depth–breadth trade-off in IEAs. Deeper agreements deliver larger emissions reductions per member country, but they also intensify domestic political opposition and reduce the probability of ratification. Broader agreements, by contrast, raise ratification probabilities by increasing the political return to lobbying in favor of ratification but also, for fixed ratification probabilities, make it mechanically harder to satisfy the MRT. Governments therefore face a trade-off between the intensive margin of environmental ambition and the extensive margins of domestic and international political feasibility when designing IEAs.

[2] Related work studies uncertainty affecting international environmental cooperation through other channels, including the benefits and costs of emissions (Ulph and Ulph 1997; Kolstad 2007) and coordination under uncertainty about participation incentives (Black et al., 1993). Ratification uncertainty has been studied more extensively in trade agreements (e.g., Maggi and Morelli 2006; Cole et al. 2021; Blanga-Gubbay et al. 2025).

The optimal depth and breadth of the IEA are therefore intrinsically linked. As governments increase emissions reductions toward the level implied by internalizing the global externality, they optimally relax the MRT. Relaxing the MRT increases the likelihood that the agreement enters into force, partially offsetting the decline in domestic ratification probabilities induced by stronger emissions commitments. In this sense, deeper agreements are designed to be narrower not because of participation externalities, but because governments optimally adjust institutional design to offset endogenous domestic political resistance to ratification.

An important implication of our analysis is that MRTs mitigate free riding through a novel political-economy channel. In standard IEA models, free riding arises because countries can benefit from emissions reductions undertaken by others without joining the agreement. In our framework, free riding instead operates within countries through domestic politics, even if the set of signatory countries is fixed: when pro-IEA interests expect the agreement to enter into force regardless of their own country's ratification decision, their incentive to exert costly lobbying effort is weakened, reducing the probability of ratification. Stricter MRTs counteract this form of political free riding by increasing the likelihood that a country's ratification is pivotal and by expanding the internalization of global emissions externalities. In this sense, MRTs support cooperation not by penalizing non-members ex post, but by reshaping domestic political incentives ex ante.

This paper makes three contributions to the literature on IEAs. First, we jointly endogenize IEA depth and breadth in a political-economy framework in which domestic ratification incentives are themselves endogenous. Second, we show that MRTs are not merely feasibility constraints, but strategic design instruments that reshape domestic political incentives by affecting pivotality and the internalization of global emissions externalities. Third, we provide a political-economy foundation for the depth–breadth trade-off and reinterpret free riding as a domestic political phenomenon rather than an enforcement problem operating through participation or sanctions.

Finally, while the parallel contest framework has been applied to the domestic ratification of international trade agreements (e.g., Cole et al. 2021; Blanga-Gubbay et al. 2025), its implications differ fundamentally in the context of IEAs. Trade agreements typically require unanimity for entry into force and primarily generate club-good benefits for members. By contrast, IEAs allow entry into force once an MRT is met and generate public-good benefits through global emissions reductions. As a result, MRTs emerge as a central institutional design choice in IEAs, shaping domestic political incentives in ways that do not arise in trade agreements.

The remainder of the paper proceeds as follows. Section 2 presents the economic environment, the structure of international negotiations, and the domestic political ratification process. Section 3 characterizes equilibrium lobbying behavior and domestic ratification probabilities, and analyzes the optimal design of IEAs by jointly determining their depth and breadth. Section 4 discusses the implications of the model for free riding and explores extensions. Section 5 concludes.

2 Model

2.1 Economic and environmental structure

We use the model of Marchiori et al. (2017) with $\bar{N}$ symmetric countries and governments.[3] The government in each country i chooses environmental policy e_i. Adopting a reduced-form approach, we assume that firms in country i will produce until they reach the emissions limit implied by e_i. Hence we equate the emissions level of country i to its environmental policy e_i.

Given the environmental policy choice of each country $\mathbf{e} = (e_1, ..., e_{\bar{N}})$, country i receives a national benefit $B(\mathbf{e})$ that only depends on its own policy e_i, but suffers environmental damage $D(\mathbf{e})$ that depends on the policies of all countries:

$$B_i(\mathbf{e}) = \beta e_i - \frac{1}{2} e_i^2 \tag{1}$$

$$D_i(\mathbf{e}) = -\omega \sum_{j=1}^{\bar{N}} e_j. \tag{2}$$

In terms of emissions, equation (1) implies diminishing marginal private benefits of emissions, while equation (2) implies the marginal damage of global emissions is constant. As a result, equation (1) says the marginal cost of a country's own emissions *abatement* is increasing, while equation (2) implies the marginal benefit of global emissions abatement is constant. Further, higher values of the parameters β and ω, respectively, increase the marginal cost of a country's own emissions abatement and increase the marginal benefit of global emissions abatement.

The government in country i cares about national welfare $W_i(\mathbf{e})$ and lobbying contributions l_i. Its national welfare is defined as the sum of the national benefit and (negative) damage from global emissions:

$$W_i(\mathbf{e}) = B_i(\mathbf{e}) + D_i(\mathbf{e}) = \beta e_i - \frac{1}{2} e_i^2 - \omega \sum_{j=1}^{\bar{N}} e_j. \tag{3}$$

In each country, there is an anti-environmental lobby (A) and a pro-environmental lobby (P). The anti-environmental lobby's payoff is the national benefit, $\pi_{A,i}(\mathbf{e}) = B_i(\mathbf{e}) \geq 0$, and the pro-environmental lobby's payoff is the damage of global emissions $\pi_{P,i}(\mathbf{e}) = D_i(\mathbf{e}) \leq 0$. Given an IEA that lowers emissions, the anti-environmental lobby is also the anti-IEA lobby and the pro-environmental lobby is also the pro-IEA lobby. These lobbies make respective contributions of $l_{A,i}$ and $l_{P,i}$, for a total of $l_i = l_{A,i} + l_{P,i}$ contributions, to their own government.

[3] We assume symmetric countries and governments so that all governments have the same preferences over the IEA design in terms of the MRT and the emissions reduction level. This rules out failure to form an IEA based on disagreement over IEA design and thus allows us to focus on the interaction between the domestic political ratification process and how IEA signatories design the IEA. Allowing for heterogeneity would introduce bargaining over IEA design but would not eliminate the domestic-political mechanisms we highlight.

2.2 IEA formation game

2.2.1 IEA design instruments

We now consider $\bar{N}$ countries negotiating an IEA that entails an MRT $\bar{R} \in \{2, ..., \bar{N}\}$ and an emissions vector $\mathbf{e_{IA}} = (e_{1,IA}, ..., e_{\bar{N},IA})$. Given that countries are symmetric, it is sufficient to focus on a single IEA signatory government maximizing its expected payoff by choosing the MRT $\bar{R}$ and the symmetric IEA emissions vector $\mathbf{e_{IA}}$ where $e_{i,IA} = e_{IA}$ for every country i.

Before the IEA, we assume each country imposes its "status-quo" emissions policy to maximize national welfare.[4] Given that countries are symmetric, each country i imposes

$$e_{SQ} \equiv e_{i,SQ} = \arg\max W_i(\mathbf{e}) = \beta - \omega. \tag{4}$$

To ensure that both the national (i.e. unilateral) and globally optimal emissions levels are strictly positive, we assume $\beta > \bar{N}\omega$. Further, we parameterize the IEA emissions level as

$$e_{IA} = \beta - \gamma\omega \tag{5}$$

so that the emissions reduction under the IEA relative to the status quo is

$$e_{SQ} - e_{IA} = (\gamma - 1)\,\omega. \tag{6}$$

The parameter γ therefore captures IEA depth, with higher values corresponding to deeper emissions reductions.[5]

An MRT of $\bar{R}$ specifies that the IEA enters into force if and only if at least $\bar{R}$ countries ratify the agreement domestically. We let R denote the number of countries that ratify the IEA and M the number of IEA members. If $R \geq \bar{R}$, the IEA enters into force with $M = R$ member countries, each of which reduces emissions from e_{SQ} to e_{IA}, while non-member countries maintain the status quo emissions e_{SQ}. If $R < \bar{R}$, the IEA does not enter into force, implying $M = 0$ members, and all countries maintain the status quo emissions e_{SQ}. The number of countries R that ratify the agreement is a random variable determined by the stochastic ratification process that takes place in each country through a parallel contest.

2.2.2 Negotiation and ratification process

We now model the contest over an IEA between all countries $i = 1, ..., \bar{N}$, drawing attention to the specific features of our parallel contest framework. Negotiation and ratification of the IEA emissions policies proceeds as follows:

Stage 1 (Participation) Each of the $\bar{N}$ governments decides whether its country i will opt out of

[4] We discuss the implications of relaxing this assumption in Appendix B.3.

[5] We will later see that, in equilibrium, $e_{IA} \in (0, e_{SQ})$.

the IEA. Those that do not opt out sign the IEA and are henceforth referred to as *signatories*.

Note that we include a participation stage for completeness. In equilibrium, all countries choose to sign the IEA. Hence, the subsequent analysis will focus on the design and ratification stages.

Stage 2 (International Negotiation of IEA Design) Given the status-quo emissions e_{SQ}, the $N \leq \bar{N}$ signatory governments of the IEA from Stage 1 announce the IEA emissions policy $e_{IA} \leq e_{SQ}$ and the MRT $\bar{R} \leq N$.

Stage 3 (Domestic Lobbying) In each IEA signatory country $i = 1, ..., N$, the anti-IEA lobby and the pro-IEA lobby simultaneously make non-negative contributions, $l_{A,i}$ and $l_{P,i}$ respectively, to their own government.

Stage 4 (Domestic Ratification) Each IEA signatory government decides whether to ratify the IEA. The IEA enters into force with $M = R$ members if $R \geq \bar{R}$ countries ratify the IEA, but the IEA has $M = 0$ members and does not enter into force if $R < \bar{R}$ countries ratify the IEA. The emissions policies e_{IA} are implemented by the M member countries of the IEA. IEA non-members continue to set e_{SQ}.

As explained above, IEA ratification decisions by governments in Stage 4 are stochastic: lobbying in Stage 3 affects the probability of ratification rather than deterministically determining outcomes. In practice, government decision-making is influenced not only by lobbying contributions but also by an inherent element of randomness. This reflects real-world uncertainty: even when one side contributes more than the other, the outcome is not guaranteed. To model this inherent uncertainty, we adopt a standard contest success function which, in our setting, maps lobby contributions into the probability of ratification. Specifically, the probability ρ_i that government i ratifies the IEA decreases with $l_{A,i}$ and increases with $l_{P,i}$:[6]

$$\rho_i \left(l_{P,i}, l_{A,i}\right) = \frac{l_{P,i}}{l_{P,i} + l_{A,i}} = \frac{1}{1 + \frac{l_{A,i}}{l_{P,i}}}. \tag{7}$$

The contest success function introduces probabilistic ratification to reflect political uncertainty. In practice, legislative outcomes are influenced by lobbying but are rarely deterministic, even when one side exerts greater effort.[7] The probabilistic formulation captures this institutional reality while allowing us to characterize how minimum ratification thresholds reshape political incentives through pivotality and externality internalization. The central mechanism of the paper—the endogenous

[6]Within the generalized contest success function $\rho_i = \frac{l^r_{P,i}}{l^r_{P,i}+l^r_{A,i}}$, our contest success function represents the 'simple Tullock contest' of $r = 1$. Skaperdas (1996) axiomatizes the simple Tullock contest. We assume that $\rho_i > 0$ if $l_{A,i} = l_{P,i}$. This nests the typical assumption that $\rho_i = \frac{1}{2}$.

[7]As we show in Cole et al. (2021), the contest success function can be interpreted as an all-pay auction with noise in that the government chooses the preferred policy of lobby P over the preferred policy of lobby A only if $\ln \left(l_P + \varepsilon_P\right) > \ln \left(l_A + \varepsilon_A\right)$ where $\varepsilon_P, \varepsilon_A$ follow the Type I extreme value distribution.

interaction between IEA design and domestic political effort—does not depend on the particular contest functional form.

Two features of the underlying economic and environmental structure are important for understanding the incentives underlying optimal choice of the IEA design instruments. First, as discussed above, the marginal benefit of emissions is decreasing but the marginal damage of emissions is constant. As a result, the marginal cost imposed on social welfare through emissions reduction increases with IEA depth, whereas the marginal benefit of global emissions reduction remains constant. Second, the damage function $D_i(\cdot)$ reflects that each country directly benefits from internalization of the negative global emissions externality. These two features will shape the domestic political consequences, mediated through the contest success function, of changes in IEA depth and breadth.

In contrast, the parameters β and ω affect levels but not the qualitative structure of the equilibrium. In particular, β drops out of the analysis of IEA design, while ω scales emissions reductions proportionally without affecting relative lobbying incentives or optimal IEA depth and breadth.[8] Further, IEA emissions reduction as a share of the emissions reduction that maximizes social welfare is also independent of ω. Thus, we hereafter set $\omega = 1$ without loss of generality.

3 Optimal IEA design

We now solve the IEA formation game using backward induction. To begin, we consider the ratification decision in Stage 4.

3.1 Stage 4: Government ratification decision process

Given the lobbying contributions received in Stage 3, the government in each country i ratifies the IEA according to the contest success function in equation (7). Given symmetry, the equilibrium ratification probability is the same in each country, so that $\rho_i = \rho$ for all i in equilibrium. Hence, the number of ratifying countries R is a binomial random variable with parameters N and ρ, implying the expected number of countries that ratify the IEA is $\mathbb{E}(R) = N\rho$. Since the IEA enters into force if and only if $R \geq \bar{R}$, the number of IEA member countries is $M = R$ when $R \geq \bar{R}$ and $M = 0$ otherwise. The expected number of IEA member countries is therefore given by

$$\mathbb{E}(M) = \sum_{r=\bar{R}}^{N} r \Pr(R = r).$$

[8] Note that $B_i(\mathbf{e}') - B_i(\mathbf{e}) = \frac{1}{2}\left(\gamma^2 - 1\right)$ is independent of β.

3.2 Stage 3: Domestic lobbying process

Given the symmetry of our model, lobby group payoffs depend only on the number of IEA member countries, M, and not on the identity of the member countries. We therefore write the ex-post payoff of lobby group $j \in \{A, P\}$ in country i as $\pi_{j,i}(e_i; M)$.

To characterize lobbying incentives, let R_{-1} denote the number of *other* countries (excluding i) that ratify the IEA. The random variable R_{-1} follows a binomial distribution with parameters $N-1$ and ρ, so that $\mathbb{E}(R_{-1}) = \rho(N-1)$. The total number of ratifying countries is then $R = R_{-1} + 1$ if country i ratifies and $R = R_{-1}$ otherwise. Further, two probabilities involving R_{-1} play a central role in shaping domestic lobbying incentives in country i. The first is the probability that the IEA enters into force (EIF) *conditional* on ratification by country i,

$$\theta_{CEIF} \equiv \Pr\left(R \geq \bar{R} \mid i \text{ ratifies}\right) = \Pr\left(R_{-1} \geq \bar{R} - 1\right). \tag{8}$$

The second is the probability that country i's ratification decision is pivotal for entry into force,

$$\theta_{PIV} \equiv \Pr\left(R_{-1} = \bar{R} - 1\right), \tag{9}$$

which measures the likelihood that ratification by country i determines whether the IEA enters into force. Both θ_{CEIF} and θ_{PIV} are functions of the equilibrium ratification probability ρ, since R_{-1} follows a binomial distribution with success probability ρ. But, for notational simplicity, we suppress this dependence except where it is essential.

The expected payoff $\mathbb{E}(u_{j,i})$ of lobby group j in country i consists of three components. The first component reflects the situation when $R_{-1} \leq \bar{R} - 2$ other countries ratify the IEA so that the IEA will not enter into force. In this case, the ex-post lobby group payoffs are $\pi_{j,i}(e_{SQ}; 0)$. The second component reflects the situation when $R_{-1} = \bar{R} - 1$ so that country i's ratification is pivotal to the IEA's entry into force. In this case, the ex-post lobby group payoffs are $\pi_{j,i}\left(e_{IA}; \bar{R}\right)$ if country i ratifies the IEA and $\pi_{j,i}(e_{SQ}; 0)$ if it does not. The third component reflects the situation when $R_{-1} \geq \bar{R}$ so that the IEA certainly enters into force. In this case, the ex-post lobby group payoffs are $\pi_{j,i}(e_{IA}; R_{-1} + 1)$ if country i ratifies the IEA and $\pi_{j,i}(e_{IA}; R_{-1})$ if it does not. These cases imply the following expected payoff prior to ratification:[9]

$$\begin{aligned}\mathbb{E}(u_{j,i}) = {} & (1 - \theta_{CEIF})\, \pi_{j,i}(e_{SQ}; 0) + \theta_{PIV}\left[(1 - \rho_i)\, \pi_{j,i}(e_{SQ}; 0) + \rho_i \pi_{j,i}\left(e_{IA}; \bar{R}\right)\right] \\ & + \sum_{r=\bar{R}}^{N-1} \Pr(R_{-1} = r)\left[(1 - \rho_i)\, \pi_{j,i}(e_{SQ}; r) + \rho_i \pi_{j,i}(e_{IA}; r + 1)\right] - l_{j,i},\end{aligned} \tag{10}$$

We can rewrite lobby group j's expected payoff more compactly as consisting of three terms: (i) its expected payoff if country i does not ratify, $\mu_{j,i}$, (ii) the absolute change in its expected payoff associated with the possibility of ratification in country i, $\rho_i v_{j,i}$, and (iii) its lobbying expenditure,

[9] Note that $1 - \theta_{\text{CEIF}} = \Pr(R_{-1} \leq \bar{R} - 2)$ since R_{-1} is discrete.

$l_{j,i}$. That is,

$$\mathbb{E}\left(u_{A,i}\right) = \mu_{A,i} - \rho_i v_{A,i} - l_{A,i} \tag{11}$$

$$\mathbb{E}\left(u_{P,i}\right) = \mu_{P,i} + \rho_i v_{P,i} - l_{P,i} \tag{12}$$

where

$$\mu_{j,i} = \left(1 - \theta_{CEIF} + \theta_{PIV}\right) \pi_{j,i}\left(e_{SQ}, 0\right) + \sum_{r=\bar{R}}^{N-1} \Pr\left(R_{-1} = r\right) \pi_{j,i}\left(e_{SQ}, r\right) \tag{13}$$

$$v_{j,i} = \sum_{r=\bar{R}-1}^{N-1} \Pr\left(R_{-1} = r\right) \left|\pi_{j,i}\left(e_{IA}, r+1\right) - \pi_{j,i}\left(e_{SQ}, r\right)\right| \geq 0. \tag{14}$$

The lobby group "valuations" $v_{j,i}$ are the absolute change in their expected payoffs conditional on their own country ratifying the IEA. Because an IEA will lower emissions below the status quo level, IEA ratification reduces (increases) the payoff of the anti-IEA (pro-IEA) lobby and hence $\rho_i v_{j,i}$ enters its expected payoff with a negative (positive) sign. Thus, $\mu_{j,i}$ captures the expected payoff to lobby group j when country i does not ratify, taking into account that the IEA will nevertheless enter into force if the MRT is met.

Given the identity of which countries ratify the IEA is irrelevant, and remembering that lobby group payoffs are $\pi_{A,i} = B_i(e)$ and $\pi_{P,i} = D_i(e)$, equations (1)-(2) imply that the valuations reduce to

$$v_{A,i} = \left|\Delta B_i(e)\right| \theta_{CEIF} = \frac{1}{2}\left(\gamma^2 - 1\right) \theta_{CEIF} \tag{15}$$

$$v_{P,i} = \left|\Delta D_i(e)\right| \left[\theta_{CEIF} + \left(\bar{R} - 1\right) \theta_{PIV}\right] = \left(\gamma - 1\right) \left[\theta_{CEIF} + \left(\bar{R} - 1\right) \theta_{PIV}\right]. \tag{16}$$

Because the IEA lowers each member's emissions by $(\gamma - 1)$, equation (15) says the value to the anti-IEA lobby of preventing this emissions reduction is quadratic in γ due to the increasing marginal cost of emission abatement for the anti-IEA group. It is also proportional to the conditional EIF probability. Equation (16) says the value to the pro-IEA lobby of lower IEA emissions is linear in γ, reflecting the constant marginal benefit of emissions reduction. It is also proportional to the sum of the conditional EIF probability and $\bar{R} - 1$ times the pivotality probability. The latter component reflects that country i's ratification leads to all other $\bar{R} - 1$ countries in the IEA cutting their emissions by $(\gamma - 1)$ when country i is pivotal.

Equations (11)-(12) express lobby group expected payoffs in a form that is standard in the contest literature, while highlighting the new features introduced by our parallel contest framework. Following the intuition of regular contests, lobbying is costly but benefits the pro-IEA (anti-IEA) lobby by increasing (decreasing) the probability of ratification in their own country and hence benefiting (suffering) from lower emissions under the IEA. However, the expected payoffs also display the strategic interdependencies introduced by our parallel contest framework. In particular, the expected payoffs and, hence, optimal lobbying expenditure for lobby groups in country i depend on the ratification probabilities in other countries. Intuitively, lobby groups in country i only have an incentive to lobby if their ratification decision can affect emission levels. But, this is only true if the conditional EIF probability is strictly positive and, in turn, depends on the ratification probabilities in other countries. That is, country i interest groups would not lobby if the probability of at least $\bar{R}-1$ other countries ratifying was zero. This strategic interdependency between contests across countries distinguishes our parallel contest setup from the prior contest literature. Nevertheless, standard solution techniques apply because the structure of lobby group preferences in equations (11)-(12) mirrors those of a standard contest.

Maximizing their expected payoffs, the anti-IEA and pro-IEA lobbies choose lobbying contributions

$$l_{A,i} = \frac{1}{2\left(1+\frac{v_{P,i}}{v_{A,i}}\right)}\bar{v}_i \tag{17}$$

$$l_{P,i} = \frac{1}{2\left(1+\frac{v_{A,i}}{v_{P,i}}\right)}\bar{v}_i \tag{18}$$

where $\bar{v}_i = \left[\frac{1}{2}\left(\frac{1}{v_{A,i}}+\frac{1}{v_{P,i}}\right)\right]^{-1}$ denotes the harmonic mean of the valuations. As in standard contest models, lobbying expenditures dissipate some of the benefits, as represented by their valuations, that the lobbies are trying to capture. Using equations (17)-(18), total lobbying expenditures can be written as

$$l_i = l_{A,i} + l_{P,i} = \frac{1}{2}\bar{v} = \rho v_{A,i} = (1-\rho)\, v_{P,i}. \tag{19}$$

Thus, total lobbying expenditures have two alternative but complementary interpretations. First, total lobbying contributions dissipate half of the "average" benefit that the lobbies are trying to capture. Second, total contributions reflect the expected rent destruction of either lobby from losing the lobbying contest. This expected rent destruction is $\rho v_{A,i}$ from the perspective of the anti-IEA lobby and $(1-\rho)\, v_{P,i}$ from the perspective of the pro-IEA lobby.

Moreover, relative lobbying expenditures depend on relative valuations:

$$\frac{l_{A,i}}{l_{P,i}} = \frac{v_{A,i}}{v_{P,i}} = \frac{\gamma+1}{2}\frac{1}{1+\left(\bar{R}-1\right)\frac{\theta_{PIV}}{\theta_{CEIF}}}. \tag{20}$$

Relative lobbying expenditure is increasing in γ because the marginal cost of emissions abatement for the anti-IEA lobby is increasing in IEA emissions reductions which, in turn, are increasing in the IEA depth parameter γ. Relative lobbying expenditure is decreasing in $\left(\bar{R}-1\right)\frac{\theta_{PIV}}{\theta_{CEIF}}$ because this captures the benefit to the pro-IEA lobby of country i being pivotal to IEA ratification and thus internalizing the global emission externality of all $\bar{R}-1$ other IEA members.

We can now establish the following result.[10]

[10]The proof is in the Appendix.

Lemma 1. *For any IEA design $(\gamma, \bar{R})$ with $\bar{R} \in \{2, \ldots, N\}$, there exists a unique interior equilibrium domestic ratification probability $\rho(\gamma, \bar{R}) \in (0, 1)$. Moreover, the equilibrium probability of ratification is decreasing in IEA depth γ and increasing in the MRT $\bar{R}$. These results hold whether $\bar{R}$ is treated as discrete or via a continuous extension of the binomial distribution.*

Substituting the equilibrium ratio of lobbying expenditures from equation (20) into the contest success function in equation (7) yields the condition characterizing the equilibrium domestic ratification probability,

$$\rho = \frac{1 + (\bar{R} - 1)\frac{\theta_{PIV}}{\theta_{CEIF}}}{1 + (\bar{R} - 1)\frac{\theta_{PIV}}{\theta_{CEIF}} + \frac{1}{2}(\gamma + 1)}. \tag{21}$$

Equation (21) defines the equilibrium ratification probability $\rho(\gamma, \bar{R})$ only implicitly, because both the conditional EIF probability θ_{CEIF} and the pivotality probability θ_{PIV} depend on ρ itself.[11] As a result, equilibrium ratification behavior is characterized by a fixed point: lobbying incentives in each country depend on expectations about ratification outcomes elsewhere—through θ_{CEIF} and θ_{PIV}—and the lobbying equilibrium must reproduce those expectations in equilibrium. The existence and uniqueness of this fixed point are established by Lemma 1.

Equation (21) further clarifies that equilibrium ratification outcomes are governed by domestic political incentives rather than by mechanical features of the ratification rule alone. IEA depth γ enters the equilibrium condition by increasing the marginal abatement costs faced by the anti-IEA lobby, thereby strengthening opposition to ratification and reducing ρ. By contrast, a stricter MRT $\bar{R}$ operates through two reinforcing political channels. First, it raises the relative importance of pivotality—captured by the ratio $\theta_{PIV}/\theta_{CEIF}$—increasing the likelihood that country i's ratification decision determines entry into force. Second, for a fixed ratification probability, a higher $\bar{R}$ increases the extent of global emissions externality internalization through the $(\bar{R} - 1)$ term, since pivotal ratification triggers emissions reductions by a larger set of countries. Both effects tilt lobbying incentives toward the pro-IEA lobby and raise the equilibrium probability of ratification. Because these incentives depend on expectations about ratification outcomes abroad, this structure also embeds a form of free riding that operates through domestic political incentives rather than through country-level participation decisions, a mechanism we revisit in Section 4.

3.3 Stage 2. Government IEA design problem

3.3.1 Government's objective function as expected IEA emissions reduction

Having fully characterized lobbying behavior and the resulting ratification probability ρ, we now turn to the government's problem. We assume the government values expected social welfare and

[11] In the case of unanimity, i.e. $\bar{R} = N$, equation (21) no longer defines a fixed-point problem because then, using equations (8)-(9), $\frac{\theta_{PIV}}{\theta_{CEIF}} = 1$ and the right hand side of equation (21) is independent of ρ.

lobbying contributions, as is standard in the political-economy literature on policy formation.[12] For consistency with the interpretation of lobby group valuations as measuring the change in lobby group payoffs relative to the status quo emissions, we also define the governments' objective function $\mathbb{G}_i$ as its expected payoff relative to the status quo. Finally, we use $W_i(e_i, M)$ to denote social welfare from country i's emissions e_i and M IEA member countries with IEA depth γ, but suppress the dependence on γ. The government's expected payoff is then

$$\begin{aligned}\mathbb{G}_i &= \mathrm{E}W_i + l_i - W_i(e_{SQ}, 0) \qquad (22)\\ &= (1-\theta_{CEIF}) W_i(e_{SQ}, 0) + \theta_{PIV}\left[(1-\rho) W_i(e_{SQ}, 0) + \rho W_i\left(e_{IA}, \bar{R}\right)\right]\\ &+ \sum_{r=\bar{R}}^{N-1} \Pr(R_{-1} = r)\left[(1-\rho) W_i(e_{SQ}, r) + \rho W_i(e_{IA}, r+1)\right] + l_i - W_i(e_{SQ}, 0)\,. \qquad (23)\end{aligned}$$

The right hand side of equation (23) separates country i's expected social welfare into three components. The first component represents social welfare when the IEA cannot enter into force because the MRT cannot be met since $R < \bar{R} - 1$ other countries ratify. The second component represents expected social welfare when country i is the pivotal country because $R = \bar{R} - 1$ other countries ratify. The third component represents expected social welfare when the IEA surely enters into force regardless of whether country i ratifies because $R \geq \bar{R}$ other countries ratify.

Using the definition of social welfare and the expressions for lobby group valuations, the government's objective function $\mathbb{G}_i$ reduces to

$$\mathbb{G}_i = \rho\,(v_{P,i} - v_{A,i}) + (\gamma - 1) \sum_{r=\bar{R}}^{N-1} r \Pr(R_{-1} = r) + l_i. \qquad (24)$$

Relative to social welfare under the status quo emissions, the right hand side of equation (24) says the ratification process impacts the government's objective function in three ways. First, IEA ratification by country i benefits the pro-IEA lobby but hurts the anti-IEA lobby. Second, regardless of whether country i ratifies, it benefits from the expected emissions reductions of other countries when at least $\bar{R}$ other countries ratify and hence the IEA surely enters into force. Third, the government collects lobby revenue. Moreover, equation (19) implies that total lobbying expenditures l_i exactly offset the expected loss $\rho v_{A,i}$ borne by the anti-IEA lobby. As a result, lobbying contributions enter the government's objective function only indirectly, through their effect on equilibrium

[12] Section 4.2 considers the setting where governments place different weights on social welfare and lobbying contributions. Appendix B.3 considers a more general formulation of the government's objective function that allows status quo emissions to differ from the national welfare maximizing emissions. Our main results are not sensitive to either alternative approach.

ratification outcomes, allowing the objective function to simplify to

$$\mathbb{G}_i = \rho v_{P,i} + (\gamma - 1) \sum_{r=\bar{R}}^{N-1} r \Pr\left(R_{-1} = r\right). \tag{25}$$

Equation (25) has a striking interpretation: the government's objective function is simply expected global emissions reduction from the IEA. As discussed above, the second term in equation (25) captures expected emissions reductions by other countries when country i is not pivotal. Using equation (16), the term $\rho v_{P,i}$ is the sum of (i) expected emissions reductions by all other countries when country i is pivotal and (ii) expected emissions reductions by country i itself. Since each IEA member reduces emissions by $(\gamma - 1)$, expected global emissions reduction from the IEA equals $(\gamma - 1)\mathbb{E}(M)$.[13] More formally, the government's objective function reduces to

$$\mathbb{G}_i = (\gamma - 1)\mathbb{E}(M) \tag{26}$$

where expected IEA membership is

$$\mathbb{E}(M) = \Pr(R \geq \bar{R})\, \mathbb{E}\big[R \mid R \geq \bar{R}\big] \tag{27}$$

which, under symmetry, simplifies to[14]

$$\mathbb{E}(M) = N\rho(\cdot)\, \theta_{CEIF}. \tag{28}$$

This representation of the government's objective implies that the IEA design problem can be studied as the constrained maximization of expected global emissions reductions, where the constraints arise endogenously from domestic political ratification processes shaped by lobbying incentives. Section 4 examines how relaxing the underlying micro-founded assumptions affects this equivalence.

3.3.2 IEA design: Optimal emissions reductions and MRT

We now turn to the government's IEA design problem. Having shown that the government's objective function reduces to expected global emissions reduction, $(\gamma - 1)\mathbb{E}(M)$, the government chooses IEA depth γ and breadth $\bar{R}$ taking into account how these design choices feed back into domestic lobbying incentives and, in turn, equilibrium ratification probabilities. Unlike existing IEA models, both margins of IEA design affect expected membership endogenously through domestic

[13] In equation (25), the government's objective is naturally expressed in terms of ratification outcomes among the $N-1$ countries other than country i, reflecting the pivotality structure of the ratification process. For interpretation, however, it is useful to relate this expression to expected IEA membership aggregated across all N countries, as in equation (26). Lemma A.1 establishes the equivalence between these representations.

[14] See Lemma A.2 in the Appendix for a formal proof.

political processes, generating non-trivial trade-offs in optimal IEA design.

The first-order condition for the IEA depth parameter γ is

$$\gamma - 1 = -\mathbb{E}(M)\left[\frac{\partial \mathbb{E}(M)}{\partial \gamma}\right]^{-1}. \tag{29}$$

This condition reflects a trade-off between the intensive and extensive margins of IEA design. Increasing γ raises emissions reductions per member country, so that the marginal benefit of greater IEA depth is proportional to expected membership, $\mathbb{E}(M)$. Absent political constraints, deeper emissions reductions would therefore always be desirable due to stronger internalization of the global emissions externality.

The constraint on IEA depth arises because larger emissions reductions weaken domestic political support for ratification. Using equation (28), the effect of γ on expected IEA membership is

$$\frac{\partial \mathbb{E}(M)}{\partial \gamma} = N\frac{\partial \rho(\gamma, \bar{R})}{\partial \gamma}\left[\theta_{CEIF}(\rho, \bar{R}) + \rho\frac{\partial \theta_{CEIF}(\rho, \bar{R})}{\partial \rho}\right] < 0. \tag{30}$$

The bracketed term is strictly positive, reflecting that a higher domestic ratification probability increases the likelihood that the MRT is satisfied and, hence, that the IEA enters into force. Given Lemma 1 implies $\partial\rho/\partial\gamma < 0$, a higher IEA depth γ reduces expected membership through its adverse effect on equilibrium domestic ratification probabilities.

The political mechanism underlying this constraint is straightforward. While deeper emissions reductions internalize more of the global emissions externality, they also intensify opposition from the anti-environmental lobby due to its increasing marginal cost of abatement compared to the constant marginal benefit of abatement for the pro-environmental lobby. As IEA depth increases, this asymmetry generates a domestic political backlash that lowers the probability of ratification and contracts expected membership. The optimal choice of IEA depth therefore balances the efficiency gains from deeper emissions reductions against the politically induced reduction in IEA membership.

We now turn to the government's choice of the MRT. Because the MRT $\bar{R}$ enters the government's objective function in equations (26)–(28) only through expected IEA membership $\mathbb{E}(M)$, the optimal MRT can be characterized as the value of $\bar{R}$ that maximizes expected membership.[15] The corresponding first-order condition is

$$\rho\frac{\partial \theta_{CEIF}\left(\rho, \bar{R}\right)}{\partial \bar{R}} + \frac{\partial \rho\left(\gamma, \bar{R}\right)}{\partial \bar{R}}\left[\theta_{CEIF}\left(\rho, \bar{R}\right) + \rho\frac{\partial \theta_{CEIF}(\rho, \bar{R})}{\partial \rho}\right] = 0. \tag{31}$$

[15]The discrete binomial probability mass function, $f(R_{-1}; N-1, \rho) = \frac{(N-1)!}{R_{-1}!(N-1-R_{-1})!}\,\rho^{R_{-1}}(1-\rho)^{N-1-R_{-1}}$, is not differentiable R_{-1}. Thus, we use the standard continuous extension of the binomial distribution based on the gamma function, $f(R_{-1}; N-1, \rho) = \frac{\Gamma(N)}{\Gamma(R_{-1}+1)\Gamma(N-R_{-1})}\,\rho^{R_{-1}}(1-\rho)^{N-1-R_{-1}}$ to evaluate $\frac{\partial \theta_{CEIF}}{\partial \bar{R}}$. This allows us to interpret the sign of the change in $\mathbb{G}_i$ when $\bar{R}$ increases from r to $r+1$ by integrating the right-hand side of equation (31) over the interval $[\bar{R} = r, \bar{R} = r+1]$. Hence, the impact of a discrete change in $\bar{R}$ on $\mathbb{G}_i$ depends only on the sign of the expression in equation (31).

Equation (31) captures a fundamental tension between international feasibility and domestic political incentives. Holding domestic ratification probabilities fixed, a stricter MRT mechanically reduces the likelihood that the IEA enters into force, since entry requires a larger number of countries to ratify domestically. Formally, this mechanical effect is reflected in $\partial\theta_{CEIF}(\rho, \bar{R})/\partial\bar{R} < 0$. In this sense, a higher MRT tightens the international feasibility constraint on cooperation.

At the same time, a stricter MRT endogenously increases the domestic probability of ratification, as established in Lemma 1. This political effect operates through the domestic lobbying process. Because the pro-environmental lobby values global emissions reductions whereas the anti-environmental lobby bears only national abatement costs, a higher MRT tilts lobbying incentives toward ratification, implying $\partial\rho/\partial\bar{R} > 0$. This occurs for two reasons. First, a higher MRT increases the likelihood that a country's ratification decision is pivotal for entry into force, strengthening incentives to lobby for participation. Second, when ratification is pivotal, a higher MRT increases the extent of global emissions externality internalization, since entry into force implies emissions reductions by a larger set of countries.

The optimal MRT balances these opposing forces. While a stricter MRT makes entry into force mechanically more difficult, it simultaneously strengthens domestic political support for ratification by increasing pivotality and the expected returns to lobbying in favor of participation. As a result, the MRT that maximizes expected IEA membership—and hence expected global emissions reductions—reflects a trade-off between tougher international feasibility and more favorable domestic political incentives.

3.3.3 Comparative statics of optimal IEA design

We now explore how optimal IEA design responds to changes in the number of signatory countries N. Closed-form solutions for the optimal IEA depth γ, minimum ratification threshold $\bar{R}$, and equilibrium ratification probability ρ are not available under the binomial distribution. We therefore solve for these objects numerically as functions of N. Figure 1 presents the resulting comparative statics. The lack of smoothness in the figure reflects the discrete nature of the MRT. Appendix B treats the MRT as continuous using a normal approximation to the binomial distribution; Appendix Figure B.1 confirms that the comparative statics are smooth and monotonic.

Panel (a) of Figure 1 shows that both the optimal IEA depth γ (red line) and the optimal MRT $\bar{R}$ (blue line) increase with the number of signatory countries N.[16] Intuitively, a larger pool of potential signatories expands the scope for cooperation by raising the expected returns to both deeper emissions reductions and broader membership. Panel (b) shows that the equilibrium domestic ratification probability ρ also increases with N. This outcome is not immediate from Lemma 1, since deeper IEAs reduce ratification probabilities while stricter MRTs increase them. The figures reveal that, at the optimum, the expansion in IEA breadth dominates the increase in

[16] Note that all equilibrium objects plotted in Figure 1 and Appendix Figure B.1 depend only on the single parameter N and therefore fully characterize the comparative statics.

depth. As a result, a larger number of signatory countries tilts domestic lobbying incentives toward the pro-environmental group and raises the equilibrium probability of ratification.

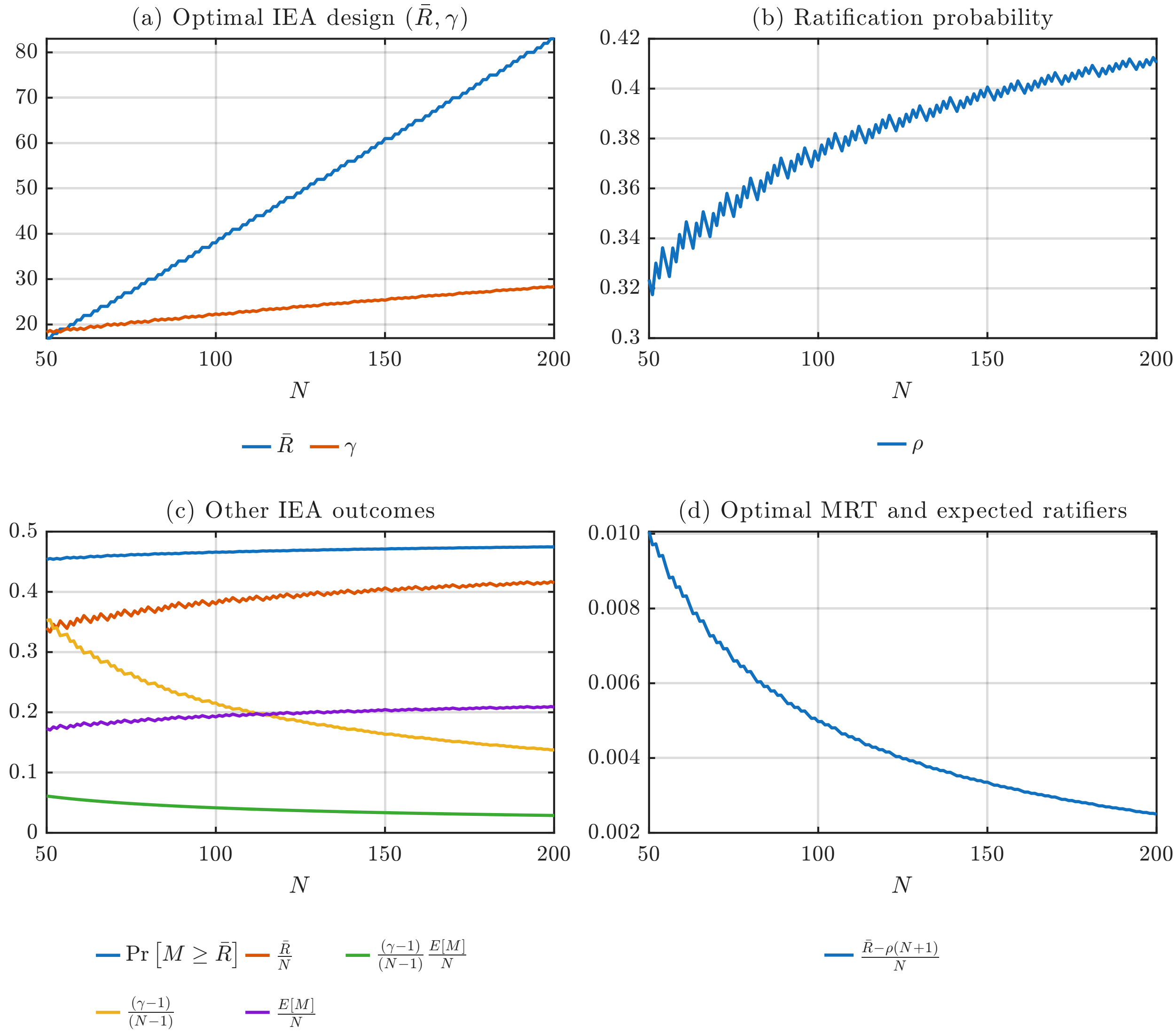

Figure 1: Comparative statics of rising number of IEA signatories (N)

Panel (c) of Figure 1 illustrates how key implementation outcomes vary with N. Despite the mechanical effect of a higher MRT reducing the likelihood of entry into force for a given ratification probability, the equilibrium probability that the IEA enters into force (blue line) increases with N. The reason is that the rise in domestic ratification probabilities more than offsets the stricter entry-into-force requirement. Consistent with this pattern, the MRT as a share of signatory countries (red line) and expected IEA membership as a share of signatory countries (purple line) both increase with N. Taken together, panels (a)-(c) show that a larger set of signatory countries leads governments to design IEAs that are broader, more demanding, and more likely to enter into force.

While a larger N leads to broader and more frequently implemented agreements, the implications for emissions outcomes are more nuanced. First, the expected total emissions reduction of signatories, $(\gamma - 1)\,\mathbb{E}\,(M)$, falls relative to the *agreement-level* socially optimal benchmark as N increases. That is, signatories find it harder to capture the gains from cooperation with more signatory countries. On the one hand, the socially optimal per-member IEA emissions reduction is $N-1$ if the N signatory countries internalize the emissions externalities they impose on each other, and the gold line in panel (c) shows that the equilibrium per-member IEA emissions reduction falls relative to this benchmark. On the other hand, the purple line in panel (c) shows that expected membership as a share of signatory countries grows with N. Overall, the green line in panel (c) shows that this positive effect on membership is more than outweighed by depth being further from the agreement-level optimum. Second, the expected total emission reduction of all members is increasing with N since both γ (red line in panel (a)) and $\mathbb{E}\,(M)$ (see purple line in panel (c)) are increasing in N. Thus, in this absolute sense, governments get closer to the outcome that maximizes global social welfare as the number of signatory countries grows.

Finally, panel (d) reveals a striking regularity in optimal IEA design. Governments choose the MRT so that domestic ratification decisions remain approximately pivotal for IEA entry into force, thereby maximizing lobbying incentives in favor of ratification. As a result, the optimal MRT closely tracks both the expected and modal number of ratifying countries. Specifically, $\bar{R}(\cdot) \approx \rho(\cdot)(N+1)$, which coincides with the modal number of ratifiers and converges to the expected number of ratifiers as N grows large.

3.3.4 The depth-breadth trade off behind optimal IEA design

The previous sections characterized the optimal depth and breadth of an IEA separately. We now examine how these two design instruments interact. Intuitively, pre-IEA (or status-quo) emissions are inefficiently high because each country fails to internalize the global emissions externality. An IEA therefore optimally reduces emissions. However, deeper emissions reductions also reshape domestic political incentives, which in turn affect the optimal minimum ratification threshold (MRT). Understanding how MRTs adjust as agreements become deeper sheds light on the political-economy origins of the depth–breadth trade-off.

Treating IEA depth γ as exogenous, governments choose IEA breadth by selecting the MRT $\bar{R}$, with a stricter $\bar{R}$ corresponding to a narrower agreement. The optimal MRT is chosen as if it maximizes expected IEA membership, which is proportional to the probability that a country belongs to an agreement that enters into force, $\rho(\gamma, \bar{R})\,\theta_{CEIF}$. The first-order condition for $\bar{R}$ therefore balances two opposing forces.

The first force is an *international political cost*. Raising $\bar{R}$ mechanically reduces the conditional probability that the agreement enters into force, θ_{CEIF}, because entry into force requires ratification by more countries. Since expected IEA membership is proportional to $\rho(\cdot)\theta_{CEIF}$, this marginal international political cost of tightening the MRT is proportional to the domestic ratification probability $\rho(\cdot)$. Because a higher γ intensifies opposition from the anti-IEA lobby and lowers the baseline probability of ratification, i.e. $\frac{\partial\rho(\bar{R},\gamma)}{\partial\gamma} < 0$, the marginal international political cost of tightening the MRT is lower when the agreement is deeper. That is, a stricter MRT reduces expected IEA membership by less when the IEA is already unlikely to enter into force.

The second force is a *domestic political benefit*. A stricter MRT increases the probability of domestic ratification, $\rho(\cdot)$, by strengthening lobbying incentives in favor of the agreement. As discussed above, $\frac{\partial\rho(\cdot)}{\partial\bar{R}} > 0$ because the pro-IEA lobby benefits more from a stricter MRT through both a higher likelihood that its country's ratification decision is pivotal for entry into force and a greater degree of global emissions externality internalization. But, how this benefit depends on IEA depth is ambiguous (i.e. $\frac{\partial^2\rho(\gamma,\bar{R})}{\partial\bar{R}\partial\gamma} \gtrless 0$). On the one hand, deeper emissions reductions raise the stakes of ratification and may increase the responsiveness of domestic political support to pivotality (i.e. $\frac{\partial^2\rho(\gamma,\bar{R})}{\partial\bar{R}\partial\gamma} > 0$). On the other hand, deeper agreements also intensify opposition from the anti-IEA lobby, reducing baseline political support and potentially weakening the extent to which a stricter MRT tilts domestic lobbying incentives toward the pro-IEA group (i.e. $\frac{\partial^2\rho(\gamma,\bar{R})}{\partial\bar{R}\partial\gamma} < 0$). If the intensification of anti-IEA lobbying dominates, then the marginal domestic political benefit of tightening the MRT declines as γ increases, pushing toward a narrower agreement as depth increases.

Under standard regularity conditions ensuring an interior optimum, and assuming higher-order interaction terms are sufficiently small, a deeper IEA is accompanied by a narrower IEA if

$$\frac{\partial\bar{R}(\gamma)}{\partial\gamma} \lesssim 0. \tag{32}$$

This can be expressed as

$$\frac{\partial^2\rho(\gamma,\bar{R})/\partial\bar{R}\partial\gamma}{\partial\rho(\gamma,\bar{R})/\partial\gamma} \gtrsim \alpha\left(\theta_{CEIF},\rho,\bar{R}\right), \tag{33}$$

where $\alpha\left(\theta_{CEIF},\rho,\bar{R}\right)$ is a positive scale factor that depends on the conditional EIF probability and its sensitivity to the MRT $\bar{R}$, and the domestic ratification probability ρ. Equation (33) says that a deeper IEA reduces the marginal domestic benefit of a stricter MRT by an amount that more than offsets the lower marginal international political cost and, in turn, deeper IEAs are narrower.

However, we cannot analytically sign the net effect of these opposing forces. Rather than imposing additional structure to resolve this indeterminacy, we numerically characterize the equilibrium response of the optimal MRT implied by the model. Figure 2 shows how the optimal MRT varies with IEA depth for different numbers of signatory countries. For every value of N, the optimal MRT declines as emissions reductions deepen: governments optimally design deeper IEAs to be narrower.

The figure illustrates a clear political-economy mechanism behind the depth-breadth trade-off. As emissions reductions become more ambitious, domestic political resistance intensifies, lowering the marginal benefit of leveraging pivotality through a stricter MRT. Governments respond by re-

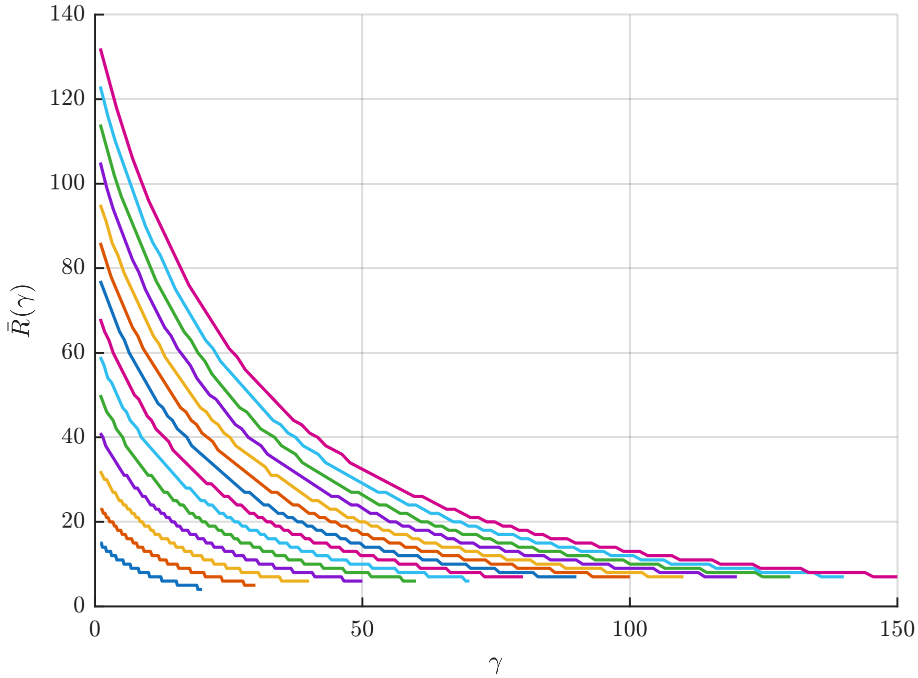

Figure 2: Optimal IEA design: Breadth vs depth

Notes: Figure shows how optimal MRT $\bar{R}$ depends on IEA emissions reductions γ and the number of IEA signatories N. Each curve corresponds to a fixed N, with successive curves increasing N by 10 from $N = 20$ to $N = 150$.

laxing the MRT, thereby increasing the probability of domestic ratification and preserving expected IEA membership. Importantly, this trade-off arises even with a fixed set of signatory countries. It is therefore driven by endogenous domestic political incentives shaped by institutional design rather than by participation or coalition-formation externalities.

3.4 Stage 1: Participation in the IEA Negotiation Process

In Stage 1, the governments of all $\bar{N}$ countries are invited to participate in the IEA negotiation process, anticipating how the IEA negotiation and domestic political ratification processes will play out in subsequent stages. Those who do not wish to do so can opt out and continue setting their status quo emissions e_{SQ}.

To make their decision, governments compare their expected payoff from participation versus opting out. For a fixed number of IEA signatories N and IEA policy design, the government of country i receives an expected payoff from participation, relative to the status quo without any IEA negotiation process, of $\mathbb{G}_i(N)$ given by equation (26). This payoff incorporates both expected national welfare and expected lobbying contributions, reflecting the endogenous design and ratification of the IEA in later stages. In contrast, a government that does not participate receives an expected payoff, relative to the status quo without any IEA negotiation process, of

$$\mathbb{G}_i^{Out}(N-1) = (\gamma - 1)\sum_{r=\bar{R}}^{N-1} r\Pr(R_{-1} = r). \tag{34}$$

This reflects pure free riding: a non-participating country benefits from expected emissions reductions undertaken by IEA members without bearing any domestic political costs of ratification or policy implementation.

Thus, the government of country i chooses to participate in the IEA negotiation process if and only if

$$\mathbb{G}_i(N) - \mathbb{G}_i^{Out}(N-1) \geq 0 \tag{35}$$

$$\Leftrightarrow (\mathbb{G}_i(N) - \mathbb{G}_i(N-1)) + \left(\mathbb{G}_i(N-1) - \mathbb{G}_i^{Out}(N-1)\right) \geq 0. \tag{36}$$

Equation (36) decomposes the government's additional payoff from IEA participation into two components. The first component is the impact on a signatory government's expected payoff due to an extra signatory country. The second component is the payoff difference between IEA signatory and non-signatory governments for a fixed number of $N-1$ IEA signatories.

All $\bar{N}$ governments strictly prefer participation in the IEA negotiation process. This follows because both components in (36) are positive. First, existing signatories benefit from greater internalization of the global emissions externality. Further, as we discussed in Section 3.3.3, the additional signatory country allows governments to design a deeper and broader IEA. Second, using equations (24) and (36), $\mathbb{G}_i(N-1) - \mathbb{G}_i^{Out}(N-1) = \rho v_{P,i} > 0$. That is, the expected government payoff is higher for signatories than non-signatories because lobbying contributions compensate the government for the political costs imposed by stricter environmental policy, and the additional payoff to the signatory reflects the pro-IEA lobby's valuation of emissions reductions. Hence, participation is universal in equilibrium. In this sense, the binding political constraint in the model is domestic ratification rather than participation in negotiations.

4 Discussion

4.1 Role of free riding

The analysis above shows how domestic lobbying behavior and its implications for ratification probabilities shape optimal IEA design. Although the model is not framed in terms of country-level participation free riding, it generates a distinct and economically meaningful form of free riding that operates through domestic political incentives. In this section, we reinterpret the comparative statics of the equilibrium ratification probability $\rho(\gamma, \bar{R})$ to show how MRTs mitigate *domestic political free riding*—a mechanism absent from canonical models of IEA formation.

Lemma 1 characterizes the equilibrium ratification probability as the outcome of a parallel lobbying contest between pro- and anti-IEA interest groups. Pro-IEA lobbying incentives depend on two forces: the expected degree of global emissions externality internalization and the probability that its country's ratification decision is pivotal for IEA entry into force. In particular, by tilting the lobbying process toward the pro-IEA group, the probability of ratification is increasing in the pivotality probability θ_{PIV}.

This structure implies a novel form of free riding. When the pro-IEA lobby expects that the MRT will be met regardless of its own country's decision—that is, when θ_{CEIF} is high relative to θ_{PIV}—the incentive to exert costly lobbying effort is weakened. Anticipated foreign ratification reduces the marginal return to domestic political effort, leading the pro-IEA lobby to free ride on expected actions abroad. As a result, equilibrium lobbying intensity and domestic ratification probabilities decline. In this sense, strong expectations of foreign ratification can undermine domestic political support for the IEA.

This mechanism differs fundamentally from free riding in canonical IEA models. In those frameworks, free riding arises at the country level: governments choose not to participate while benefiting from emissions reductions undertaken by others. In contrast, free riding in our framework operates within countries, through domestic political processes, and affects ratification probabilities rather than participation decisions.

MRTs play a central role in mitigating this form of domestic political free riding. Holding fixed the depth of the agreement, a stricter MRT raises the probability that a country's ratification decision is pivotal, increasing θ_{PIV}. By doing so, it increases the expected return to domestic lobbying effort by the pro-IEA interest group, since successful ratification is more likely to determine whether global emissions externalities are internalized. This shifts the domestic lobbying contest in favor of the pro-IEA group and raises the equilibrium probability of ratification.

This role of MRTs contrasts sharply with their function in canonical models of IEA formation. In existing frameworks, MRTs mitigate free riding by conditioning implementation on sufficiently broad participation, thereby altering governments' participation incentives through ex post payoff consequences. In our framework, MRTs operate earlier in the political process. Rather than disciplining governments through the threat of exclusion or enforcement, MRTs mitigate free riding ex ante by reshaping domestic political incentives during ratification.

Viewed through this lens, MRTs are not merely feasibility constraints. They are strategic institutional instruments that counteract domestic political free riding by increasing the likelihood that lobbying effort is pivotal. By doing so, MRTs sustain domestic political support for ambitious agreements even when foreign ratification is widely expected.

4.2 Government preferences

So far, we have assumed that the government of each country i places equal weight on its social welfare $W_i(\cdot)$ and the lobby contributions l_i it receives. However, in general, governments may place a weight $a \neq 1$ on social welfare relative to lobbying contributions so that it places relatively more weight on social welfare (lobbying contributions) when $a > 1$ ($a < 1$). That is, while still nesting our earlier functional form of the government's objective function in equation (24) as the special case of $a = 1$, we can extend beyond this special case:

$$\mathbb{G}_i\left(a; \gamma, \bar{R}, N\right) = a\left[\rho\left(v_{P,i} - v_{A,i}\right) + (\gamma - 1)\sum_{r=\bar{R}}^{N-1} r\Pr\left(R_{-1} = r\right)\right] + l_i \tag{37}$$

The parameter a captures the degree to which governments internalize social welfare relative to political rents. Using the result that $l_i = \rho v_{A,i}$ in equilibrium (see equation (19)) and equation (25), we can rewrite equation (37) as

$$\begin{aligned}\mathbb{G}_i\left(a; \gamma, \bar{R}, N\right) &= (1 - a)\,\rho v_{A,i} + \mathbb{G}_i\left(a = 1; \gamma, \bar{R}, N\right) &(38)\\ &= a\left(1 + \alpha\left(a, \gamma, N\right)\right)\mathbb{G}_i\left(a = 1; \gamma, \bar{R}, N\right). &(39)\end{aligned}$$

Here, the scale factor $\alpha\left(a, \gamma, N\right) = \frac{(1-a)}{a}\frac{(\gamma+1)}{2N}$ captures the distortion induced by lobbying revenue when governments deviate from the benchmark $a = 1$.

Crucially, the scale factor $\alpha\left(a, \gamma, N\right)$ does not depend on the MRT $\bar{R}$. As a result, government preference distortions affect IEA depth directly but affect breadth only indirectly, through the depth–breadth interaction. In our earlier analysis when $a = 1$, governments designed the optimal IEA breadth as if they maximized expected IEA membership which is proportional to the probability of a country ratifying an IEA that enters into force $\rho\left(\gamma, \bar{R}\right)\theta_{CEIF}$ (see equations (26)-(28)). Similarly, the additional $(1 - a)\,\rho v_{A,i}$ term in equation (38) is also proportional to $\rho\left(\gamma, \bar{R}\right)\theta_{CEIF}$. Thus, the additional weight placed on lobby revenue that leads to this term in equation (38) does not alter the incentives faced by governments when designing optimal IEA breadth.

In contrast, the increasing marginal cost of emissions reduction faced by the anti-IEA lobby implies that IEA depth has a stronger impact on the anti-IEA lobby's payoff than the government's expected payoff. That is, $v_{A,i}$ is proportional to $\gamma^2 - 1$ whereas the government's expected payoff when $a = 1$ is proportional to $\gamma - 1$. In turn, the scale parameter $\alpha\left(a, \gamma, N\right)$ depends on γ and setting $a \neq 1$ has a direct effect on the optimal IEA depth chosen by governments.

Using the generalized government objective function in equation (39) evaluated at the optimal IEA depth γ from earlier sections when $a = 1$, the impact of a deeper IEA on the government's objective function when $a \neq 1$ is

$$\left.\frac{\partial \mathbb{G}_i\left(a; \gamma, \bar{R}, N\right)}{\partial \gamma}\right|_{\frac{\partial \mathbb{G}_i\left(a=1;\gamma,\bar{R},N\right)}{\partial\gamma}=0} = \frac{(1-a)}{2N}\mathbb{G}_i\left(a = 1; \gamma, \bar{R}, N\right) \gtrless 0 \text{ for } a \lessgtr 1. \tag{40}$$

Equation (40) has clear implications for optimal IEA design when $a \neq 1$. When $a < 1$, governments place relatively greater weight on lobbying contributions (and relatively less weight on social welfare). Intuitively, all else equal, a deeper IEA increases the benefit to the pro-IEA (anti-IEA) lobby of ratifying (not ratifying) the IEA and hence increases lobbying intensity. In turn, this leads to a deeper agreement than in the benchmark case of $a = 1$. Conversely, when $a > 1$, governments place greater weight on social welfare, attenuating the influence of lobbying distortions and resulting in shallower emissions reductions.

Given the inverse relationship between optimal depth and breadth established in Section 3.3.4 and illustrated in Figure 2, these changes in depth translate into systematic differences in optimal MRTs. Governments that design deeper agreements optimally relax the MRT, while governments that design shallower agreements impose stricter MRTs. Taken together, these results imply that governments that place greater weight on lobbying contributions design deeper but narrower IEAs, while governments that place greater weight on social welfare design shallower but broader IEAs. Government preferences therefore shape IEA design not only directly through emissions ambition, but indirectly through institutional choices that govern ratification.

4.3 Lobby group preferences

While the economic and environmental structure underlying our lobbying framework follows Marchiori et al. (2017) and is necessarily stylized, the key assumptions play distinct roles in driving our results. In particular, one may question the assumption that the pro-IEA lobby cares solely about global emissions rather than placing greater weight on domestic environmental damages. This assumption is not essential. What matters for our mechanism is not that the pro-IEA lobby values global and domestic emissions equally, but that it places relatively greater weight on global emissions than does the anti-IEA lobby. Any preference structure that preserves this asymmetry would generate similar qualitative results.

By contrast, the curvature of lobbying payoffs is central to our analysis. In the model, the anti-IEA lobby faces an increasing marginal cost of emissions abatement, while the pro-IEA lobby enjoys a constant marginal benefit from emissions reductions. This asymmetry implies that deeper IEAs intensify opposition from the anti-IEA lobby, reducing domestic ratification probabilities. As a result, governments optimally limit IEA depth and relax the MRT as emissions reductions become more ambitious, using institutional design to counteract the ensuing domestic political backlash.

The importance of this curvature asymmetry is underscored by a simple counterfactual. If the anti-IEA lobby instead faced a constant marginal cost of abatement while the pro-IEA lobby experienced increasing marginal benefits from emissions reductions, deeper IEAs would tilt the domestic lobbying process toward greater political support. In that case, governments could leverage higher ratification probabilities to impose stricter MRTs without jeopardizing entry into force, resulting in deeper and broader agreements.

This distinction helps rationalize differences in institutional design across international agreements. MRTs are common in IEAs precisely because deeper environmental commitments tend to generate an anti-agreement backlash that must be politically managed. By contrast, in international trade agreements, deeper liberalization often strengthens pro-trade political coalitions. As shown in Cole et al. (2021), deeper tariff cuts tend to tilt lobbying incentives toward the pro-trade lobby, reducing the need for participation thresholds. More generally, whether deeper agreements become broader or narrower depends on how increased policy ambition reshapes domestic political support.

5 Conclusion

IEAs frequently condition entry into force on minimum ratification thresholds (MRTs), yet ambitious environmental commitments often face intense domestic political resistance. This paper applies a parallel-contest framework for domestic ratification, introduced in Cole et al. (2021) in the context of international trade agreements, to the design of international environmental agreements (IEAs). Within this framework, the breadth and depth of IEAs are jointly designed in anticipation of domestic ratification contests. By endogenizing ratification incentives through lobbying competition between pro- and anti-IEA interest groups, we show that MRTs are not merely feasibility constraints or enforcement devices, but strategic institutional instruments that shape domestic political incentives ex ante.

A central insight of the paper is that governments face two distinct but interrelated trade-offs when designing IEAs. First, optimal IEA depth balances economic efficiency against domestic political feasibility. While deeper agreements internalize the global emissions externality and increase aggregate welfare, they also raise abatement costs for anti-environmental interests, intensifying domestic opposition and reducing the probability of ratification. Second, optimal IEA breadth—implemented through the MRT—balances international feasibility against domestic political incentives. Stricter MRTs mechanically reduce the likelihood that an agreement enters into force, but they simultaneously strengthen domestic support by increasing both the extent of global externality internalization and the likelihood that a country's ratification is pivotal.

These trade-offs interact to generate a political-economy foundation for the classic depth–breadth trade-off in IEAs. As governments move IEA depth toward its optimal level, they optimally relax the MRT and thus design deeper agreements to be narrower. Relaxing the MRT raises the probability that the agreement enters into force, offsetting the decline in domestic ratification probability caused by more ambitious emissions commitments. Breadth and depth are therefore not independent design choices, but are jointly determined through their effects on domestic political incentives rather than participation payoffs.

Endogenizing ratification incentives also yields a novel interpretation of free riding. In existing IEA models, free riding arises at the country level, as governments prefer to remain outside an agreement while benefiting from emissions reductions undertaken by others. In our framework, free riding operates through domestic political channels. Pro-IEA interests have weaker incentives to lobby for ratification when they expect the agreement to enter into force regardless of their own country's decision, reducing the probability of ratification. Stricter MRTs mitigate this political free riding by increasing the pivotality of domestic ratification and expanding the degree of global externality internalization, thereby strengthening pro-IEA lobbying incentives. In this sense, MRTs support cooperation not by penalizing non-members ex post, but by reshaping domestic political incentives ex ante during the ratification process.

More broadly, our analysis shows that optimal IEA design reflects not only strategic interaction among governments, but also how international institutions structure domestic political behavior. Viewed through the lens of our parallel-contest framework, participation thresholds such as those used in the Kyoto Protocol and embedded more implicitly in the Paris Agreement are not merely conditions for entry into force. They are strategic policy instruments that shape domestic political incentives during ratification and thereby determine how ambitious—and how broad—international environmental cooperation can ultimately be.

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Appendix

A Proofs

Proof of Lemma 1. We can rewrite equation (21) as

$$\rho = \frac{1 + (\bar{R} - 1)\frac{\theta_{PIV}}{\theta_{CEIF}}}{1 + (\bar{R} - 1)\frac{\theta_{PIV}}{\theta_{CEIF}} + \frac{1}{2}(\gamma + 1)} \equiv \Omega(\rho). \tag{A.1}$$

By the intermediate value theorem, there is a unique interior fixed point of $\Omega(\rho) : [0,1] \times [0,1]$ if (i) $\Omega(\rho)$ is continuously decreasing in ρ and (ii) $0 < \lim_{\rho \to 1} \Omega(\rho) < \lim_{\rho \to 0} \Omega(\rho) < 1$.

First, consider (ii). All of the mass in the binomial distribution shifts to the highest possible number of successes as the binomial success probability ρ approaches 1. Formally,

$$\lim_{\rho \to 1} \frac{\theta_{PIV}}{\theta_{CEIF}} = 0 \tag{A.2}$$

given that

$$\lim_{\rho \to 1} \theta_{PIV} = \lim_{\rho \to 1} \binom{N-1}{\bar{R}-1} \rho^{\bar{R}-1} (1-\rho)^{N-\bar{R}} = 0 \tag{A.3}$$

$$\lim_{\rho \to 1} \theta_{CEIF} = 1 - \lim_{\rho \to 1} \sum_{i=0}^{\bar{R}-2} \binom{N-1}{i} \rho^{i} (1-\rho)^{N-1-i} = 1. \tag{A.4}$$

Similarly, conditional on realizing at least $\bar{R}-1$ successes, all of the mass in the binomial distribution shifts to the lowest number of possible successes $\bar{R}-1$ as the binomial success probability approaches 0. Formally,

$$\lim_{\rho \to 0} \frac{\theta_{PIV}}{\theta_{CEIF}} = \lim_{\rho \to 0} \frac{\binom{N-1}{\bar{R}-1} (1-\rho)^{N-\bar{R}}}{\sum_{r=\bar{R}-1}^{N-1} \binom{N-1}{r} \rho^{r-(\bar{R}-1)} (1-\rho)^{N-1-r}} \tag{A.5}$$

$$= \frac{\binom{N-1}{\bar{R}-1}}{\binom{N-1}{\bar{R}-1}} = 1. \tag{A.6}$$

Hence, using equation (A.1),

$$0 < \lim_{\rho \to 1} \Omega(\rho) = \frac{1}{1 + \frac{1}{2}\gamma} < \lim_{\rho \to 0} \Omega(\rho) = \frac{\bar{R}}{\bar{R} + \frac{1}{2}\gamma} < 1.$$

Second, consider (i). $\Omega(\rho)$ is continuously increasing in $\frac{\theta_{PIV}}{\theta_{CEIF}}$ using equation (A.1). And, using equation (A.5),

$$\frac{\theta_{PIV}}{\theta_{CEIF}} = \binom{N-1}{\bar{R}-1} \left[\sum_{r=\bar{R}-1}^{N-1} \binom{N-1}{r} \left(\frac{\rho}{1-\rho} \right)^{r-(\bar{R}-1)} \right]^{-1} \tag{A.7}$$

is continuously decreasing in ρ. Thus, $\Omega(\rho)$ is continuously decreasing in ρ.

The comparative static results follow from implicitly differentiating $\rho - \Omega(\rho) = 0$ after establishing that, for a fixed ρ, $\frac{\partial \Omega(\rho)}{\partial \gamma} < 0$ and $\Omega(\rho)$ is increasing in $\bar{R}$. Inspection of equation (A.1) immediately reveals $\frac{\partial \Omega(\rho)}{\partial \gamma} < 0$. For $\Omega(\rho)$ increasing in $\bar{R}$, we need to establish $\frac{\theta_{PIV}}{\theta_{CEIF}}$ is increasing in $\bar{R}$. Intuitively, conditional on realizing at least $\bar{R}-1$ successes, all of the mass in the binomial distribution shifts to the lowest number of possible successes $\bar{R}-1$ as the threshold number of successes $\bar{R}-1$ grows. Formally, log-concave probability mass functions are increasing in $\bar{R}$ (Bagnoli and Bergstrom, 2005, Corrolary 2) and the probability mass function of the binomial distribution is log-concave (Keilson and Gerber, 1971, p.386). Given $\rho\left(\gamma, \bar{R}\right)$ is increasing in $\bar{R}$ on the interval $[1, N]$, we have $\rho(\bar{R}+1) \geq \rho(\bar{R})$ for any integer $\bar{R} \in \{1, \ldots, N-1\}$. Thus, we have our desired comparative static result for continuous and discrete $\bar{R}$.

Lemma A.1.

$$(\gamma-1)\mathbb{E}(M) = \rho v_{P,i} + (\gamma-1)\sum_{r=\bar{R}}^{N-1} r \Pr(R_{-1} = r) \tag{A.8}$$

Proof. First, note that equation (16) implies equation (A.8) reduces to

$$\mathbb{E}(M) = \rho\theta_{CEIF} + \left(\bar{R}-1\right)\rho\theta_{PIV} + \sum_{r=\bar{R}}^{N-1} r\Pr(R_{-1} = r) \tag{A.9}$$

$$= \bar{R}\rho\theta_{PIV} + \sum_{r=\bar{R}}^{N-1} (\rho + r)\Pr(R_{-1} = r). \tag{A.10}$$

Second, let $f(r, n)$ denote the binomial pmf with parameters (n, ρ) and note that

$$\mathbb{E}(r) = \sum_{r=\bar{R}}^{N} r f(r, N) = \bar{R}\rho f\left(\bar{R}-1, N-1\right) + \sum_{r=\bar{R}}^{N-1} (\rho + r) f(r, N-1). \tag{A.11}$$

Applying equation (A.11) to equation (A.10) establishes the lemma. Thus, we simply need to prove equation (A.11). This can be established as follows:

$$\sum_{r=\bar{R}}^{N} rf(r,N) = \sum_{r=\bar{R}}^{N} r\Big[(1-\rho)f(r,N-1) + \rho f(r-1,N-1)\Big] \tag{A.12}$$

$$= (1-\rho)\sum_{r=\bar{R}}^{N} rf(r,N-1) + \rho \sum_{r=\bar{R}}^{N} rf(r-1,N-1) \tag{A.13}$$

$$= (1-\rho)\sum_{r=\bar{R}}^{N-1} rf(r,N-1) + \rho \sum_{r=\bar{R}-1}^{N-1} (r+1)f(r,N-1) \tag{A.14}$$

$$= \rho\bar{R}f(\bar{R}-1,N-1) + \sum_{r=\bar{R}}^{N-1} \Big[(1-\rho)r + \rho(r+1)\Big]f(r,N-1) \tag{A.15}$$

$$= \rho\bar{R}f(\bar{R}-1,N-1) + \sum_{r=\bar{R}}^{N-1} (\rho+r)\, f(r,N-1). \tag{A.16}$$

Equation (A.12) uses the fact that $f(r,N) = (1-\rho)f(r,N-1) + \rho f(r-1,N-1)$. Equation (A.13) rearranges equation (A.12). Equation (A.14) uses $f(N,N-1) = 0$ and re-defines the index variable r. Equation (A.15) isolates the $r = \bar{R}-1$ term in the second summation in equation (A.14) and collects terms. Equation (A.16) rearranges the square parentheses in equation (A.15). □

Lemma A.2.

$$\mathbb{E}(M) = \rho N\theta_{CEIF} \tag{A.17}$$

Proof. Let $X \sim \text{Bernoulli}(\rho)$ denote the probability of ratification by the Nth signatory country and $R_{-1} \sim \text{Bin}(N-1,\rho)$ denote the number of signatory countries that ratify out of the $N-1$ other signatory countries. Then, the number of ratifying countries is $R \equiv R_{-1} + X \sim \text{Bin}(N,\rho)$ and the number of IEA members is

$$M = \begin{cases} R \text{ if } R \geq \bar{R} \\ 0 \text{ otherwise,} \end{cases} \tag{A.18}$$

$$\Rightarrow M = R\,\mathbf{1}\{R \geq \bar{R}\}. \tag{A.19}$$

In turn, the expected number of members is

$$\mathbb{E}[M] = \mathbb{E}\big[R\,\mathbf{1}\{R \geq \bar{R}\}\big] = \sum_{r=\bar{R}}^{N} r\binom{N}{r}\rho^r(1-\rho)^{N-r}.$$

Using the binomial identity $r\binom{N}{r} = N\binom{N-1}{r-1}$ and re-arranging yields

$$\mathbb{E}[M] = N\rho \sum_{r=\bar{R}}^{N} \binom{N-1}{r-1} \rho^{r-1}(1-\rho)^{(N-1)-(r-1)} \tag{A.20}$$

$$= N\rho \sum_{r=\bar{R}-1}^{N-1} \binom{N-1}{r} \rho^{r}(1-\rho)^{(N-1)-r} \tag{A.21}$$

$$= N\rho\theta_{CEIF}, \tag{A.22}$$

as required. □

B Using the normal approximation

B.1 Setup

It is well known that the standard normal distribution approximates the binomial distribution when ρN is sufficiently large, with a common rule of thumb being $\rho N \geq 5$ and $(1-\rho)\,N \geq 5$. To this end, we let $z \equiv z\left(\bar{R}, \rho, N\right) = \frac{\bar{R}-1-\mu}{\sigma}$ where $\mu \equiv \rho\,(N-1)$ and $\sigma = \sqrt{(1-\rho)\,\rho\,(N-1)}$ so that $G\,(z)$ and $g(z) = \frac{\phi(z)}{\sigma}$ are the CDF and PDF of the standard normal. In turn, we define $\bar{G}(z) \equiv 1 - G(z)$ as the upper tail probability and $\tilde{g}\,(z) = \frac{g(z)}{\bar{G}(z)}$ as the conditional PDF. Further, we generalize the status quo emissions to $e_{SQ} = \beta - \eta$ so that the IEA emissions reduction is $e_{SQ} - e_{IA} = (\gamma - \eta)$ with $\eta = 1$ corresponding to the analysis in the main text. The government's objective function and the first order conditions for γ and $\bar{R}$ can now be written as

$$\mathbb{G}_i = (\gamma-\eta)\rho N \bar{G}(\bar{R}-1, N-1, \rho) \tag{B.1}$$

$$-\frac{\gamma}{(\gamma-\eta)} = \left[1 + \frac{\rho}{\bar{G}}\frac{\partial \bar{G}}{\partial \rho}\right]\frac{\gamma}{\rho}\frac{\partial \rho}{\partial \gamma} \tag{B.2}$$

$$\left(\bar{R}-1\right)\tilde{g}(z) = \left[1 + \frac{\rho}{\bar{G}}\frac{\partial \bar{G}}{\partial \rho}\right]\frac{\bar{R}-1}{\rho}\frac{\partial \rho}{\partial\left(\bar{R}-1\right)}. \tag{B.3}$$

And, given the valuations

$$v_{A,i} = \frac{1}{2}(\gamma^2 - \eta^2)\bar{G}(z) \tag{B.4}$$

$$v_{P_i} = (\gamma-\eta)\left[1 + x\tilde{g}(z)\right]\bar{G}(z), \tag{B.5}$$

the contest success function is

$$\rho = \frac{2\left[1 + \left(\bar{R}-1\right)\tilde{g}(z)\right]}{2\left[1 + \left(\bar{R}-1\right)\tilde{g}(z)\right] + (\gamma+\eta)}. \tag{B.6}$$

B.2 Optimal IEA design and comparative statics

We can now solve for the optimal $\bar{R}$ and γ as well as the equilibrium ρ. First, we characterize the optimal MRT. Dividing the FOCs in equations (B.2) and (B.3) and using the contest success function in equation (B.6) to eliminate the $\gamma + \eta$ term yields the equilibrium condition

$$(\bar{R} - 1 - \mu)\left(\frac{\bar{R} - 1}{\mu}\right) = \eta\rho. \tag{B.7}$$

Substituting $\mu \equiv \rho(N-1)$ and re-arranging yields the following quadratic equation:

$$f\left(\bar{R}; \eta, \rho, N\right) \equiv \left(\bar{R} - 1\right)^2 - \left(\bar{R} - 1\right)\rho(N-1) - \eta\rho^2(N-1) = 0. \tag{B.8}$$

Solving this equation and substituting $\eta = 1$ to correspond to the main text yields

$$\bar{R}(\rho, N, \eta) = \frac{\rho}{2}\left((N-1) + \sqrt{(N-1)^2 + 4\eta(N-1)}\right) + 1 \tag{B.9}$$

$$\Rightarrow \bar{R}(\rho, N) \equiv \bar{R}(\rho, N, \eta = 1) = \rho N + 1 - \rho\left[1 - \left(\frac{2}{1 + \sqrt{1 + \frac{4}{(N-1)}}}\right)\right]. \tag{B.10}$$

Thus, $\bar{R}(\rho, N)$ only depends on γ through ρ and $\lim_{N\to\infty} \bar{R}(\rho, N) = \rho N + 1$.

Second, we solve the equilibrium ρ. Using the FOC for γ from equation (B.2) and the contest success function in equation (B.6) to eliminate the $\gamma + \eta$ term from the FOC yields an implicit equation for ρ:

$$\rho - \frac{\left(\bar{R}(\rho, N) - 1\right)\tilde{g}(z)}{2\left(1 + \left(\bar{R}(\rho, N) - 1\right)\tilde{g}(z)\right)} = -\rho\frac{\tilde{g}(z) + 2\left[1 - \frac{\rho\tilde{g}(z)}{2(1-\rho)}\right]}{2\left(1 + \left(\bar{R}(\rho, N) - 1\right)\tilde{g}(z)\right)}. \tag{B.11}$$

Given $z \equiv z\left(\bar{R}, \rho, N\right)$, the implicit solution to equation (B.11) is $\rho(N)$ that only depends on the parameter N. In turn, substituting $\rho(N)$ into $\bar{R}(\rho, N)$ gives the optimal MRT $\bar{R}(N) \equiv \bar{R}(\rho(N), N)$ solely as a function of N.

Third, we solve for the optimal γ. Substituting $\bar{R}(N)$ and $\rho(N)$ into the contest success function in equation (B.6) with $\eta = 1$ and re-arranging yields $\gamma(N)$. Thus, we have solutions for the optimal $\bar{R}$ and γ as well as the equilibrium ρ and each only depends on the parameter N and η where $\eta = 1$ corresponds to the analysis in the main text. Figure B.1 shows how using the normal approximation to the binomial distribution smooths out the comparative static results from Figure 1 in the main text.

B.3 Status quo emissions as maximizing national benefit

While we imposed $\eta = 1$ in the main text, this was for model consistency purposes so that the status quo emissions maximized national welfare. However, we can now analyze the model for

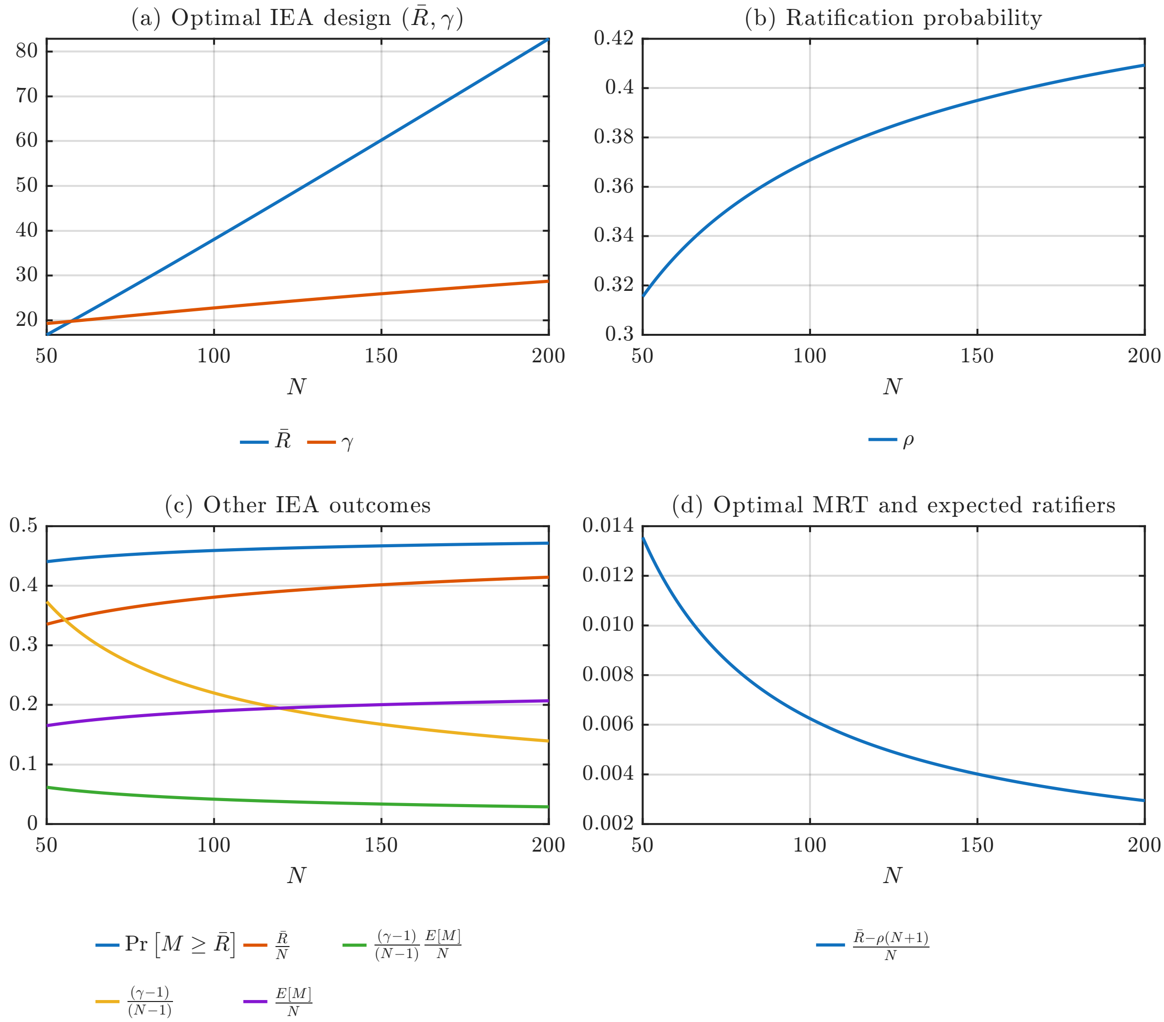

Figure B.1: Comparative statics of rising number of IEA signatories (N)

status quo emissions other than the national welfare maximizing emissions level by setting $\eta \neq 1$. Another focal point for status quo emissions would be the level that maximizes the national benefit $B_i(\cdot)$. That is, $e_{SQ} \equiv \arg\max B_i(\mathbf{e}) = \beta$ which implies $\eta = 0$.

For the optimal MRT, substituting $\eta = 0$ into equation (B.9) yields

$$\bar{R}(\rho, N) = \rho(N-1) + 1, \tag{B.12}$$

which implies $z \equiv z\left(\bar{R}, \rho, N\right) = \frac{\bar{R}-1-\mu}{\sigma} = 0$. The equilibrium ρ characterized by equation (B.11) relied on $\eta = 1$. Indeed, the right hand side of equation (B.11) is zero when $\eta = 0$. In turn, after setting the right hand side of equation (B.11) to zero and substituting $\bar{R}(\rho, N)$ using equation (B.12), solving for ρ yields:

$$\rho(N) = \frac{1}{2}\left(1 - \sqrt{\frac{\pi}{2(N-1)+\pi}}\right). \tag{B.13}$$

Finally, we can solve for γ by setting the right hand side of equation (B.11) to zero and substituting for ρ on the left hand side of equation (B.11) using the contest success function (B.6). Then, setting $\eta = z = 0$ and re-arranging yields:

$$\gamma(N) = \sqrt{\frac{(N-1)(1-\rho(N))}{\rho(N)^3}\frac{2}{\pi}}. \tag{B.14}$$

Figure B.2 confirms our previous results when $\eta = 1$ extend to the case of $\eta = 0$.

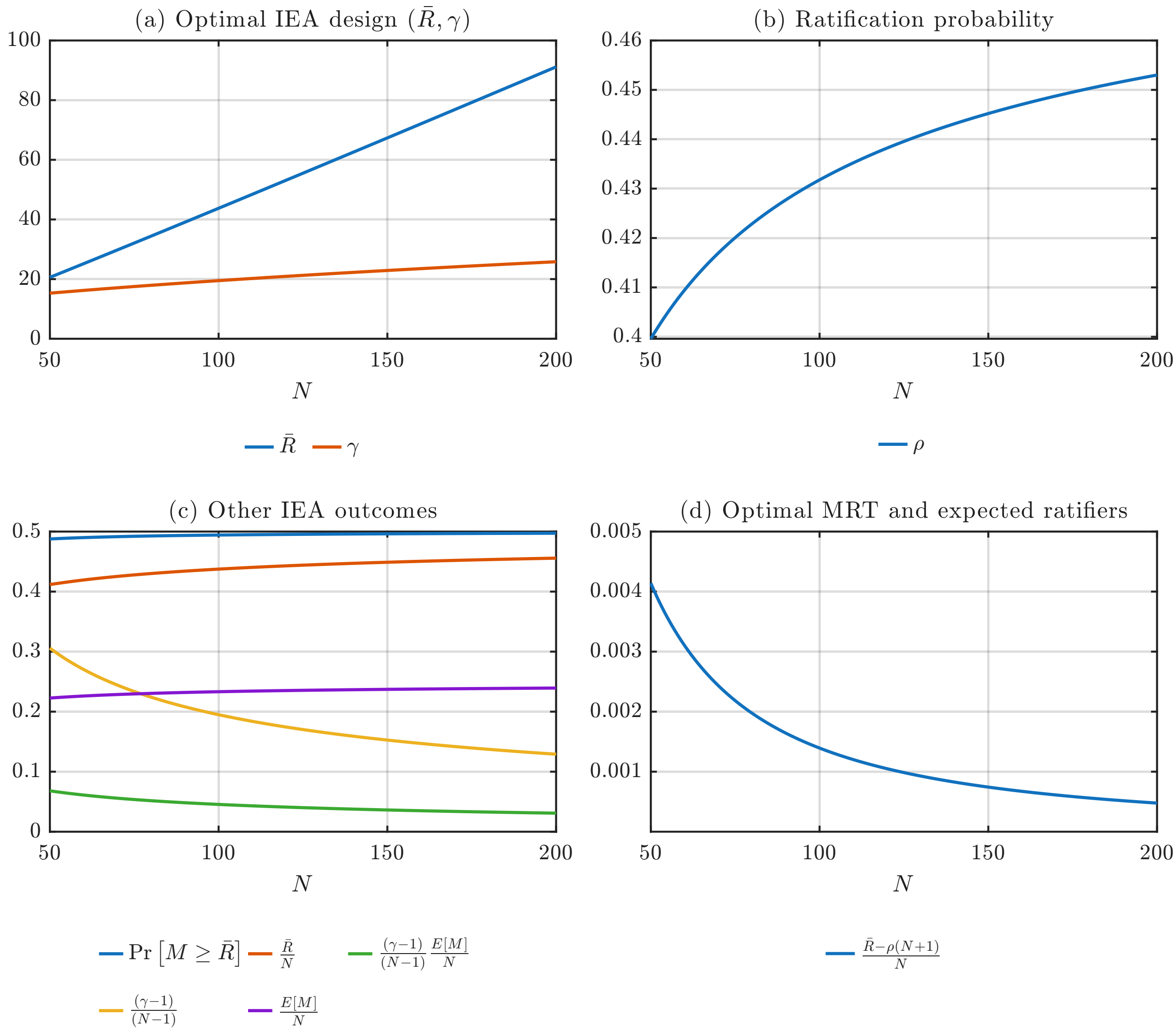

Figure B.2: Comparative statics of rising number of IEA signatories (N)