The Climate Policy Hold-Up:

How Intellectual Property Rights turn International Environmental Agreements into Buyer Cartels for Abatement Technologies

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Abstract

The success of global climate policies over the coming 20 to 25 years depends on the effective diffusion of 'green' technologies. This requires that climate agreements and international rules about access to advanced technologies such as trade-related intellectual property rights (TRIPS) interact productively. This paper examines the interaction between the formation of international environmental agreements (IEAs) and TRIPS in a simple and tractable model. The model's contribution is to highlight the presence and size of the strategic reduction in abatement commitments by countries on account of a hold-up effect. This effect induces countries negotiating an IEA to change their behavior in anticipation of the rent extraction by the innovator. As a result, IEAs undergo a drastic change in character. They have fewer signatories, who provide less abatement, conceivably less than non-signatories. Global welfare from diffusion of new technologies remains positive, but can be associated with less global abatement. Also, while countries hosting intellectual property owners extract innovation rents from TRIPS that can offset own abatement expenditures, the country may be better off without TRIPS than with, in particular if the domestic firm owns IP in breakthrough technologies.

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1 Introduction

Understanding what institutional designs will optimally coordinate, at a global level, both technological change and greenhouse gas (GHG) emissions reduction is acknowledged as a key research need both among academics and policy-makers. As economists know, however, responding to this need is far from trivial. This is because such institutional designs need to address simultaneously the complexity of building effective international mitigation agreements on the one hand (Barrett and Toman 2010) and the complexity of managing, on the other hand, what is a multi-step process of research, invention, innovation, adoption, and diffusion (Hall and Helmers 2010, Newell 2008, Requate 2005b). While there is an emerging literature on the possible scale and shape of institutions that could resolve these challenges, for example in the form of international technology-oriented agreements (De Coninck et al. 2008), the theoretical support underpinning such strategies still needs to be built.

Given the complexity of the challenge, researchers have begun to methodically break the task up into more manageable parts and to answer a set of narrower questions. The present paper follows this logic, taking existing institutions as a point of departure for a strictly positive analysis. Starting with the final stage of technological change, diffusion, we derive a number of results on how international institutions for mitigation agreements and for technology policy interact. Specifically, we examine the interaction between international environmental agreements (IEAs) on GHG abatement on the one side and trade-related intellectual property rights (TRIPs) over new technologies on the other. The results, some of them surprising, form the first of a number of building blocks that, together, will allow economists to answer the overarching question of what institutions allow addressing climate change and technological change simultaneously.

Apart from being a building block, the insights gained at the diffusion stage are also important in their own right. The reason is that over the next 20 to 25 years, much of climate-relevant technological change is expected to consist of the international diffusion of technologies that are already known (Metz and Meyer 2007).[1] The technologies are to a large extent owned by corporations in industrialized countries (Hall and Helmers 2010, Reichman et al. 2008). These corporations expect to enjoy the benefits of ownership of their intellectual property rights (IPRs) both at a domestic and at an international level for most of the next two decades. The IPRs, however, are under debate: International bodies have floated ideas for drastic limitations on TRIPs for climate-relevant technologies, including compulsory licensing and revocation of IPRs in developing countries (UNFCCC 2010). In contrast, policy-makers in industrialized countries have declared their intention to defend vigorously the international protection of 'green' IPR (Rimmer 2009), not least because many have embraced the notion that some of the domestic costs of climate policies can be offset by the inflow of rents that TRIPS on diffusing 'green' technologies will generate (Foxon 2010, Fankhauser et al. 2008). If the consensus is correct that diffusion of existing innovations will determine the success of the next 20 years of international climate policy, then the debate about the merits of IPRs in a climate context needs to advance swiftly.

This paper is a first attempt to study the interaction between TRIPs and IEAs. Appropriately, we focus at this stage on proofs of principle rather than on a realistic depiction

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[1] Influential research has claimed that stabilizing the carbon stock in the atmosphere until 2050 at around 500 ppm can be plausibly met by a portfolio of currently existing technologies ('stabilization wedges') while underlying output growth continues (Pacala and Socolow 2004).

of the real-world institutions.[2] Our aim is to derive results for useful limiting cases, to aid intuition, and to deliver results that are intelligible in the context of a well-established literature. Our modelling strategy therefore follows a parsimonious approach and builds directly on the now classic model by Barrett (1994). In the same spirit, we take the limiting case of perfect TRIPs, i.e. an international system of perfectly enforceable IPRs, as given and study how its presence impacts on the formation of an IEA, on aggregate abatement, on global welfare, and on the welfare of countries that host innovators. The main engine of the paper has some parallels with Barrett (2006) which also models the simultaneous presence of an old and a new technology, differentiated by unit abatement costs. These models conceive of IEAs as a participation game of identical countries in a linear-quadratic world of benefits and costs of abatement. We employ this framework to model the technology user countries. One difference is that as in Gancia and Zilibotti (2005) and Perino (2008), countries can choose a continuous combination of abatement technologies rather than a discrete choice between technologies as in Barrett (2006). In other words, technological change is horizontal rather than vertical. Since international IPRs in the model are perfectly enforceable, the innovator can engage in proprietary pricing of the new technology.

We derive and compare the optimal abatement levels and coalition sizes under three scenarios. One is a benchmark scenario based on Barrett (1994) in which a single technology is competitively provided at the international level. The second is that same benchmark in the presence of two technologies with (potentially) different marginal costs curves. We

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[2] Limitation of space dictate leaving out some important subtleties and problems raised by the recent literature on IEAs. Crucial problems arising in implementation have been addressed e.g. by Böhringer and Lange (2005), Eichner and Pethig (2009) and Gersbach and Winkler (2011).

show that in a model of horizontal technological change, abatement increases in the number of technologies in an essentially linear fashion,[3] while the size and stability of the IEA is invariant with respect to the number of technologies. By implication, innovation is welfare increasing both at the global and the national level, as expected. The third scenario is one in which the second technology exists and is ready for diffusion, but is privately owned by an innovator. The patent holder sets the royalty on the abatement technology after countries inside the IEA have decided on their abatement commitment. A comparison of these scenarios leads to our main propositions.

A setting in which the second innovation is provided by a monopolist will naturally restrict diffusion, decrease abatement, and give rise to a lower level of welfare than a competitive provision. This deadweight loss is both expected and the necessary static price for the dynamic benefits of IPR-based rewards for innovation. The novel finding is the presence and unexpected scale of a welfare loss on account of the strategic effects that play out at the interface of IEA formation and TRIPS. Our results show, first, that in the presence of TRIPS, IEAs have typically fewer signatories (Proposition 2). In addition, those countries that sign the IEA strategically reduce their abatement commitment in anticipation of rent extraction by the innovator. *In extremis*, signatories might abate **less** than non-signatories (Proposition 3). The reason is the presence of a hold-up problem in abatement commitment: Mitigation efforts committed to during the negotiation of the IEA reduce the demand elasticity of countries with respect to new technologies. Under TRIPS, innovators price their innovations such as to exploit their proprietary control over access to the technology and increase the license fee to be paid for the use of the new abatement technology when

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[3] Abatement is strictly linear if marginal cost curves are identical.

signatories have more ambitious abatement targets. Anticipating this, signatories not only internalize the public good dimension of their abatement efforts but also the effect on the future license fee. In effect, TRIPS on abatement technologies induce signatories to act as a buyer cartel. This reduces their abatement efforts compared to a world without proprietary pricing of the new technology. To make this point stark, we demonstrate that offering a second privately owned technology alongside an existing competitive one can lead to **lower** aggregate abatement overall (Proposition 4). Globally, a second technology always improves welfare on account of the cost diversification effect (Proposition 5). However, the country hosting the innovator is **worse off** with TRIPS in force than without (Proposition 6). While it is correct that TRIPS generate patent rents that contribute to national welfare, it also crowds out abatement by all other countries, and disproportionately so by the IEA. Since all countries, with or without the innovator, are linked together through the climate commons, the resulting climate change damages from enforcing TRIPS are always strictly larger than the patent rents.

This is by no means the first paper to look jointly at green technologies and abatement at an international level. Buchholz and Konrad (1995) study strategic technology choice by countries prior to negotiations. Stranlund (1996) considers strategic technology transfers and its welfare effects. Tol et al. (2001) examine issue linkage through technology diffusion in a climate game. Most recently Barrett (2006) and Hoel and de Zeeuw (2010) frame the problem as two global public goods provision games in which countries need to cooperate on both R and D provision and abatement. Harstad (2012a,b) studies a different hold-up problem arising from investment in superior abatement technology prior to international negotiations taking place. Benchekroun and Ray Chauduri (2012) find that eco-innovations can reduce the stability of IEAs when using a farsighted stability concept. While our contribution shares features with these other papers, there are several key differences. One is our interest in the effect of TRIPS on the international adoption of existing technologies and on the IEA formation process. Given this focus on diffusion, we do not consider upstream innovation and investments into national or international R&D programs such as Harstad (2012b), Benchekroun and Ray Chauduri (2012), Hoel and de Zeeuw (2010) and Barrett (2006). Connected to this, our paper features a firm holding IPRs in an advanced technology rather than a country. In this, the paper relates to a different literature that studies endogenous pricing of abatement technologies under environmental regulation (Laffont and Tirole 1996, David and Sinclair-Desgagné 2005, Requate 2005a, Perino 2010) in which the regulatory choices of a government and the pricing by the innovator interact in a sometimes deleterious fashion. This parallel is in clear evidence in our headline results.

In the following section, we succinctly introduce the basic benchmark model of a climate change participation game by Barrett (2006). We then extend the model in the direction of a competitive supply of a horizontal innovation and demonstrate the optimal technology mix and coalition formation. These are summarized in Proposition 1. In section 4, we study the same setting, but now under proprietary technology supply. This gives rise to five additional propositions on abatement levels, coalition size, and welfare effects of the IPR regime. Section 5 concludes.

2 Analytical framework and benchmark 1 with one freely available technology

The impact of a perfect TRIPs regime on international regime formation is most easily understood by reference to well-known benchmarks in the literature such as the results on self-enforcing agreements by Barrett (1994). Following a recent variant Barrett (2006), we assume that there are N ex-ante identical countries facing a global public good problem. Each country i receives a benefit of

$$B^i = \frac{b}{N}Q, \tag{1}$$

where $Q = \sum_i q^i$ is the aggregate level of contribution to the public good (GHG abatement). Abatement q^i is costly,

$$C^i = \frac{c}{2}(q^i)^2. \tag{2}$$

This is the standard case analyzed in Barrett (1994, 2006) which serves as a lower benchmark. The timing is as follows. First, countries simultaneously decide whether to join the IEA, then the signatories cooperatively choose their abatement levels and last non-signatories simultaneously and non-cooperatively set abatement levels.

In the last stage, a non-signatory solves the following optimization problem taking abatement by signatories and the size of the IEA-coalition as given.

$$\max_{q^i} \frac{b}{N}Q - \frac{c}{2}\left(q^i\right)^2, \tag{3}$$

where q^i is abatement by a non-signatory country i using the incumbent technology.

Imposing symmetry among all non-signatories (n) the equilibrium abatement levels are

$$q^n_{one} \quad = \quad \frac{b}{cN}, \tag{4}$$

$$\tag{5}$$

which is increasing in the marginal benefits of abatement and decreasing in the cost parameter and the number of countries (i.e. the extent of the free-rider problem).

Anticipating choices by non-signatories, signatories solve the following (cooperative) optimization problem

$$\max_{q^i} k_{one}\frac{b}{N}\left[\sum_{k_{one}} \bar{q}^i + (N - k_{one})\frac{b}{cN}\right] - \frac{c}{2}(\bar{q}^i)^2, \tag{6}$$

where k_{one} is the number of signatories (i.e. $N - k_{one}$ is the number of non-signatories) in the case where only one technology is available.

Equilibrium abatement by a signatory (s) is

$$\bar{q}^s_{one} \quad = \quad k_{one}\frac{b}{cN}, \tag{7}$$

which is k_{one} times abatement by non-signatories.

The conditions for the number of signatories k^* of a self-enforcing IEA are well known from Barrett (1994). They require that in equilibrium no signatory has an incentive to unilaterally leave the IEA and no non-signatory an incentive to unilaterally join the IEA.

$$\pi^n_{one}(k^*_{one} - 1) \quad \leq \quad \pi^s_{one}(k^*_{one}), \tag{8}$$

$$\pi^n_{one}(k^*_{one}) \quad \geq \quad \pi^s_{one}(k^*_{one} + 1), \tag{9}$$

where $\pi^s_{one}(k)$ and $\pi^n_{one}(k)$ is the welfare of a signatory or non-signatory country respectively for the case with only one technology being available. As in Barrett (2006) the number of signatories k^*_{one} is three for all $N \geq 3$. A proof is given in the appendix.

3 Benchmark 2 with two freely available technologies

In contrast to the previous section, we now introduce a new abatement technology that is simultaneously available with the incumbent one. This new technology is non-proprietary and therefore freely available. Total abatement $q^i = x^i + y^i$ by country i can hence be achieved by using any mix involving non-negative abatement levels of the incumbent (x^i) and the new (y^i) technology.[4] A country's abatement costs are given by

$$C^i\left(x^i, y^i\right) = \frac{c}{2}(x^i)^2 + \frac{d}{2}(y^i)^2. \tag{10}$$

The timing is the same as in the previous section. In the last stage, a non-signatory solves the following optimization problem

$$\max_{x^i, y^i} \frac{b}{N}Q - \frac{c}{2}\left(x^i\right)^2 - \frac{d}{2}\left(y^i\right)^2. \tag{11}$$

Imposing symmetry among all non-signatories (n), equilibrium abatement levels are

$$x^n_{two} = \frac{b}{cN}, \tag{12}$$

$$y^n_{two} = \frac{b}{dN}. \tag{13}$$

Note that non-signatory countries' abatement levels neither depend on existence or size of the coalition nor on signatories' abatement. A signatory solves the following optimization problem

$$\max_{x^i, y^i} k_{two}\frac{b}{N}\left[\sum_{k_{two}} \bar{q}^i + (N - k_{two})\frac{b}{N}\frac{c+d}{cd}\right] - \frac{c}{2}\left(x^i\right)^2 - \frac{d}{2}\left(y^i\right)^2. \tag{14}$$

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[4] The ability to use both technologies at the same time deviates from Barrett (2006) where technologies are mutually exclusive.

Again, imposing symmetry among all signatories (s), equilibrium abatement by a signatory is

$$x^s_{two} = k_{two}\frac{b}{cN}, \tag{15}$$

$$y^s_{two} = k_{two}\frac{b}{dN}. \tag{16}$$

The conditions for the number of signatories k^*_{two} of a self-enforcing IEA are analogous to those presented above. Profit functions of both signatories and non-signatories are multiples of their counterparts in the previous section. The size of a self-enforcing IEA is therefore again three ($k^*_{two} = k^*_{one} = 3$). A proof is given in the appendix.

Proposition 1 *(Additional technology) For horizontal innovation, the presence of a second abatement technology that is freely available unambiguously increases abatement by both signatories and non-signatories but does not affect the size and stability of an IEA.*

While the stability and size of the IEA are not affected by the presence of a second, competitively provided technology, aggregate abatement levels increase. Country-level and aggregate abatement by the incumbent technology are the same as in the case when only the incumbent technology is available. However, for any finite d there will be some additional abatement provided by the new technology. For all $d < c$ abatement is more than twice that provided if only the incumbent technology is available.

4 TRIPs and monopolistic technology pricing

With the benchmarks with free technologies established, we now turn to the core of the paper. Assume that in contrast to the previous section, the new technology is managed in a proprietary way: The owner of the technology is an innovator that holds a global patent to the new abatement technology. Implicitly, of course, this assumes that global patents exist and are perfectly enforceable at zero cost. This scenario provides a useful limit case for thinking about the impacts of proprietary innovations on IEAs and yields the benefits of tractable analysis and stark results.

Assume for the sake of argument that the potential innovator is a private firm and that the technology itself can be produced at zero cost. The firm's profits therefore consist exclusively of revenues from intellectual property rents or royalties. The firm maximizes profits, which implies monopoly pricing of the technology. These assumptions generate a stylized representation of the commonly held belief that technological leadership in abatement or green technologies could not only solve the climate (or other global environmental) problem, but also generate national wealth in the form of royalties.

The sequence of environmental and technology management decisions of the players in this game could be imagined to play out in a number of different ways. For example, the eco-innovator could be imagined to move first and announce a price for access to the new technology prior to negotiations on abatement taking place. Alternatively, international negotiations could precede the price announcement. Here, the timing is as follows. First, countries simultaneously decide whether to sign an IEA. Second, signatories cooperatively commit to minimum abatement efforts anticipating monopolistic pricing of the new technology, their own future abatement decisions and finally the response by non-signatories. Third, the innovator sets per-unit prices (license fees) for the use of the new technology for signatories and non-signatories exploiting third-degree price discrimination. Fourth, signatories make adoption decisions honoring any abatement commitment made in the third stage.

Fifth, non-signatories simultaneously and non-cooperatively make abatement and adoption decisions.

There are several reasons why this sequence of play is - in our mind - the most appropriate choice for modeling the strategic environment of a game of international technology diffusion and global abatement. One decisive reason for this timing is the heterogeneity in reaction times between different decision makers. Since the technology already exists, the innovating firm does not have to commit to a course of action early in the game, for example through investment. International negotiations and re-negotiations on the other hand take a considerable amount of time. That the innovating firm can change license fees faster than countries can change their participation and abatement decisions therefore seems a fair portrayal of the strategic environment. Its defining feature is that the patent holding firm has the opportunity to react to any abatement target specified in an IEA. A key implicaion is that signatories of an IEA can anticipate the effect of abatement efforts agreed as part of the IEA on the license fee to be paid for the use of the new technology. Note, also, that the strategic environment allows signatories to commit on minimum abatement levels. On first sight, this might seem contrary to the spirit of self-enforcing IEAs. But there is a subtlety here: The requirement of self-enforcement in IEAs highlight the difficulties of international policy commitment. These are the difficulties of sovereign nations entering into binding long-term commitments in negotiations with other sovereign nations. The domestic policy commitment assumed here is less demanding. It allows a government to resolve time-inconsistency issues in policy making at home. While domestic policy commitment is not perfect, its successful provision is one of the very function of government institutions. If governments could not restrict their own future actions at least to some degree, they would not have been able to establish a credible patent system or get firms to invest in abatement technologies. Models in which governments deliver domestically on their internationally declared abatement efforts rely on this ability of government to commit at home. To this extent, the commitment we make explicit here is already implicitly present in the basic Barrett model.

4.1 Abatement and adoption by non-signatories

As usual, the international game is solved by backwards induction. In the last stage, non-signatories solve the following optimization problem

$$\max_{x^i,y^i} \frac{b}{N}Q - \frac{c}{2}\left(x^i\right)^2 - \frac{d}{2}\left(y^i\right)^2 - p^n y^i, \tag{17}$$

where x^i and y^i, again, are the amounts of abatement provided by the old and new technology, respectively. p^n is the license fee paid by non-signatories for using the new technology.

Assuming an interior solution and imposing symmetry among all non-signatories (n) the equilibrium abatement levels are

$$x^n_{IPR} = \frac{b}{cN}, \tag{18}$$

$$y^n_{IPR} = \frac{b - p^n N}{dN}. \tag{19}$$

Note that abatement by non-signatories using the old technology is the same as in the previous two cases while the amount of abatement provided by the new technology depends on the level of the license fee payable by non-signatories p^n.

4.2 Abatement and adoption by signatories

In the abatement and adoption stage signatories solve the following optimization problem

$$\max_{x^i,y^i} \frac{b}{N}\left[\sum_{k_{IPR}}(x^i+y^i)+(N-k_{IPR})\left(\frac{b}{cN}+\frac{b-p^nN}{dN}\right)\right]-\frac{c}{2}\left(x^i\right)^2-\frac{d}{2}\left(y^i\right)^2-p^sy^i, \quad (20)$$

$$s.t. \quad x^i+y^i \geq \bar{q}^s,$$

where $\bar{q}^s$ is the minimum level of abatement each signatory committed to in the IEA. Signatories maximize their domestic welfare. Cooperation is therefore limited to the commitment stage of the IEA, the signing of which again is driven purely by national interests. This highlights the commitment character of abatement choices as part of an IEA that was not explicitly modeled in the standard Barrett model where commitment and abatement occur in the same stage of the game.

Two cases can arise at the abatement stage. The constraint imposed by the IEA can be binding since the country, ideally, would like to abate less. Or the IEA constraint is not binding since the country would choose the same or more abatement even in the absence of the IEA. If the minimum level committed to in the IEA binds, abatement is split as follows over the two technologies (proof see appendix)

$$x^s_{IPR-bind} = \frac{d\bar{q}^s+p^s}{c+d}, \quad (21)$$

$$y^s_{IPR-bind} = \frac{c\bar{q}^s-p^s}{c+d}. \quad (22)$$

Signatories (s) choose the cost minimizing way to achieve their abatement commitments made in the IEA which is achieved by applying the equi-marginal principle. As a result, abatement levels of both technologies depend on the level of commitment $\bar{q}^s$ and price paid for the new technology by signatories p^s.

If the minimum level of abatement committed to in the IEA does not bind, signatories' abatement levels for the two technologies are

$$x^s_{IPR-nonbind} = \frac{b}{cN}, \tag{23}$$

$$y^s_{IPR-nonbind} = \frac{b - Np^s}{dN}, \tag{24}$$

and therefore identical to non-signatories' abatement choices (if the license fee is the same). In this case actual abatement levels are independent of the initial commitment and only the usage of the new technology depends on the level of the license fee.

Which of the two cases prevails, depends of course on the license fee chosen by the innovator. The critical fee level for the commitment to bind $\hat{p}^s(\bar{q}^s)$ is

$$\hat{p}^s(\bar{q}^s) = (c + d)\frac{b}{cN} - d\bar{q}^s. \tag{25}$$

A proof is given in the appendix. Demand for the new technology by signatories is therefore given by

$$y^s_{IPR}(p^s) = \begin{cases} \frac{b-Np^s}{dN} & if \quad p^s \leq \hat{p}^s(\bar{q}) \\ \frac{c\bar{q}^s-p^s}{c+d} & if \quad p^s > \hat{p}^s(\bar{q}) \end{cases} \tag{26}$$

At this point, it is useful to note that for the case where $p^s \geq \hat{p}^s(\bar{q})$ the elasticity of demand for the new technology by signatories is a function of their commitment.

$$\epsilon_{y^s_{IPR}} = \frac{p^s}{c\bar{q}^s - p^s}, \tag{27}$$

with $\epsilon_{y^s_{IPR}}$ being decreasing in $\bar{q}^s$. An immediate implication of expression (27) is that the more ambitious the abatement target of signatories, the higher the market power of the firm holding the patent for the new technology. This implication has strategic ramifications as the innovator considers the question of optimal technology pricing.

4.3 Technology pricing

The two prices p^s and p^n charged for using the clean technology are set by the innovator to maximize its profits $\pi = k_{IPR} \cdot p^s \cdot y^s_{IPR}(p^s) + (N - k_{IPR}) \cdot p^n \cdot y^n_{IPR}(p^n)$. As the two markets (signatories and non-signatories) are perfectly separated and identities easily observable, the innovator can treat each market independently with demand functions for the new technology given by (19) and (26), respectively. The equilibrium prices are

$$p^n = \frac{b}{2N}, \tag{28}$$

$$p^s = \begin{cases} \frac{b}{2N} & if \quad \bar{q}^s \leq \hat{q} \\ \frac{c\bar{q}^s}{2} & if \quad \bar{q}^s > \hat{q} \end{cases} \tag{29}$$

High levels of commitment by signatories in the IEA stage therefore have strong strategic implications for the innovator. At the critical level $\hat{q} = \frac{b}{cN}\sqrt{\frac{c+d}{d}}$ the innovating firm is exactly indifferent between two pricing strategies that treat every country in an identical fashion or single out high abatement countries. Note that this critical level is below equilibrium abatement by non-signatories ($\hat{q} < x^n_{IPR} + y^n_{IPR}$) but, as we will see below, nevertheless sometimes imposes a binding restriction. Whenever the innovator is indifferent between the two strategies ($\bar{q}^s = \hat{q}$), it is assumed that the innovator chooses the strategy that induces commitments to be non-binding and sets $p^s = \frac{b}{2N}$. The proof is given in the appendix.

To summarize, abatement by country type and technology is therefore

$$x^n_{IPR} = \frac{b}{cN}, \tag{30}$$

$$y^n_{IPR} = \frac{b}{2dN}, \tag{31}$$

$$x^s_{IPR}(\bar{q}^s) = \begin{cases} \frac{b}{cN} & if \quad \bar{q}^s \leq \hat{q} \\ \bar{q}^s \frac{c+2d}{2(c+d)} & if \quad \bar{q}^s > \hat{q} \end{cases} \tag{32}$$

$$y^{s}_{IPR}\left(\bar{q}^{s}\right) \;=\; \begin{cases} \frac{b}{2dN} & if \quad \bar{q}^{s} \leq \hat{q} \\ \bar{q}^{s}\frac{c}{2(c+d)} & if \quad \bar{q}^{s} > \hat{q} \end{cases} \tag{33}$$

4.4 The IEA

Signatories cooperatively agree to commit to minimum abatement levels $\bar{q}^{s}$. As in the previously discussed cases of one or two competitively provided technologies, signatories internalize the public good character of abatement within the group of signatories. This allows self-enforcing IEAs to improve on the pure non-cooperative state and at the same time creates incentives to form an IEA as abatement by signatories is increasing in the number of countries joining the IEA. However, in the present case with a proprietary supply of the new abatement technology there is a second market failure in the form of monopolistic pricing by the patent holding firm. As has been shown above, the elasticity of demand for the new technology by signatories and the license fee they have to pay is a function of their commitment in the IEA (if it is binding). The more a signatory is committing to abate, the more it becomes exploitable by the patent holder. This is the fundamental hold-up problem created by the interaction between TRIPs over new abatement technologies and IEAs. The cooperative nature of the abatement decision by signatories implies that signatories now also internalize the effect of their commitment on the price all members are going to pay for using the new technology. The nature of the IEA changes to reflect the benefits to signatories of acting as a demand-side or buyer cartel. However, the partial internalization of the public good problem and of the cartel effect work in opposite directions. The former increases abatement by signatories compared to non-signatories but the latter reduces it. This and the following sections analyze how this new strategic effect changes size, stability and performance of an

IEA in the presence of IPRs on new abatement technologies.

Signatories face the following optimization problem

$$\begin{aligned} \max_{\bar{q}^i} \quad & k_{IPR}\frac{b}{N}\left[\sum_{k_{IPR}}\left[x^s_{IPR}\left(\bar{q}^i\right)+y^s_{IPR}\left(\bar{q}^i\right)\right]+\left(N-k_{IPR}\right)\left(\frac{b}{cN}+\frac{b}{2dN}\right)\right] \\ & -\frac{c}{2}\left(x^s_{IPR}\left(\bar{q}^s\right)\right)^2-\frac{d}{2}\left(y^s_{IPR}\left(\bar{q}^i\right)\right)^2-p^s\left(\bar{q}^i\right)y^s_{IPR}\left(\bar{q}^i\right). \end{aligned} \tag{34}$$

Note that for all $\bar{q}^s \leq \hat{q}$ welfare of signatories is independent of $\bar{q}^s$ because commitments are not binding below the threshold $\hat{q}$. Signatories are indifferent between all $\bar{q}^s \in [0, \hat{q}]$ and each of these outcomes would be equivalent to a case without an IEA. This is apparent when considering that the critical level of abatement $\hat{q}$ is smaller than abatement by non-signatories. Hence, agreeing on a minimum abatement level below $\hat{q}$ has no effect on outcomes and leaves signatories in the same position as non-signatories. As we show below, this gives rise to multiple equilibria (one without and a continuum with an IEA) under some parameter constellations that are, however, payoff-equivalent for all parties.

The solution to (34), ignoring $\hat{q}$ for a moment and imposing symmetry, yields the welfare maximizing level of abatement that signatories commit to is of amount (a proof is given in the appendix)

$$\bar{q}^s_{uncon} = \frac{bk_{IPR}}{cN}\frac{4(c+d)}{4(c+d)-c}, \tag{35}$$

which is a function of the number of signatories k_{IPR}. Note that $\frac{bk}{cN}$ is commitment by a country in the case where only the incumbent technology is available (benchmark 1) and that $\frac{4(c+d)}{4(c+d)-c}$ is strictly between 1 and 4/3. For any given number of signatories, commitment with proprietary technology supply is higher than without a new technology but smaller than if the technology is provided at marginal costs (benchmark 2).[5] The latter is a direct result of

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[5] The latter follows from comparing (35) with the sum of (15) and (16).

the cartel effect that induces signatories to reduce abatement compared to a situation where the new technology is provided at marginal cost.

Whether this unconstrained optimum $\bar{q}^s_{uncon} > \hat{q}$ is achievable depends on the cost parameter of the new technology. The unconstrained optimum requires that

$$d > \hat{d}(c, k_{IPR}) = \frac{3 - 2k_{IPR}^2 + k_{IPR}\sqrt{4k_{IPR}^2 - 3}}{4(k_{IPR}^2 - 1)} \cdot c. \tag{36}$$

$\hat{d}$ is decreasing in k_{IPR}, i.e. the set of technologies for which the unconstrained welfare maximum in the IEA's commitment stage can be obtained is increasing in the number of signatories.

Condition (36) divides the outcome of the commitment stage of the IEA into two sections. For any number of signatories k_{IPR} and for all $d > \hat{d}(c, k_{IPR})$, commitments by signatories are feasible and given by (35). For $d \leq \hat{d}(c, k_{IPR})$ signatories choose any $q^s \leq \hat{q}$ which results in the commitment not being binding and all countries behaving like non-signatories.

In the final step of the analysis, we now assess the stability of a self-enforcing IEA.

4.5 Signing stage

This section analyzes how monopolistic provision of the new technology affects the equilibrium size of the coalition forming an IEA, aggregate welfare and abatement and welfare of the innovator's home country. We start by applying the equilibrium conditions for a self-enforcing IEA (the same as above) to the two possible outcomes of the commitment stage.

Any successful coalition has to meet the stability as well as the feasibility constraint with the latter being a function of the number of signatories. Assuming that the feasibility constraint is met, the only stable coalition contains two countries ($k^*_{IPR} = 2$) and requires that $d \geq \frac{\sqrt{7}-2}{4}c \approx 0.1614c$. This threshold is always less restrictive than $\hat{d}(c, k_{IPR})$ evaluated at $k^*_{IPR} = 2$ ($\hat{d}(c, 2) = \frac{2\sqrt{13}-5}{12} \cdot c \approx 0.184c > \frac{\sqrt{7}-2}{4} \cdot c \approx 0.1614c$). Note that as long as $N \geq 3$, the optimal coalition size is independent of both b and N as stability conditions do not depend on them. In this case the number of signatories is always smaller than in both benchmark cases.

For $d \leq \frac{2\sqrt{13}-5}{12} \cdot c$, all countries are indifferent between no IEA and any IEA with one or more signatories. The multiplicity of equilibria arises because commitments made as part of the IEA are non-binding and hence have no effect on outcomes and payoffs. All countries continue to behave like non-signatories. Hence, there might be IEAs (with up to N signatories) that set minimum abatement levels that will be exceeded by all signatories. Proofs are given in the appendix.

Taken together the results above give rise to the following proposition

Proposition 2 *(Number of Signatories)*

- *For all* $d > \hat{d}(c, 2) = \frac{2\sqrt{13}-5}{12} \cdot c \approx 0.184c$ *the equilibrium number of signatories is two* ($k^*_{IPR} = 2$).
- *For all* $d \leq \hat{d}(c, 2)$ *the equilibrium number of signatories to an IEA is between zero and* N*, but all countries behave strictly like non-signatories and abatement levels and payoffs are independent of the number of signatories.*

Intellectual property rights on the new abatement technology have a detrimental effect on the stability of effective IEAs. The intuition for this is straightforward. Recall that incentives to join (or not to leave) an IEA are created by the response induced by other signatories. However, compared to a world without TRIPs on the new abatement technology, this response is dampened by the demand-side cartel effect. The attraction of joining (or staying in) an IEA is reduced compared to the benchmark with two freely available technologies. As a result, the equilibrium number of signatories drops from three to two if a global patent is granted for all but the most productive of abatement technologies. Moreover, for sufficiently productive new technologies IEAs become totally ineffective and the outcome in all equilibria is equivalent to one without an IEA as signatories' commitments become non-binding.

When the innovator is granted a global patent this does not only reduce the number of signatories to an IEA but also affects how much signatories abate relative to non-signatories. The amount by which signatories abate more than non-signatories is unambiguously smaller with a global patent than without - and signatories might even abate less than non-signatories.

Proposition 3 *(IEA) If the new abatement technology is protected by a global patent, then*

- *For all* $d \geq \bar{d}(c) = \frac{c}{8}\left(\sqrt{33}-3\right) \approx 0.3431c$ *signatories abate (weakly) more than non-signatories,*

- *For all* $d \in \left[\hat{d}(c,2), \bar{d}(c)\right[\approx [0.184c, 0.3431c[$ *signatories abate strictly less than non-signatories,*

- *For all* $d < \hat{d}(c,2)$ *signatories abate the same as non-signatories.*

A proof is given in the appendix. The somewhat surprising effect that signatories sometimes abate less than non-signatories is again caused by the strategic interaction between signatories and the firm owning the new abatement technology. Proposition 3 states that for a specific class of technologies the cartel effect dominates the public good effect and hence joining an IEA results in reducing instead of increasing abatement (see Figure 1). The international environmental agreement in effect becomes an international buyer cartel.

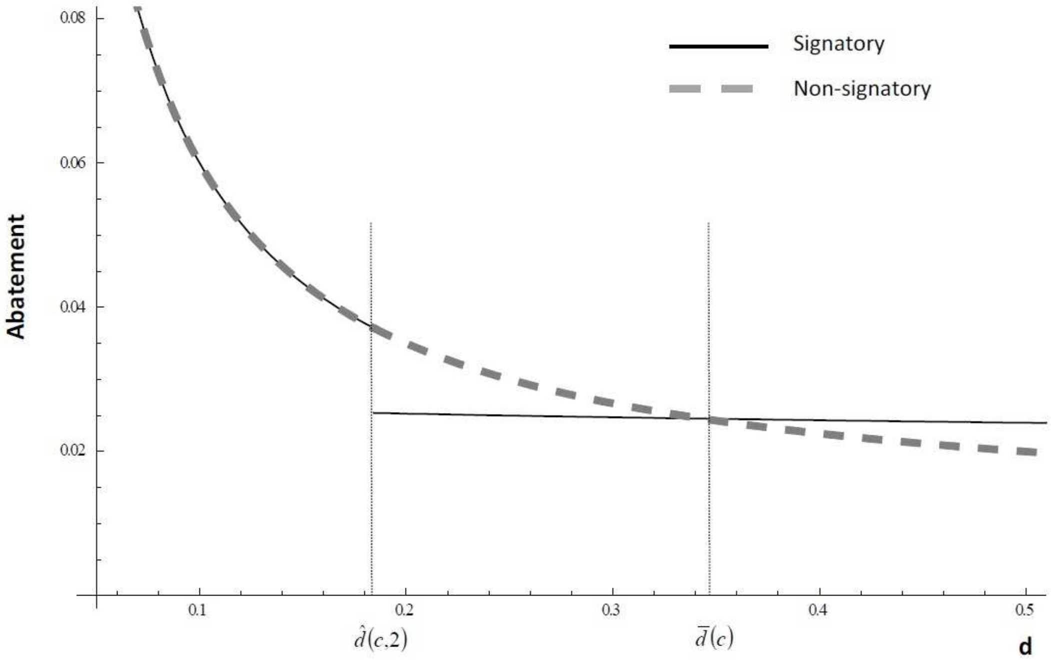

Figure 1: Abatement by signatories and non-signatories under a global patent.

We now turn to global abatement levels. The effect of TRIPs on global abatement relative to the case when the new technology is priced competitively, is clear. Both signatories to the IEA and non-signatories abate less under a global patent than their counterparts that have access to the new technology at marginal costs. Moreover, there are fewer signatories under a global patent (two instead of three) and hence aggregate abatement under a global patent is always less than with a competitively priced new technology, everything else equal.

The comparison with benchmark 1 - the case where the new technology is not available at all - is less straightforward. While both signatories and non-signatories always abate more if the new technology is available than if this is not the case, the number of signatories is reduced by one (or if there are more than two signatories with IPRs, the IEA is totally ineffective). The following proposition compares global abatement under monopolistic provision of the new technology and the case without a new technology.

Proposition 4 *(Aggregate abatement) For all* $N \geq 3$*,* b *and* $d > \tilde{d}(c, N) = \frac{c}{16}\left(N - 6 + \sqrt{N^2 + 12N - 12}\right)$*, a second technology becoming available on a proprietary basis is associated with less aggregate abatement than when a single technology is available.*

A proof of this surprising result is given in the appendix. To understand better the impact on abatement of new technologies becoming available under a TRIPs regime, figure 2 presents global abatement under the monopolistic provision of the new technology and the two benchmark cases using a specific numerical example. The reduction in abatement costs and the corresponding increase in aggregate abatement brought about by a new abatement technology is counteracted by the proprietary pricing strategy of the innovator for new technologies below a certain productivity threshold. The intuition involves two separate effects. The first of these is the diversification effect of horizontal innovation that increases abatement. Everything else (including the size of the IEA) the same, countries always abate more in the case where a patent-protected new technology is available than if only the incumbent technology exists. The size of the diversification effect, however, becomes smaller

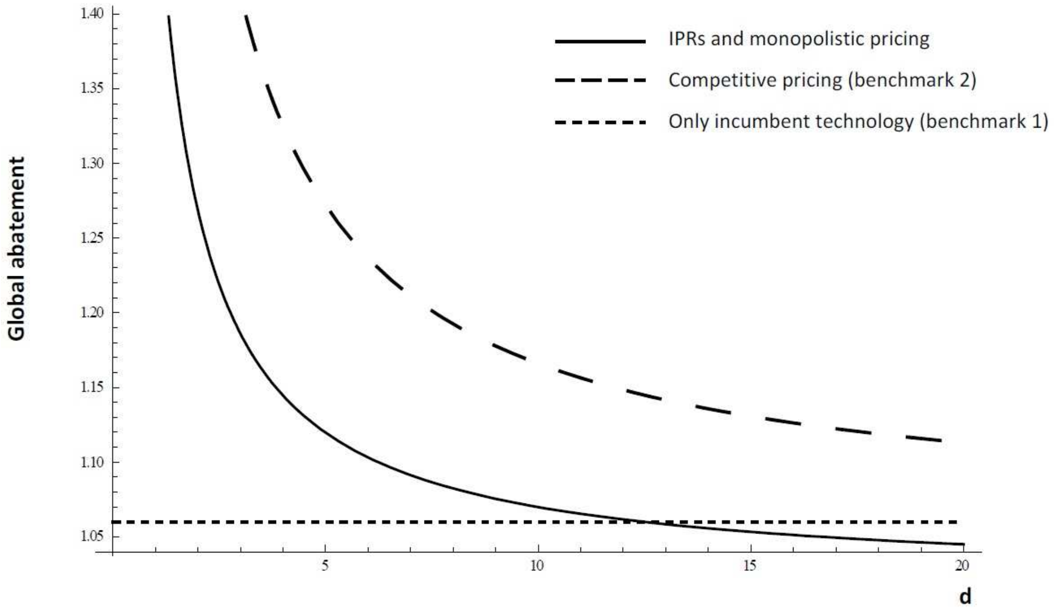

Figure 2: Global abatement with and without a global patent and with only the incumbent technology.

the higher the cost parameter d of the new proprietary technology: Expensive technologies deliver fewer gains from diversification. The second effect is the IEA size effect and affects abatement negatively: As seen above, the number of signatories of an effective IEA is only two in the presence of globally enforced IPRs on the new technology, compared to three in the case of a single incumbent technology being available. Since the positive diversification effect becomes weaker for higher d and the negative IEA size effect remains constant, for cost parameters above the threshold $\tilde{d}(c, N)$ specified in Proposition 4 the IEA size effect dominates the diversification effect. As a result, in a world with IPRs, eco-innovation can reduce global abatement.

Does Proposition 4 imply that innovation reduces welfare if patents are granted? Not so. On the one hand, a reduction in global abatement results in a loss of social benefits induced by a deterioration of environmental quality. On the other hand, the horizontal nature of innovation and the fact that both technologies are used in equilibrium imply that any given level of abatement is achieved at lower social costs than if only one technology is available. Hence, if the cost saving effect dominates the loss incurred due to lower overall abatement, global welfare increases as a result of innovation even in situations when global abatement is reduced. The dominance of the cost saving effect in the present set-up is the message of the following proposition.

Proposition 5 *(Global welfare) Global welfare is, ceteris paribus, always higher when the additional technology is protected by IPRs compared to only the incumbent technology being available.*

The proof is given in the appendix. Propositions 4 and 5 jointly speak to the global outcome of proprietary technology diffusion on environmental quality and welfare. Taken together, their message confirms that from a welfare perspective, diffusion is desirable irrespective of the presence of TRIPs regime. However, the gains from diffusion do not necessarily give rise to enhanced environmental quality. It is a distinct possibility that abatement will even decrease. The welfare effects arise in the form of lower abatement costs. The interplay of IEA and TRIPs therefore introduces an additional layer of subtlety when considering what benefits technology diffusion will deliver to global society.

A final consideration in our analysis are the welfare effects not at the aggregate level, but at the level of the country that host the innovating firm. These effects are of interest in light of the arguments that green technologies will yield significant patent rents to host countries that we reviewed in the introduction. Is it true that proprietary management of green innovations is a boon to the countries hosting the innovator? Do countries benefit from being a winner of the so-called 'green race' (Friedman 2006). The answer depends on the benchmark used for comparison. Given the symmetry assumed in our model, it certainly holds that, given a global patent is granted to the innovating firm, it is always strictly better hosting the successful firm than not. Clearly, it is better winning the prize than paying for it. However, an interesting insight from the simple model of IEA and TRIPs is that such proprietary management of the innovation may not be in the interest of the host country. Given a domestic firm wins the race, a globally enforceable perfect patent turns out to be harmful to the host country's welfare.

Proposition 6 *(Host country welfare) The home country of the innovating firm is worse off under a global patent than when the new technology is competitively available to all countries at marginal costs.*

A proof is given in the appendix. Proposition 6 holds regardless of whether the home country is a signatory or not. Generally, the result that patents induce static inefficiencies and hence a loss in post-innovation welfare compared to a competitive provision of the new technology would not be surprising. What makes it noteworthy is that this holds in the present case despite the fact that most of the deadweight loss of the firm's monopolistic pricing occurs in other countries and most of the royalties are paid by foreigners. The capturing of rents via the royalty payments is outweighed by the negative impact on the global public good induced by monopoly pricing. The proponents of green patent rents are therefore half right: Narrow measures of economic performance like GDP are likely to be higher with proprietary management of green innovations than without. Broader domestic welfare measures, however, that include damages from the global environmental good are unambiguously lower without patents. Enforcing IPRs in green innovations backfires. The presence and nature of the effect is most easily verified for non-signatories due to the linear-quadratic specification of the model. Abatement provided by the incumbent technology is not affected by IPRs and hence can be ignored in this context while abatement by the new technology in the case with IPRs ($\frac{b}{2dN}$) is half of what it would be in the absence of monopolistic pricing ($\frac{b}{dN}$). Hence, the base on which the license fee is charged and the reduction in abatement are exactly the same. For each non-signatory, the country hosting the innovating firm receives royalties of size $\frac{b}{2N} \cdot \frac{b}{2dN} = \frac{b^2}{4dN^2}$ but sees its environmental benefits reduced by $\frac{b}{N} \cdot \frac{b}{2dN} = \frac{b^2}{2dN^2}$, where $\frac{b}{2N}$ is the license fee and $\frac{b}{N}$ the marginal domestic benefit of abatement. The latter is exactly twice the former. A similar argument can be made for signatories and hence IPRs generate a net loss in terms of domestic social welfare given the new technology exists, even for the country receiving all the royalty payments.

5 Conclusion

By general agreement, the success of global GHG mitigation policies will over the coming 20 to 25 years depend on the effective diffusion of green technologies from corporate laboratories in industrialized countries to the rest of the world. If correct, such a dependence implies that the success will be shaped by how the institutions for international environmental agreements on emissions reductions and for access to advanced technologies interact. These institutions, the IEAs on GHG emissions and trade-related intellectual property rights, and their interaction is the subject of intense political debate at the international level, but is only beginning to be properly understood due to the inherent complexities of simultaneously resolving problems of international environmental policy and technology policy. This paper examines the interaction between IEA formation and TRIPS in a simple and tractable model. In addition to the predictable result that rent extraction possibilities afforded by a global IPR regime lead not only to higher prices for the new technology and hence less technology adoption than would be globally optimal, the model more importantly highlights a strategic reduction in abatement commitments by countries. As we discuss, the reason is a hold-up effect that induces countries negotiating an international environmental agreement to change their behavior in anticipation of the rent extraction by the innovator. They act as a buyer cartel for abatement technologies. As a result of this hold-up problem, international environmental agreements undergo a dramatic change in character. They decrease in size (except if they are totally ineffective), and at the same time turn from an institutional response to a coordination problem into an institutional response to a market structure problem. Global welfare from diffusion remains positive, but may perplexingly be associated with less abatement. Also, pursuing green patent rents may not be in the interest of the country hosting the innovator. While it is correct that the innovation rents extracted can offset own abatement expenditures, the gains to the country from a socially optimal global adoption of the technology may exceed the losses from foregoing patent rents. Perhaps surprisingly, countries should find it more profitable to give away breakthrough technologies rather than technologies of incremental improvements. The spirit of this paper is strictly positive, and our modeling framework of perfect global patents is deliberately stark in order to draw the effects out as clearly as possible. The weaker patent regimes of the real world may already go some way towards attenuating some of the effects brought out in this paper.

However, these weaknesses are typically more accidental than deliberate. A comprehensive reconsideration of the regimes that should govern international cooperation on abatement and the diffusion of technologies required to accomplish these abatement goals will need to show awareness of the issues raised here.

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A Appendix

A.1 Number of signatories with incumbent technology only

Using equation (7), the profit of signatories is $\pi^s_{one} = \frac{b^2}{2cN^2}\left(2N - 2k_{one} + k^2_{one}\right)$ and the profit of non-signatories is $\pi^n_{one} = \frac{b^2}{2cN^2}\left(2N - 2k_{one} + 2k^2_{one} - 1\right)$. Substituting both into condition $\pi^n_{one}(k^*_{one} - 1) \leq \pi^s_{one}(k^*_{one})$ yields $k^2_{one} - 4k_{one} + 3 \leq 0$. This implies $1 \leq k^*_{one} \leq 3$.

Condition $\pi^n_{one}(k^*_{one}) \geq \pi^s_{one}(k^*_{one} + 1)$ requires that $k_{one} - 2 \geq 0$. The equilibrium number of signatories is hence $k^*_{one} = 3$.

A.2 Optimal abatement and adoption by signatories

The Kuhn-Tucker conditions of optimization problem (20) are

$$\begin{aligned} \frac{b}{N} - cx^s - \lambda &= 0 && \text{(A.1)} \\ \frac{b}{N} - dy^s - p^s - \lambda &= 0 && \text{(A.2)} \\ \bar{q}^s - x^s - y^s &\leq 0 && \text{(A.3)} \\ \lambda &\geq 0 && \text{(A.4)} \end{aligned}$$

If constraint (A.3) is not binding and hence $\lambda = 0$, (A.1) and (A.2) yield . If (A.3) is binding, combining (A.1), (A.2) and (A.3) yields (21) and (22).

A.3 Proof of equation (25)

The price threshold is determined by (23) being equal to (21) and (24) being equal to (22). Using either condition and solving for p^s yields (25).

A.4 Technology pricing

The innovator's profit from license fees paid by a non-signatory is $\pi^n = p^n \cdot y^n_{IPR}(p^n)$. Using (19), the first order condition yields

$$\frac{b - 2p^n N}{dN} = 0. \tag{A.5}$$

Solving for p^n yields (28).

The profit obtained from a signatory is $\pi^s = p^s \cdot y^s_{IPR}(p^s)$ where demand for the new technology is given by the piecewise function (22). For $p^s \leq \hat{p}$, the first order condition requires $\frac{b-2p^sN}{dN} = 0$ and hence $p^s = \frac{b}{2N}$. For the latter to be in the specified range ($p^s \leq \hat{p}$) it has to hold that, $\bar{q}^s \leq q^{non-bind} = \frac{b(c+2d)}{2Ncd}$.

For $p^s > \hat{p}$, the first order condition requires $\frac{c\bar{q}^s - 2p^s}{c+d} = 0$ and hence $p^s = \frac{c\bar{q}^s}{2}$. For the latter to be in the specified range ($p^s > \hat{p}$) it has to hold that, $\bar{q}^s > q^{bind} = \frac{b(c+d)}{Nc(c/2+d)}$.

Note that $q^{bind} < q^{non-bind}$ and hence there is a range where the innovator can choose whether signatories' commitment $\bar{q}^s$ is binding or not. The innovator is indifferent between the two outcomes if

$$\begin{aligned} \frac{b}{2N} \cdot \frac{b}{2dN} &= \frac{c\hat{q}}{2} \cdot \frac{c\hat{q}}{2(c+d)}, && \text{(A.6)} \\ \hat{q} &= \frac{b}{cN}\sqrt{\frac{c+d}{d}}. && \text{(A.7)} \end{aligned}$$

Hence, signatories' commitment binds for all $\bar{q}^s > \hat{q}$ but does not for all $\bar{q}^s \leq \hat{q}$.

A.5 Proof of equation (35)

(34) is a straightforward maximization problem. Taking the first order condition and solving for $\bar{q}$ yields (35).

A.6 Proof of Proposition 2

Condition $\pi^n_{IPR}(k^*_{IPR} - 1) \leq \pi^s_{IPR}(k^*_{IPR})$ imposes an upper bound on the number of signatories.

$$k^*_{IPR} \leq \frac{8d(c+d) + \sqrt{d\left(16d^3 + 32cd^2 + 13c^2d - 3c^3\right)}}{4d(c+d)}. \tag{A.8}$$

Which is bound from below by 2 and from above by 3 (if $c = 1$ and d approaches plus infinity).

Condition $\pi^n_{IPR}(k^*_{IPR}) \geq \pi^s_{IPR}(k^*_{IPR} + 1)$ imposes an lower bound on the number of signatories.

$$k^*_{IPR} \geq \frac{4d(c+d) + \sqrt{d\left(16d^3 + 32cd^2 + 13c^2d - 3c^3\right)}}{4d(c+d)}, \tag{A.9}$$

which is bound from below by 1 and from above by 2 (if $c = 1$ and d approaches plus infinity).

Conditions (A.8) and (A.9) have no real solutions if $d < \frac{\sqrt{7}-2}{4}c \approx 0.1614c$.

A.7 Proof of Proposition 3

Output by signatories is given by (35) and and output by non-signatories is

$$q^n_{IPR} = \frac{b(c+2d)}{2cdN}. \tag{A.10}$$

Substituting $k^*_{IPR} = 2$ into the former it is smaller than the latter if

$$d < \frac{c}{8}\left(\sqrt{33} - 3\right) \approx 0.3431c. \tag{A.11}$$

A.8 Proof of Proposition 4

Using $k_{one} = 3$, (4) and (7) yields global abatement $Q_{one} = (N+6)\frac{b}{cN}$ if only the incumbent technology is available. Using $k_{IPR} = 2$, (30), (31), (32) and (33) in combination with (35) yields global abatement $Q_{IPR} = \frac{b}{cN}\left[(N-2)\frac{c+2d}{2d} + \frac{16(c+d)}{3c+4d}\right]$ with two technologies and IPRs. Setting $Q_{one} = Q_{IPR}$ and solving for d yields the critical point $\tilde{d}(c,N) = \frac{c}{16}\left(N - 6 + \sqrt{N^2 + 12N - 12}\right)$. For all $d > \tilde{d}(c,N)$ global abatement under a patent is less than when only the incumbent technology is available and vice versa.

A.9 Proof of Proposition 5

Global welfare in the benchmark with only the incumbent technology is $W_{one} = \frac{b^2}{cN^2}\frac{(N-12)}{2}$. Global welfare with two technologies and IPRs is $W_{IPR} = \frac{b^2}{cN^2}\frac{27c^2(N-2)+64d^3(N-2)+16cd^2(9N-2)+4c^2d(27N+10)}{8d(3c+4d)^2}$. It holds that $\frac{\partial W_{IPR}}{\partial d} = -\frac{b^2}{8d^2(3c+4d)^3N^2}\left[64d^3(3N+10) + 16d^2(27N+26) + 324c^2d(N-2) + 81c^3(N-2)\right]$ which is negative for all $N \geq 2$. Since $\lim_{d\to\infty} W_{IPR} = \frac{b^2}{cN^2}\frac{(N-2)}{2} > W_{one}$ welfare with two technologies and IPRs is always higher than in the benchmark with only the incumbent technology.

A.10 Proof of Proposition 6

If the home country is a non-signatory, welfare is given by

$$\pi^n_{IPR} = \frac{b^2}{N^2}\left[16\frac{c+d}{c(3c+4d)} + (N-2)\frac{c+2d}{2cd} - \frac{1}{2c} - \frac{1}{8d} + 32\frac{c+d}{(3c+4d)^2} + \frac{(N-3)}{4d}\right], \qquad (A.12)$$

if the country grants a global patent to the innovator and

$$\pi^n_{two} = \frac{b^2}{N^2}\left[(N+6)\frac{c+d}{cd} - \frac{1}{2c} - \frac{1}{2d}\right], \qquad (A.13)$$

if it does not. Taking the difference between π^n_{IPR} and π^n_{two} and simplifying yields,

$$\begin{aligned}\pi^n_{IPR} - \pi^n_{two} &= 16\frac{(c+d)\cdot(5c+4d)}{(3c+4d)^2} - \frac{2Nc+59c+64d}{8d}, & (A.14)\\ &= -c^3(18N+531) - c^2d(48N+1912) - cd^2(32N+2336) - 960d^3 < 0 & (A.15)\end{aligned}$$

The proof for signatory host country is analogous. The host country's welfare is therefore unambiguously higher if it does not grant a patent to the innovator.