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International Technology Agreements for Climate Change: Analysis Based on Co-Invention Data

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INTERNATIONAL TECHNOLOGY AGREEMENTS FOR CLIMATE CHANGE: ANALYSIS BASED ON CO-INVENTION DATA

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Keywords: Climate Policy, Technology, Innovation
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ABSTRACT

This paper examines the effect of multilateral energy technology initiatives, so called "Implementing Agreements", on international research collaboration in seven important climate change mitigation technologies. The analysis is conducted using patent data on 33 OECD countries during the period 1970-2009. We find that co-invention is significantly affected by the membership in the Implementing Agreement. Extending adherence to other countries would increase co-invention by about 90% in the case of wind and fuel cells, and even more in the case of biofuels, solar PV and CCS. Given the urgency to develop effective international mechanisms to mitigate climate change, these results are encouraging and the topic is an important area for further policy research.

JEL Classification: Q54, Q55, Q56, Q58, Q42, Q48, O31, O38

Keywords: Climate Policy, Technology Agreements, Technology, Innovation

RÉSUMÉ

À partir des données sur les brevets de 33 pays de l'OCDE pour la période 1970-2009, ce document analyse la manière dont les initiatives multilatérales de technologies énergétiques, dits « accords de mise en œuvre », influencent la collaboration internationale dans sept grands domaines de la recherche sur les technologies d'atténuation climatique. Le constat est que l'identité des acteurs associés à l'accord de mise en œuvre est un facteur déterminant de co-invention. Extension de l'adhésion à d'autres pays augmenterait co-invention d'environ 90% dans le cas de l'éolien et de piles à combustible, et encore plus dans les cas de biocarburants, solaire photovoltaïque, et CSC. Vu l'urgence de disposer de cadres internationaux efficaces pour atténuer les changements climatiques, il s'agit de résultats encourageants et d'une question importante pour la suite des travaux de recherche sur les politiques.

Classifications JEL: Q54, Q55, Q56, Q58, Q42, Q48, O31, O38

Mots-clés: Politique climatique, Accords sur les technologies, Technologie, Innovation

FOREWORD

This report is a contribution to the OECD Environment Directorate project on Environmental Policy and Technological Innovation (www.oecd.org/environment/innovation). It has been authored by Ivan Haščič and Nick Johnstone of the OECD Environment Directorate and Nadja Kahrobaie (formerly SciencesPo/Ecole Polytechnique in Paris). A previous version of this report was presented at the November 2011 meeting of the OECD's Working Party on Climate, Investment and Development (WPCID) and the report has benefited from the comments received. It has also benefited from the technical support for data preparation of Hélène Dernis and Dominique Guellec (OECD Directorate for Science, Technology and Industry).

This document does not necessarily represent the view of either the OECD or its member countries.

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INTERNATIONAL TECHNOLOGY AGREEMENTS FOR CLIMATE CHANGE: ANALYSIS BASED ON CO-INVENTION DATA

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1. Introduction

1. A global effort is required to reduce emissions of greenhouse gases. This can only be achieved by accelerating the development and utilization of climate change mitigation technologies (CCMT) on an international scale. The issues of technology and knowledge transfer have received special attention in recent discussions on climate mitigation. A number of commentators have seen international technology-oriented agreements as a potentially useful complement to emissions-based agreements at the international level (see, De Coninck et al. 2007; Popp 2011; Ockwell 2010). In particular, measures which support international collaborative research activities across countries can be a helpful mechanism to encourage the development and diffusion of climate mitigation technologies internationally.

2. In order to measure collaborative research activities, we build on previous work undertaken by the OECD Environment Directorate on identifying environmental and climate change mitigation technologies using patent data. Based on the search algorithms developed in close collaboration with patent examiners at the European Patent Office we are able to identify those patents which are directly relevant to climate mitigation. Moreover, the documentation allows us to identify those patents for which 'inventors' are residents of different countries – i.e. so called co-inventions.

3. This is of particular interest since until recently, studies on the internationalization of technology and knowledge focussed on foreign direct investment or international trade. Knowledge transfer through co-invention remains under-researched, and has not been examined at all in the context of climate mitigation technologies, except in a qualitative manner. In this paper we look at the specific role of the International Energy Agency's "Implementing Agreements".[1]

4. The organization of the paper is as follows. In the second part, it reviews the economics literature on the internationalization of research and diffusion of technologies. In the third part, the role of international research collaboration for climate change mitigation will be discussed. In the next section, the links between co-invention of climate mitigation technologies and Implementing Agreements are discussed. In the fifth part, the modelling strategy will be explained and the results of the econometric estimation presented. The paper concludes with some tentative conclusions and discussion of further work.

2. Literature Review

5. The general literature on the internationalization of technology is large, often using firm-level internationalization of R&D expenditures as a measure (e.g. Guellec and Zuniga 2006). This strand of literature presents the internationalization as the product of the exploitation of a firm's own knowledge assets or of knowledge external to it, usually undertaken by multinational companies (UNCTAD 2005). It reflects joint involvement of the headquarters with research facilities of affiliates or subsidiaries based in a different country (intra-firm collaboration), or research joint ventures amongst several firms or institutions in at least two different countries (inter-firm collaboration).

[1] http://www.iea.org/techno/

6. In an advanced country-level analysis Guellec and Zuniga (2006) investigate the motives for globalization of cross-border R&D investment by MNCs since the early 1990s. The authors identify two motivations:

- The dominant one being that companies source for knowledge abroad, by 'tapping talents', to make up for a lack of technological competences. Joint research endeavours allow companies to overcome shortages of resources by hiring complementary knowledge from abroad, at lower cost.

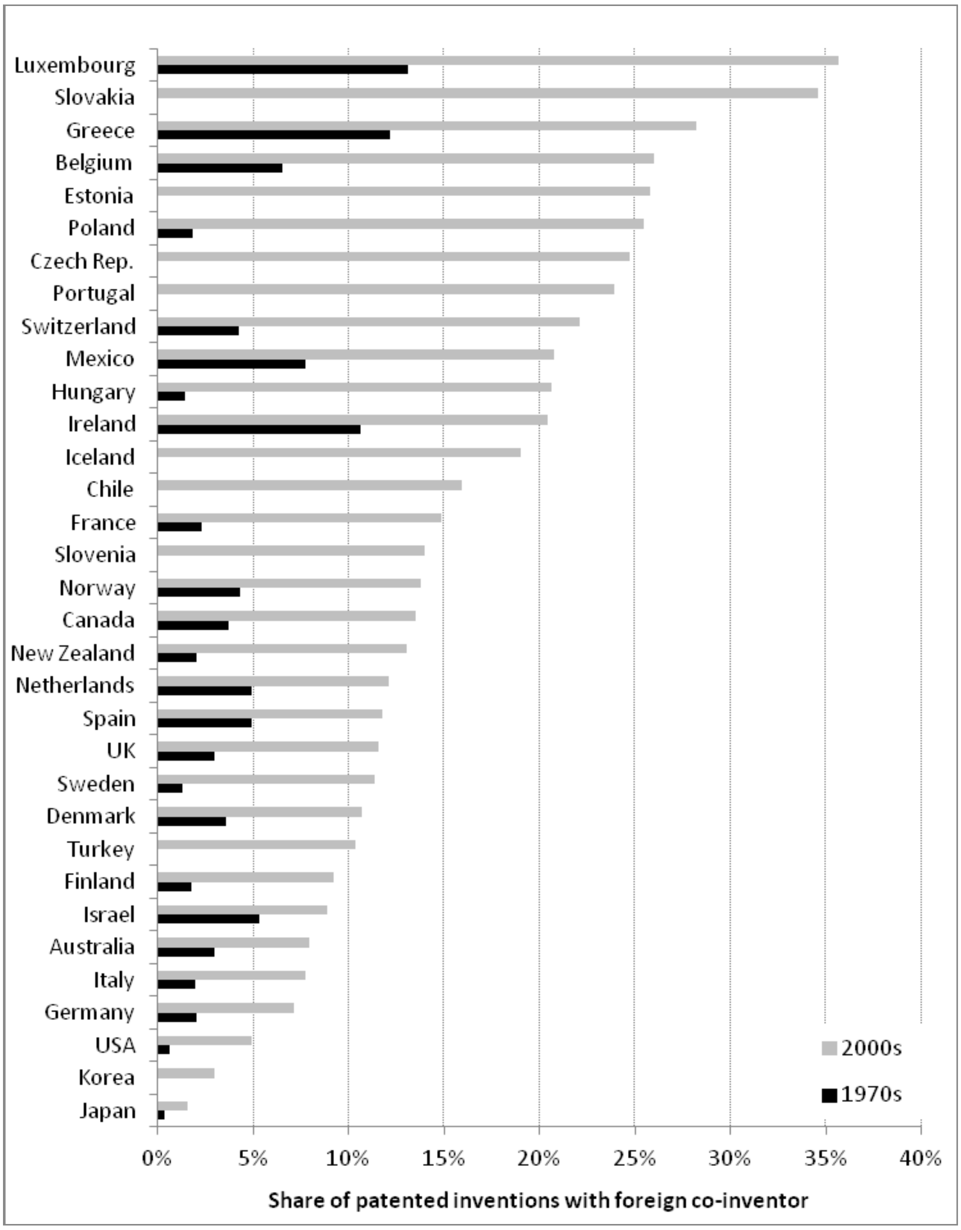
- The second, and perhaps less prominent, motivations for the globalization of activities is product adaptation to local characteristics with which market access will be increased.

7. Archibugi and Iammarino (1999) developed a taxonomy of the internationalization of innovation and technology, which has been applied by subsequent researchers. Nonetheless, investigations of patterns of internationalization of research are relatively new and remain descriptive. However, an influential paper by Guellec and Van Pottelsberghe (2001) uses patent data to understand major trends in international patenting. By creating three patent-based indicators of internationalization of technology, they find an increasing trend of globalization of technology within the OECD area. They support previous findings which indicate that for applications filed at the United States Patent and Trademark Office as well as at the European Patent Office the share of cross-border inventions in total inventions was between one and two percent until the 1980s (Bergek and Bruzelius 2005). In recent years however, this share increased rapidly, reflecting the globalization of technology due to increases in FDI or R&D investment abroad by MNCs, or simply a higher propensity to patent.

8. There is a branch of the literature which uses co-invention data in the context of network and spatial analysis to quantify geographically localized spillovers (see e.g. Jaffe et al. 1993; Breschi and Lissoni 2009; Cowan et al. 2007). For example, Ejermo and Karlsson (2006) quantify localized knowledge spillovers in interregional inventor collaboration networks in Sweden by analysing co-authorship of patents (i.e. interregional co-invention). Broekel et al. (2011) find positive evidence of inter-regional collaboration and increases in firms' innovation performance in Germany. Regional innovation systems are also investigated by Maggioni et al. (2007) who use co-invention data as one aspect in their exploration of the importance of traditional 'geographical' spillovers *vis-à-vis* 'relational' spillovers. Fontana and Geuna (2008) investigate determinants of the governance structure for a sample of successful collaborative inventive activities and find that firm size and spillovers have a positive impact on the probability to co-invent. In a study of a particular patent class Stolpe (2002) found that 969 of 1398 patents (69%) listed more than one inventor, and only 246 of 2115 inventors (12%) had always patented without help of collaborating inventors.

9. Amongst these patents, there is a sub-group in which at least two inventors reside in different countries. Those internationally co-invented patents will be the subject of our investigation. Within the OECD (OECD 2009), the world share of co-invented patents more than doubled between 1990 and 2000 to over five percent (Guellec and van Pottelsberghe 2001; see also Ma and Lee 2008). Other papers have found that co-invention is subject to large heterogeneities across time, countries, industries and firms (Guellec and van Pottelsberghe 2001; Bergek and Bruzelius 2005). Large differences in the share of co-inventive activity between inventors in different countries show that it is the smaller and less developed countries, i.e. those with lower technological intensity, that have the higher degree of technological internationalization (Guellec and van Pottelsberghe 2001; OECD 2008), such as Belgium, Ireland, the Czech Republic, Hungary and Poland. These studies also establish that inventors from two countries are more likely to collaborate if they are closer geographically and have similar technological specialization. Figure 1 gives co-invention data for the sample of OECD countries.

Figure 1. Co-Invention Rates in OECD (2000s compared with 1970s)



Note: The Figure shows cases with at least 10 inventions per year on average (in all technological fields). Constructed based on data prepared for this paper; for further details see the discussion below.

10. Overall, the rate of co-invention among OECD countries has increased significantly since the 1970s, with the highest increases in Slovakia and Poland and the lowest increases in Israel, Japan and Korea. However, in some countries co-invention has actually gone down, particularly in Chile and Turkey.

11. To our knowledge, there has not yet been a quantitative analysis of co-invention in fields relevant to climate change mitigation. This paper provides the first step in this direction.

3. International Research Collaboration in CCMTs

12. The benefits of international research collaboration may be particularly important in sectors that require large-scale investments and/or a diverse mix of research capability. In the context of climate change, many of the research efforts involve significant expenditures of resources and a wide variety of expertise.

13. National policy incentives are motivated in large part by commitments made at the international level in the context of the UNFCCC. However, the protracted and unpredictable nature of climate change negotiations has encouraged researchers to examine the role of international technology-oriented agreements and mechanisms (see De Coninck et al. 2007 for a discussion.) This approach is justified by previous theoretical research: Golombek and Hoel (2011) find that – in the light of the shortcomings of the Kyoto protocol in inciting countries to reduce emissions – the probability of collaboration on climate-friendly technologies is higher than that on emission reductions.

14. In the study by De Coninck et al (2007)[2] technology-oriented agreements are classified as:

- Knowledge-sharing and coordination;
- Research, development and demonstration and cost-sharing;
- Technology transfer; and,
- Technology mandates and incentives.

15. The International Energy Agency has established a range of multilateral energy technology initiatives in various areas such as energy efficiency, fossil fuels, fusion power and renewable energy technologies from 1975. The creation of new initiatives and increases in member numbers can be closely linked to national policy priorities: While their activities reflect patterns of close collaboration in fossil fuels in the 1980s, since the 1990s focus has been on energy savings, GHG emissions, climate change, technology transfer and renewable energies (IEA 2010). For an excellent summary of the governance of the Implementing Agreements see Figueroa (2010).

16. These so called 'Implementing Agreements' (IAs) have the objectives of sharing knowledge about these technologies across borders and creating research collaboration synergies. Membership includes member and non-member countries, businesses, industries, international organisations and non-government organisations (see Figueroa 2010). An increase in participation has been observed coming from non-IEA member countries, in particular China and India since 2007.

17. IAs are closest in nature to the first two classes of technology-oriented agreement set out above, but can have important implications for the objectives (technology transfer and standards) related to the latter two types of agreement as well. Through activities such as joint development of energy related technologies, exchanges of scientists and information and undertaking joint studies, IAs provide a unique platform to foster co-invention in CCMTs.

18. In 2010, 42 active initiatives had been registered, amongst which we will focus on seven agreements since they are closely related to climate change mitigation and they can be 'married' to search algorithms developed for the extraction of patent data:

[2] See also Hagedoorn et al. (2000), for a more general discussion.

- *Advanced Motor Fuels*: the objective of this IA is to promote understanding of alternative motor fuels, to assess their economic and environmental impacts, and to facilitate harmonization of legislation and standards.

- *Greenhouse Gases*: the goals of this IA go beyond dissemination of information, and comprise instead the evaluation of technologies, preparation of R&D proposals and projects. "Activity under the program initially focused on the capture and storage of carbon dioxide from power stations and has since broadened to explore a range of opportunities for reducing emissions of greenhouse gases. [Two of the] research and development [annexes initiated are]: geological storage of carbon dioxide, [...] and modeling of ocean storage of carbon dioxide." This has become the core focus of the agreement.

- *Advanced Fuel Cells*: this IA advances co-operative research to reduce cost and improve performance of advanced fuel cells, by establishment of expert networks, and information exchanges. According to the website, these have "strengthened national capabilities and are expected to lead to the achievement of significant technical objectives."

- *Photovoltaic (PV) Power Systems*: this IA contributes to the cost reduction of PV applications, increases awareness of their potential and value, fosters their market deployment by removing technical and non-technical barriers, and enhances technology co-operation with non-IEA countries.

- *Hydrogen*: the work of the Agreement is "directed towards the development of advanced technologies, including direct solar production systems, low-temperature metal hydrides, and room-temperature carbon nano-structures for storage." The agreement covers "research, development and demonstration stages, [over] validation of environmental and economic performance, to final market deployment". Amongst other achievements, activities have led to the establishment of a database of metal hydride material properties.

- *Energy Storage*: the goal of this IA is to develop and demonstrate various advanced energy storage technologies for application, to encourage their use by formulation of case studies, demonstrations, deployment measures and design tools. "The work program includes a range of tasks relating to development of underground thermal energy storage systems in the buildings, industrial and agriculture sectors; examination of the potential role of electrical storage technologies in optimizing electricity supply and use; examination of the role of phase-change materials and thermo-chemical reactions in energy systems; and development of procedures and screening and decision tools to facilitate the adoption of energy storage in project designs."

- *Wind Energy Systems*: "The Agreement has a purpose to produce objective information and analysis that will inform government policy."

19. IAs potentially contribute to achieving faster technological innovation at lower cost, since the financing works through cost-sharing or task-sharing of the participating countries. Collaborations bring the benefit of scale, and permit research in instances where the scale or scope is too large for a national project (The Royal Society 2011). Experiences and results of the IAs are accessible and hence create a knowledge pool and infrastructure that enhances the efficiency of future collaboration by avoiding replication of errors, duplication of efforts etc. Dissemination of information, on which a strong emphasis lies, happens by various means such as technology bulletins, and monthly or yearly publications about achievements and outputs. The activities often require the organization of conferences, workshops, and the maintenance of informative websites about proceedings and working papers (IEA 2010).

20. According to the IEA (2003 and 2010) the benefits of signing an Implementing Agreement, include:

- shared costs and pooled technical resources
- avoided duplication of effort, reduce technological and research risk, and repetition of errors
- harmonized technical standards, protection of intellectual property rights
- active network of researchers
- stronger national R&D capabilities
- improved effectiveness of future research programs
- accelerated technology development and deployment
- better dissemination of information
- easier technical consensus
- boosted trade and exports.

21. The financial cost of participation depends upon the agreement. A potentially more significant concern is loss of rents associated with knowledge diffusion. However, special provisions are applied to protect intellectual property rights (IPRs), "existing proprietary information, as well as inventions and patents developed under the IA are appropriately protected" (IEA 2010). This indicates that in principle there are no IPR-related disincentives from the establishment of genuine partnerships.

22. The Framework for International Energy Technology Co-operation of the IEA provides the legal structure and establishes the commitments of the participants to the IAs. For example, annual reports on achievements and resources need to be published while the centralized Committee on Energy Research and Technology of the IEA (CERT) reviews and evaluates those activities. The duration of every IA is time-delimited and since extensions only happen on 'exceptional circumstance and sufficient justification', the problem of inactive initiatives is reduced.

23. The benefits of being a member of an Implementing Agreement are supported indirectly by previous literature on the benefits of research partnerships. Scott (2003) uses patent cross-citations to test his hypothesis that research partnerships expand firms' absorptive capacities. He finds that efficiency gains are produced, since scarce research resources of multiple organizations are brought together, extending the range of potential outputs. Geyer et al. (2004) and Philibert (2004) investigate one Implementing Agreement on solar energy (SolarPACES) and confirm that even if international policy may not be substitutable to domestic policies; international energy technology collaboration "plays an important role [...] in reducing costs and multiplying benefits of many R&D efforts thanks to cost-sharing collaboration and information exchanges."

24. This paper evaluates cross-country collaborative research activity in the seven climate change mitigation technologies in a panel data framework. In doing so, it bridges a gap in the literature on cross-country comparisons of co-inventive activity in climate change mitigation technologies. The recent availability of co-invented patent data for climate change mitigation technologies makes it possible to investigate the following hypothesis:

Does membership in an Implementing Agreement in selected sectors of climate change mitigation technologies lead to an increase in international research collaboration?

4. The Implementing Agreements and Co-Invention in CCMTs

25. To investigate this hypothesis, we assembled the data to construct a variable for each Implementing Agreement. Since there is no source that provides the adherence dates of signatory countries in a disaggregated manner, information was collected from the respective websites and annual reports

which were then, where necessary, complemented with information communicated by the IEA Secretariat directly.[3]

26. As noted, we rely on patent data to develop our measure of co-invention. Patents are exclusive rights to an invention providing protection for a period of usually 20 years, granted by national or regional patent offices. This invention can be a device or process and is required to meet three patentability conditions: be 'new' (novelty), involve a non-obvious inventive step (non-triviality) and be considered industrially applicable (usefulness) (see OECD 2008). The earliest application date worldwide is referred to as the priority year (Dernis, Guellec and Van Pottelesberghe 2001).

27. The advantages of using patent data for tracking the internationalization of technology are numerous. First, the documentation provides a complete description of the invention. In addition, a classification of the invention in technology fields is possible. And finally, information on the inventor(s) name(s) and address(es) are registered as well as dates and a variety of other data (OECD 2009 Patent Statistics Manual). The inventor is always an individual, usually a researcher employed by the patent applicant.

28. For the purpose of this paper, co-invention occurs when two, or more, of the registered inventors declare different countries of residence. The indicators of co-invention are constructed as frequency counts of co-invented inventions. In doing so, care is taken to consider inventor information only once for each patent family in order to avoid double counting. Exploiting the inventor data can tell us much about the geographical organization of co-inventions.

29. Some care needs to be taken when analyzing international co-invention activity using patent data. The first set of limitations is conceptual and relates to the definition of what constitutes co-invention. In particular, the definition of co-invention as adopted in this paper restricts the range of hypotheses that can potentially be examined. For example, it is impossible to exclude inventions from two inventors of the same nationality but located in different countries. Also, since submission of company information, i.e. ownership or country of origin is not required in patent applications, co-invented patents may not be perfectly accurate indicators for international research collaboration, i.e. a patent may be classified as co-invented, if it results from common efforts of two laboratories of the same company, located in different countries and listed as inventors' addresses. Decisions within a company of whom to mention as listed inventor certainly play a role.

30. The second set of limitations is more general in nature and relates to the usual set of limitations concerning the use of patent data to measure innovation (see Griliches 1990). For example, care needs to be taken to control for differences in propensities to patent across industries, technological sectors, and countries. These may emerge due to differences in regulations between countries or the use of alternative strategies of protection other than patents (e.g. secrecy, reputation, or lead-time) which changes across industries. Equivalently in panel data settings, differences in the propensity to patent over time within one country or industry, i.e. due to changes in the breadth of protection of patents or in the protected technologies, need to be controlled for. In the same spirit, patents from different patent offices may have different 'breadth' and are thus not strictly comparable to each other. As explained below, we control for these concerns econometrically.

31. Finally, the third set of limitations relates to data quality issues. As with many other sources of data, patent databases do not always contain complete information (i.e. some patents included in the database may have missing attributes) and, more broadly, their coverage may vary over time and across

[3] The provision of the relevant data by Anne Lechartier of the Office of the Legal Counsel at the IEA is very much appreciated.

countries (i.e. some patents may not be included in the database, compared with the 'true' population of patents worldwide). While the availability of data on inventors appears to be of particular importance in our case, the broader question of idiosyncratic coverage is relevant as well – an aspect frequently overlooked in empirical studies using patent data. Again, we control for both of these issues econometrically.

32. In this paper, indicators of co-invention are constructed using data extracted from the European Patent Office's Worldwide Patent Statistical Database, or PATSTAT (EPO 2010). The data set was created by extracting patent information using search strategies defined by the OECD's indicator of environmental technologies (ENV-Tech). The indicator covers a broad range of environment-related technology fields. Identification of such technologies is possible using the International Patent Classification (IPC) system as well as its extension the European Classification (ECLA).

33. As noted above, in this paper patent data is used to construct indicators of co-invention in seven technological fields that are the primary focus of IAs, including wind energy, solar photovoltaics, energy from biofuels, energy storage, hydrogen, fuel cells, and carbon capture and storage (CCS). These selected fields are relevant to climate change-mitigation in energy generation. (For a list of the search strategies applied see www.oecd.org/environment/innovation). It is not the goal of the paper to cover an exhaustive list of all important climate change mitigation technologies.

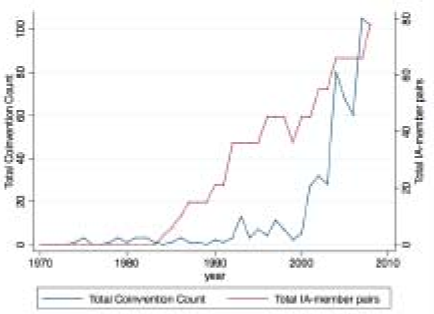
34. Table 1 indicates that there are large differences in co-invention counts between the sectors analyzed. An additional 'control sector' is included and this allows us to compare the co-invention shares of the selected CCMTs with shares for all technologies overall (TOTAL). Three CCMTs – biofuels, CCS, and fuel cells – have higher co-invention rates than what is found for all technologies overall. What might explain the relative ranking? Two factors come to mind: The degree of technology maturity and the extent to which benefits of technology development have public versus private good aspects.

Table 1. Co-Invention Rates by Technology Field

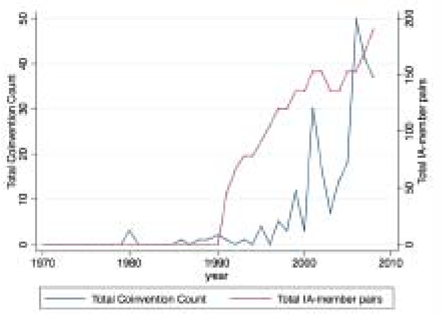
	Co-inventions	All inventions	% Co-inventions
Biofuels	603	6286	9.6
CCS	253	3501	7.2
Fuel cells	1985	34713	5.7
Solar PV	1160	22327	5.2
Hydrogen	252	5035	5.0
Energy storage	2511	54422	4.6
Wind	390	10060	3.9
PATSTAT TOTAL (all tech fields)	454998	8457380	5.4

35. The double y-plots presented in Figure 2 show the change in the number of member country-pairs over time and the total co-invention counts for the OECD sample. There are very few cases in which countries exit the Implementing Agreement. Furthermore, they have been established as early as the mid-1970s (hydrogen, energy storage, and wind) and as late as 1990 (CCS, fuel cells, and solar PV). The biofuels IA was signed in the mid-1980s. Most of the sectors display a short lag between the establishment of the implementing agreement and the increases in co-invention. Since in the areas of biofuels and wind this lag is greater than ten years, one might surmise that Implementing Agreements may be less effective in inducing co-invention in these cases. Interestingly, not all IAs grow in terms of membership in a similar fashion. Hydrogen displays 15 years of little growth, where no additional member country pairs joined the agreement.

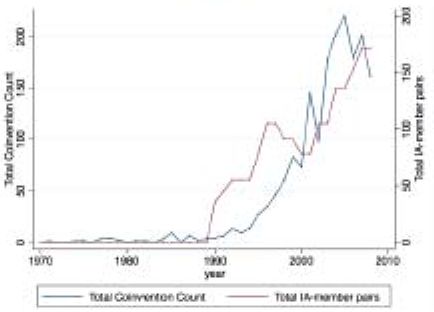
Figure 2. IEA Membership and Trends in Co-Invention Rates



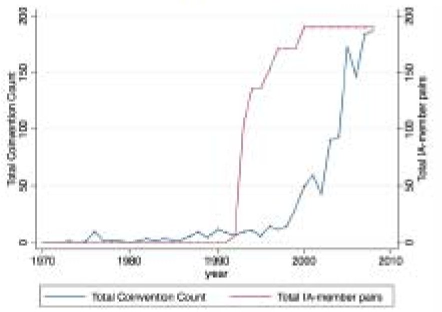
(a) Biofuels



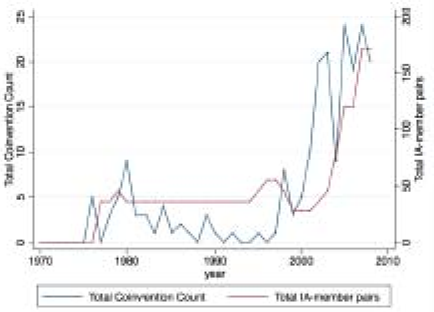
(b) CCS



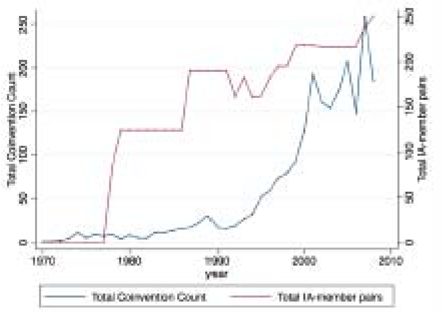
(c) Fuel cells



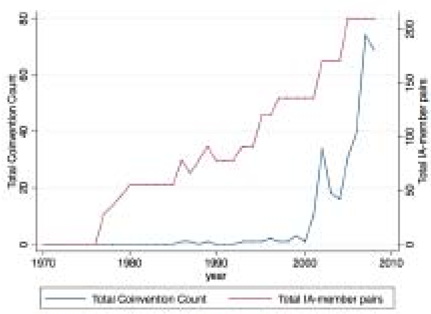
(d) Solar PV



(e) Hydrogen



(f) Energy Storage



(g) Wind

36. Bearing in mind the descriptions of the Implementing Agreements, it is not surprising to find important discrepancies in the descriptive data. In the case of Wind Energy Systems, which has the sole objective of producing and sharing information, co-invention rates are low. The Photovoltaic Power Systems (PPS) IA encompasses a large array of different activities, and co-invention rates are higher. This may indicate that the effect of information dissemination has a slower effect on co-invention; while the effect of PPS, since it emphasize development and deployment, leads to faster results in co-invention.

37. When investigating top co-inventing country pairs by levels, the United States and Germany stand out, while Japan, which is a top-inventor country, is relatively under-represented. This indicates that there may be major differences in inventive activities and co-inventive ones: Countries which have a high propensity to innovate do not necessarily have a high share of co-invented patents. The converse is also true. For instance, Denmark and New Zealand feature as first and second in selected fields in Table 2.

Table 2. Top 10 Co-inventor Country Pairs, Levels (2000-2008)

Sector / Rank	Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	Energy storage	Wind	PATSTAT TOTAL
1	DK-US	CA-US	JP-US	JP-US	DE-US	GB-US	DK-GB	GB-US
2	NL-US	NL-US	CA-US	DE-US	JP-NZ	CA-US	DE-US	DE-US
3	CA-US	GB-US	DE-US	GB-US	CH-DE	DE-US	CA-US	CA-US
4	DE-US	FR-US	GB-US	CH-DE	IT-US	JP-US	DE-NL	CH-DE
5	**CN-DK**	DE-US	**CN-US**	AT-DE	CA-US	JP-KR	NL-US	JP-US
6	DE-GB	AU-NL	KR-US	CA-US	CH-US	FR-US	DE-DK	FR-US
7	GB-US	DE-GB	FR-US	**CN-US**	FI-SE	CH-DE	**IN-US**	NL-US
8	CH-DE	GB-NL	CH-DE	DE-FR	DE-FR	CA-FR	**BE-ZA**	DE-FR
9	GB-NL	NO-US	CA-FR	DE-NL	DE-GB	**CN-US**	**RU-US**	CH-FR
10	JP-US	**CN-US**	CA-DE	GB-IT	**IN-US**	KR-US	DK-ES	CH-US

Note: The two-letter standard international country codes refer to: Austria (AT), Australia (AU), Belgium (BE), Canada (CA), Switzerland (CH), China (CN), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), United Kingdom (GB), India (IN), Italy (IT), Japan (JP), Korea (KR), the Netherlands (NL), Norway (NO), New Zealand (NZ), Russia (RU), Sweden (SE), the United States (US), and South Africa (ZA).

38. Amongst the emerging economies it is also interesting to note that China is amongst the top 10 co-inventor pairs in five of the technologies examined, and India in the remaining two technologies. Russia is also present (wind), as is South Africa (wind). Conversely, no BRICS country figures in the top ten co-invention pairs for all technologies, indicating that collaboration in CCMTs may be particularly important for them.

5. Modelling Strategy and Results

5.1 Modelling Strategy

39. The goal of this paper is to assess the effect of participation in Implementing Agreements on co-inventive activity between OECD countries. In order to correctly specify this relationship it is however important to control for other factors that may motivate international research collaboration. In our reduced-form model these factors are controlled for through the use of variables which reflect inventive capacity in the specific field, as well as propensity to collaborate in general. The following empirical model is specified:

$$COINV_{ij,t} = f\,(IA_{ij,t}\,, RD_{ij,t}\,, TOTALCOINV_{ij,t}\,, \alpha_i\,, \alpha_j) + \varepsilon_{ij,t}$$

where *ij* indexes country-pairs and *t* indexes time (1970-2009). The models are run separately for each technological field, and country dummies are included. The maximum sample consists of 514 country-pairs (including 33 OECD member countries) over the period of 40 years (1970-2009) and contains 8610 observations. However, we have only retained those observations in which there is evidence of at least some co-invention in any field.

40. The dependent variable COINV is the count of bilateral co-inventions in each technological field. It measures the number of patented inventions (claimed or unclaimed priorities) whose inventors come from at least two different countries, specifically countries *i* and *j*. The priority date of the invention (i.e. the earliest date when an application for patent protection has been made worldwide) defines year *t*.

41. IA is a binary variable indicating whether both countries were members of the relevant energy technology "Implementing Agreement" in year *t*. In addition to the joint membership dummy (IA_BOTH), in some model specifications we also include a dummy for the case when only one of the countries participated (IA_EITHER). The sign of these variables is expected to be positive.

42. RD controls for research & development capacity and is constructed in two alternative ways. First, a variable (RD_EXP) is constructed as an unweighted sum of R&D expenditures by the two countries (*i* and *j*) for the budget category which most closely relates to the technology field in question. This data has been obtained from the IEA Energy Technology R&D Database (IEA 2010). In an alternative specification, we include a covariate (RD_INV) which measures the sum of patented inventions (claimed or unclaimed priorities) in the specific technological field registered by inventors from country *i* or *j*. This variable is constructed using data extracted from the PatStat database discussed above. Sample sizes are slightly larger in the latter case due to some missing R&D expenditure data.

43. TOTALCOINV is the count of bilateral co-inventions in all technological fields (that is, not only climate-related). It is important to point out that this variable is constructed in exactly the same manner as the dependent variable. This variable reflects co-invention patterns in patenting activity overall, and not only in a specific field. As such, it controls for the differences in general propensity to co-invent and patent over time and across countries. It thus captures all of the more general economic factors that are likely to influence patented co-invention (e.g. openness, common language, geographic distance, FDI, labour mobility, regional trade agreements, etc.), but that are not specific to a narrow technological field.[4] And perhaps most importantly, it controls for database idiosyncrasies (coverage, completeness of data) as discussed above. The sign of this covariate is expected to be positive.

44. Since the dependent variable is the count of bilateral co-inventions, the analytical framework is within the realm of discrete dependent variable regression models and specifically within the sub-category of count models. The variable displays frequent zero counts and low integer values. In this paper we primarily present results based on the estimation of negative binomial models, but a number of other count data models were estimated with similar results (incl. the conditional fixed-effects negative binomial and the zero-inflated negative binomial model). (For general references on count data models see Wooldridge 2002; Cameron and Trivedi 1998; Hausman, Hall and Griliches 1984).

[4] In a related manner, Johnstone et al. (2012) estimate sector-specific models for innovation in selected environmental technologies and use total invention to control for these generic factors. To address the concern that estimating a reduced-form model may not sufficiently control for these general economic factors they also estimate a two-stage model. Using a two-stage model they confirm that "although the coefficient of the predicted total patents is smaller in magnitude, the expected positive sign and statistical significance persist. The findings suggest that an estimation of the reduced-form model, where total patents are considered to be exogenous, provides closely comparable results with those of the two-stage estimation."

45. The model is estimated only on those observations where (any) co-invention actually occurred. That is, all models are estimated on a sample where total co-invention is non-zero ($TOTALCOINV_{ij,t} > 0$). This is because we are interested in whether IA ‘bends’ the direction of co-invention towards more climate-related technologies. This gave us a maximum sample size of 8610 observations. See Table 3 for summary statistics.

Table 3. Descriptive Statistics for the Full Estimation Sample

Variable	Obs	Mean	Std. Dev.	Min	Max
COINV					
_Biofuels	8610	0.073	0.664	0	24
_CCS	8610	0.031	0.413	0	24
_Fuel cells	8610	0.213	1.656	0	39
_Solar PV	8610	0.148	0.881	0	21
_Hydrogen	8610	0.025	0.226	0	8
_En.Storage	8610	0.272	1.629	0	36
_Wind	8610	0.038	0.449	0	17
IA_BOTH					
_Biofuels	8610	0.115	0.320	0	1
_CCS	8610	0.258	0.437	0	1
_Fuel cells	8610	0.222	0.416	0	1
_Solar PV	8610	0.293	0.455	0	1
_Hydrogen	8610	0.194	0.396	0	1
_En.Storage	8610	0.437	0.496	0	1
_Wind	8610	0.363	0.481	0	1
IA_EITHER					
_Biofuels	8610	0.434	0.496	0	1
_CCS	8610	0.352	0.478	0	1
_Fuel cells	8610	0.393	0.488	0	1
_Solar PV	8610	0.324	0.468	0	1
_Hydrogen	8610	0.503	0.500	0	1
_En.Storage	8610	0.259	0.438	0	1
_Wind	8610	0.468	0.499	0	1
RD_EXP					
_Biofuels	7066	1.61	5.48	0	65
_CCS	7066	20.10	247.45	0	4121
_Fuel cells	7066	10.69	36.18	0	344
_Solar PV	7066	31.51	47.89	0	439
_Hydrogen	7066	6.74	26.227	0	269
_En.Storage	7066	12.29	30.20	0	462
_Wind	7066	15.01	21.12	0	219
RD_INV					
_Biofuels	8610	15.24	48.45	0	565
_CCS	8610	5.21	20.22	0	269
_Fuel cells	8610	79.26	239.57	0	2619
_Solar PV	8610	51.49	138.24	0	1465
_Hydrogen	8610	8.16	26.51	0	311
_En.Storage	8610	136.59	302.41	0	2647
_Wind	8610	23.46	56.10	0	703
TOTALCOINV	8610	58.014	224.00	1	3468

5.2 Base Model Results

46. The base model results support the principal hypothesis that membership in Implementing Agreements (IA) increases international research collaboration and leads to higher co-invention. All coefficients of IA_BOTH are positive and statistically highly significant, with the exception of hydrogen (Table 4). For example, the results indicate that a change in the IA_BOTH variable from 0 to 1, and holding all other variables constant, increases the count of co-inventions by 0.0155 for biofuels (per year and per country-pair). The biggest impacts are for solar PV, fuel cells, and energy storage. Effect of the key control variable TOTALCOINV is, as expected, positive and significant in all of the models estimated, while effect of R&D expenditures varies.

Table 4. Estimated Marginal Effects of Co-invention (Model A)

	A1	A2	A3	A4	A5	A6	A7
	Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	EnStorage	Wind
IA_BOTH (d)	0.0155**	2.93e-05***	0.0512***	0.104***	1.33e-04	0.0433***	1.42e-03**
	(0.0059)	(5.59e-06)	(0.0112)	(0.0175)	(1.60e-04)	(0.0126)	(4.78e-04)
TOTALCOINV	6.72e-06**	7.12e-09***	3.11e-05***	2.95e-05**	4.34e-07**	1.52e-04***	1.62e-06***
	(2.32e-06)	(2.14e-09)	(9.44e-06)	(1.01e-05)	(1.37e-07)	(3.78e-05)	(4.08e-07)
RD_EXP	2.34e-04***	1.82e-09	1.32e-04***	-1.48e-04***	2.93e-06**	3.50e-05	-2.99e-06
	(6.86e-05)	(9.44e-10)	(4.04e-05)	(4.59e-05)	(9.34e-07)	(6.28e-05)	(3.88e-06)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ln(alpha)	2.58***	1.32***	1.09***	0.95***	1.27***	1.11***	2.38***
AIC	2287.1	1161.4	4003.3	3846.6	1264.9	5467.3	1488.7
BIC	2506.7	1381.1	4222.9	4066.2	1484.5	5686.9	1708.3
N	7066	7066	7066	7066	7066	7066	7066

Note: * p<.05; ** p<.01; *** p<.001 based on robust standard errors (in parentheses). The estimates give the predicted number of events on the margin, evaluated at sample means. For binary regressors (d) indicates effect for a discrete change from the base level. The estimation sample includes an unbalanced panel of 368 country-pairs (including 27 OECD countries) over a period of 36 years (1974-2009).

47. Next, we replace the RD_EXP covariate with RD_INV as an alternative measure of research capacity (Table5). As a consequence, the marginal effects of IA_BOTH decrease in magnitude but remain positive and significant in all models except, again, for hydrogen. The RD_INV variable is positive and significant in all models estimated, suggesting that having active research capacity in a given field is one factor that determines the level of international co-invention.

Table 5. Estimated Marginal Effects of Co-invention Using an Alternative Model Specification (Model B)

	B1	B2	B3	B4	B5	B6	B7
	Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	En.Storage	Wind
IA_BOTH (d)	0.0046**	1.94e-07***	0.0248***	0.0404***	1.26e-04	0.0158*	8.17e-05*
	(0.0017)	(4.18e-08)	(0.0058)	(0.0066)	(9.72e-05)	(0.0082)	(3.59e-05)
TOTALCOINV	1.24e-06*	2.17e-08***	1.22e-05**	1.26e-05*	8.28e-08	7.23e-05***	5.79e-08**
	(5.56e-07)	(6.34e-09)	(4.67e-06)	(5.34e-06)	(6.16e-08)	(2.08e-05)	(1.85e-08)
RD_INV	2.18e-05***	5.05e-07***	2.00e-05***	5.76e-05***	4.58e-06***	9.01e-05***	4.87e-07***
	(3.07e-06)	(1.12e-07)	(4.67e-06)	(1.01e-05)	(8.57e-07)	(1.67e-05)	(8.32e-08)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ln(alpha)	2.51***	1.15**	1.02***	0.75***	1.19***	0.96***	1.79***
AIC	2422.1	1143.6	4167.6	4052.0	1344.2	5800.3	1421.8
BIC	2690.4	1411.9	4435.9	4320.3	1612.5	6068.6	1690.1
N	8610	8610	8610	8610	8610	8610	8610

Note: * p<.05; ** p<.01; *** p<.001 based on robust standard errors (in parentheses). The estimates give the predicted number of events at sample means. For binary regressors (d) indicates effect for a discrete change from the base level. The estimation sample includes an unbalanced panel of 514 country-pairs (including 33 OECD countries) over a period of 40 years (1970-2009).

5.3 Extensions and Tests of Robustness

48. Having only considered situations in which both co-invention partners were members of the Implementing Agreement, we lost information about research collaboration between members and non-members. In order to be able to take into account also those country-pair relationships, we consider a specification in which we keep the interaction term previously called IA_BOTH in the regressions. Recall:

- IA_BOTH = 1 if [1;1]
- IA_BOTH = 0 if [0;1] or [1;0] or [0;0]

49. Now, an additional term is added which takes on the value 1 if and only if either one of the country is a member, and 0 if both or neither are:

- IA_EITHER = 1 if [0;1] or [1;0]
- IA_EITHER = 0 if [1;1] or [0;0]

50. The results suggest that while the IA_BOTH variable is still positive and significant in all models but hydrogen, IA_EITHER is significant only for biofuels, fuel cells, solar PV and energy storage (Table 6). The impact of either co-invention partner being member of the agreement leads to an increase in co-invention counts of approximately half of the magnitude, *ceteris paribus*, of that if both co-invention partners are members. The difference between the two coefficients is statistically significant (Wald test rejects the null hypothesis that both coefficients are equal), except for the case of hydrogen.

51. Intuitively, the finding that the propensity to co-invent is significantly higher if both co-invention partners are members suggests that the agreement facilitates research collaboration between members to a higher degree, e.g. due to more symmetric cost and cost sharing and access to the knowledge pool provided by the agreement. If an outside country co-invents with a member then maybe access to the benefits of the IA are restricted.

Table 6. Estimated Marginal Effects of Co-invention Using Two Policy Variables (Model C)

	C1	C2	C3	C4	C5	C6	C7
	Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	En.Storage	Wind
IA_BOTH (d)	0.0237*	5.35e-05***	0.0918***	0.1184***	2.25e-04	0.0670***	0.0021*
	(0.0094)	(1.16e-05)	(0.0196)	(0.0219)	(1.90e-04)	(0.0168)	(0.0009)
IA_EITHER (d)	2.87e-03*	1.05e-05	0.0371***	0.0509***	9.58e-05	0.0390*	3.67e-04
	(1.24e-03)	(5.43e-06)	(0.0081)	(0.0125)	(1.12e-04)	(0.0194)	(4.11e-04)
TOTALCOINV	4.96e-06**	8.12e-09***	2.11e-05**	2.29e-05**	3.75e-07**	1.40e-04***	1.52e-06***
	(1.67e-06)	(2.16e-09)	(6.90e-06)	(7.42e-06)	(1.20e-07)	(3.68e-05)	(3.72e-07)
RD_EXP	1.82e-04**	2.15e-09*	9.57e-05**	-1.20e-04**	2.47e-06**	3.02e-05	-3.47e-06
	(6.03e-05)	(1.06e-09)	(3.03e-05)	(3.80e-05)	(8.02e-07)	(5.86e-05)	(3.83e-06)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ln(alpha)	2.54***	1.32***	0.98***	0.90***	1.26***	1.07***	2.38***
AIC	2280.8	1158.2	3937.6	3802.3	1266.1	5455.8	1489.4
BIC	2507.3	1384.6	4164.1	4028.8	1492.6	5682.3	1715.9
N	7066	7066	7066	7066	7066	7066	7066

Note: * p<.05; ** p<.01; *** p<.001 based on robust standard errors (in parentheses). The estimates give the predicted number of events at sample means. For binary regressors (d) indicates effect for a discrete change from the base level. The estimation sample includes an unbalanced panel of 368 country-pairs (including 27 OECD countries) over a period of 36 years (1974-2009).

52. We also estimated conditional fixed effects models (xtnbreg) with fixed effects for the country-pairs, rather than individual countries. The results are qualitatively similar. However, it should be noted that the xtnbreg regression uses only a sub-sample of observations and the subsample used differs somewhat across the various technologies, rendering the results not strictly comparable. Results from all models are summarized in Table 7. Overall, the findings are rather consistent in that the marginal effect of joint membership (IA_BOTH) is greatest for solar PV, fuel cells, energy storage and biofuels, but less for wind, hydrogen and CCS.

Table 7. Summary of Marginal Effects of the IA Variables from the Various Models Estimated

a. IA_BOTH

Model			Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	En.Storage	Wind
A	nbreg	RD_EXP	0.0155**	2.93e-05***	0.0512***	0.104***	1.33e-04	0.0433***	1.42e-03**
B	nbreg	RD_INV	0.0046**	1.94e-07***	0.0248***	0.0404***	1.26e-04	0.0158*	8.17e-05*
C	nbreg	RD_EXP	0.0237*	5.35e-05***	0.0918***	0.1184***	2.25e-04	0.0670***	0.0021*
D	nbreg	RD_INV	0.0084**	5.79e-06***	0.0460***	0.0513***	2.73e-04	0.0327**	8.23e-05*
E	xtnbreg	RD_EXP	0.0676***	0.1214***	0.3266***	0.4233***	0.0606*	0.1525***	0.0681***
F	xtnbreg	RD_INV	0.0716***	0.1174***	0.2928***	0.3513***	0.0413	0.0779**	0.0591***
G	xtnbreg	RD_EXP	0.1284***	0.1589***	0.5412***	0.5342***	0.0791	0.2769***	0.0764**
H	xtnbreg	RD_INV	0.1449***	0.1609***	0.5092***	0.4479***	0.0946*	0.1929***	0.0753**

b. IA_EITHER

Model			Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	En.Storage	Wind
C	nbreg	RD_EXP	2.87e-03*	1.05e-05	0.0371***	0.0509***	9.58e-05	0.0390*	3.67e-04
D	nbreg	RD_INV	0.0012**	1.29e-06*	0.0186***	0.0235***	1.10e-04	0.0288*	1.18e-05
G	xtnbreg	RD_EXP	0.0553***	0.0623	0.2944***	0.2777***	0.0187	0.2335***	0.0115
H	xtnbreg	RD_INV	0.0590***	0.0759	0.2880***	0.2543***	0.0512	0.2282***	0.0249

Note: * p<.05; ** p<.01; *** p<.001 based on robust standard errors. Given that IA_BOTH and IA_EITHER are binary regressors, the values indicate effect for a discrete change from 0 to 1.

5.4 Policy Simulations

53. What do these results tell us about the economic significance of technology agreements? What would be the benefits to non-members of joining the agreements? To provide some indication we simulate two policy scenarios, taking the observed joint-membership as given (baseline). First, we compare co-invention activity in the baseline with a scenario that no country was a member of an IA (scenario 1). Second, we compare co-invention activity in the baseline with a scenario that non-member country-pairs accede to technology agreements (scenario 2). In both cases we calculate the average proportional change in co-invention implied by such shifts in joint membership for the relevant sub-sample of country-pairs (that is, for those that change membership status). The results for both scenarios are reported in Table 8.

54. Based on results from our preferred model, we find that the effect of joint-membership (as observed – scenario 1) on co-invention has been greatest for CCS (83%), followed by biofuels and fuel cells (over 70%), wind and solar PV (over 60%), and the lowest effect has been found for energy storage (28%). (The effect for hydrogen is statistically insignificant.) These differences may be partly due to the nature of technologies but they are also due to the differences in substance and the institutional characteristics of the agreements.

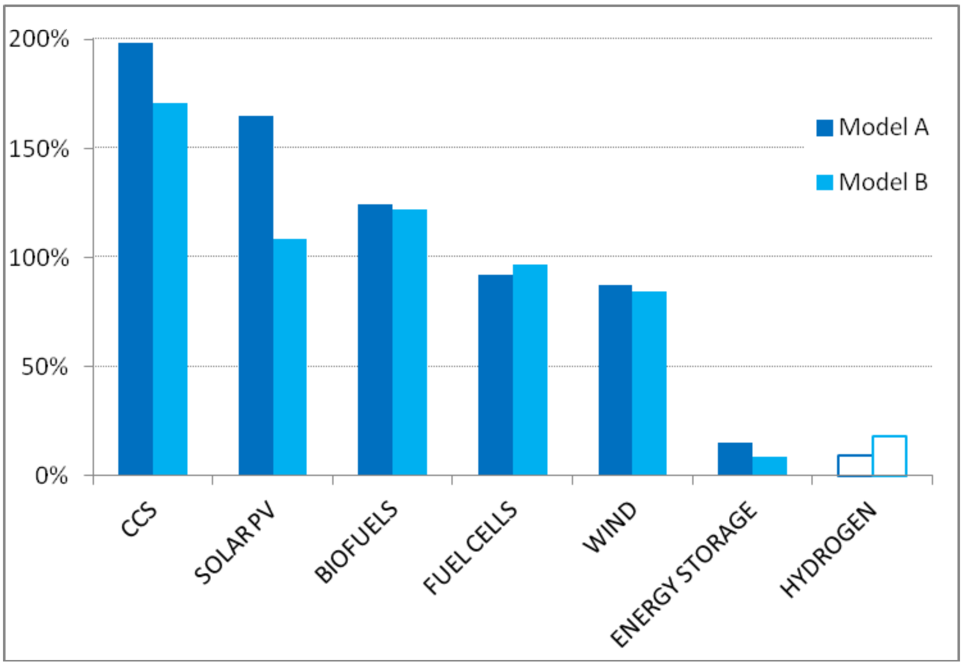
55. Concerning the simulated impact for non-members (scenario 2), we find that adherence of countries to an IA would increase co-invention in non-member countries by about 90% in the case of wind and fuel cells, and even more in the case of biofuels, solar PV and CCS (Figure 3). However, these figures represent only the direct impacts on co-invention and additional spillover impacts on domestic inventive activity may occur. The overall impact of technology agreements may thus be higher.

Table 8. Simulated Effect of Joint Membership Relative to the Baseline Prediction

	Biofuels	CCS	Fuel cells	Solar PV	Hydrogen	En.Storage	Wind
Members:							
Model A	77%	83%	74%	64%	24%	28%	68%
Model B	74%	79%	73%	69%	33%	18%	66%
Non-members:							
Model A	124%	198%	92%	165%	9%	15%	87%
Model B	122%	171%	97%	109%	18%	8%	84%

Note: These values indicate the average effect under the policy scenario relative to the baseline prediction, evaluated at observed sample values.

Figure 3. Simulated Effect of Joint Membership for the Non-Member Countries



Note: The values represent the proportional change in co-invention for a discrete 0-1 change in joint membership calculated using predicted effects for country-pairs that are not joint members. Bars shown "without fill" represent estimates that are not statistically significant at the 5% level.

6. Conclusions and Future Work

56. This paper has investigated the relationship between the international policy mechanism of 'Implementing Agreements' and co-invention. We found good evidence to support our hypothesis that IAs have an impact on co-inventive activities between inventors residing in different member states. They have a lesser impact on encouraging co-invention between an inventor residing in a member of the agreement and those in non-member countries. However, the impacts vary widely across the different agreements. These differences may be partly due to the nature of technologies but they are also due to the differences in substance and the institutional characteristics of the agreements.

57. An important avenue for further research would involve the assessment of the value of co-inventions relative to purely domestic inventions. Does international research collaboration help countries develop their innovation capacity by giving them greater access to foreign knowledge and expertise? And does this have positive impacts downstream? For instance, in the area of wind and solar power it would be interesting to assess whether countries benefit particularly from international research collaboration in terms of reduced electricity generating costs or increased market penetration.

58. Eventually, these activities may create lasting knowledge pools and research infrastructures that lead to increases in innovation and absorptive capacities. This may be particularly valuable for emerging and developing economies. Since the achievement of significant reductions in greenhouse gas emissions at an international scale is also dependent upon mitigation in fast-growing non-OECD countries, further work could focus on the role of IA's in which emerging economies are members.

59. Indeed, it is interesting to note that countries such as India and China have started to play increasingly important roles in those IAs which have important implications for the development of climate mitigation technologies. Moreover, based on Table 2 above, it is clear that they have become important co-inventing partners with a number of emerging economies featuring amongst the top ten bilateral relationships in different fields.

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