AN EMPIRICAL ANALYSIS OF INSTITUTIONAL BARRIERS TO EUROPEAN HYDROGEN RD&D COOPERATION

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Abstract

The paper applies and elaborates environmental and evolutionary theorising in the context of international research, development and demonstration (RD&D) cooperation. The theoretical framework of analysis lays particular emphasis on identifying and overcoming institutional barriers to international cooperation for the RD&D that contributes to radical and environmentally friendly systemic changes. The paper can be characterised as empirically based theory-building as it elaborates the conceptual framework and attests its validity with the interview findings and empirically based literature reviews. The empirical analysis is based on the HY-CO Era-Net interview results of government officers of national funding agencies responsible of the coordination of ERA-Net programmes.

Key words

Evolutionary economics, hydrogen, innovation policy, institutions, path dependence, technology lock-in

1. Introduction

A transition towards sustainable development depends on drastic changes in production and consumption patterns. Technological change has a relevant role to play in this transition to reduce the impacts from energy production and manufacturing processes. The application of hydrogen (H2) based energy systems has potential environmental and other benefits. In addition to H2 opportunities related to the climate change mitigation and to improvements in local air quality, H2 solutions, especially when combined with the renewable energy sources, may help to improve energy security (reduction of foreign oil imports) and international competitiveness (Solomon and Banerjee, 2007)[1]. However, there are substantial barriers to the deployment of H2 based energy systems, including the absence of a H2 refuelling infrastructure, high costs (of fuel cells and of low-carbon H2 production) and technological immaturity[2]. Rapid transitions to H2 are likely to occur only under conditions of strong governmental participation combined with, or as a result of, major 'discontinuities' such as shifts in society's environmental values, 'game changing' technological breakthroughs, or rapid increases in the oil price or speed and intensity of climate change (McDowall and Eames, 2006).

In this setting, international research, development and demonstration (RD&D) cooperation offers relevant opportunities to harmonise energy and innovation policies and exploit synergies (Haug, 2004) to foster the deployment of H2 based systems. Barret (2006) has identified specific cases where formal international technology co-operation is important: where RD&D can lead to breakthrough technologies that exhibit increasing returns to scale and where RD&D co-operation might sustain a strong international response. Examples of technologies where formal international co-operation may offer significant benefits include the development of the infrastructure and networks required to support the use of H2. Coherent, urgent and broadly based action to develop new systemic breakthrough technologies with significant environmental benefits requires international understanding and co-operation, embodied in a range of formal multilateral agreements and informal arrangements.

In the context of the European Research Area, already in the Fifth Framework Programme (FP5) the Commission implemented a strategic shift from the funding of technological development towards a more comprehensive innovation policy with the emphasis on the open-method of coordination (OMC), which is an inter-governmental mechanism of voluntary cooperation of European policies (Arrowsmith et al., 2004; Kaiser & Prange, 2004; Schäfer, 2006). In the innovation policy field, the OMC has been implemented by introducing new networks, stakeholder forums and policy processes or, more generally, *coordination tools* which encourage stakeholders to co-ordinate and self-organize the formation of common RD&D agendas (Könnölä et al., in press). Such coordination tools have been promoted, for example, within 'Integrated Projects', 'Networks of Excellence', 'ERA-Nets', 'European Technology Platforms' and most recently 'Technology Initiatives'. In practice, the coordination efforts have had a chequered history, partly due to the fragmentation of innovation activities and the dispersal of resources. Indeed, because more than 80% of research in the EU is financed at the national level, European coordination must account for major variations among national and regional innovation systems which, in turn, are influenced by various legislative and budgetary powers.

In spite of the many benefits from international RD&D cooperation[3], this faces diverse techno-institutional barriers, which are explored in this paper in connection with the European H2 RD&D activities. Expectations concerning formation of international research and technology development (RTD) networks and programs are not necessarily easy to fulfil due to the complexities that are driven by vertical and horizontal coordination challenges of national innovation systems (Könnölä et al, in press). The paper constructs and tests a novel framework of analysis with the emphasis on identifying and overcoming institutional barriers to international cooperation for the RD&D that contributes especially to the radical systemic changes that are needed for the demonstration and diffusion of H2 based energy systems. The framework builds on (i) the recent evolutionary theorising on institutional and technological change (e.g. Nelson and Winter, 2002), (ii) on the 'double externality' problem in the environmental economics (e.g. Rennings, 2000) and (iii) on the studies on internationalisation of innovation systems (e.g., Kuhlmann and Edler, 2003).

The paper can be characterised as empirically based theory-building as it elaborates the conceptual framework and attests its validity with the interview findings and empirically based literature reviews conducted in connection with the HY-CO Co-ordination Action to Establish a Hydrogen and Fuel Cell ERA-Net[4]. Accordingly, the paper is organised as follows. The next section develops the framework for analysis. Section 3 describes the findings from the empirical study, which are discussed in Section 4 in view of the framework of analysis. Section 5 concludes the paper.

2. Framework of Analysis on Institutional Barriers to International H2 RD&D Co-ordination

International RD&D cooperation can take many forms, from "soft" versions entailing only some sort of coordination of research priorities, discussion of the main issues or sharing of information or knowledge, to "hard" versions, which involve the creation of common pots of funds which are contributed by countries and which are distributed irrespective of the nationality of the beneficiary (cost-sharing). Furthermore, levels of ambition of international coordination can be categorized as follows: information exchange and best practices, common strategies issues, joint activities, joint/common calls, common programs (Könnölä, 2007). Co-operation can thus go beyond soft-forms of sharing information and co-ordinating of national priorities to include hard versions of cooperation that require formal arrangements to spread the risk and cost of investing in new technologies (for example, investing in demonstration projects). Different forms of cooperation are likely to entail also different kinds of barriers. While the soft versions are relatively easy to implement since they do not require major or radical institutional changes, the hard versions are prone to face considerable barriers to implementation.

The management of international H2 RD&D coordination must account for (i) the different national and regional conditions of technological infrastructures and social institutions and ii) market imperfections and potential free-riding behaviour of companies and national governments. These two perspectives are discussed in more detail in subsequent sections and later on combined towards the common framework of analysis.

2.1 Techno-Institutional Complex and Barriers to International RD&D cooperation

Experiences from the vertical coordination between local, regional and (inter-)national levels provide insights into the challenges of managing multi-layered innovation systems. Such challenges have been attributed to the systemic nature of innovation (Smits & Kuhlmann, 2004), performance of innovation systems (Lundvall, 1992; Edquist, 1997), and processes of regionalization (Kaiser and Prange, 2004) which have resulted in complex multi-layered policies especially in Europe. In effect, this complexity differentiates innovation policy from other policy areas – such as social or employment policies – where the OMC has applied earlier on in Europe. At present, innovation policies are challenged by the global market conditions where Member States, regions or even industrial or local clusters compete for critical resources, such as knowledge, human resources, and foreign RTD investments (Kaiser & Prange, 2004).

The implementation of innovation policies is typically linked to other policy fields and thus requires horizontal coordination between innovation and other policy areas. In case of H2 related RD &D, the innovation policy actions are strongly connected with the international and national energy policies. Thus, international H2 RD&D cooperation is likely to be conditioned by the diverse set of multi-layered innovation and energy systems emerged through their path-dependent techno-institutional development paths.

There is extensive evolutionary literature on the barriers to the development, adoption and diffusion of new technologies and the emergence of technological lock-in conditions (see, e.g., Dosi et al., 1988; Arthur, 1994; Nelson and Winter, 2002). Such approaches have been extended recently to cover also institutional aspects. Technological systems are best understood as being composed of both *physical technologies* -in the form of components and infrastructure, and *social technologies* – in the form of organizational hierarchies and managing institutions. Nelson and Sampat (2001) as well as North (1990) have posited that the co-evolutionary features identified as creating increasing returns for physical technologies may also be applied to social technologies that have come to be regarded by the relevant social group as standard in the context.

In line with Nelson and Sampat, we consider that not all social technologies are institutions, but rather only those that have become a standard and expected thing to do. Institutions are "the rules of the game" interpreted as broad constraints, such as regulatory conditions, or governing structures embodied in particular organizational forms or cultural beliefs and norms. In addition to being embodied in and moulded by particular organizational and governance structures, standardized social technologies are formed, and held in place, in the context of the broader social system that prevail in a society. Routines, practices and organizational hierarchies characterize social technologies. A routine involves a collection of procedures which result in a predictable and specifiable outcome. (Nelson and Sampat, 2001.)

Institutional barriers have been discussed in the organizational level for example by Van de Ven (1986) and Tushman and O'Reilly (1997). Van de Ven (1986) discusses three universal limitations that lead to organizational inertia, including focus on short-term demonstrable progress, inadequate problem definitions and the tendency of human behaviour to protect existing practices. Tushman and O'Reilly (1997) extend these ideas by distinguishing between structural and cultural inertia: the former rooted in the size, complexity and interdependence in the organization's physical structures, systems, and processes while the latter is embedded in the organizations social structure including shared expectations, norms, values and social networks. As organizations grow, structural and cultural inertia intensify, hindering proposed changes and innovations, especially if they demand radical or discontinuous modifications to currently successful activities.

Within such premises, the barriers for the development and application of H2 technologies can be understood from the perspective of the Techno-Institutional Complex (TIC) framework which sees the inertia in large technological systems arising from co-evolutionary interactions among physical infrastructures and the social institutions that build and perpetuate them (Unruh, 2000, 2002). Del Río and Unruh (2007) have defined the key elements and inter-relations of the TIC (Figure 1). They posit that the TIC emerges through a path-dependent co-evolutionary process that begins when innovation creates several technological variants that compete in an environment of technological increasing returns to scale. Ultimately one variant emerges from the competition as a dominant design, locking-in key technological architectures. Surviving dominant design-producing firms organizationally lock-in around standardized decision routines, core competencies, distribution networks and customer–supplier relationships, which condition their investments in non-dominant design technologies. As the system scale expands, complementary industry and inter-industry networks, including financial institutions, emerge and lock-in coordination standards, relationships and capital investment patterns. If the system becomes socially pervasive, advocacy groups, voluntary associations and the media socialize the system, adapting preferences and expectations to continued system dominance. Finally, government may intervene in system growth for policy reasons (national security, universal service, anti-trust/natural monopoly, etc.) and encourage system expansion through subsidies, incentives or outright ownership. The intervention by government, which overrides market forces, signals the emergence of a techno-institutional complex. (del Río & Unruh, 2007).

Insert figure 1

Indeed, several authors have argued that techno-institutional changes[5] are difficult to achieve, because the prevailing system acts as a barrier to the creation of a new system (e.g. Kemp and Soete, 1992; Jacobsson and Johnson, 2000; Unruh, 2000; Kline, 2001; Geels, 2002; Carlsson and Jacobsson, 2004; Frenken et al., 2004; Foxon, T. J., R. Gross, et al., in press). The need for such a system-level change is apparent in case of H2 technologies; for components like fuel cells to be useful they will have to be integrated into a new larger energy system that includes H2 production, transportation, storage, transformation, generation and end uses (Clark and Rifkin, 2006).

Institutional barriers create path dependencies that constrain the horizontal and vertical coordination of international RD&D cooperation. However, the international cooperation may also open up opportunities for overcoming national-level constrains both in view of physical and social technologies. Hence, the international RD&D cooperation are also likely to challenge governments to re-evaluate their role within the national systems. In addition, the TIC framework can be complemented with the perspectives of 'double externality' problem to understand the possible free-riding behaviour of companies as well as national governments.

2.2 'Double Externality' Problem and Barriers to International RD&D Cooperation

Related to the system change constrains, environmental economists have identified sub-optimal investment in environmental technologies caused by a 'double externality' problem (Rennings, 2000; Del Río, 2004): (i) social (or environmental) costs are not typically transferred in parallel to private costs (and prices) and (ii) spill-over effects often enable copying of innovations, which reduces the incentives to innovate and to create radical systemic changes. The 'double externality' problem is useful for understanding not only the barriers for RD&D of environmental technologies but also for the international cooperation of such activities which both are prone to suffer from the free-riding behaviour of both companies and national governments.

Due to the existence of market failures (with regard to environmental externalities) the increase in social costs does not directly lead to a parallel increase in private costs (and prices). As a result, firms may not react to this increase by developing or adopting technologies that reduce the consumption of increasingly scarce natural resources, such as H2 based low-carbon energy systems (del Río 2004; Jaffe et al. 2005). However, the government intervention toward the environmental improvements is not likely in the conditions of the techno-institutional complex emerged through the close cooperation of the government and the incumbent industries.

If innovation results developed by one firm spill over to other firms, there is an incentive for firms to distort their innovation effort (Carraro 2003). Innovation produces benefits above and beyond those enjoyed by the individual firm ('knowledge spillovers'), which fosters rather copying than innovation activities. The positive externality of innovation comes from the public good nature of new knowledge: Innovating firms cannot keep other firms from also benefiting from their new knowledge and therefore cannot capture for themselves all the benefits of the innovation. While patents and other institutions are employed to protect firms' investments in innovation, such protection may not be sufficient. A successful innovator will capture some rewards, but those rewards will always be only a fraction of the overall benefits to society of the innovation. Hence innovation creates positive externalities in the form of "knowledge spillovers" for other firms, and spillovers of value or consumer surplus for the users of the new technology (Jaffe et al 2005, p.167).

This problem is particularly compounded in an international context. Significant cross-border spillovers and a globalized market for most technologies offer an incentive for countries to free-ride on others who incur the learning cost and then simply import the technology at a later date. The basic scientific and technical knowledge created by a public RD&D programme in one country can spill-over to other countries with the capacity to utilise this progress. While some of the learning by doing will be captured in local skills and within local firms, this may not be always enough to justify the learning costs incurred nationally.

International patent arrangements, such as the Trade Related International Property Rights agreement (TRIPs10), provides some protection, but IPR can be hard to enforce internationally. Knowledge is cheap to copy if not embodied in human capital, physical capital or networks, so RD&D spillovers are potentially large. A country that introduces a deployment support mechanism and successfully reduces the cost of that technology also delivers benefits to other countries. International co-operation can also help to address this by supporting formal or informal reciprocity between RD&D programmes (Stern 2006, p.351).

Hence, international RD&D collaboration is likely to suffer from free-riding behaviour. Cooperative action will greatly reduce the costs of investing in RD&D, including the avoidance of the duplication of efforts. For example, co-operation to accelerate the development and diffusion of low-carbon technologies is likely to reduce the costs and the benefits of developing cost-effective low-carbon technologies will be mainly global but most costs will be incurred locally. Therefore, international RD&D cooperation raises a similar problem to climate change mitigation: the benefits of RD&D (climate change mitigation) might be global but the costs of investing in RD&D (climate change mitigation) are local.

International co-operation requires that nations perceive sufficient benefits that they are willing to participate in RD&D arrangements. They must also recognise that without their involvement, international collective action may fail. National RD&D policy focuses on technologies where there is a compelling local need or a perceived first-mover advantage, in order to capture national benefits linked to lower cost energy, local health or agricultural priorities, and the development of new industries. In other words, the fact that the benefits from RD&D cooperation are global and that the costs are mostly local is a major barrier for RD&D cooperation.

2.3 Linkages between the TIC and the 'Double Externality' Problem

The approaches of the TIC framework and the 'double externality' problem are complementary to explain the barriers to the development of radical systemic changes, e.g. of H2 based energy systems. The incentives to free-ride on the H2 RD&D efforts of others are an obstacle which prevents public and private parties from investing in H2 RD&D. This reinforces the path-dependent character of technological change, which makes it difficult for emergent H2 technologies to enter the market.

The TIC and the public good character of international RD&D cooperation reinforce the lack of international H2 RD&D cooperation. On the one hand, the global benefits and the local (national) costs of RD&D cooperation reduces the incentive for countries to engage in international RD&D cooperation, especially if it is not guaranteed that national actors will benefit from it. On the other hand, even if there are clear benefits from international RD&D cooperation, powerful path-dependent forces lead to institutional lock-in and can make the costs of RD&D cooperation too high. These aspects are related in complex ways. However, the influence of international RD&D cooperation can also be of a different character: it can be a source for escaping the institutional lock-in. In fact, the international RD&D cooperation arrangements may open up opportunities for overcoming national-level constrains both in view of developing new physical and social technologies. Hence, the international H2 RD&D cooperation also challenges the governments to re-evaluate their role within the national system.

The national TIC creates particularly stable and path dependent conditions for national energy and innovation policy to strengthen the TIC driven national energy system, which is likely to be less favourable for alternative energy systems, for example those based on H2. Furthermore, the TIC creates path dependences in laws, routines and practices that create difficulties for international cooperation, even when there may exist a strategic interest. Thus, the international RD&D cooperation is challenged by the diversity of self-perpetuating national systems with different interests and institutional conditions. The national TICs are strengthened by the conditions that disregard negative externalities produced by the TIC activities, in particular the impacts of the use of fossil fuel. Furthermore, the public good nature of R&D activities create incentives to free-ride with the spillovers both at the national level among companies and R&D organisations and at the international level between the Member States (Figure 2).

Insert figure 2.

3. Empirical analysis of European H2 RD&D Cooperation

The elaboration of the theoretical approaches described in Section 2 was motivated by the research project conducted in connection with HY-CO ERA-Net (Co-ordination Action to Establish a H2 and Fuel Cell ERA-Net). The objective of the study was to identify legal and other barriers that hinder international RD&D Cooperation on the program level in H2 and fuel-Cells. The study identified the obstacles and some recent approaches to overcome institutional barriers to the development of international H2 RD&D research programs within the ERA-Net scheme. Hence, the findings focus particularly on the institutional and regulatory barriers in funding, organizational setup and program management as well as in forming the basis for continued international cooperation. In addition to the theoretical and empirically based literature, the coordinators of 10 different ERA-Nets[6] were interviewed and respective website and online materials were examined for detailed analysis. In the project, institutional barriers and respective enablers to overcome the barriers are explored in the context of the formation of common trans-national RD&D program activities in the three specific areas: (i) legal and institutional restrictions to co-operation; (ii) the format and timescales of calls and (iii) running the program. The findings of the project are subsequently discussed in these categories and discussed afterwards in connection with the framework of analysis elaborated in Section 2.

3.1 Legal and institutional restrictions to co-operation

Legal and institutional restrictions to co-operation are related to the different forms of funding, eligible costs and contributions, required contracts and IPR issues.

- Based on the interviews of ERA-Net coordinators, it seems that the ERA-Nets are initiating common RD&D activities at least in three different levels of intensity of common funding: i) exchange of information and simultaneous national calls, ii) virtual common pots and iii) common pots based funding. Within the HY-CO activities, the interest in promoting not only R&D but also demonstration of H2 based energy systems creates challenges related to the competitiveness issues such as IPR and possible difficulties in funding foreign industries. Therefore, it seems that exchange of information, simultaneous national calls and the exploration of the possibilities for the use of virtual common pot are the most feasible options.

- The preparations of the trans-national RD&D programs face diverse barriers how to agree upon the costs and contributions. It is likely that partners have different national policies in view of costs and contributions. Hence, it is recommendable that joint activities are designed in view of national differences and providing the possibility for each partner to define its role in accordance with its national policies.

- The preparations may face barriers how to agree on the needed contracts for the RD&D cooperation. Typically contracts exist at different levels. It is common that the national ERA-Net partners sign a contract with the organization that they fund. Often they also require or recommend project consortia to sign a contract. In addition to these two levels, at the ERA-Net level, the partners sign the memorandum of understanding on the participation to the ERA-Nets. Some of the ERA-Nets preparing common calls sign also additional agreements on the call. In case of article 169 application it is necessary to establish a legal entity to manage the program. It is likely that partners have different national policies in view of contracts that need to be considered. However, there are no explicit obstacles to develop contract guidelines and explore the possibilities for synchronization of contract practices.

- IPR issues may create some barriers for trans-national RD&D cooperation especially when demonstration and commercialization aspects are included in the scope of the ERA-Net, for example in the ACENET and the ERABUILD. Even though when the focus is on the basic research, the IPR issues need to be dealt with, for instance, in the INNER, the specific guidelines are developed. Different national IPR policies need to be taken into account. The easiest way to initiate common activities may be to leave the IPR issues to be agreed between the project partners. However, the ERA-Net level support may be required especially when demonstration projects enclose various stakeholders. Toward this end, in addition to taken into account national policies it is relevant to explore how IPR issues have been dealt with for instance within HFP and H2 light house projects.

3.2 The format and timescales of calls

The funding organizations have diverse routines and practices how to organize the format and timescales of calls including the form of the call, form of response to call, evaluation of proposals, informing applicants of decision, and different timescales.

- Organizational barriers concerning the organization of the calls can create some obstacles in the preparations of joint programs. The ERA-Nets seem to overcome barriers, related for instance to the form and focus of calls and the type of further guidance, with different kinds of learning processes. Depending on the chosen approach, the ERA-Nets utilize open or restricted calls for proposals or specified tenders to receive applications for the programs and improve the understanding of possible obstacles. Both the different phases of calls and the use of intermediaries provide further opportunities for learning and networking that may improve the quality of joints calls and the formation of common program activities. This also supports the compilation of explicit guidance of calls for applicants. However, such activities need to be balanced with the possible time constrains.

- The ERA-Nets seem to have different approaches for the participants to respond to the call, for instance responding directly to the ERA-Net office, to national funding organizations or in some cases to both of them. The barriers may emerge partly because of the different national practices among the funding organizations but also partly because of different levels of expertise among the participants to work with (online) application forms. Despite national differences, opportunities exist to avoid extra work by requiring applicants to compile many applications. Such opportunities need to be carefully studied before launching the calls. Especially, the use of electronic solicitation of applications is recommendable when suitable.

- The practices of how the proposals are evaluated vary among the ERA-Nets. Sometimes the evaluation starts within the ERA-Net level and after that the recommended projects are evaluated at the national level (e.g. the ERASME); other times the national level evaluation is followed by the ERA-Net level evaluation (e.g. the MATERA). The evaluation approaches vary depending on the ERA-Net, there seems to be tendency toward further coordination and the creation of ERA-Net level expert groups for the evaluation of proposals. This needs to be evaluated also within HY-CO activities. The evaluation work and the criteria for evaluation will be however difficult to agree upon, especially because of the interests also in demonstration activities that are complicated to evaluate with objective criteria, for instance, expected societal impacts related to different national interests.

- In forming the applicants of the decision has not created any major discussions among the interviewed ERA-Nets, the applicants are informed either directly by the ERA-Net office or the national funding organization. Among the interviewed ERA-Nets it seemed to be common that the applicants are informed also informally to provide the news in a good time. There seems to be no barriers to coordinate informing of applicants at the ERA-Net level. However, still the partners may find it attempting to inform their national researchers also informally.

- The preparations of ERA-Nets face considerable barriers with regard to timing. The ERA-Net partners seem to have three major difficulties related to timescales. First, they need to agree on the timing for joint calls in line with the national schedules. Second, the preparations of the proposals among the participants from many countries may require extra time. Third, the evaluation processes of the proposals are often dependent on the different national evaluation practices that may require considerable time. Timing of different national activities is likely to be complicated. Therefore, feasible approach may be organizing several phases of calls that create required flexibility. In the timing of responses and evaluations it is recommendable to include some lag time in different actions.

3.3 Running the program

Furthermore, funding organizations need to balance also the differences in the practice of running the programs, such as monitoring of projects, dissemination of project results and project and program evaluation.

- There is little experience how to monitor the ERA-Net project activities, because most of the ERA-Nets have not yet the projects running. It seems that ERA-Nets are still largely discussing on the issue and the agreements on how the monitoring will be organized will be discussed after dealing with the calls. However, there appears to be a common view that the national funding organizations monitor the projects that they are funding. Furthermore, there are different forms how the ERA-Nets tend to organize the monitoring at the ERA-Net level. Among ERA-Nets, there exists little experience on the monitoring of projects at the moment. However, some plans exist already, as discussed above, that may provide further guidance for planning also HY-CO monitoring activities.

- In view of the dissemination of project results, some barriers may emerge because of the possible IPR issues. However, most of the ERA-Nets have not discussed these issues. The expectations are mainly positive trusting on the usual national level dissemination and additional ERA-Net level dissemination activities. For example, in the ERABUILD, there seems to be no major problems related to publication and dissemination of results, because the participants are primarily public research institutions in the fields of construction. IPR issues are not expected to create major barriers for the dissemination. However, because of the HY-CO focus also on demonstration activities, this needs to be discussed thoroughly to avoid conflicts later on during the project implementation and reporting.

Within the ERA-Nets, there exist different kinds of general expectations on the purpose, results and collaboration that make the initial collaboration challenging and it may take considerable time to create a common working agenda, for instance:

- In the management and preparations of common ERA-Net activities, the partners need to deal with the possible language differences. Especially among the new member states the level of English creates further barriers in the communication. However, the language skill is considered rather as a prerequisite for the participation rather than a barrier.

- Funding organizations have also different kinds of institutional cultures, routines and expectations how the processes are implemented. Such differences create difficulties among the ERA-Net coordination if particular attention is not given to the communication of the expectations of all the partners.

- To initiate trans-national RD&D programs, it is not necessary to harmonize a lot of regulations, even though some of the ERA-Nets have worked intensively with the adjustment of regulations, especially the SAFEFOOD-ERANET. Much of the national differences can be overcome with the novel interpretations of the existing regulations and with the changes in national procedures and practices.

- In several ERA-Nets it is recognized that different procedures and practices create contradictions leading to excessive extra work and time.

- The ERA-Net scheme is considered as a European politically sensitive instrument of which continuity may not be as certain as of national activities. For a successful ERA-Net it is considered relevant that the European Commission ensures financial support for the secretariat functions and also secures an acceptable standard of quality within the ERA-Nets.

4. Discussion

The empirical results confirm that the aforementioned institutional barriers make it more feasible to implement the "soft" versions rather than the "hard" ones. This may be largely due to the considerable risks of investing in emerging technologies when there are strong path-dependent forces (TIC argument) and due to the risk of free-riding from other countries (RD&D as a global public good argument).

This seems to be confirmed also by the other existing international collaboration in H2 RD&D. The first initiatives that are taking place follow the soft model. This is for example the case with the G8 and OECD Action Plan on Science and Technology for Sustainable Development, which launched an international partnership on hydrogen[7]. Another example is the IEA's Hydrogen Agreement. Projects within this programme have focused on collaborative research support among member nations on cost-effective H2 production, transportation, distribution, end use and storage based on renewable energy sources (Elam et al, 2003). Finally, the International Partnership for the Hydrogen Economy (IPHE)[8] also seems to a mechanism to organise and implement cooperative RD&D and deployment activities (Solomon and Banerjee, 2007).

In the European context, there are examples of countries pooling significant funds for RD &D and investment in innovative new technologies, including the EU's RD&D framework programme and the arrangements for public-private co-operation that have underpinned the Galileo satellite navigation system. The European Commission is proposing that the model for European collaboration used in the Galileo project should now be rolled out as a new Community Instrument - the Joint Technology Initiative. These initiatives, mainly resulting from the work of European Technology Platforms and covering one or a small number of selected aspects of research in their field, will combine private sector investment and national and European public funding, including grant funding from the Research Framework Programme and loan finance from the European Investment Bank (Stern, 2006, p.525).

There is currently a proposal for a Joint Technology Initiative for hydrogen and fuel cells. EU research priorities are aligned using European Technology Platforms. These provide a framework for stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues where achieving Europe's future growth, competitiveness and sustainability objectives are dependent upon major research and technological advances in the medium to long term (op.cit.). In this context, a major report and action plan issued by the UE (European Commission) in 2003, outlining the H2 vision (EC 2003) recommends the creation of a European Hydrogen and Fuel Cell Technology Partnership. It also suggests drafting of a Strategic Research Agenda and a Roadmap to define research priorities, for planning, to set technical targets and to outline pathways for the development of European H2 and fuel-cell technologies (Solomon and Banerjee, 2007)[9]. This means that a combination of "soft" and "hard" elements is being adopted. The following section provides an empirical investigation of the issue. Thereat, the empirical findings provide support for the thesis that as a result of the different barriers, international RD&D H2 cooperation will initially take the form of the "soft" model mentioned above[10]. Indeed, this "soft" model has been the starting point for the application of the European coordination tools of innovation policy. This seems to be the case also within the European H2 RD&D cooperation.

Empirical results provide further evidence on the institutional barriers with regard to the techno-institutional complex as well as the ‘double externality’ problem, which are discussed subsequently.

4.1 Institutional Path Dependencies as Barriers to International H2 RD&D Cooperation

Understanding the techno-institutional conditions of different national innovation systems creates the starting point for explaining the barriers to international RD&D cooperation. The empirical findings provide support for the thesis that institutional path dependencies at the national level lead to barriers in the form of routines, practices and organizational hierarchies which constrain the horizontal and vertical coordination of international RD&D cooperation. This is shown in several aspects of EU H2 RD&D cooperation.

The funding organizations have diverse routines and practices on how to organize the format and timescales of calls, including the form of the call, form of response to the call, evaluation of proposals, informing the applicants of the decision and different timescales. Within the ERA-NETs, there exist different kinds of general expectations on the purpose and results of cooperation that make the initial collaboration challenging. This may lead to considerable time being taken to create a common working agenda. These can create obstacles in the preparation of joint programmes. Furthermore, funding organizations need to balance also the differences in the practice of running the programs, such as monitoring of projects, dissemination of project results and project and program evaluation. In several ERA-Nets it is recognized that different procedures and practices create contradictions leading to excessive extra work and time, increasing the transaction and administrative costs of international RD&D cooperation. The preparation of transnational RD&D programs may face barriers regarding an agreement on the needed contracts for RD &D cooperation. It is likely that partners have different national policies concerning contracts. Funding organizations have also different kinds of institutional cultures, routines and expectations on how cooperation processes are implemented. Such differences create difficulties among the ERA-Net coordination if particular attention is not given to the communication of the expectations of all the partners.

The funding organizations participating in ERA-Net activities have a truly challenging task to develop European cooperation that responds also to national interests. Participating funding organizations have evolved through path-dependent processes that reflect the characteristics of their respective national innovation systems, thus they are intent on advancing their national interests (ERA-Net TRANSPORT, 2005). The funding organizations have different priorities for research themes and resource allocation; they also operate subject to different regulatory and institutional constraints that limit what kinds of organizations and activities they can fund (e. g., availability of funding to foreign researchers). Furthermore, they have different management practices that concern the launching, monitoring and evaluation of RTD projects. This means that ERA-Nets must operate in the presence of a multitude of governance cultures.

4.2 Free-riding and TIC related national interests as Barriers to International H2 RD&D Cooperation

The results provide evidence that, in some cases, the national regulations inhibit funding of foreign activities. Such constraints are related both to the TIC argument but also to public good arguments ("national interests") embedded in organizational practices or routines. In the most severe cases, this means that foreign RD&D activities can not be funded. National funding organizations need to ensure the national benefits. In most ERA-Nets examined, overcoming these constrains seems to depend on the efforts done to communicate the differences and to search for common ground. Still, the national resources for the international RD&D cooperation can be difficult to obtain nationally, because they are seen to be taken away from some national uses. According to those interviewed this seemed to be the case both in some smaller countries, e.g. Denmark, and larger countries, e.g. Germany[11].

It is also found out that the preparations of the international RD&D programs face diverse barriers concerning an agreement on the costs and contributions. It is likely that partners have different national policies in view of costs and contributions. For example, it was found that the interest in promote not only RD&D but also demonstration of H2 based energy systems creates challenges related to competitiveness issues such as IPR and possible difficulties in funding foreign industries. Furthermore, especially demonstration activities are complicated to evaluate with objective criteria, for instance, expected societal impacts related to different national interests.

In the HY-CO activities, the interest to promote not only R&D but also demonstration of H2 based energy systems has created additional challenges related to the competitiveness issues such as IPR and possible difficulties in funding foreign industries. For example, in common pots based funding, national partners can not assure that their contributions will necessarily benefit national RD&D activities (the international RD&D cooperation as a public good argument). In the other alternatives, the national authorities keep the control at the national level. Therefore, these barriers point out that the exchange of information, simultaneous national calls and the exploration of the possibilities for the use of virtual common pot are the most feasible options.

5. Concluding remarks

The paper deals with an emerging relevant topic: institutional change as a result of necessary international RD&D coordination in the field of H2 technologies and, particularly, institutional barriers to the EU coordination of H2 RD&D activities. Despite the benefits of international RD&D cooperation, several barriers stand in the way of undertaking the "harder" versions of RD&D cooperation.

The paper contributes to the conceptualization of the co-evolution of large and complex techno-institutional systems. The application and elaboration of the TIC framework provides systematic approach to examine the European context of the RD&D cooperation of H2 based energy systems. The inclusion of the 'double externality' problem to complement the TIC framework offers some promising directions for the conceptualisation of international RD&D coordination challenges. The preliminary findings of the empirical study provide some evidence on the usefulness of the elaborated framework. Therefore, it can provide relevant support for further conceptual and practical work especially in the fields related to the co-evolution of large techno-institutional systems such as energy, transport and agricultural systems.

While this paper has identified existing institutional barriers to international H2 RD&D cooperation, especially to the formation of common programs within other ERA-Nets, there was only limited information how to run, monitor and evaluate such programs. Therefore, in view of the management of European coordination tools, in particular of ERA-Nets, it is recommendable to communicate actively between different initiatives for further learning and development of the coordination tools and common RD&D activities in the future.

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Footnotes

[1] This encompasses a range of concerns over the finite nature of oil and gas reserves, their geopolitical instability, sensitivity and location, energy prices (threats of price shocks), and vulnerability of centralised energy systems to attack.

[2] Other frequently cited barriers include safety, public acceptability and the absence of codes and standards.

[3] International R&D cooperation makes special sense when the benefits from R&D are large and above its costs. International co-operation can complement national support strategies in enhancing investors' confidence for future markets, and thus encouraging innovative investments.

[4] http://www.hy-co-era.net/

[5] Also terms 'socio-technological transformation' (Geels, 2002), 'system innovation' (Edqvist, 1997) and 'transition' (Rotmans et al., 2001) have been used to describe similar kind of fundamental transformation processes of the co-evolution of technological and institutional systems.

[6] The institutional barriers for international H2 RD&D cooperation were explored with regard to the following ten ERA-NETs: ACENET Applied Catalysis European NETwork, ERA-NET Bioenergy, BONUS for the Baltic Sea science - network of funding agencies, ERABUILD Strategic cooperation between national programs promoting sustainable construction and operation of buildings, ERASME ERA-NET on National and Regional Programs to Promote Innovation Networking and Co-operation between SMEs and Research Organizations, INNER Innovative Energy Research, MATERA MATERA - ERA-NET Materials, NORFACE New Opportunities for Research Funding Co-operation in Europe, VISION A collaborative network of nationally leading innovation policy agencies, WoodWisdom-Net Networking and integration of national programs in the area of wood material science and engineering.

[7] According to Stern (2006, p.522), "The OECD Roundtable on Sustainable Development brought together scientists, heads of research councils and policymakers to undertake a full assessment of the current portfolio of research in energy technologies. The report, discussed by science and energy ministries from OECD and developing countries in June 2006, recommended that more attention should be given to funding research in solar, battery technologies and carbon capture and storage. These international assessments build on and complement existing national processes to allocate research funding and offer a model for further efforts at co-ordination of energy and transport priorities".

[8] http://www.iphe.net/

[9] The driving forces behind these recommendations are both to secure a sustainable energy future and to not contribute to climate change. In addition, the initiative is designed to secure diverse energy sources and to avoid over-reliance on Middle East oil imports (op.cit.).

[10] Recall that levels of ambition of international coordination can be categorized according to softer/harder degrees, including information exchange and best practices, common strategies issues, joint activities, joint/common calls, common programs (Könnölä, 2007).

[11] In the INNER, the big countries, especially Germany, have had difficulties to participate in international RD&D programs because of the organizational challenges how to get the funding approvals from the higher levels of the administration.

FIGURES

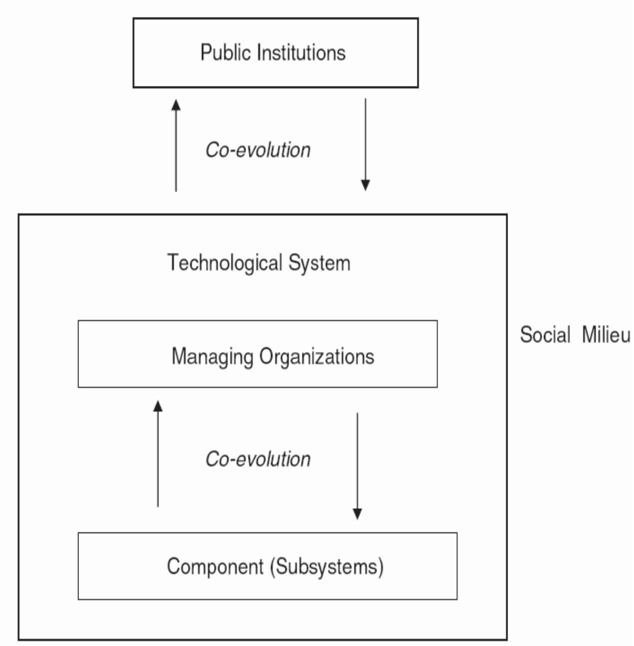

Figure 1: Elements of Techno-Institutional Complex (del Río & Unruh, 2007).

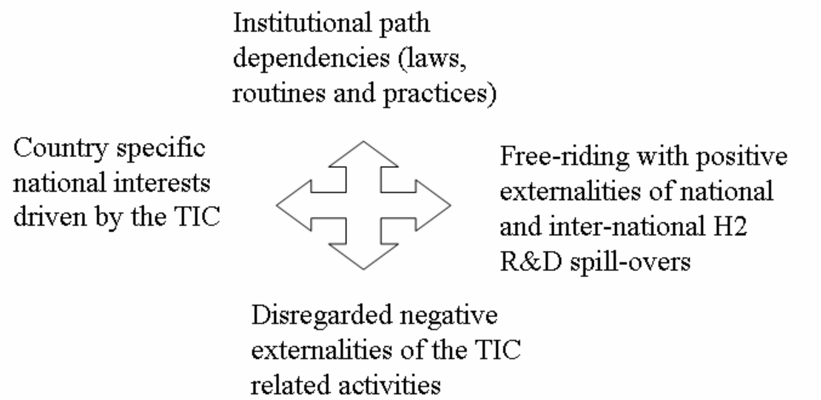

Figure 2: Inter-relations of key barriers to international H2 RD&D cooperation.

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