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The limits to internationalization of scientific research collaboration

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Abstract This study analyses international research collaboration for eight science-based technologies in the Netherlands for the period 1988–2004. It is found that the share of international research collaborations in research collaboration is high, but not rising during the period investigated. This result suggests that the process of internationalization has reached an end. It is also found that collaboration between academic and non-academic organizations is less likely to take place at the international level than collaboration between academic organizations. This suggests that collaborating within national research systems helps academia, firms and governmental organizations to overcome differences in norms, values and incentives. Nonetheless, international collaboration between academic and non-academic organizations is also frequently occurring. Some consider these collaborations as undesirable, insofar academic research funded domestically is 'leaking' to foreign firms in such research collaborations. Such unwanted knowledge spillovers has lead some to plea for a 'technology-nationalism' in science policy instead of a 'techno-globalization'. An analysis of the 'balance of trade' in international collaborations between Dutch academia and foreign firms and between Dutch firms and foreign academia shows that fears for unwanted knowledge spillovers are unfounded.

Keywords Research collaboration · Internationalization · University–industry collaboration

JEL Classifications O32 · O38

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1 Introduction

Collaboration in research is a growing phenomenon. In the last years, this phenomenon has been studied extensively by various authors (see for example Wagner-Doebler 2001; Katz and Martin 1997). Collaboration in research is associated with an enhancement of the quality of the research (Narin et al. 1991; Frenken et al. 2005). Collaborative research is also assumed to lead to a faster diffusion of scientific knowledge (Breschi and Lissoni 2003; Singh 2005). As a result, policymakers in different countries and at the international level are increasingly stimulating research collaboration. For example, the European Commission aims to create a European Research Area (ERA) by stimulating research collaboration between different member states. National policymakers on the other hand are generally focusing on the stimulation of academia-industry collaboration within their country with goal to improve the interaction between science and technology and, hereby, to stimulate innovation. It has been argued that research collaboration between academic and non-academic organizations has been growing over time (Gibbons et al. 1994), leading towards an increasing intertwining of academic organizations, firms and governmental organizations in research activities (Etzkowitz and Leydesdorff 2000). At the same time, research collaboration at the international level has been growing as well (Glänzel 2001; Zitt and Bassecoulard 2004). As a result there is no reason to assume that the potential benefits of the increased academia–industry interaction remain within regional or national borders. The rise of international research collaboration renders the occurrence of international knowledge spillovers from public research more likely to occur. This could be the case when a university collaborates and exchanges knowledge with a foreign firm, which in turn reaps the economic benefits of this knowledge.

The possible tension between policies stimulating collaboration between academia and industry and policies promoting internationalization of research collaboration can be considered as a tension between 'technology-nationalism' and 'techno-globalism' (Ostry and Nelson 1995; Archibugi and Michie 1997). The former refers to the idea that national technology policies should try, amongst other things, to the benefits of international collaboration by focusing on specific science and technology areas where national firms might develop international competitiveness. Several Asian countries have been seen as countries adopting such a policy (Niosi and Bellon 1994), which has been not unsuccessful (see for example Sung and Carlsson 2003; Chung 2002). Policy responses to the internationalization of science and technology based on a 'techno-nationalism' view are generally driven by concerns on reciprocity in international collaboration and prevention of a too high level of international knowledge spillovers from domestic research (Edler and Boekholt 2001). The techno-globalism view sees the internationalization of science and technology as a "natural" trend where countries are increasingly integrated into international research networks, which is in the end beneficial for all countries. According to Edler (forthcoming), that the growth of internationalization in public and private R&D is best considered as a positive-sum game for the countries involved.

Due to the ongoing internationalization of science and technology more and more firms will be able to appropriate knowledge stemming from academic research in other countries. As a result, a continuation of national science and technology policies focusing primarily on the strengthening of the knowledge base of national industries can ultimately result in conflicts of interest between nations in the area of science and technology. Mowery (1998) argues that the increasing importance of intellectual property rights issues and the characteristics of technology policies on negotiations on international trade are prime examples of this. This might result in increasing overlap between foreign policy and some fields of science and technology policy in the future (Wagner 2001).

Given the potential conflict between national policies and the increasing international research collaboration, it seems somewhat surprising that not we know little about the levels of internationalization for different types of collaboration, nor about the 'balance of trade' of countries in the number of collaborations between domestic academia with foreign firms and between domestic firms with foreign academia. This paper tries to contribute to the scientific and policy debate on the case of international research collaboration by focusing on these two issues. We show that the level of international research collaboration in eight leading science-based technologies in the Netherlands is indeed impressive. Around three out of four collaborations take place at the international level, showing the globalised nature of science. However, no evidence has been found that during the 17-year period of investigation the level of internationalization has grown more rapidly than the level of collaboration at the national level. This suggests that the globalization of research has come to an end. We also find that the national embeddedness of research is mainly related to collaboration between academic and non-academic organizations. The national dimension seems to be important in order to overcome potential problems due to differences in incentives, and norms and values by providing some common institutions. Finally, we show that the number of international collaborations between Dutch academia and foreign firms and between Dutch firms and foreign academia have become more balanced over time and no longer shows a persistent asymmetry.

This paper continues as follows. In Sects. 2 and 3, we discuss the rationales for the growth of (international) research collaboration in general and the growing importance of research collaboration between academic and non-academic organizations. The data and methodology used will be described in the Sect. 4. Section 5 presents the outcomes of the regression models on the effect of time and different types of collaboration on the probability of international collaborations to occur. In Sect. 6 we present results on the changing balances in international collaboration between academia and industry. Section 7 concludes and discusses the policy implications.

2 Research collaboration

Research collaboration is an increasing phenomenon during the last decades and has drawn the attention of various authors (see for an overview Katz and Martin 1997). Despite this growing interest in collaboration in research and inter-organizational partnerships, Hagedoorn et al. (2000) conclude that there is no uniform definition of the phenomenon. Taking into account that any attempt towards a formal definition will be subject of debate, they argue that it is necessary to have a clear idea on what is meant by research collaboration and research partnership in studies on this subject. Here, we define research collaboration in the way proposed by Hagedoorn et al. (2000, p. 58): a collaborative arrangement between organizations to pool resources for a common R&D goal. This study is focusing on scientific research collaboration, which implies that the goal of this collaboration is based on the development of new scientific knowledge that might or might not be used for the development of new products or services.

Several studies have shown that collaboration is growing over time in different fields (Wagner-Doebler 2001) and in different countries (Glänzel 2001). Different reasons for the growth of collaboration in research can be distinguished. First, the costs of conducting scientific research (e.g. the building of large laboratory facilities such as CERN—Centre

Européen de Recherche Nucléaire) have been rising sharply which brings along a need for the pooling of resources from different organizations. As a result researchers from these organizations collaborate more intensively as well (Katz and Martin 1997). The second reason is the growth of the number of scientific fields and subfields, which results in an increasing specialization within these fields (Stichweh 1996). This division of labor leads consequently to a greater propensity to collaborate. This is even further enhanced by the growth of interdisciplinary fields such as biotechnology. Third and related to this, the increase in the use of complex instrumentation has lead to the growth of specialized experts in the use of these instruments (Katz and Martin 1997). All these developments lead to an increase in the division of labor between individual researchers and individual organizations, which is accompanied by a higher propensity to collaborate.

Several of the factors enhancing collaboration in general are enhancing international collaboration as well, such as the creation of international research facilities. Next to this, international research collaboration is enhanced by the rapid fall of transport costs. This makes it easier to collaborate with distant partners and to visit international conferences to meet new potential collaborators. This is further stimulated by the increasing importance of English as the ‘lingua franca’ of most scientific fields. Also, the rise of the Internet and the improvement of other communication technologies are considered as an important enabling factor making it more easy to collaborate. Nonetheless Laudel (2001) argues, based on qualitative research on collaborating scientists that face-to-face contacts and physical proximity remain at the beginning of nearly all research collaborations. This does not have to imply that collaborating researchers have to be located nearby each other; temporarily physical proximity (Rallet and Torre 1999), for example at international conferences, can be sufficient. Another potential reason for the increase in international research collaboration is given by Wagner et al. (2001) who suggest that over time the number of countries worldwide that provide public support for scientific research has grown, leading to a larger number of potential collaborators worldwide. Finally, international organizations such as the EU are becoming an increasingly important source of funds and this is often accompanied with specific conditions for collaboration. Especially in the EU framework programmes funding depends on collaboration between organizations from different member states (Caloghirou et al. 2001).

The above-mentioned factors contributing to research collaboration at both the national and the international level are partly overlapping and, even more important, mutually reinforcing. Several factors that are internal to science, such as the increasing specialization, lead to a greater propensity to collaborate. The propensity for international collaboration is further enhanced by factors external to science, such as the rise of ICT, the rapid decrease of transport costs and the growing importance of English. Given these developments, one would expect international collaboration to increase more rapidly than national collaboration.

3 Collaboration between academic and non-academic organizations

A second and partly related trend in scientific knowledge production has been the rise collaboration between academic and non-academic organizations. According to several authors (Gibbons et al. 1994; Etzkowitz and Leydesdorff 2000), science and technology are increasingly organized in collaborative relations between academic organizations, firms and governmental organizations. Over time the boundaries of these types of organizations have become blurred and their activities are increasingly overlapping. This is often illustrated by concepts as academic capitalism and entrepreneurial universities (Slaughter and Leslie 1997; Etzkowitz et al. 2000). The interaction between academic organizations, firms and governmental organizations has been subject of empirical analysis of several authors trying to measure academia-industry-government relations. Although methodologies differ widely, ranging from patents citations analysis (Narin et al. 1997; Meyer 2000), scientific publications from firms (Godin 1995) and questionnaires on academic patentees (Meyer et al. 2003), the common conclusion seems that there is an increase of cross-institutional interaction and collaboration. The growing importance of non-academic organizations in science may be commonly agreed upon, the fact that this leads to a 'new mode of scientific production' or a change into a Triple-Helix model is less undisputed. Some authors argue that scientific research has always been based on interaction between universities, firms and governments and, that in that sense 'nothing new is going on' (Weingart 1997; Godin and Gingras 2000). Possibly, over time the form and intensity of this interaction may have changed and this is reflected in the rise of cross-institutional research collaboration.

An important reason for the rise of these cross-institutional collaborations is the growth of science-based industries (Pavitt 1984), like biotechnology and ICT. Innovation in science-based industries is strongly related with, and often based on the outcomes of scientific research. Firms in these industries are actively involved in scientific research and collaborate intensively with academia. Governmental research organizations are also actively involved in these fields, which is especially apparent in case of the life sciences. Within these industries new technologies are complex and often based on the fusion of existing technologies and new scientific subfields. Organizations are generally unable to keep up with the increasing complexity and the rapid development within these technologies and scientific fields. As a result different types of organizations are increasingly collaborating (Hagedoorn 2002) and some authors argue that inter-organizational networks are becoming the 'locus of innovation' in biotechnology and other science-based industries (Powell et al. 1996; Stuart 2000).

The management of these academia-industry-government collaborations, however, is inherently difficult due to fundamental differences in the underlying incentives, norms and values (Dasgupta and David 1994). Researchers working in academic organizations have an incentive to maximize the diffusion of their knowledge by publishing the outcomes of their research. The incentive structure also stimulates to do research on subjects that are most likely to enhance the scientific discourse. Firms by contrast produce knowledge to maximize the rents that can be derived from the right to use this knowledge. As a result, firms have an incentive to minimize knowledge diffusion (at least before it is possible to appropriate it) and to do research on subjects where it is most likely to be successfully applicable in new products and goods. Governmental research organizations have an incentive to produce knowledge that is in the interest of the government and its policy goals.

The differences in incentive structures can give rise to conflicts regarding the direction of the research as well as the diffusion strategy. Since it is impossible to formalize all contingencies of joint research projects in a contract, trust, common norms and values, and mutual understanding are also important for successful collaboration. This explains why research collaboration is especially difficult in case of international collaboration and between different types of organizations. Organizations located in the same country share norms and values, a common legal framework and (often) a language, and also have access to national funding schemes. As a result, successful research collaboration between organizations with different institutional backgrounds is expected to occur more often within national borders than across national borders. Academic collaboration, by contrast, is expected to be less restrained by national borders due to the common incentive structure and the 'universal' norms of science. Therefore the main hypothesis here is that academic collaboration has a higher propensity to take place at the international level than collaborations between academic and non-academic organizations.

4 Data and methodology

Research collaboration can take place in different ways and through different channels. Consequently, research collaboration can be analyzed by several indicators (Levy et al. forthcoming). Among the most commonly used indicators of scientific research collaboration are co-publications. The notion of a growing importance of collaboration is generally based on the comparison of the number of co-authored scientific publications and the number of single authored papers. A co-publication in this context can be seen as the tangible result of a successful collaboration. The general assumption is that researchers from the organizations listed on the publication have in some way pooled resources, for example by working together or exchanging knowledge (Cockburn and Henderson 1998). Some disadvantages of using co-publications exist, however, including the fact that not all forms of collaboration are reflected by co-publications and that not all co-publications are alike in terms of the intensity of collaboration between the organizations and authors mentioned (see Katz and Martin 1997 for a broader discussion). Nonetheless co-authorship is generally considered to be a valid and useful indicator (Lundberg et al. 2006), especially due to its comparability across time and across countries.

In this paper the main interest lies in the analysis of research collaboration in scientific disciplines that are closely connected to science-based technologies. The selection of specific technologies was based on a study of Van Looy et al. (2003). They analyzed the citations from patents to scientific articles in different technological classes.[1] The science-intensity of a technology was estimated by comparing the average share of citations on patents to scientific articles in the total number of citations for each technology. In the second stage the relevant scientific fields for each science-based technology were detected by analyzing the journals in which these scientific articles were published. Based on the classification of sub-disciplines provided by Web of Science, we defined the relevant scientific subfields for each technology. Using this methodology, we selected eight science-based technologies, which are shown in Table 1 together with their scientific subfields. The following technologies were selected: (1) Agriculture & food chemistry, (2) Biotechnology, (3) Organic fine chemistry, (4) Analysis, measurement & control technology, (5) Optics, (6) Information technology, (7) Semiconductors and (8) Telecommunications. As can be seen in Table 1, there is some overlap between the science base of various technologies. In the following, we will refer to life sciences based technologies (1, 2 and 3) and physical sciences based technologies (5, 6, 7 and 8). Analysis, control and measurement technology (4) is a technology with a more mixed science base.

Research collaboration can be defined at the level of individual researchers or organizations and, by aggregating using address information, at the level of cities, regions or countries as well (Katz and Martin 1997; Ponds et al. 2007). In the database format of Web of Science it is not possible to link individual researchers to organizations and as a result the addresses of the organizations cannot be used to identify the location of individual

[1] Based on the so-called OST-INPI/FhG-ISI technology classification.

Table 1 The relevant science-fields[a] for technological innovation the eight selected technologies

Agriculture & food chemistry	*Optics*
(n = 40,369)	(n = 16,499)
Biochemistry & Molecular Biology	Optics
Plant Sciences	Electrical & Electronical Engineering
Microbiology	Applied Physics
Genetics & Heredity	Polymer Science
Food Science & Technology	
Agriculture Dairy & Animal Science	
Nutrition & Dietetics	
Analysis, measure & control technology	*Organic fine chemistry*
(n = 31,175)	(n = 46,504)
Biochemistry & Molecular Biology	Biochemistry & Molecular Biology
Applied Physics	Organic Chemistry
Instruments & Instrumentation	Pharmacology & Pharmacy
Electrical & Electronical Engineering	Immunology
Immunology	Genetics & Heredity
Analytical Chemistry	Microbiology
Biotechnology	*Semiconductors*
(n = 43,250)	(n = 16,289)
Biochemistry & Molecular Biology	Electrical & Electronical Engineering
Microbiology	Physics Condensed Matters
Genetics & Heredity	Crystallography
Immunology	Applied Physics
Virology	Nuclear Science and Technology
Biophysics	Material Science
Biotechnology & Applied Microbiology	
Information technology	*Telecommunication*
(n = 8,184)	(n = 14,158)
Electrical & Electronical Engineering	Electrical & Electronical Engineering
Computer Applications	Telecommunications
Computer Cybernetics	Optics
Telecommunications	Applied Physics
Acoustics	Computer Applications
	Computer Cybernetics

[a] As defined by the Institute for Scientific Information (ISI)

researchers. This has as a consequence that a single-authored paper with two or more affiliations is counted as research collaboration whereas a multi-authored paper with one affiliation is not. Figure 1 shows the share of co-publications in the total number of publications per year. From Fig. 1 it can be concluded, that the share of co-publications is clearly rising for each technology. This tendency reflects a higher propensity to collaborate in research as suggested by several other authors (such as Katz and Martin 1997; Frenken 2002).

In order to derive collaboration patterns from co-publications involving more than two organizations the 'full counting' method was used. This means that every co-occurrence of

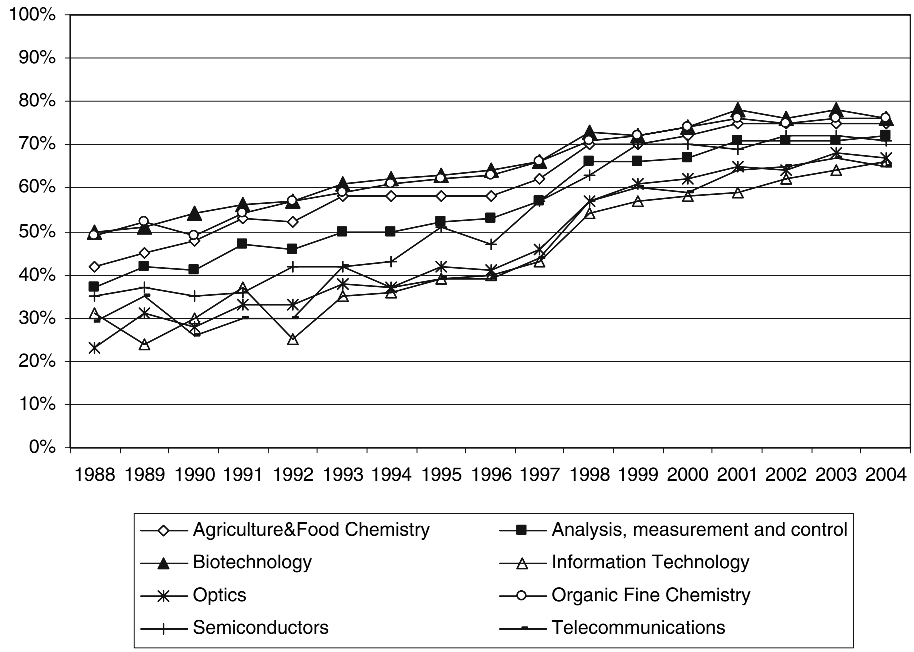

Fig. 1 The share of co-publications in the total number of publications

two organizations on a co-publication has been counted as one collaboration. Based on the addresses of the organizations on co-publications the spatial scale—national or international—of each collaboration was determined. Figure 2 shows the share of national and international collaboration in the total number of collaborations. The static comparison in the figure shows that the share of international collaboration is significantly higher than the share of national collaboration[2] in all technologies, ranging from 81% till 67%. From Fig. 2 it can be concluded that the level of internationalization in scientific research collaboration in the Netherlands is rather high.

In order to see whether there is a trend towards internationalization, Fig. 3 shows the share of international collaborations in the total number of collaborations over time for each technology. In Fig. 3, it can be seen that the share of international collaboration in the total number of collaborations remains fairly stable in all technologies. Given the growth of research collaboration in general (Fig. 1), this implies that the number of both national and international collaborations is rising at more or less the same pace.[3]

We distinguished between three types of organizations; academic organizations, firms and governmental/non-profit organizations. Universities and national academic research organizations such as the Max Planck institutes in Germany have been labeled as academic organizations'. In the Netherlands the largest national academic research organizations are NWO (Netherlands Organization for Scientific Research), KNAW (the Royal Netherlands Academy of Arts and Sciences) and academic hospitals. Research organizations such as

[2] Tested by *t*-tests on differences in shares.

[3] Note that in case of information technology there seems to be a rather strange sudden drop of the share of international collaboration in 1995. We were not able to find another explanation than the relative low number of total collaborations in information technology, which make sudden shocks more likely to occur.

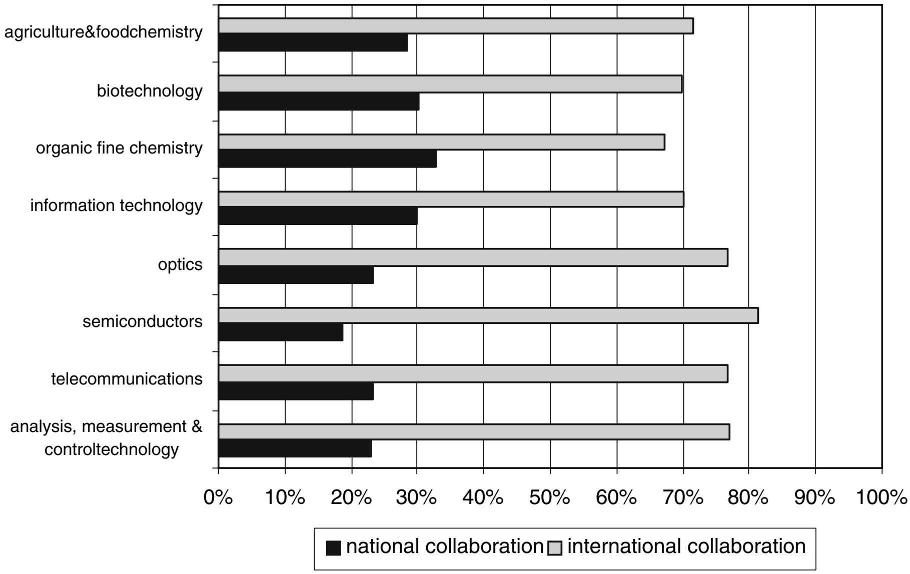

Fig. 2 Share of national and international collaborations in total

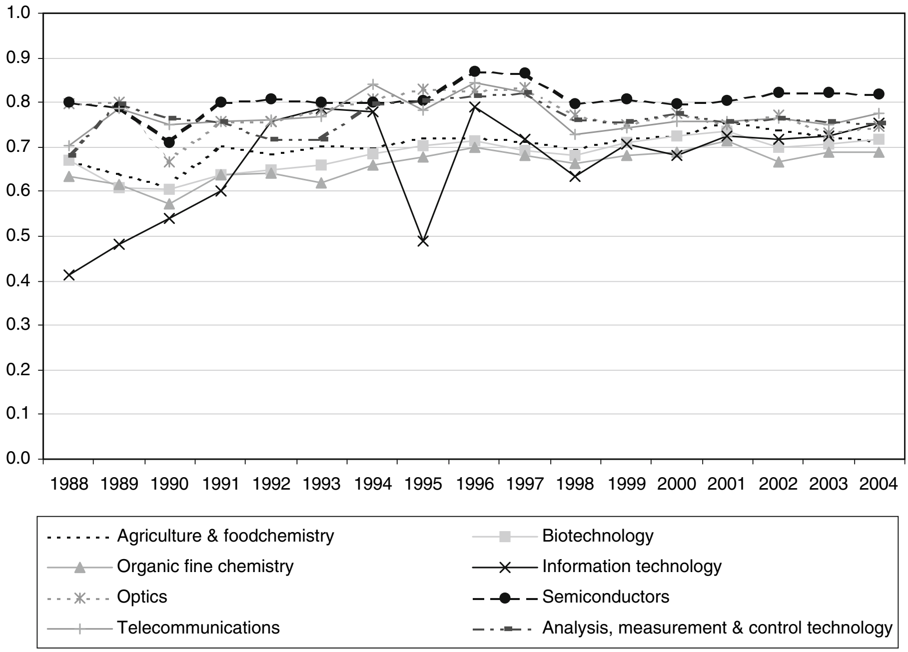

Fig. 3 Share of international collaborations over the years

TNO in the Netherlands or the National Institutes of Health in the USA and non-profit organizations are labeled governmental organizations. Based on a primary classification of organizations into these three categories an algorithm was designed to assign each

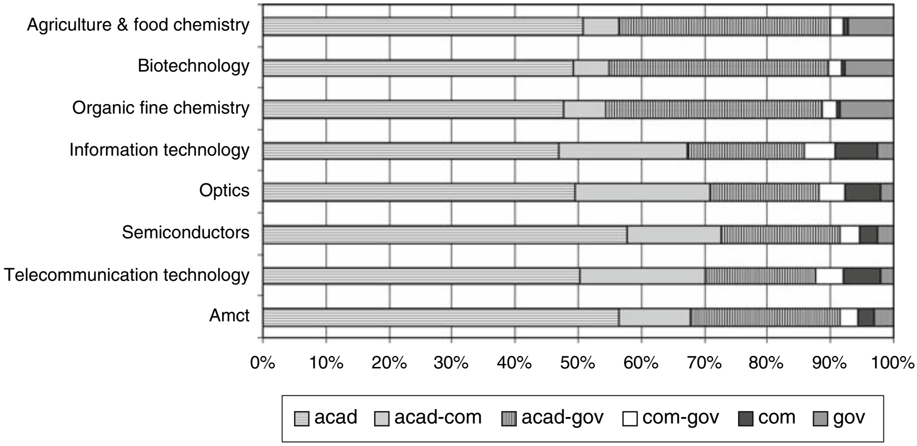

Fig. 4 Share of different forms of collaboration in science per technology

organization to one category. A test on a subset of collaborations revealed that up to 99% of the organizations was assigned correctly. The remaining collaborations have been classified manually. Six types of collaborations can be distinguished. These have been abbreviated as 'acad' 'gov', 'com', (collaboration between respectively two academic organizations, two governmental organizations and two firms), 'acad-com' 'acad-gov' and 'com-gov' (collaboration between different type of organizations). Figure 4 shows the relative importance of each type of collaboration in the total number of collaborations.

In Fig. 4 it can be seen that, not surprisingly, academia accounts in all technologies for the largest share of collaborations (about 50%). Collaborations between academic organizations and governmental organization and between academic organizations and firms are also frequent, whereas the shares of other collaboration categories are rather small. This does not mean that these organizations do not collaborate in research, but these collaborations are less likely to end up in co-publications as mentioned earlier. The focus in this paper lies therefore primary on the possible differences between academic collaboration and collaboration between academic and non-academic organizations.

The aforementioned hypothesis holds that different types of collaboration have different probabilities to take place at the international level. As a result the variable of interest in this analysis is binary; it can take only two values, national (value '0') or international (value '1'). The effect of the type of collaboration on the probability that this collaboration is international can be analyzed by the use of probit (or logit[4]) models (Long and Freese 2003). These models are based on a function, which takes strictly values between 0 and 1, and is given by:

$$P(y = 1|x) = G(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k) = G(\beta_0 + x\beta)$$

The function G is an underlying latent variable model with y^* as the latent variable:

$$y^* = \beta_0 + x\beta + \varepsilon, \quad y = 1 \ [y^* > 0]$$

[4] The difference between probit and logit models lies in the underlying specification of function G. In logit models G is a logistic function and in probit models G is a standard normal cumulative distribution function (Wooldridge 2003).

The coefficients in a probit model reflect the effect of a one-unit change in variable on y^* and are therefore not very easy to interpret, since we are interested in the effect on y. It is more useful to analyze the marginal effect of a variable, which indicates the effect on y and therefore on the change in the probability of the collaboration to be international or national. The marginal effect can be calculated in two ways, depending on the type variable. If x is a continuous variable, its marginal effect is obtained by the partial derivative at a specific value of x, often the average. If x is as binary (dummy) variable, the marginal effect is simply calculated by deducting the values for G with and without x, holding the other variables constant.

5 What type of collaboration is more likely to be international?

For each technology two different models are estimated. The first one includes a time trend variable in order to analyze if the probability of a collaboration taking place at the international level has been rising over time as previous studies on research collaboration repeatedly suggested. The second model includes the time trend variable and dummy variables for each form of collaboration. Academic collaboration is the reference dummy since the main interest lies in possible differences between academic collaborations and collaborations involving academic and non-academic organizations. Following our main hypothesis, the expectation is that the dummy variables for collaborations involving a non-academic organization and an academic organization (acad-com and acad-gov) are negative and significant, since these types of collaboration have a smaller probability to take place at the international level. Table 2 shows the results for each technology. The life sciences based technologies are shown in Table 2a together with the analysis, measurement and control technology and the physical science based technologies are shown in Table 2b. In the table only the marginal effects are shown.

The results of the models 1 suggest that the level of internationalization in research collaboration is increasing over time only in some technologies. In five out of eight technologies the time trend variable has a positive effect on the probability of a collaboration being international. Table 2a shows that within life sciences, agriculture & food chemistry and biotechnology have a positive and significant time-trend as does analysis, measurement and control technology, indicating a trend towards a growing level of internationalization. From Table 2b it can be concluded that this also holds for semiconductors and information technology, but not for the other two physical sciences technologies. Within Table 2b, optics and telecommunications even show a significant negative effect of the time trend on the probability of an international collaboration, suggesting a decreasing level of internationalization. And, in models 2, the time trend variable is no longer significant in case of the semiconductors (Table 2b) as well. In all, the results suggest that there might be a trend towards internationalization in research collaboration, but this trend is not so evident as often assumed and apparently different across technologies and scientific fields.

The results in models 2 include the dummy variables for different types of collaborations. The general conclusion seems to be that academic collaboration is indeed more likely to occur at the international level than other forms of collaborations in all technologies. A comparison of the marginal effects shows that 31 out of 40 are negative and significant whereas only one is positive and significant (collaboration between companies in case of information technology in Table 2b). Collaboration between academia and non-

Table 2 Results of the probit regression on the probability of a collaboration being international

(a)

	Agriculture & food chemistry		Biotechnology		Organic fine chemistry		Analysis, measurement & control technology	
	Marginal effect		Marginal effect		Marginal effect		Marginal effect	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Year-trend	0.004***	0.005***	0.005***	0.005***	−0.001	−0.000	0.005***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Dummy com		−0.005		−0.017***		−0.092***		−0.019
		(0.025)		(0.022)		(0.017)		(0.028)
Dummy gov		−0.136***		−0.164***		−0.127***		−0.117***
		(0.008)		(0.007)		(0.015)		(0.008)
Dummy acad-com		−0.143***		−0.094***		−0.195***		−0.098***
		(0.009)		(0.008)		(0.009)		(0.009)
Dummy acad-gov		−0.094***		−0.116***		−0.095***		−0.096***
		(0.004)		(0.004)		(0.006)		(0.004)
Dummy gov-com		−0.091		0.010		−0.033***		−0.009
		(0.015)		(0.012)		(0.015)		(0.013)
Log-likelihood	−33,744	−33,365		−42,372	−19,083	−18,703	−39,949	−39,590
LR statistic (df)	80.1***	837.9***		1249.4***	1.8	762.5***	155.1***	873.5***
McFadden R^2	0.001	0.012		0.015	0.000	0.020	0.002	0.019
N	56,606	56,606	65,286	65,286	68,076	68,076	35,292	35,292

Table 2 continued

(b)

	Information technology		Optics		Semiconductors		Telecommunications	
	Marginal effect		Marginal effect		Marginal effect		Marginal effect	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Year-trend	0.007***	0.008***	−0.003***	−0.004***	0.002**	0.000	−0.002*	−0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Dummy com		0.064***		−0.117***		−0.114***		−0.057***
		(0.021)		(0.019)		(0.023)		(0.019)
Dummy gov		−0.051		−0.164***		−0.088***		−0.118***
		(0.038)		(0.031)		(0.025)		(0.034)
Dummy acad-com		−0.129***		−0.235***		−0.227***		−0.213***
		(0.016)		(0.011)		(0.012)		(0.012)
Dummy acad-gov		−0.063***		−0.085***		−0.065***		−0.051***
		(0.016)		(0.012)		(0.009)		(0.012)
Dummy gov-com		0.020		−0.096***		−0.103***		−0.024
		(0.029)		(0.022)		(0.023)		(0.022)
Log-likelihood	−4,214	−4,161	−6,862	−6,604	−7,165	−6,916	−5,909	−5,731
LR statistic (df)	30.9***	138.4***	11.6***	526.6***	6.8***	505.5***	3.2*	359.1***
McFadden R^2	0.004	0.015	0.001	0.038	0.000	0.035	0.000	0.030
N	6,932	6,932	12,687	12,687	14,830	14,830	10,920	10,920

*** Significance at the 1 percent level

academic organizations is thus more likely to take place at the national level confirming the hypothesis formulated. This suggests that national research systems indeed facilitate interaction between academia and organizations outside academia, while collaborations within academia are less dependent on such a system.

In sum, we can draw two important conclusions from our results. First, the level of internationalization in research collaboration is clearly high, but no convincing evidence for an increasing internationalization trend can be found. Given the rise of collaboration in general, as shown in Table 1, the conclusion holds that that the rise of collaboration in general is much more pronounced as a trend than internationalization of research collaboration (cf. Frenken 2002). Second, the national level remains important, especially for collaboration between academic and non-academic organizations. This suggests that co-location in the same country might provide advantages in overcoming problems of collaboration between academic and non-academic organizations due to differences in incentive structures, norms and values. This might limit the effectiveness of policies stimulating international academia-industry collaboration as long as national systems do not converge institutionally.

6 The 'balance of trade' in international academia–industry collaboration

Despite the importance of the national level for collaboration between academic and non-academic organizations, the phenomenon of international academia–industry collaboration should not be neglected in discussions about the role of national science policies. According to some (Edler and Boekholt 2001; Edler forthcoming), most national governments are still—despite some 'strategic rhetoric'—mostly concerned with reciprocity in international collaboration and the danger of international knowledge spillovers from public research. It is therefore interesting to gain insight in the balance between national academic organizations collaborating with foreign firms on the one hand and foreign academic organizations collaborating with national firms on the other. Although far from a complete picture of international knowledge spillovers, the analysis of the development of this 'balance of trade' can give some indication of asymmetries in gains from international academia–industry collaboration, and the possible change herein over time.

We perform such an analysis by computing the standardized proportion of the absolute number of Dutch academic organizations working with foreign companies and the absolute number of Dutch firms working with foreign academic organizations. The development of this standardized proportion is then plotted in graphs. The proportion is calculated by the following formula:

$$P = \left(\frac{x_{ij}}{x_{ji}} - 1\right) \Big/ \left(\frac{x_{ij}}{x_{ji}} + 1\right)$$

where P is the proportion between Dutch academic organizations working with foreign firms and foreign academic organizations working with Dutch firms. x_{ij} is the absolute number of collaborations between Dutch universities working with foreign firms and x_{ji} is the absolute number of collaborations between foreign universities working with Dutch firms. The value of P lies between -1 and 1 and has value 0 if x_{ij} and x_{ji} have exactly the same value, which reflects a 'perfect balance'. If P is positive (negative) it indicates that foreign firms collaborate more (less) with Dutch academia than vice versa. Figure 5a and b shows the changes of the standardized proportion P over time for respectively the life

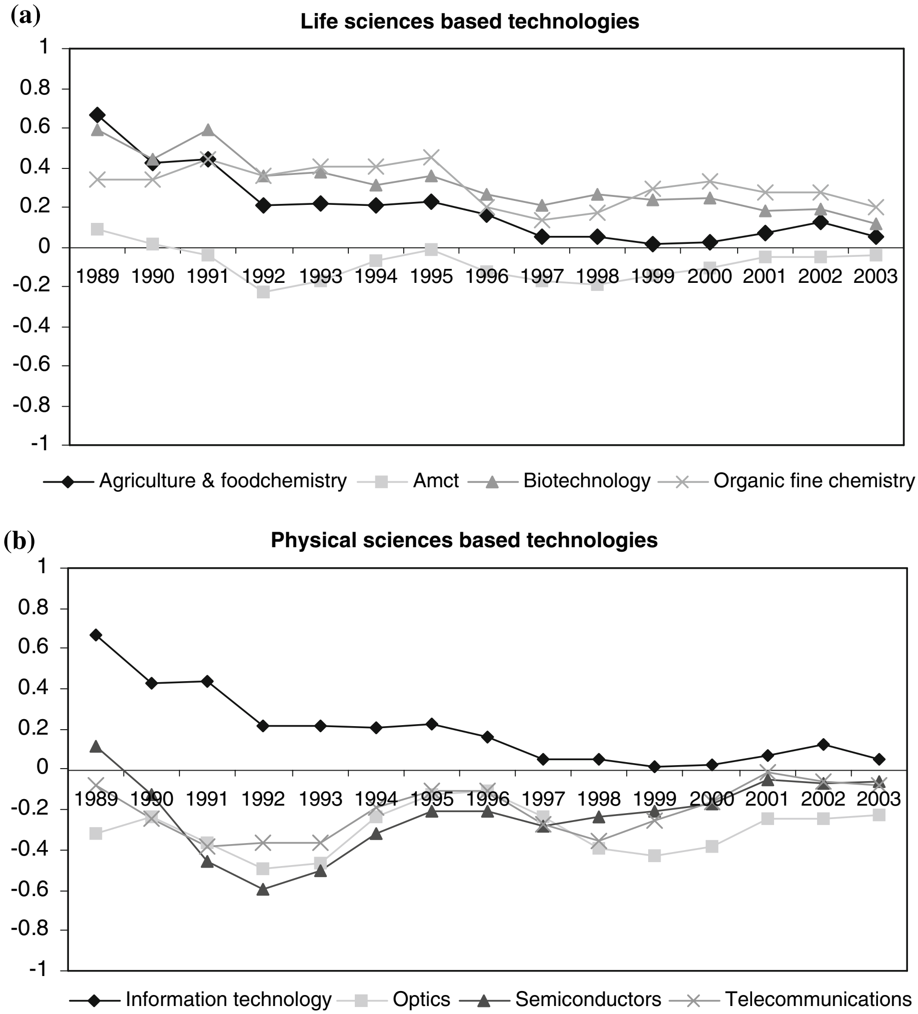

Fig. 5 Change of standardized proportion of international academic–industry collaboration over time—three year moving average: (**a**) Life sciences based technologies and (**b**) Physical sciences based technologies

sciences based technologies (including analysis, measurement & control technology) and the physical sciences based technologies.

Figure 5a shows that in life sciences based technologies the value of *P* is positive, indicating that Dutch academia collaborate more with foreign firms than vice-versa. In the mid-90s the value of *P* has declined till nearly 0 and it remains fluctuating around 0 till 2004. It can be concluded that within life sciences, international academia–industry collaborations have become more balanced over time. This implies a decrease of the size of what maybe can be seen as international knowledge spillovers from public research. Contrary to the life sciences based technologies, the value of *P* is negative till the mid-90s for the physical sciences (with the exception of information technology) after which it is slowly increasing till its value is around zero as shown in Fig. 5b. Thus, in both the life sciences and the physical sciences based technologies the value of P has become more stable over time and got closer to 0.[5] 'Techno-nationalist' fears that foreign firms profit disproportionally more from Dutch academia than Dutch firms profit from foreign academia, seem unfounded.

A general conclusion is that international academia–industry collaboration has become more balanced over time, although small differences between life sciences and physical sciences remain. Given this dynamic trend towards symmetry, unbalanced patterns and consequently a high level of possible international knowledge spillovers from domestically funded public research, might be a temporarily phenomenon. This imbalance might be necessary to enter the international system of science and technology in a specific field (Archibugi and Iammarino 1999). This could have been the case in life sciences in the Netherlands where international academia–industry collaboration was dominated by Dutch academic organizations and foreign firms in the beginning of the period of analysis. Through these collaborations valuable learning effects on the valorization of scientific knowledge in these fields might have taken place, which could have resulted in the more balanced pattern hereafter. At this moment not much is known about the mechanisms of these learning and observation effects and how this affect the science and technology dynamics in a country. Future research on this topic might reveal valuable insights for the ongoing discussion on national science and technology policy and internationalization.

7 Conclusions and discussion

This study analyzed the internationalization of research collaboration for eight science-based technologies in the Netherlands from 1988 till 2004. The growth of international research collaboration has increased the interest of scholars and policymakers in this phenomenon. The main goals of this study were to analyze the development of internationalization over time, to detect possible differences in the level of internationalization between different types of collaborations and to gain some insights in the balance of international academia–industry collaboration. Co-publications involving two or more organizations have been used as an indicator for research collaboration.

International research collaboration is clearly an important phenomenon; the majority of all collaborations involving a Dutch organization are international. Yet, contrary to the conclusions of some other authors, we do not find compelling evidence for an increasing trend of internationalization of research collaboration. Some technologies exhibit a small steadily increase in international collaboration while that share remains constant or is even decreasing in case of others. It is thus important to distinguish between the growth in international research collaboration in absolute numbers, and the growth in the level of internationalization of research collaboration. The rise of international research collaboration in absolute numbers goes hand in hand with a rise of research collaboration at the national level, leaving the share of international research collaboration more or less constant. This means that the rise of international research collaboration in absolute numbers reflects an increasing tendency of collaboration in general, and regardless of the spatial level, rather then an increase of the level of internationalization.

The outcomes of this study have important policy implications at two spatial levels. The importance of the national scale for collaboration between academic and non-academic

[5] The fluctuations in the beginning of the period may be partly due to the smaller amount of observations in these years as compared to the more recent period.

organizations points to the continuing importance of national institutions for systems of innovation (Carlsson 2006). Research collaboration between organizations with different institutional backgrounds and incentive structures seems to be eased by being located in the same country. Potential problems resulting from these differences might be (partly) overcome due to a common legal framework, the use of the same language and similar norms and values. Furthermore, the high level of national academia-industry collaboration could also reflect effects of national science and technology policies. In case of the Netherlands this can be related to the launch of national 'leading technology institutes' in 1996. These institutes were set up as public–private partnerships for fundamental research collaboration between academic organizations and firms in designated fields such as ICT and food related biotechnology.

The outcomes of this study are also interesting from an international policy point of view. For example, the EU stimulates international research collaboration in general and university–industry collaboration in particular by means of the framework programmes. Based on the continuing importance of national borders, there might be several barriers that can limit success of the stimulation of international research consortia consisting of firms, governmental and academic organizations from different countries, some of them being cultural defined whereas others might be more related to regulation issues (Frenken et al. 2007).

Nevertheless, international collaboration between academic organizations and firms is frequently occurring as well. International academia–industry collaboration can be seen as a mechanism of international knowledge spillovers. Policy makers might be concerned with the occurrence of asymmetric benefits of these types of collaborations when foreign firms appropriate knowledge being produced within national publicly funded research programmes. In case of the Netherlands these asymmetries (both positive and negative) were found in the earlier stages of the period under investigation. Over time patterns of international academia–industry collaboration have become more balanced suggesting that the occurrence of asymmetrical benefits is a temporarily phenomenon, possibly reflecting a dynamic necessary in order to enter the international field (as suggested by Archibugi and Iammarino 1999). Therefore, the mere possibility that the outcomes of public funded R&D are being appropriated by foreign firms does not seem to legitimate policy measures preventing these types of collaboration to occur. Moreover the chance of success of such measures is rather low as shown by Mowery (1998), who argues that the (sporadic) efforts of US policymakers to restrict foreign participation in publicly funded R&D programs turned out to be infeasible. Mowery (1998) also warns that such policy measures impair the fundamental open nature of the science system. According to Archibugie and Michie (1997) this form of techno-nationalism versus techno-globalism dilemma is best encountered by the abandoning of tax measures that financially stimulate R&D by firms. They and others (such as Edler forthcoming) conclude that governments should try to avoid tax competition and focus on the support of a national science and technology infrastructure in order to make a country attractive for science and technology activities for both private and public organizations. Nonetheless managing the tensions between national science and technology policies and international interdependencies remain a major policy challenge.

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