

Support

From sectoral to horizontal public policies: the evolution of support for biotechnology in Europe, 1994–2001

Vincent Mangematin

A number of policies have been developed in Europe, to facilitate the scientific and commercial development of high-technology sectors. How effective have these policies been? This paper addresses this question by exploring the impacts of policy on the development of biotechnology in the Member States. It analyses policy effects on the performance of different actor types that are crucial for a prospering biotechnology innovation system (start-ups, established firms, research labs, universities, and so on). The diversity of the measures and schemes to encourage the development of biotechnology reflects the diversity of the framework conditions, cultural preferences and political priorities in the Member States. Priority could have been given to research or to commercialisation. Incentive schemes and support policies could be dedicated to biotechnology as a sector, or targeted towards all innovative sectors, depending on national context. The organisation of research and development may be more or less efficient, depending on how funds are allocated and on the extent to which they are linked to priorities.

Vincent Mangematin is at GAEL – INRA/UPMF, 38040 Grenoble Cedex 09, France; Tel: +33 4 76 82 56 86; Fax: +33 4 76 82 54 55; E-mail: vincent@grenoble.inra.fr.

BASED ON THE RESULTS of the EPOHITE project,¹ this paper provides a common analytical and political framework for biotechnology policy in Europe. It analyses the extent to which public policies in Europe are derived from national innovation system (NIS) approaches or from the sectoral innovation system (SIS) concept. It assesses effectiveness of public policies measures according to the organisation of the research system and the degree of interactions amongst the actors.

This paper aims to offer an understanding of the diversity of the public policies impacting the biotechnology sector across the European countries and via the different national innovation systems and follows the evolution of public policy between 1994 and 2001. The respective biotechnology policies (taking into account non-policy influencing factors) are thus linked with the performance information for each country (cluster) based on quantitative indicators as presented in the Reiss *et al* (2004, this issue) paper. This analysis of the effectiveness of public policies will also contribute to the understanding of the relevance of the NIS and SIS approaches.

Public policy design

The evolution of public policies regarding high-tech sectors can be analysed from two different perspectives. On the one hand, the national and cultural features can be examined to analyse the fit between public policy and national features. On the other hand, sectoral specificities can be identified for

Vincent Mangematin is senior researcher at INRA/University Pierre Mendès France in Grenoble, France. His main fields of research are the strategic management of knowledge creation and circulation. He focuses on technology transfer and the management of public-sector research organisations. He also characterises the industrial organisation of high-tech sectors and the leading forces of their development. He has written about 30 papers, published in leading journals such as *Research Policy*, *International Journal of Technology Management and Small Business Economics*, *Science and Public Policy*, and two edited books on trust. He is an active member of the European Group of Organisation Studies.

studying which public policies fit the sector best. National public policies suppose that the development of biotechnology in Europe is mainly determined by the institutional features of particular NIS, while, in contrast, public policies dedicated to biotechnology as a sector assume that development takes place at the sectoral level.

In fact, the characteristics of the biotechnology sector (science push, network as the locus of innovation, role of public-sector research organisations and universities, small and medium-sized enterprises (SMEs), and mainly business to business markets) transcend the national context; the sector is quite similar in all developed countries (Allansdottir *et al*, 2002). The concept of a sectoral innovation system (SIS), defined by Breschi and Malerba (1997, page 131) as a

“system (group) of firms active in developing and making a sector’s products and in generating and utilising a sector’s technologies; such a system of firms is related in two different ways: through processes of interaction and co-operation in artefact-technology development, and through processes of competition and selection in innovative and market activities”

clearly accounts for the dynamics of the biotechnology sector. The key actors in an SIS are the private firms. Breschi and Malerba (1997) emphasise that competition and selection processes involve firms with different capabilities, capacities to mobilise other actors — large firms, universities, research institutes — and innovative performances.

The SIS approach highlights the key role of firms in the dynamics of innovation. As it is a science-based sector, critical resources are access to scientific competencies and techniques developed by academic research, and to capital markets. The connection with the scientific network is a condition for growth, but connections with large firms that represent the market are also necessary. The emergence of new technologies induces a new division of work amongst large and small firms, especially during the innovation process. It also generates new markets for a large number of small firms mainly involved in providing biotechnology services for the

whole life science sector (Mangematin *et al*, 2003).

In this paper, two categories of public policy are described: horizontal and vertical. Horizontal policies represent public instruments supportive of research and innovation regardless of the sector targeted (instruments to support basic research, commercialisation of technologies, creation of start-ups, for example). Horizontal public policies refer to the national context, and are based on NIS approaches. Vertical public policies are policy instruments dedicated (in this case) to biotechnology, such as specific programmes to support biotech research, to stimulate instrumentation (in genomics, for example) or to enable commercialisation of biotech (creation of biotech start-ups through bio-incubators, for example).

Public policies based on SIS approaches are mainly supporting firms as the key actor of the sector’s dynamic. They also encourage industry–university relationships to facilitate knowledge circulation and commercialisation of knowledge. However, public authorities not only support the development of the biotechnology sector through vertical policies. They also design horizontal policies in favour of research in general, of firm creation and more generally to stimulate entrepreneurial responses to identified weaknesses in the NIS.

One of the aims of policy makers is to limit the weaknesses of the national or regional system of innovation and research so as to meet the strategic goals of the government. The NIS can be defined as the process of the support of innovation within a national economy as well as the production and distribution of knowledge. The NIS provides a comparative method that can be used to identify problems or weaknesses that might be addressed in public policy. It deals with the set of actors related to innovation processes and the way they interact. According to Edquist and Johnson (1997), organisations (actors) are formal structures with an explicit purpose.

NIS approaches give a broad overview relevant to understanding the development of biotechnology. The description of the evolution of the national public policies is mainly based on existing reports (Inventory project (Enzing *et al*, 1999) and European Biotechnology Innovation System (EBIS) (Senker *et al*, 2001) and the national case studies performed within the EPOHITE project (<http://www.epohite.fhg.de/>). Qualitative data as well as global economic figures have been used to portray the economic situation and to describe public policies.

The two sets of data complement each other and should help to provide a fairly comprehensive picture of the performance of different national biotechnology innovation systems. We compare national policy profiles with the quantitative indicators at a country level. Since the national policy profiles provide information on policy goals, this approach enables us to draw conclusions as to how far such goals have been achieved, which in turn allows conclusions on policy effectiveness.

However, several questions remain unanswered and it is important, at the European level, to analyse the extent to which national evolution and European evolution are correlated in terms of leading sectors such as biotechnology. The first set of questions refers to how countries deal with globalisation and the mechanisms of wealth creation through innovation. Innovations are created locally but they circulate (as do knowledge, product, funds, and so on) at the world level. This might imply that the way in which innovation is produced and diffused is quite similar from one country to another. However, Europe appears to be a patchwork of national public policies, which shows up the strengths and weaknesses of each national system. However, to what extent are these public policies similar?

The second set of questions refers to the effectiveness of the organisation of research and innovation that is directly related to NIS.

The third set of questions is linked to the leading actors. What are the targeted actors for public policy? What are the efficient ways to stimulate biotechnology development through public policies? This set of questions is linked to the relative complementarity and substitutability between vertical and horizontal policies.

Data and method

To assess how effective public policies are, it is necessary to characterise systems of innovation and public policies.

Systems of innovation

National systems of innovation literature (Edquist, 1997; Lundvall, 1988; Niosi *et al.*, 2000) usually characterises the organisation of the national economy and society towards research innovation in a very detailed way. It insists on the idiosyncratic nature of each system. To compare the different European economies, three dimensions have been defined, based on the characterisation provided by the inventory project (Enzing *et al.*, 1999):

- The relative priority of R&D in each country compared to the relative size of the country. Four categories of country are defined:
 - countries of large economic size with high R&D intensity that are the big players on the European scientific scene;
 - countries of large economic size with low R&D intensity that do not benefit from long-term investment in R&D and higher education;
 - countries of small economic size with high R&D intensity — these are countries that benefit from a long tradition of investment in higher education and R&D and appear to be very important in the knowledge-based economy and

- countries of small economic size with low R&D intensity that do not prioritise R&D and innovation as a key mechanism for wealth creation.
- The configuration of the biotechnology policy-making system in Europe. In all countries, government bodies, ministries and institutes play a key role in organising biotechnology policy strategy and implementation. The inventory report characterised biotechnology policy-making system according to two dimensions (Enzing *et al.*, 1999):
 - *Ex ante* or *ex post* convergence of actors in the strategic decision-making process. The intensity of interactions is interpreted as an indicator for the degree of co-ordination amongst actors in the definition of their strategic goals. Accordingly, a country with weak interactions is fragmented, actors are defining strategies with high levels of independence. The reverse situation is a country where interactions amongst actors are strong and generate co-ordination.
 - One of the hypotheses that can be made is that the research system is much more fragmented in large countries than in small ones.
 - However, multiplicity of policy players does not necessarily mean that strategic decision-making process are uncoordinated. The main criterion is the *ex ante* co-ordination of strategic decision. When countries are fragmented, there are a large number of actors who can promote their own objectives with specific assessment criteria. There is no *ex ante* co-ordination, and public policies thus have to achieve *ex post* co-ordination of initially independent decisions: the decision-making process is divergent. In contrast, countries in which the decision making process is convergent, where actors have high levels of interaction, have *ex ante* co-ordination. While the former system encourages diversity, the latter is more targeted.
 - The organisation of the research system. In order to understand better the NIS, it is

To compare the different European economies, three dimensions have been defined: the relative priority of R&D in each country compared to the country's relative size; the configuration of the biotechnology policy-making system in Europe; and the organisation of the research system

necessary to picture the interactions among the different levels of decisions. The scientific community defines its goals considering scientific advances and problems to solve. Public authorities define their strategies for stimulating research and innovation. Three different systems have been depicted according to two dimensions, the way in which funds are allocated and complementarities among institutions:²

National systems based on public research institutes: those institutions define priorities and research programmes, fund and coordinate their own research infrastructures and incentive schemes;

National systems based on research councils: the characteristic of these countries is their strong programme orientation and their flexibility in subjects and themes of research. Allocation is based on (mainly scientific) competition, and research councils have autonomy, with ministries not being closely involved.

National systems based on funding organisation: most of these countries adopt a two-head organisation — one tool for basic research and the second for applied research and interactions with industry.

Public policy profiles

Public policy instruments are categorised within three dimensions to compare public policies of the European countries. No European country has a single policy actor responsible for biotechnology relevant policies (Enzing *et al*, 1999). Therefore, to picture the public policy framework, we formulate a combined policy profile, taking into account the diversity of the policy-making national systems per country,³ in effect constructing a kind of 'virtual' policy profile for each country.

- Vertical public policies (dedicated to biotechnology — support the creation of the knowledge base in biotech, for commercialisation)
- Horizontal public policies (instruments to support the knowledge base, including mobility of researchers; instruments to support the commercialisation of technologies, including mobility of researchers; firm creation) not targeted on any one sector.
- Public policies to build infrastructures (regulation matters for the biotechnology industry, legislation on intellectual property rights (IPR), measures to assure the availability of financial capital in high growth sectors, policies with socio-economic and ethical dimensions).

Policy profiles have been defined according to these three dimensions so as to compare the situations in 1994 and 2001. The importance of each target of

public policy (knowledge base, firm creation and so on) has been ranked on an ordinary scale from 1 to 5 from not important (1) to extremely important (5).

The importance has been assessed by the EPOHITE project team based on information from the inventory project (Enzing *et al*, 1999) and, if possible, from national experts. A global picture of the policy instruments implemented in each country has been depicted, as well as the relative priority of each instrument. In each national report, the agencies responsible for the policy instrument and the history of the instrument (is it recent or more long-standing?) have been analysed. To assess the importance of the public policy, we combine expert evaluations, figures and policy announcements.

The effectiveness of public policies is based on the fit between systems of innovation and public policies in the short run and on the ability of public policies to adapt systems of innovation to complement actors strategies in the long run.

Results

The first two sub-sections portray the main characteristics of the system of innovation and of national public policies on a comparative basis, while the third section assesses the effectiveness of public policies.

Country comparison of systems of innovation

Table 1 presents the general frame within which each country defines its R&D and innovation policy. It displays four sets of variables to categorise the position of each country on two dimensions: size of the economy and relative R&D intensity:

As far as the intensity of R&D efforts in 1994 and in 2001 is concerned, France, UK, Italy and Ireland have a decreasing ratio GERD (gross expenditure on R&D)/GDP (gross domestic product). In all other countries, the proportion of wealth dedicated to R&D is increasing. This is especially the case for Sweden and Finland, which started from a high level of R&D expenditure. Public policy indicates that a high priority is given to R&D in both countries.

The balance between public and private R&D indicates the sources of investments in R&D and the share of private firms and institutions that are investing in R&D. In low R&D-intensive countries, public R&D dominates. In high R&D-intensive countries, the proportion of public R&D to total R&D expenditure is between 24% and 38%, with France and Denmark having the highest shares of public investment. The investment in R&D from firms remains low in Italy, Portugal, Greece and Spain.

The third indicator underlines the R&D expenditures in each country. Germany, UK and France show a high priority for biotechnology. Large countries with high R&D intensity represent more than 85% of national biotechnology R&D expenditure in

Table 1. General features about biotechnology public policies

Country	GERD/GDP 1994 (%) (Inventory project: Enzing <i>et al</i> , 1999)	GERD/GDP 1999* (EPOHITE country reports: Reiss <i>et al</i> , 2003)	Balance of public/private R&D expenditure (OECD, MSTI database, 2001)	Biotechnology R&D expenditure 1994–1998 (Mecu) (Inventory project: Enzing <i>et al</i> , 1999)	Clusters (Reiss <i>et al</i> , 2004)
Large countries, high R&D intensity					
Germany DE	2.3	2.45 (2000)	33.0	3021	2
France FR	2.4	2.15	37.3	2115	3
UK	2.2	1.86	27.9	2572	2
Large countries, low R&D intensity					
Italy IT	1.2	1.04	51.1	207	4
Spain ES	0.8	0.94	40.8	47	4
Small countries, high R&D intensity					
Finland FI	2.3	3.19	29.2	248	1
Denmark DK	1.8	2.0	36.1	138	1
Netherlands NL	2.0	2.02	37.9	314	2
Sweden SE	3.3	3.8	24.5	271	1
Small countries, low R&D intensity					
Belgium BE	1.6	2.0	24.9	551	2
Austria AT	1.5	1.63 (1998)	39.3	49	3
Ireland IE	1.4	1.37 (1997)	22.2	46	3
Portugal PT	0.6	0.77	69.7	73	4
Greece GR	0.5	0.57 (1997)	53.5	20	4

Note: * Other years of reference are indicated in brackets

Europe. Small countries (even with high R&D intensity) represent less than 4% of the total expenditure.

The last column indicates the clusters of effectiveness. As pointed out by Reiss *et al* (2004, this issue), cluster 1 is the best performing cluster, cluster 2 is the second best, both in terms of renewal of the knowledge base and commercialisation, while clusters 3 and 4 represent those countries that have lower performances.

Table 1 presents the national contexts in which biotechnology public policies have been designed.

Table 2 assesses the degree of co-ordination amongst national actors, that is, firms, universities, local or national public authorities, in the definition

of their strategic goals. It presents the characterisation of each country under review based on the Inventory report (Enzing *et al*, 1999) and the national case studies performed during the EPOHITE project.

In small countries that invest heavily in R&D such as Denmark (DK), Finland (FI) and the Netherlands (NL), decision making is convergent. (The situation in Denmark changes between 1994 and 2001, with *ex ante* co-ordination being reinforced during the period.) In small countries, where R&D intensity is low, even though few actors may be involved, they do not *ex ante* co-ordinate their research and innovation strategies, leading to a fragmented (divergent) system. In large countries (except the UK) decision-making tends to be divergent.

Table 3 presents the organisation of the research system. It is pictured as the research funding allocation mechanisms.

Resource allocation mechanisms are stable during the period under review. Small countries with high

Table 2. Co-ordination of strategic decision-making process

Divergent Decision-making processes amongst actors with no <i>ex ante</i> co-ordination	Convergent <i>ex ante</i> co-ordination of the decision making processes
DK 1994 ←	→ DK 2001
SE 1994–2001	UK 1994–2001
BE 1994–2001	NL 1994–2001
PT 1994–2001	FI 1994–2001
FR 1994–2001	IE 1994–2001
DE 1994–2001	
AT 1994–2001	
GR 1994–2001	
IT 1994–2001	
ES 1994–2001	

Resource allocation mechanisms are stable during the period under review: small countries with high R&D intensity are mainly based on research councils, while countries with low R&D intensity are mainly based on funding organisations

Table 3. Evolution of resource allocation mechanisms

Funding system based on:	Country and period
Funding organisations	AT 1994–2001
	BE 1994–2001
	GR 1994–2001
	PT 1994–2001
	FI 1994–2001
	IE 1994–2001
Research councils	DK 1994–2001
	SE 1994–2001
	UK 1994–2001
	NL 1994–2001
Public research institutes	FR 1994–2001
	DE 1994–2001
	IT 1994–2001
	ES 1994–2001

Source: *Inventory report (Enzing et al, 1999, EPOHITE adaptation)*

R&D intensity are mainly based on research councils, while countries with low R&D intensity are mainly based on funding organisations.

To sum up, the following observations on the evolution of the decision-making processes in biotechnology policy can be made:

- Most countries show a real stability in their resources allocation mechanisms over the past ten years. Only Denmark has changed from a divergent framework to a more convergent system, in which the number of actors involved is diminishing and becoming more interrelated.
- Organisation systems are diverse and stable;
- Except for the UK, most of the convergent R&D systems are found in small countries with high R&D intensity (such as Finland, Denmark, the Netherlands and, to a lesser extent, Ireland). Systems based on public research institutes group large countries with both high R&D intensity (Germany and France) and low R&D intensity (Italy and Spain).
- Systems based on research councils appear to be those that are able to change more easily, from

divergent to convergent. It appears to be the more flexible system, as funding organisations are more flexible than systems based on public institutes.

- Tables 2 and 3 illustrate that *ex ante* or *ex post* convergence of actors' strategic decision making process are the key variables in the evolution of the biotechnology sector.

From vertical to horizontal public policy

While structures are fairly stable, public policies have changed radically during the period under review. Policy profiles have been defined according to detailed items for each theme. The importance of public policies during the period has been assessed on an ordinary scale from 1 to 5 for the periods 1994–98 and 1998–2002. The scores of each category (knowledge base, commercialisation, horizontal and infrastructure) have been added (see Reiss *et al*, 2004). Thus the highest mark that could be achieved in each of the categories is 15, where national public authorities have given the highest priority to that category.

The four categories of Table 4 are:

- Vertical policies for knowledge base support These instruments aim to support the creation and renewal of the knowledge base, that is, they encourage and fund basic research and support scientists, instruments to encourage industry-oriented (and applied) research in PSROs (public-sector research organisations) (research programmes targeting industry-oriented research, funding of PSROs–industry joint research, support for patenting activities in PSROs) and instruments for strengthening academic cooperation among PSROs and disciplines (support for centres of excellence and programmes for interdisciplinary research, encouragement of the mobility of researchers, establishment of, and support for, research networks).
- Vertical policies for commercialisation support These instruments represent tools to stimulate economic commercialisation of the knowledge base and scientific results. The category includes instruments to build up technological capabilities for the industry (creation of research institutes and technology centres of industrial interest, grants for industrial research), instruments to encourage the

Table 4. Evolution of public policies

	Vertical for knowledge base	Vertical for commercialisation	Horizontal policies	Framework policies
1994–1998	8.1	7.2	8.3	4.7
1998–2002	8.7	8.5	10.1	6.6
Trend	(+)	+	++	+++

Note: The assessment of the weight of vertical and horizontal policies has been made for each country separately on a comparable basis

commercialisation of scientific results from public research institutions (spin-off biotech formations/start-up companies and establishment of biotech-specific public venture funds, establishment of biotech science parks and incubators) and instruments to encourage the collaboration between public and industrial research (research programmes requiring industry involvement, support of temporary personal exchange between industry and PSROs).

- Horizontal science and technology policies These instruments cover tools to stimulate R&D and innovation that can be applied to all sectors, but especially high-tech ones. It includes instruments to support the knowledge base, including mobility of researchers (open call systems of research councils, block grants to research institutes, funding of research institutes), instruments to support the commercialisation of technologies, including mobility of researchers (technology transfer offices, support for network formation and collaboration between industry and PSROs, grants for industrial research, industry involvement in decisions concerning public-sector research, advisory and consulting services for the industry regarding grant application, legislation, IPR and so on) and firm creation (firm creation, establishment of science parks and incubators).
- Framework policies These instruments cover regulation tools (harmonisation with European legislation for drugs, GMO release, labelling), legislation on property rights (legal protection of inventions and share of IPR between scientists and institutions) and measures to assure the availability of financial capital in high growth sectors (establishment of attractive credit market conditions for technology-based firms, venture capital market support, stock exchange markets for small companies).

Table 4 presents an overview of the evolution of public policies for 14 countries in Europe by giving the mean score in each time period for each public policy category. The third row indicates the general trend. In detail:

- Creation and renewal of the knowledge base in general (horizontal) and in biotechnology (vertical) has been the main priority of public authorities during the period 1994–98 in the UK, the Netherlands, Denmark, Sweden, Portugal, Belgium, France and Germany. Since 1998, the priority of the creation and renewal of the knowledge base has decreased in France, and increased in Finland.
- Vertical policies to support the creation and renewal of the knowledge base are the tools that slightly increase during the period everywhere.
- Vertical policies in favour of commercialisation have been supportive in Finland, UK, Ireland, the Netherlands and Germany. For these countries,

policies towards commercialisation remain a priority. They increase in importance for Austria, France and Belgium in the second period. Vertical policies supporting commercialisation are rather weak for Italy, Denmark, Sweden, Spain, Greece and Portugal for both periods.

- Horizontal policies appear to have been one of the main tools during the two periods under review. In the second period, public policy emphasised horizontal policies more than vertical policies. Instruments to support the knowledge base and those to support commercialisation are equally important. The growing importance of horizontal instruments may be because of the generic nature of biotechnology, especially biotechnologies that design new instruments to explore life. Instruments in favour of firm creation and start-ups have been created and reinforced in Denmark, Germany, France, Ireland and the Netherlands, especially during the second period.
- Table 4 shows that infrastructure policies appear to be of growing importance. Rather than stimulating knowledge or commercialisation directly, these policy tools are dedicated to the creation of a favourable environment in terms of IPR, availability of venture capital and stock exchange for high-tech SMEs.

To sum up, it appears that most of the countries define and implement public policies to support biotechnology, R&D and innovation. Apart from Greece, Portugal, Italy and Spain, European countries have given strong support to biotechnology during the last ten years. Tools were quite similar, that is, funding for basic research, support for researcher mobility, instruments to support PSROs and industry co-operation, science parks and incubators, tax credit for R&D, technology transfer offices and creation of a favourable environment for innovation and research.

The main differences are based on the relative emphasis on vertical and horizontal policies on the one hand, and knowledge base renewal and commercialisation on the other. The general evolution of public policies is heterogeneous in Europe. Highly R&D-intensive countries and large R&D countries have a balanced policy, which combines support for the knowledge base and commercialisation. Over time, support for commercialisation has increased in the UK and France, while support for both commercialisation and the knowledge base has increased in Austria, Belgium, Ireland, and the priority for knowledge base support has increased only in Germany and the Netherlands.

Vertical public policies for supporting commercialisation and the knowledge base seem to have been substitutable rather than complementary. As regards the balance between vertical and horizontal public policies, Table 4 emphasises the increasing importance of horizontal policies compared to vertical ones. It also highlights the growing importance of framework policies.

Effectiveness: R&D structures and public policies

In the following R&D structures, co-ordination and public policies will be related to performance as presented in the cluster analysis (see Reiss *et al.*, 2004, this issue) in order to analyse the influence and effectiveness of the different public policy measures implemented in different national contexts. Tables 5 and 6 reveal the linkages among R&D structures, co-ordination amongst actors, public policies and effectiveness. In Table 5, convergent or divergent indicates the co-ordination amongst actors as regards the strategic decision-making process.

Table 5 assesses the relationship between the convergence of strategic decision-making processes and the effectiveness of public policies in favour of biotechnology. It highlights that a convergent decision-making process seems to be more efficient than a divergent one. For all countries, even large ones, the fragmentation of actors represents a weakness. Concentration of the strategic decision process amongst a few actors allows a visible, stable and coherent policy, even with specialised institutions dedicated to basic or applied researches.

Table 5 also reveals that convergent systems (*ex ante* co-ordination of strategic decisions) appear to perform better than divergent ones. Moreover, research systems based on research institutes seem to be more divergent than systems based on research councils or funding organisations. One of the explanations can be found in basic models of sociology of organisation, which emphasise that the strategy of organisations is to compete to survive (Crozier, 1963). To do so, they have to differentiate themselves from their closest rivals. Thus, it is difficult to co-ordinate *ex ante* the strategies of public institutes. In contrast, funding organisations and research councils appear to be two mechanisms of more flexible and effective co-ordination.

Table 6 compares the performance of the various countries with the national policy approaches in terms of focus (vertical or horizontal) and intensity (weak is below the average for the period, strong is above average), showing that public policies play a role. Countries that invest the most in R&D (GERD/GPD) are also those that belong to the best performing clusters (except for France). In all these countries, except Sweden for the second period, R&D and biotechnology have been strongly supported through both horizontal and vertical public policies. Horizontal and vertical policies therefore seem to be complementary rather than substitutable, even if the emphasis on horizontal policies has been growing.

The empirical findings of EPOHITE suggest that strong support could lead to better performances, and that concentration can have a positive effect on performance. Countries where strategic decisions regarding public policies are concentrated belong to the better performing clusters. Actually, concentrated versus fragmented policy reveals more about *ex ante* versus *ex post* co-ordination. In countries in which strategic decisions are concentrated, co-ordination is more effective because it is done *ex ante*, before the implementation of a strategic decision. In reverse, when the strategic decision is fragmented and split among independent actors, co-ordination has to be done *ex post*.

Ex ante co-ordination appears to be more effective. It could be one of the reasons why no system based on research institutes appears amongst the most effective. Institutes have their own autonomy and they are not *ex ante* co-ordinated. Moreover, in large countries, such as the UK, the research council system appears to be one of the ways to encourage concentration. It is also a means of reinforcing effectiveness through competitive funding to support both the knowledge base and commercialisation.

Table 5. Convergence versus divergence and effectiveness

Qualitative characterisation of biotechnology policy systems				
		System based on funding organisation	System based on research councils	System based on public research institutes
Cluster 1	FI SE DK	Convergent	Convergent Convergent	
Cluster 2	UK DE BE NL	Divergent	Convergent	Divergent Convergent
Cluster 3	FR AT IE	Divergent Convergent		Divergent
Cluster 4	IT GR ES PT	Divergent Divergent		Divergent Divergent

Table 6. Horizontal versus vertical public policies

		Vertical	Horizontal
Cluster 1	FI	Strong	Strong
	SE	Strong	Strong (94–98) to weak (98–02)
	DK	Strong	Strong
Cluster 2	UK	Strong	Strong
	DE	Strong	Strong
	BE	Weak (94–98) to strong (98–02)	Strong
	NL	Strong	Strong
Cluster 3	FR	Weak	Weak
	AT	Weak	Strong
	IE	Weak (94–98) to strong (98–02)	Strong
Cluster 4	IT	Weak	Weak
	GR	Weak	Weak
	ES	Weak	Weak
	PT	Weak	Weak

Discussion and conclusions

From 1994 to 2001, support for biotechnology research and development has increased in the 14 European countries under review. Despite a wide variety of public policies and measures, priorities can be identified as follows:

- Reinforcement of commercialisation. In countries where the percentage of the national wealth dedicated to R&D decreases or is stable, the priority given to commercialisation leads to the reduction of funding for the increase of the knowledge base, as in France.
- A move from vertical to horizontal public policies. This shift from vertical to horizontal and framework-oriented public policies may also reflect the evolution of the biotechnology sector as it has matured during the last ten years. The emergence of a new technological paradigm may potentially destroy the traditional barriers to entry, representing a threat to incumbents using the old set of technologies as well as opportunities for new entrants, and this phase is characterised by radical and rapid technical change.

The second phase reveals technological consolidation and stabilisation around dominant designs (Anderson and Tushman, 1990). New firms are created on the basis of the differentiated knowledge to test, refine and exploit opportunities. The exploitation phase also represents the diffusion of biotechnology and its use by a large set of users, from biotechnology firms to the whole life sectors. It induces an evolution of the actors involved in the biotechnology sector as well as a modification of patterns of collaboration (Nesta and Mangematin, 2002). Thus public policies dedicated to biotechnology may be less adapted than they previously were.

- Greater attention paid to the creation of a favourable environment, which stabilises the rules of the game and promotes private investments through the reduction of uncertainty.

- Public policies in favour of technology transfer from university or PSROs to industry.

The performance of the system, which may result from the effectiveness of public policies, seems to be higher when public policies are *ex ante* co-ordinated rather than *ex post*. Thus strategic decisions have to be designed and implemented by a limited number of actors. Greater effectiveness is shown when the research and innovation system is based on competitive funding mainly through research councils and funding organisations, than when based on public research institutes.

R&D systems based on research councils or funding organisations appear to be more flexible and adaptable to the evolution of the biotechnology sector. The performance of the system is higher in countries that stabilise the environment (regulation issues, IPR, and so on). The organisation of the competition amongst actors is more effective than direct co-ordination through research institutes or specific programmes. Policy instruments to support commercialisation and the knowledge base appear to be more complementary than substitutable.

This paper emphasises the fit between national contexts or innovation systems and public policies. It highlights greater flexibility for systems based on research councils or funding organisations compared to those based on public research institutes. The configuration of the biotechnology system in Europe reveals similarities amongst different nations according to the organisation of research system. At the same time, European countries have reached different stages of development of biotechnology in terms of both the knowledge base and the industrial sector (number of firms, presence of national leaders, presence of large firms, rate of growth).

The generic term national innovation system groups the two dimensions (organisation of the research and innovation system and the stage of development) within a single concept that could be misleading with regard to the benchmarking of public policies, which not only have to adapt to the

organisation of the research and innovation system, but also have to take into account the stage of development when designing policy tools. Results highlight that, as the industry matures, public policies are based more on NIS approaches than on sectoral ones.

Focused as it is on national public policies and instruments, the analysis does not integrate the growing role of some regional public authorities in large countries such as Germany or France. Thus, neither coordination amongst national and regional policies are analysed, nor complementarities with European Community (EC) measures, which are especially important for Ireland and Portugal during this period.

Notes

1. The project Effectiveness of innovation policies in high technology sectors in Europe (EPOHITE), contract no HPVI-CT-2001-00005 was carried out by a research team from Fraunhofer ISI (Germany), TNO Institute for Strategy, Technology and Policy (Netherlands), SPRU (United Kingdom) and UMR GAEL (France) between April 2001 and July 2003 (see Reiss *et al*, 2003). For more details see <<http://www.epohite.fhg.de/>>, last accessed ??please supply date??.
2. This is only a rough classification to portray the global evolution of each national system and public policy. It should not imply that the complete system in a country follows the classification presented.
3. The analysis only takes into account the national level of public policy. Regional public policies are not reviewed in this article.

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