Evaluating Research Efficiency within National R&D Programmes[i]

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Abstract

Relying on efficiency analysis we evaluate to what extent policy makers have been able to promote the establishment of consolidated and comprehensive research groups to contribute to the implementation of a successful innovation system for the Spanish food technology sector, oriented to the production of knowledge based on an application model. Using data envelopment analysis techniques that allow calculation of a generalized version of the traditional distance function model for productive efficiency, we find pervasive levels of inefficiency and a typology of different research strategies. Among these, in contrast to what has been assumed, established groups do not play the pre-eminent benchmarking role; rather, partially oriented, specialized and "shooting star" groups are the most common patterns. These results correspond with an infant innovation system, where the fostering of higher levels of efficiency and promotion of the desired research patterns are ongoing.

Key words: Innovation System Management, Research Efficiency, Data Envelopment Analysis, Spanish Food Technology Program.

1. Introduction

Efficiency analysis has been applied in many fields, but there are fewer examples of its application to study the socioeconomic impact of public R&D policies (Batterbury, 2006; Chelimsky, 1998; Cozzens, 2002), despite its relevance to evaluation studies (Cook and Scioli, 1972; Cozzens, 2003; Joyce, 1980; Pedersen, 1977; Shapira and Kuhlmann, 2003). This stream of work has been addressed mainly to the design of efficiency measures related to university teaching and research activities – e.g. Beasley (1990, 1995), Cherchye and Vanden Abeele (2005). We develop these ideas, focusing on the role played by particular public R&D instruments and policies – specifically the R&D projects financial scheme within Spanish Food Technology Programme (SFTP).

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In our efficiency analysis we introduce Data Envelopment Analysis (DEA) techniques necessary to implement Chavas and Cox's (1999) generalized distance function. The generalized distance function allows for enhancement of outputs and contraction of inputs at the benchmark frontier, defined by the performance of the leading research groups. Analysis of efficiency rankings allows us to characterize different categories of research groups and their individual direct roles in generating a multidimensional output mix[1] that contributes to the relative success of policy in shaping a comprehensive Spanish Food Innovation System (SFIS).

This work contributes to the literature by illustrating the benefits of using another critical and relatively neglected function of evaluation research, such as efficiency, which in our case is aimed at contributing to the policy learning process by providing policy makers with information on how well research programmes measure up to their particular targets.

In 1986, Spain's central administration took the decision to fully institutionalize public support for research and development (R&D) and innovation activities. Within the Spanish R&D Plan, many public actions have been introduced to foster activities in public research organizations (PRO), technology institutes and business firms. All of these actions or R&D Programmes, have their particular sectoral objectives, but a common goal of *better articulation* of the Spanish innovation system (CICYT, 1988), *i.e.* the creation of a system in which the different agents involved in the innovation process – mainly public R&D managers, research groups operating in technology centres and universities, and private firms - are closely related through supportive networks (Lundvall, 1988, 1992). The R&D Programmes were accompanied by several financial tools, addressed to achieving the above-mentioned goal, which, for R&D projects, provided financial support for research groups in PROs to carry out applied research, embodied mainly in international scientific publications, scientific personnel training, patent applications, etc. which are seen as the most relevant measurable outputs.

In this article we show how research groups supported by the SFTP, have indirectly contributed to this objective by generating a multidimensional research output mix (Godin and Gingras, 2000; Tassey, 2003). The efficient performance of these groups within the innovation system is paramount as they are the providers of new knowledge that eventually should have commercial value for the private sector, and should orient public R&D managers towards the most suitable allocation of public funding for research to enable business firms to benefit from the knowledge created, enabling them to generate innovations to increase wealth and employment across the whole economy.

We evaluate the SFIS by focusing on the performance of public research groups, normally embedded in research and technology institutes and universities, in fulfilling this knowledge generation and diffusion role –see Olazarán et al. (2004) for a general introduction to the historical roles of research groups in the Spanish R&D system, and. We adopt an efficiency analysis methodology, which enables us to identify the output production performance of different types of research groups and to check whether it represents a multidimensional, balanced and comprehensive output mix (Menrad, 2004). This methodological approach has proved valid when analyzing performance within the Spanish innovation system as Revilla et al. (2003) show for a particular policy instrument known as concerted projects—i.e., collaborative partnerships between companies and public research institutions. Their main result is that large organizations perform better than smaller ones as a result of increasing returns to scale, and therefore the larger the

[1] We provide a thorough description of this "multidimensional research output mix" later in the paper; however, it can be characterized as the output of R&D projects in terms of training (measured as completed PhD theses and trained people), science and technology (ISI articles and registered patents) and socioeconomic output (R&D contracts).

companies and research centres involved in a partnership, the higher the synergy that can be expected from it.

The paper is structured as follows. Section 2 discusses the methodological approaches proposed in the literature to justify public intervention in R&D activities when trying to shape a successful innovation system based on the expected multidimensional and comprehensive roles of research groups. This is followed by a discussion in Section 3 of the institutional framework that characterizes the Spanish innovation system (IS). In particular, we look at public managers – in charge of the design and implementation of R&D policies, and research groups – responsible for the execution of research activities that will contribute to the system. Section 4 introduces the efficiency measure adopted in this research, and shows how it is rendered operational by exploiting the generalized distance function and the specific DEA techniques that allow the calculation of productive efficiency. Section 5 presents our results, outlining and discussing the particularities of the data. Section 6 concludes with an overall assessment of the degree to which Spanish R&D policy and instruments have succeeded in promoting different patterns of research groups contributing to the establishment of a SFIS.

2. Public policies and the promotion of research

Arguments in the Economics of Science and Technological Change that favour public intervention are mainly responding to two opposite streams within this literature: the neoclassical, and the structuralist-evolutionary. According to the former, public intervention rests on the existence of market failures; production of new knowledge is associated with positive externalities and, thus, public R&D policies are justified (Arrow, 1962). The latter approach sees knowledge as an imperfect good that does not satisfy the usual characteristic of non-excludability (David et al., 1994). If we accept the non-rival nature of knowledge, then the agents generating it will be able to appropriate only a small fraction of the social benefit produced, and it will be necessary to foster R&D activities at above optimal market level to justify public policies supporting these activities. This approach is linked to the systemic view of the innovation process in which the concept of IS is used to justify the existence of different agents and the relationships among them, to carry out innovation activities (Freeman, 1987; Lundvall, 1992). Within a structuralist-evolutionary approach, R&D public policies, to an extent, respond to the need to strengthen the role and involvement of IS agents (Lipsey and Carlaw, 1998; Metcalfe, 2002).

We rely on the concept and terminology of the IS articulation introduced by Rip and Nederhof (1986), to measure and test the capacity of the SFIS to establish a network of fluent and continuous knowledge flows among public and private agents. This articulation and concept is in line with Gibbons et al.'s (1994) description of the change over in scientific knowledge production from mode I to mode II and the subsequent role of relationships among agents to generate new and economically productive knowledge. Using benchmark efficiency analysis methodology we assess whether the SFTP has succeeded in promoting multidimensional output from the Spanish research groups, in terms of a focus on different research dimensions to ensure the transition to mode II knowledge production, while at the same time strengthening their relationships with private firms within the IS. In this context, and taking into account that diversity and specialization are key aspects of every IS (Jacobs, 1998), we assume different sets of research groups in terms of an efficient research output mix, with each playing a particular and meaningful role within the SFIS. To enable the participation of these different groups and to ensure the emergence of new path breaking groups in line with policy objectives, we need an appropriate management and allocation of R&D funds. It has been acknowledged that in the initial stages of any IS, and in order to maximize its future success, R&D and innovation policies should be aimed at establishing multiple new research groups or providing “seeding”, to afford a mix from which comprehensive and leading groups will emerge (Gerchak and Kilgour, 1999). The research question we address is: to what extent have R&D projects financed by SFTP become tools suited to the promotion of the productive efficiency in multidimensional research groups?

3. The institutional framework of the SFTP

The SFTP was launched in 1988 as part of the 1st National R&D Plan, and has continued to be an element of all its subsequent announcements. The financial support it receives represents around 5% of the national R&D Plan budget (Jiménez-Sáez, 2005). Thus, the importance of evaluating the SFTP in order to assess whether and to what extent its original objectives have been achieved is evident. Based on the resources devoted to the SFTP, the evaluation in this study could serve as a model for the other programmes within the Plan. Also, this analysis will complement other analyses and evaluations in this context (Acosta and Modrego, 2001) and will contribute to filling the gap in Spanish R&D public policy evaluation.

The SFTP was defined in 1988 as a: systematic group of research and development projects oriented towards the encouragement of research, technology innovation and development in the Spanish Food Technology sector. It is co-ordinated and complemented by other actions among which the training of specialized personnel[2] and the establishment of an infrastructure that favours technology transfer from knowledge producing sectors to users stand out. (CICYT, 1988)

There are four milestones along the path to the central goal of the SFTP: *(i) training personnel; (ii) support for firm R&D and innovation activities; (iii) support for research groups’ R&D activities; and (iv) support for technology transfer from research groups to firms.* The SFTP, similar to other R&D Programmes within the Spanish R&D Plan, was designed to cover all the stages in the innovation process, offering the potential of participation by a wide variety of agents, and fostering co-operation among them. The present study focuses mainly on support for the R&D activities of research groups.

The initial budget for the Programme announced in 1988 was approximately €45 million. The highest share of this budget was earmarked for the creation of infrastructures (€14.7 million, 33% of the total budget), and support for R&D activities (€12 million, 26.7%) through a variety of financial tools. Support for R&D activities carried out by research groups in PROs went to *R&D projects* whose output might be of interest to private firms for commercialization. It also was designed to enable cooperation between research groups and firms through *bilateral R&D contracts* forged outside of the SFTP financial scheme. It was expected that both sources of financial support would translate into multidimensional research outputs involving science-technology, training and socio-economic gains that would be basis of lasting cooperation with the private sector.

[2] The SFTP originally included in the training of specialized personnel two different outputs: young researchers (grant holders) finalizing their PhD (thesis writing) and technical support personnel. The data for the analysis in this paper accounts for both these categories as completed PhD theses and technical trained personnel.

4. The measurement of research efficiency

We characterize the production technology of public research using the generalized graph distance function introduced by Chavas and Cox (1999), which is more flexible than those used in the previous literature to assess research performance—e.g. Revilla *et al.* (2003). We consider a panel of = 1,...,I research groups transforming input vectors $x_i = (x_{1i}, ..., x_{Ni}) \in \Re_+^N$ into output vectors $y_i = (y_{1i}, ..., y_{Mi}) \in \Re_+^M$, according to the technology represented by the production possibility set: T = {(*x*,*y*): *x* can produce *y*} —see Färe and Primont (1995) and Shephard (1970) for a formal presentation of these concepts.

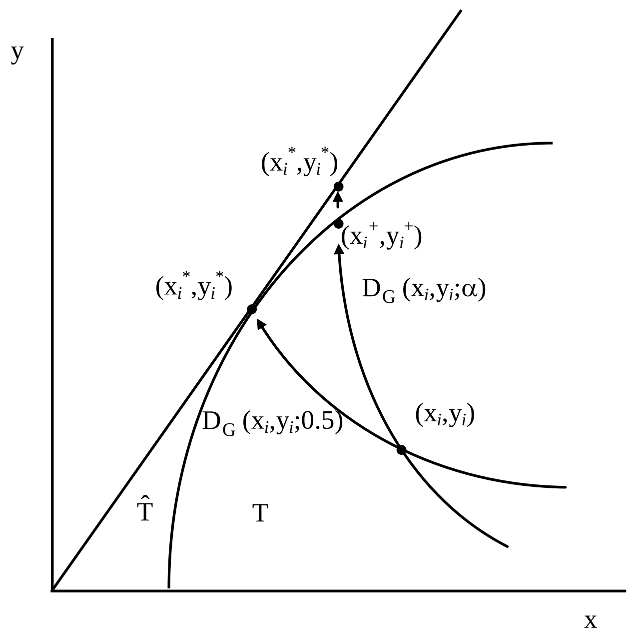
Given the technology, the generalized distance function corresponds to the maximum expansion of the outputs vector and the reduction in the inputs vector feasible: $D_G(x, y; \alpha) = \min\left\{\delta > 0 : (x\delta^{1-\alpha}, y/\delta^{\alpha}) \in T\right\}, \quad x \in \Re_+^N, y \in \Re_+^M$, where $0 \le \alpha \le 1$ represents the relative weight that the distance function places on outputs and inputs –a balanced weight is given by $\alpha=0.5$ as $\alpha/(1-\alpha) = 1$. The generalized distance function can be interpreted as a measure of technical efficiency in the sense of Farrell (1957), i.e. how far is the research group from its reference peers at the *best practice* frontier. Therefore, if $D_G(x, y; \alpha) = 1$ for a particular research group, this observation is deemed efficient in defining the frontier, while if $D_G(x, y; \alpha) < 1$ it is inefficient and, given the technology, it could increase its productive performance by reducing its inputs, while increasing its outputs.[3] In addition to the variable returns to scale (VRS) case considered in the definition of $D_G(x, y; \alpha)$, the technology may exhibit global increasing, decreasing and constant returns to scale (CRS). In the latter case, it defines by $\hat{T} = \{(\psi x, \psi y): (x,y) \in T, \psi > 0\}$, while the generalized distance function is denoted as: $\hat{D}_G(x, y; \alpha) = \min\left\{\delta > 0 : (x\delta^{1-\alpha}, y/\delta^{\alpha}) \in \hat{T}\right\}, \quad x \in \Re_+^N, y \in \Re_+^M$. This function can be also interpreted as a measure of *productive* efficiency, placing an observation on the *benchmark* frontier represented by $\hat{T}$.

We illustrate the efficiency interpretation of the generalized distance functions assuming VRS and CRS. The production possibility set shown in Figure 1 for N=M=1 reflects all feasible output–input combinations enabled by the state of the technology and the projections of the particular ***i***-th observation (x_i, y_i) towards the production frontiers that correspond to both definitions of the generalized distance function. Compared to its partially oriented output and input counterparts, the generalized distance function $D_G(x, y; \alpha)$ allows for a flexible course towards the production frontier by taking account of both sides of the production process and setting a direction that simultaneously contracts inputs and expands outputs. As we do not want to stress a particular dimension of the production process when measuring research efficiency, in this study we opted for a neutral direction that weights inputs contraction and outputs expansion equally, i.e. $\alpha = 0.5$. In general $D_G(x, y; \alpha)$ pushes a particular research unit (x_i, y_i) to the best practice frontier T. For this particular illustration the projection (x_i^*, y_i^*) is not only technically efficient, but also constitutes the most productive scale size in the presence of CRS – achieving the highest average product, and

[3] This accounts for the radial expansion of outputs and contraction of inputs. Nevertheless, individual changes in outputs and inputs might still be possible once the research unit is projected to the best practice (VRS) or benchmark (CRS) frontiers. A formal discussion of the alternative concepts of weak and Pareto-Koopmans efficiencies can be found in Jiménez-Sáez *et al.* (2007).

therefore it also represents the benchmark production frontier in $\hat{\mathrm{T}}$ when (x_i, y_i) is projected by $\hat{\mathrm{D}}_{\mathrm{G}}(x, y; \alpha)$, *i.e.* because of the productive optimality of (x_i^*, y_i^*)—from both a technical and a scale perspective, $\mathrm{D}_{\mathrm{G}}(x, y; \alpha)$ and $\hat{\mathrm{D}}_{\mathrm{G}}(x, y; \alpha)$ are equivalent distance functions (for a formal demonstration see Zofío and Prieto, 2006).

Figure 1: Generalized Distance Functions



On this basis, we can consistently decompose productive efficiency into mutually excluding technical and scale components. Since the VRS generalized distance function can be regarded as a technical efficiency measure: TE = $\mathrm{D}_{\mathrm{G}}(x, y; \alpha)$, while its CRS counterpart represents productive efficiency: PE = $\hat{\mathrm{D}}_{\mathrm{G}}(x, y; \alpha)$, any difference between the two would signal that the research group, when projected toward the best practice production frontier, does not produce on the relevant optimal CRS *loci* that would render it scale efficient and, thus, a productivity maximizer benchmark. Accordingly, it is possible to define a scale efficiency measure as: $\mathrm{SE}(x, y; \alpha) = \hat{\mathrm{D}}_{\mathrm{G}}(x\ , y\ ; \alpha) / \mathrm{D}_{\mathrm{G}}(x, y; \alpha)$. Therefore, productive efficiency can decomposed into a technical component capturing the distance between a research group and its VRS best practice frontier, and a scale component representing how far this technically efficient projection is from the benchmark frontier represented by the most productive scale sizes, *i.e.* PE = $\hat{\mathrm{D}}_{\mathrm{G}}(x, y; \alpha) = \mathrm{D}_{\mathrm{G}}(x, y; \alpha) \cdot \mathrm{SE}$ = TE · SE.

Finally, we present the non-parametric DEA technique that allows us to calculate the efficiency of public research groups operating within the SFTP by way of the generalized distance function. Assuming a piecewise linear approximation of the technology—including its VRS and CRS characterizations, calculation of the generalized distance function representing productive efficiency for a particular observation *i'* requires solution of the following non-linear program:

$$\hat{\mathrm{D}}_{\mathrm{G}}(x_{i'}, y_{i'};\alpha) = \min_{\delta, z_{i'}} \left\{ \delta : (x_{i'}\delta^{1-\alpha}, y_{i'} / \delta^{\alpha}) \in \hat{\mathrm{T}} \right\}$$

$$\text{s.t.}$$

$$\sum_{i=1}^{\mathrm{I}} \mathrm{z}_i \, \mathrm{x}_{in} \leq x_{i'n}\delta^{1-\alpha}, \quad n = 1,...,\mathrm{N}, \tag{1}$$

$$\sum_{i=1}^{\mathrm{I}} \mathrm{z}_i \, \mathrm{y}_{im} \geq \mathrm{y}_{i'm} / \delta^{\alpha}, \quad m = 1,...,\mathrm{M},$$

$$z \in \Re_{+}^{\mathrm{I}},$$

where z is a intensity vector whose values determine the linear combinations of *facets* that define the production frontier. As shown in the previous section, the productive efficiency measure (1) can be decomposed into a technical efficiency term, represented by the VRS generalized distance function $\mathrm{D}_{\mathrm{G}}(x, y;\alpha)$, and a scale efficiency term equivalent to the ratio of the former to the latter. $\mathrm{D}_{\mathrm{G}}(x_{i'}, y_{i'};\alpha)$ can be calculated to resolve problem (1), but adding the convexity constraint $\sum_{i=1}^{\mathrm{I}} \mathrm{z}_{i'} = 1$, which allows for VRS−see Banker *et al.* (1984). When both values have been determined, the scale efficiency term can be derived by dividing the generalized distance functions defined under CRS (1) by its VRS counterpart. [4]

5. Evaluating the SFTP

5.1 Data

We constructed a data base including inputs and outputs provided to and generated by the research groups participating in research and development (R&D) projects financed by the Spanish Food Technology Program (SFTP) between 1988 and 1999. Our analysis is conducted at the micro level. We define our units of analysis or Decision Making Units (DMU) as the various research units[5] operating within the host public research organizations (PRO) —see Olazarán et al. (2004). Thus, there may be more than one research group from the same PRO participating in the Programme; all are considered in our analysis.

Our target DMUs include research groups receiving financial and human capital inputs from the Spanish Central Administration to promote applied research within the SFTP. Institutionally, they belong to the Spanish National Research Council (CSIC). We chose to focus on the CSIC groups for two reasons. First, the application of efficiency methodologies requires homogeneity among the units to be evaluated (Cherchye and Vanden Abeele, 2005): the CSIC research groups are all based

[4] As discussed in footnote 3 some individual output expansions and input reductions may still be feasible while still belonging to radially defined best practice (VRS) and benchmark (CRS) frontiers. In our empirical application we account for these non-equiproportional changes by calculating the slacks corresponding to the above optimal Data Envelopment Analysis solution of the generalized distance function (1). This requires solving an additional linear program counterpart to (1), whose formulation is presented in Jiménez-Sáez *et al.* (2007).

[5] We define a research unit as the set of researchers that participates in a research project when at least 75% of the researchers continue unchanged from project to project. Any individual research group can evolve, decompose into or merge with a new or different research group, according to our definition.

on the same organizational structures, norms, incentives, etc. Second, CSIC has been engaged in research on food technology since the 1940s through the provision of financial support for applied research. Therefore, when the SFTP was launched in 1988, the CSIC research institutes were the only centres operating in the food technology area that were ready to apply for funding under this new scheme. This resulted in a large percentage (up to 60%) of the financial support for R&D projects being awarded to CSIC research groups between 1988 and 1991 (Ist Spanish R&D Plan). Due to this large proportion of R&D projects awarded to CSIC research groups, the homogeneity of CSIC centres in terms of their internal structure, research behaviour and other contextual variables – and especially the absence of teaching duties – we restricted our analysis to these research groups.

Data on inputs were gathered from the central administrative body responsible for project management—*Dirección General de Enseñanza Superior e Investigación Científica*, which is also responsible for collecting, processing and checking the final statements submitted by research groups detailing each project's research outputs. Hence, the indicators employed in our analysis are directly dependent on the structure and procedures included in these final reports. Cook and Reichardt (1986) suggest a similar approach to the acquisition of real data concerning the participation of certain agents in a particular research programme, and this method was also adopted by Van der Meulen and Rip (2000) to evaluate public sector research activities in the Netherlands.

We need to address some of the problems related to programmes such as the SFTP in terms of their evaluation. Several scholars have pointed to problems related to evaluation (Van der Meulen and Rip, 2000; Van Raan, 2000): (a) measurement (data gathering) problems, and (b) attribution problems, i.e. "how to determine whether and to what extent the programme caused the results observed" (Treasury Board of Canada, 2002: 6). This latter is a major concern in evaluation. In terms of data, we have to trust the final reporting of the (CSIC) research groups in terms of the results achieved as a result of the funding obtained from the SFTP.

For the purposes of our study we focus on the role of R&D projects in terms of financial and human capital inputs, and three categories of outputs jointly representing a multidimensional output mix, namely training (number of contracted technician personnel and number of completed PhD dissertations), science-technology outputs (published international articles included in the SCI database, and registered patents), and socio-economic outputs (bilateral R&D contracts with firms). Following Beise and Stahl (1999) we consider that this last type of cooperation, between public research groups and firms, can be seen as additional funding that would not have been raised if the research group had not shown itself to be reliable and successful, demonstrated by the outcomes of previous research activities.

Some explanation for the periodicity in our study is needed. The time period of our analysis, 1988-1999, covers the first three Spanish R&D Plans – each of which ran for four years. We do not adopt a four year periodicity, as R&D projects within the SFTP last for up to three years (CICYT, 1987; Jiménez-Sáez, 2005). A successful research group, which obtains funding every time it applies, i.e. every three years thus overlapping different R&D Plans, would have a chain of four projects – each of three years' duration – over the 12-year period. Hence, we define four periods for our analysis, covering the natural periodicity of an R&D project: 1st period: 1988-1990; 2nd period: 1991-1993; 3rd period: 1994-1996; and 4th period: 1997-1999.[6] In order to resolve time-lag problems that could

[6] In terms of the problems related to the time lag between inputs endowment and outputs production, and the attribution of certain outputs to a particular time period, studies of productive efficiency in university departments and R&D managers in official agencies (Beasley, 1990, 1995; Cherchye and Vanden Abeele, 2005; Martínez Cabrera, 2003) face similar problems. With regard to the SFTP we conclude that the schedule of the R&D agency responsible for the management of the programme, i.e. 3 years, is sufficiently long to establish a link between inputs usage and the results obtained. In any case, it should be borne in mind that the

exist between R&D input endowments and output production, we decided on a forward moving average which calculates output production in a given period t as the average between the outputs produced in periods t and t+1.[7] This smooths outputs over the 12 year period considered, reducing the effects of misallocation on output variability, over the four periods. This gives us a sample population of 64 CSIC research groups, of which 42 participate in the first period, 46 in the second period, 49 in the third period and 36 in the last period.

Preliminary descriptive statistics[8] are shown in Table 1, which summarizes the variables used in the analysis, classified under input and output categories.

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environmental conditions for outputs are the same across all research units (e.g. delays over publication of articles, time for patent registration, viva for doctoral thesis, etc.), so for efficiency measurements over period of time considered here there is a level playing field.

[7] For the last period 1997-99 we do not calculate the moving average since we do not have data on the subsequent period (00-02), but it would be reasonable to assume that the next period's outputs would remain unchanged, and the moving average under this assumption would yield the same result.

[8] Note that our data set has several zero entries on the outputs side, which is a fundamental characteristic of the decision-making process of research groups, *i.e.* the result of conscious behaviour. From a computational point of view, we follow the theoretical results presented in Thomson et al. (1993), who state that if a complementary pattern of input or output zeros exists, then the DEA efficiency measures of the DMU's subdomain, obtained by excluding those presenting variables with zero values, are the same as those for the complete data domain including all DMUs –Theorem 9A in Charnes et al. (1991).

Table 1. Variables and descriptive statistics							
	INPUT		MULTIDIMENSIONAL OUTPUT MIX				
			TRAINING		SCIENCE & TECHNOLOGY		SOCIO-ECONOMIC
Variables	Personnel	Public Funding	Trained people	PhD Theses	International Papers	Registered Patents	R&D Contracts
Research Groups (R.G.)	FTE	Euro	# of people	# of theses	# of papers	# of patents	Euro
1988-1990. 42 R.G.							
Mean	6.3	118 471.1	4.7	2.1	8.3	0.5	18 680.9
Median	5.5	92 991.6	3.5	2.0	6.0	0.0	0.0
Standard Deviation	3.3	71 870.4	4.5	1.6	8.2	1.3	35 084.1
Maximum	14.0	311 813.5	22.0	6.0	37.0	6.0	139 693.3
Minimum	2.0	29 780.1	0.0	0.0	0.0	0.0	0.0
1991-1993. 46 R.G.							
Mean	6.0	92 198.0	4.6	2.2	11.0	0.2	20 607.8
Median	5.0	86 605.8	3.5	2.0	9.0	0.0	525.9
Standard Deviation	2.8	42 785.4	4.7	1.8	8.7	0.5	38 888.6
Maximum	13.0	218 167.4	28.0	8.0	45.0	2.0	191 915.2
Minimum	2.0	13 222.3	0.0	0.0	0.0	0.0	0.0
1994-1996. 49 R.G.							
Mean	5.1	90 345.9	4.0	2.0	10.6	0.3	45 345.4
Median	4.0	83 300.3	3.0	1.0	8.0	0.0	9 015.2
Standard Deviation	2.8	43 628.8	3.4	1.8	8.0	0.8	92 844.6
Maximum	13.0	222 729.1	18.0	10.0	34.0	4.0	570 624.9
Minimum	1.0	9 916.7	0.0	0.0	0.0	0.0	0.0
1997-1999. 36 R.G.							
Mean	4.7	108 067.5	6.3	1.4	11.7	0.6	49 788.5
Median	3.0	85 373.8	5.0	1.0	8.0	0.0	6 602.1
Standard Deviation	4.4	80 171.4	7.2	1.5	15.2	0.9	81 178.3
Maximum	25.0	388 193.7	37.0	5.0	90.0	4.0	307 159.3
Minimum	1.0	15 025.3	0.0	0.0	0.0	0.0	0.0

In terms of inputs, based on number of research groups, both number of personnel and overall budget devoted to the SFTP, decline markedly from the first to the last period. From an output perspective, there is a marked growth in the number of contracts forged between research groups and private firms to diffuse and apply the results of research output. This may be an indication of the efforts of Spanish public research bodies to contribute to the articulation of the SFIS. The average private funding per contract received by the research groups in the 1988-1990 period amounted to €18 680.9, rising to €49 788.5 in the last period, which represents an average annual growth rate of 9.3% and cumulates to 166.5% over the whole 12 years. This increase in private funding is in sharp contrast to the trend in public funding of R&D projects, which reflects the shortages in public finance in the SFTP over this period, and the efforts and success of research groups with reliable results and credibility in rising private funding for their research activities (García-Martínez and Briz, 2000). We tested to what extent CSIC research groups are able to make efficient use of diminishing budgets, and whether traditional mode I research behaviour is changing towards mode II.

In terms of the output variables related to training, the number of trained people and number of doctoral theses show no noticeable increases. On average, the number of trained people within the research groups remained constant at around 4.5 during the first three periods, increasing to 6.3 in the last period. The number of PhD theses was similarly stable at around 2.1 per research group between 1988 and 1996 (first three periods), but decreased to 1.4 in the last period. Finally, in terms of the variables representing science and technology outputs, number of patents and training show similar trends, while scientific articles published in international journals shows a cumulated 8.9% rate of growth in the four periods, rising on average from 8.3 in the first period, to 11.7 in 1997-1999.

Besides individual efficiency rankings, we analyse the type of research output mix of CSIC research groups through their participation in the SFTP. In terms of financial support and recruitment of capable human resources to conduct research activities, they contribute to the SFTP in three output areas: *specialized* in a particular dimension, *partial* when two of the three output dimensions are considered, or a *comprehensive* research output mix. Our hypothesis is that the higher the efficiency score, along with output production in *all* research categories, the more comprehensive will be the research group. However, we acknowledge the important role played within the IS by other research groups that may eventually show lower efficiency scores, generating outputs in several categories or being specialized in just one. For example, many different research patterns might be financed in the hope that consolidated and efficient research groups will eventually emerge. Therefore, financial support should be available for all possible research categories, but bearing in mind the opportunity costs that such a pattern of funding might have in terms of research inefficiency and productivity losses (Gerchak and Kilgour, 1999). If support is channelled towards specialized groups, researching in a specific area, this will encourage behaviours that will not facilitate the transition from mode I to mode II knowledge production, and will provide a less than optimal contribution to an integrated IS. Bearing in mind that the SFTP is aimed at creating a critical mass of research in this field, it is understandable that policy makers assume that these opportunity costs will favour the establishment and consolidation of the SFIS.

5.2. Efficiency results

Our analysis is based on CSIC research group taxonomy (Fernández-de-Lucio et al., 2003; Jiménez-Sáez, 2005). Using DEA techniques we try to determine cross-sectional features and time efficiency trends for each group, and check our main hypothesis that R&D decision makers within the SFTP have been able to promote the creation and consolidation of an IS based on research groups that undertake a comprehensive range of research activities.

The results for research groups participating in the SFTP that have been efficient in at least one period are presented in Table 2. As described in Section 4, constant (CRS), variable (VRS) and scale efficiency scores are computed to solve the corresponding generalized distance functions, as in equation (1). These results show the degree of efficiency of each research group over a given time period, and the stability of the production frontier defined by the efficient groups. On average, the mean value of the efficiency score along the four periods under CRS is 0.69 (0.77 assuming VRS), with average standard deviations of 0.25 (and 0.22) respectively. This demonstrates the broad differences that exist among the different research groups participating in the SFTP, and the wide margins for efficiency improvement. Only 19 of the 64 research groups participated in the four periods under study, i.e. only 28% of the research groups applying to the SFTP show continuity over time, and just two of them were consistently efficient over the entire 12 year period.

These two groups, which show the highest efficiency scores, produce a multidimensional research output in the three categories and are considered to be the most consolidated research groups within the Spanish Food Innovation system (SFIS). In addition, they belong to the most important public research centres, with strong international network connections with firms and technology institutes, as evidenced by the number of contracts signed with these organizations.

Table 2. CRS, VRS and scale efficiency (only fully efficient research groups).

Period	1988-1990			1991-1993			1994-1996			1997-1999		
Research Unit	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale
CEBAS-01	0,763	0,798	0,956	0,665	0,681	0,976	*1,000*	*1,000*	*1,000*	0,759	0,759	1,000
CEBAS-02	*1,000*	*1,000*	*1,000*	0,516	0,815	0,633	0,537	0,546	0,982	*1,000*	*1,000*	*1,000*
CEBAS-05	-	-	-	*1,000*	*1,000*	*1,000*	0,996	1,000	0,996	0,693	0,704	0,985
EEZ-02	-	-	-	*1,000*	*1,000*	*1,000*	0,598	0,606	0,988	-	-	-
IATA-02	0,652	0,836	0,779	*1,000*	*1,000*	*1,000*	0,594	1,000	0,594	0,321	0,478	0,673
IATA-03	*1,000*	*1,000*	*1,000*	0,380	0,381	0,997	0,458	0,464	0,985	*1,000*	*1,000*	*1,000*
IATA-04	*1,000*	*1,000*	*1,000*	0,732	0,834	0,878	*1,000*	*1,000*	*1,000*	-	-	-
IATA-06	-	-	-	-	-	-	0,750	0,986	0,761	*1,000*	*1,000*	*1,000*
IATA-07	*1,000*	*1,000*	*1,000*	0,981	0,985	0,996	0,588	0,590	0,998	-	-	-
IF-01	0,177	0,332	0,533	0,718	0,723	0,993	0,423	0,627	0,674	*1,000*	*1,000*	*1,000*
IF-03	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
IF-04	0,689	0,843	0,818	*1,000*	*1,000*	*1,000*	0,433	0,834	0,519	0,562	0,712	0,790
IFI-01	0,579	0,579	1,000	0,392	0,415	0,944	-	-	-	*1,000*	*1,000*	*1,000*
IFI-05	0,263	0,624	0,422	*1,000*	*1,000*	*1,000*	-	-	-	-	-	-
IFI-08	0,565	0,604	0,935	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	-	-	-
IG-01	*1,000*	*1,000*	*1,000*	0,346	0,364	0,952	0,121	0,177	0,688	0,596	1,000	0,596
IG-02	*1,000*	*1,000*	*1,000*	0,934	1,000	0,934	0,708	1,000	0,708	*1,000*	*1,000*	*1,000*
IG-03	*1,000*	*1,000*	*1,000*	0,788	0,788	1,000	0,689	0,693	0,995	0,871	0,874	0,997
IG-04	0,457	0,549	0,832	0,710	0,724	0,981	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
IG-05	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	0,198	0,249	0,793	-	-	-
IG-07	-	-	-	0,756	0,958	0,790	0,880	1,000	0,880	*1,000*	*1,000*	*1,000*
IG-08	-	-	-	0,961	0,964	0,998	0,479	0,489	0,980	*1,000*	*1,000*	*1,000*
IG-10	-	-	-	*1,000*	*1,000*	*1,000*	0,365	0,446	0,817	*1,000*	*1,000*	*1,000*
IIM-01	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	-	-	-	*1,000*	*1,000*	*1,000*
INB-01	*1,000*	*1,000*	*1,000*	-	-	-	-	-	-	-	-	-
INB-02	-	-	-	*1,000*	*1,000*	*1,000*	-	-	-	0,327	0,735	0,444
IPLA-01	0,763	0,901	0,847	0,660	0,685	0,963	*1,000*	*1,000*	*1,000*	0,846	0,875	0,966
IQOG-02	*1.000*	*1.000*	*1.000*	-	-	-	*1.000*	*1.000*	*1.000*	-	-	-
All R.G.												
Mean	0.718	0.808	0.878	0.728	0.799	0.907	0.582	0.655	0.894	0.748	0.822	0.897
St. Dev.	0.258	0.206	0.182	0.235	0.210	0.145	0.251	0.264	0.138	0.255	0.218	0.164
Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Minimum	0.177	0.332	0.186	0.301	0.346	0.301	0.121	0.177	0.519	0.228	0.260	0.363
Inefficient R.G.												
Mean	0.605	0.732	0.828	0.642	0.740	0.878	0.512	0.597	0.877	0.612	0.732	0.846
St. Dev.	0.219	0.195	0.194	0.203	0.202	0.155	0.197	0.241	0.142	0.211	0.217	0.180
Maximum	0.983	1.000	1.000	0.987	1.000	1.000	0.996	1.000	0.999	0.924	1.000	1.000
Minimum	0.177	0.332	0.186	0.301	0.346	0.301	0.121	0.177	0.519	0.228	0.260	0.363

Next we focus on the results related to the efficiency of those research groups which are efficient in at least one of the four periods covered, but can be inefficient in the remaining periods. In terms of the inefficient research groups, their mean values remain more or less constant over time (0.605 in the first period and 0.612 in the last). Similarly, scale efficiency is generally homogenous, although minimum values show an increase over the period. In other words, the SFTP has helped very inefficient research groups to increase their relative efficiency by approximating the optimal scale of the most efficient benchmark groups. Therefore, as they constitute the comparative benchmark, we study those research groups that are consistently driving the frontier while performing a comprehensive role within the SFTP and, which, from a policy perspective, can be seen therefore as a benchmark for the other groups.[9] Of the 64 research groups in the sample, 12 are considered efficient in the first period under CRS, 11 in the second, 7 in the third and 12 in the fourth. A cross-section perspective allows us to see whether their research activity is comprehensive or whether they are specialized in any of the input and output dimensions included in the analysis. A time perspective allows us to judge whether they can be considered consolidated, emerging, or one-period "shooting stars".

The information presented in Table 3 allows us to characterize each efficient research group within the different research categories.[10] On the inputs side, we can see the amounts required by each efficient group as a percentage of the minimum amount of inputs employed across all efficient groups. As a result of the DEA methodology, if an efficient group uses the lowest amounts of any given input, it will be shown to be efficient, with a zero value for that input dimension. In the same way, for outputs we can see the amount of outputs achieved by each efficient group as a percentage of the maximum amounts attained in the same period. Accordingly, if an efficient group achieves the highest amount of any output it will score 100 for that output dimension.

In the first period, two groups from the Agro-Chemistry and Food Technology (IATA) Public Research Organization –IATA-04 and IATA-03-, show opposite behaviour: IATA-04 had fewer FTE personnel (2) and used the least public funding (€29 780) to become input-side efficient, since IATA-03 was endowed with the highest amount of presonnel and absorbed more public funding than any other IATA group to become output-side efficent during the same period of time. This behaviour is consistent with a large PRO which head office tends to provide support to emerging groups in cohexistence with the development of consolidated ones. This is a common behaviour of large PRO in the Food Technology area, being IATA, IG (Institute for Fats Research) and IF (Institute of Refrigeration) the larger and more representative Spanish PRO of this research area. We can appreacitate in Table 3 that this is also de case for the IG during the first analised period (IG-03 and IG-02), PRO that gives support to both small and large research groups.

Overall, these small research groups, which despite being classed as efficient based on the CRS specification, are not making a real contribution to a comprehensive SFIS. More relevant outputs are: IATA-03 training the highest number (22) of scientific personnel; IG-02 achieving the highest number (6) of completed PhD theses and the highest number of international publications (37); and IF-03 with the highest number of patents (4) and cooperative contracts (€139 693), in the period. In

[9] In order to characterize the environmental factors that might explain the efficient or non-efficient patterns (Fried et al., 1999, 2002) we designed a questionnaire that is currently being administered to the research groups participating in the SFTP. The responses to this questionnaire will provide information on qualitative aspects which should help our interpretation of the different patterns we found.

[10] For reasons of space, only the specifications observed in the first and the last period are included in Table 3.

addition to groups that are efficient by default as a result of using the minimum amounts of inputs or achieving the maximum amounts of outputs, the remaining groups listed in Table 3 are those producing with a combination of outputs to inputs that results in relatively efficient performance. This characterization can be applied to all four periods to allow some inferences about the research technology of these groups, i.e. using the minimum amount of inputs, focusing on specialization to obtain the maximum amounts of outputs, using relatively lower levels of inputs to obtain significant outputs. In Table 3 we show the values for the initial and final periods, but in the following section we discuss the different strategies and efficiency evolution, i.e. increasing—as would be the case of new emerging research groups—or decreasing performance, over the four time periods analysed.

Table 3. Characterizing the efficient units under a CRS specification

	INPUT		MULTIDIMENSIONAL OUTPUT MIX				
			TRAINING		SCIENCE & TECHNOLOGY		SOCIO-ECONOMIC
Period	Personnel	Public Funding	Trained people	PhD Theses	International Papers	Registered Patents	R&D Contracts
1988-1990							
CEBAS-02[2]	100.0	24.3	27.3	33.3	10.7	0.0	0.0
IATA-03[2]	300.0	601.1	100.0	50.0	30.7	0.0	4.3
IATA-04[2]	50.0	0.0	27.3	16.7	10.7	0.0	0.0
IATA-07[1]	150.0	355.2	72.7	33.3	13.3	0.0	15.9
IF-03[4]	400.0	654.4	18.2	66.7	56.0	100.0	100.0
IG-01[1]	200.0	123.6	31.8	0.0	29.3	12.5	0.0
IG-02[2]	600.0	618.0	63.6	100.0	100.0	62.5	55.7
IG-03[1]	100.0	127.9	9.1	16.7	22.7	25.0	53.8
IG-05[2]	150.0	186.2	0.0	0.0	0.0	0.0	91.7
IIM-01[3]	50.0	186.4	13.6	16.7	18.7	25.0	0.0
INB-01[1]	100.0	190.8	18.2	33.3	40.0	0.0	0.0
IQOG-02[2]	50.0	167.9	18.2	66.7	32.0	0.0	0.0
1997-1999							
CEBAS-02[2]	200.0	376.8	8.1	0.0	14.4	0.0	99.3
IATA-03[2]	250.0	303.2	21.6	40.0	12.2	0.0	34.4
IATA-06[1]	0.0	499.2	0.0	0.0	0.0	50.0	0.0
IF-01[1]	200.0	0.0	8.1	40.0	8.9	25.0	0.0
IF-03[4]	2 390.0	2 483.6	100.0	100.0	100.0	50.0	39.3
IFI-01[1]	600.0	492.0	59.5	0.0	5.6	0.0	1.4
IG-02[2]	900.0	1 278.4	24.3	20.0	30.0	100.0	18.7
IG-04[2]	300.0	416.4	21.6	60.0	8.9	50.0	0.0
IG-07[1]	250.0	764.8	18.9	40.0	21.1	50.0	0.8
IG-08[1]	200.0	292.0	5.4	20.0	16.7	0.0	0.0
IG-10[2]	180.0	420.0	13.5	100.0	14.4	0.0	0.0
IIM-01[3]	0.0	266.4	16.2	20.0	5.6	0.0	39.1

Note: superscripts indicate the number of periods in which a particular research group is efficient.

5.3 Alternative research strategies

Based on the evolution and research features of efficient and inefficient groups, four categories of groups emerge: time consolidated groups performing multidimensional research, specialized groups (training, science and technology, socioeconomic); partially oriented groups focusing on two output dimensions, and “shooting stars”. The *consolidated* research groups include those observed to be efficient over several periods, with in depth knowledge of the SFIS, and producing outputs in all dimensions. *Specialized* groups are those research groups that are consistently efficient, and thus are clearly following a research strategy oriented towards the achievement of particular goals in one of the three output dimensions in our analysis. *Partially oriented* research groups are those whose activities are directed towards the two output dimensions that characterize mode I scientific knowledge production, i.e. training and science and technology. Finally, *“shooting stars”* describes those efficient research groups that sporadically participate in the SFTP with the objective of achieving a particular goal (i.e. based on presence of PhDs, R&D contracts with firms, etc.), but which, having achieved their goal, “disappear” in part due to the fact that their research is not really aligned to the food technology area. Table 4 summarizes the typologies of the efficient and inefficient research groups according to their multi or partial research output orientation, allowing differentiation among the diverse research groups within the SFTP, which should enable policy makers to assess the financial support embedded in different R&D projects in order to optimize allocation of SFTP funding according to the specific circumstances and needs of the SFIS.

Table 4. Clusters of efficient and inefficient research groups (CRS) according to their research output orientation.

<table>
<tr><th colspan="4">1988-1990</th><th colspan="4">1997-1999</th></tr>
<tr><td colspan="8">Efficient R.G.</td></tr>
<tr><td>Multi-dimensional</td><td>Training</td><td>Science & Technology</td><td>Socio-Economic</td><td>Multi-Dimensional</td><td>Training</td><td>Science & Technology</td><td>Socio-Economic</td></tr>
<tr><td>IF-03</td><td colspan="2">IG-01</td><td>IG-05</td><td>IF-03</td><td></td><td>IATA-06</td><td>CEBAS-02</td></tr>
<tr><td>IG-02</td><td colspan="2">IATA-03</td><td></td><td>IG-02</td><td colspan="2">IF-01</td><td></td></tr>
<tr><td>IATA-07</td><td colspan="2">IATA-04</td><td></td><td>IATA-03</td><td colspan="2">IFI-01</td><td></td></tr>
<tr><td>IG-03</td><td colspan="2">CEBAS-02</td><td></td><td>IIM-01</td><td colspan="2">IG-08</td><td></td></tr>
<tr><td>IIM-01</td><td colspan="2">INB-01</td><td></td><td>IG-04</td><td colspan="2">IG-10</td><td></td></tr>
<tr><td></td><td colspan="2">IQOG-02</td><td></td><td>IG-07</td><td colspan="2"></td><td></td></tr>
<tr><td colspan="8">Inefficient R.G.</td></tr>
<tr><td>Multi-dimensional</td><td>Training</td><td>Science & Technology</td><td>Socio-Economic</td><td>Multi-Dimensional</td><td>Training</td><td>Science & Technology</td><td>Socio-Economic</td></tr>
<tr><td>IATA-01</td><td>IATA-12</td><td>IEG-01</td><td>IF-09</td><td>CEBAS-01</td><td>IBMCP-1</td><td></td><td>IG-01</td></tr>
<tr><td>IATA-02</td><td colspan="2">CEBAS-01</td><td>IFI-05</td><td>IATA-01</td><td>INB-02</td><td></td><td></td></tr>
<tr><td>IATA-05</td><td colspan="2">CEBAS-04</td><td></td><td>IATA-02</td><td colspan="2">CEBAS-05</td><td></td></tr>
<tr><td>IATA-09</td><td colspan="2">CEBAS-06</td><td></td><td>IATA-08</td><td colspan="2">IATA-05</td><td></td></tr>
<tr><td>IF-05</td><td colspan="2">CID-01</td><td></td><td>IATA-09</td><td colspan="2">IBMB-1</td><td></td></tr>
<tr><td>IF-06</td><td colspan="2">IATA-11</td><td></td><td>IATA-10</td><td colspan="2">IBMCP-2</td><td></td></tr>
<tr><td>IFI-01</td><td colspan="2">IF-02</td><td></td><td>IATA-11</td><td colspan="2">IF-07</td><td></td></tr>
</table>

IFI-02 IG-04 IG-09 INB-03	IF-04 IFI-02-IQOG-01 IFI-08 IIM-02 INB-04 INB-05 IPLA-01			IF-04 IF-08 IFI-02 IFI-03 IG-03 IG-09 IPLA-01	IG-06 IIM-02		
Mean value of Inefficient R.G.							
0.640	0.983	0.540	0.335	0.633	0.626	-	0.596
	0.659				0.567		

We also look at the performance of the multidimensional and time consolidated research groups, which constitute the backbone of the SFIS. We highlight some of the main features of those groups considered to be representative of the specialized, partial and "shooting stars" research groups. Within the leading *consolidated* category, there are five research groups. Only one of these, IF-03, is efficient over time in all four periods while achieving high values in most outputs categories[11]. In general, to attain and maintain these standards of output mix production within the system, consolidated groups use substantial amounts of inputs, but they manage them efficiently. They are not specialized in any one single output, and engage in comprehensive research activity, participating in all three output dimensions in all four periods, achieving first-rate measures (see Table 3). This supports the hypothesis that the higher the efficiency and the more comprehensive the research activity, the more consolidated will be the research group over time, and consequently the higher will be its potential to contribute to the SFTP's objectives. This is exemplified by the numbers of patent applications and contracts with firms related to these groups (see Table 3). With reference to IG-02 and IG-03 their patterns are also regarded as being comprehensive, despite their efficiency levels drop in the second and third periods (see Table 2). Again, these two groups follow opposite development patterns, being IG-02 a large and consolidated one and IG-03 a smaller but emerging one. Since the large groups is able to overcome those two intermediate periods to become efficient again in the fourth, the smaller one has not been able to give a response in the same terms. The consolidation process takes a loong time and the support from both the mother institution -the PRO itself and the Spanish National Research Council, (CSIC) as main institution- and policy makers who have to redsesign the SFTP according to those needs already detected. In short, IG-02 led PhD dissertations (6) and international publications (38) output dimensions during the first period, being also concerned with the registration of patents and R&D contracts with firms, following the pace of IF-03. Then its efficiency decreased during the second period due to the fact that no PhD theses were defended. This is also related to the personnel, and accordingly to the budget received from the SFTP, which respectively decreased from 14 to 11 researchers (personnel) and from € 213 810 to € 154 700 (funding). Then, the group became efficient again in the fourth period mainly due to a better balance between the inputs received from the SFTP and the production of a multidimensional output mix. As to IG-03, the explanation for its decreasing efficiency differs from that of IG-02. During the first period, IG-03 produced a balanced output mix, not leading any of the dimensions included in our analysis, but producing all of the outputs. However, during the remaining three periods, the R&D contracts they managed to sign with firms decreased from €75

[11] IG-02, IG-03 and IF-03 show similar trends and output orientation, although the two IG groups are less efficient in the second and third periods.

132.53 (first period), to €12 212.57 in the second, and even none in the third. So, their declining efficiency is mainly due to these difficulties with the R&D contracts, as the input dimensions and the other output measures kept almost constant in time. Summing up, the funding received from the SFTP scheme and the signed R&D contracts with firms have a direct influence on the efficiency levels achieved by these comprehensive research groups. However, other environmental and contextual aspects may have played an important role in these relative efficiency levels and subsequent evolving paths. In this respect the research area of IG-02 (Food biotechnology), has been far more supported by the SFTP than that of the IG-03 (Food characterisation and quality) in terms of the number of financed projects and financial support (Jiménez-Sáez, 2005). This tendency is more evident from 1992 on. This is also supported by the fact that the number of publications in the food biotechnology area is much larger, and grows to a higher rate, than that of the latter area. In addition, one of the key researchers in the IG-03 group passed away in 1992 and the group began a reorganization process not finished by 1999. On the other hand, two key researchers from IG-02 have promoted in their professional careers reaching top positions, fostering the growth of the research group.

Only five groups are considered *specialized*, including IG-05 which ranks among the efficient set in the first period based on an unambiguous strategy of heavy involvement in contracts with firms. Also in the first period IF-03 received the most funding from private contracts, €139 693; however, in the second period IG-05 leads, with €91 915. This niche strategy allows IG-05 to maintain its ranking in the first two periods – from 1988 to 1993, but in the third period its competitive position decreases dramatically (see Table 2). It is overtaken in the ranking by other units following a similar strategy; its efficiency score is 0.198 under CRS (0.249 under VRS), despite being ranked fourth for value of contracts €139 056 (IG-04 is ranked 1st with €570 624) in the third period. Although the amount of public funding awarded to IG-05 almost doubled from one period to another, from €47 930 in 1991-1993 to €81 978 in 1994-1996, this was not enough for it to remain efficient by default. This negative trend resulted in IG-05 disappearing from the efficient subset and the SFTP, and eventually its participation in programmes ceases altogether.

The third set of research groups represents the middle ground characterized by *partial* research orientation. Our observations evolve along different paths, with groups trying to consolidate their positions efficiently using alternative strategies. This category includes the highest number of research groups in our analysis. We first highlight the evolution of IG-04, IATA-03 and CEBAS-02. Despite their strategies differing over time, they all managed to strengthen their positions. Based on a strategy oriented to producing many different outputs that could qualify it as being multi-dimensional, IG-04 started as a low efficiency unit (0.457 under CRS assumptions and 0.549 with VRS in the first period), improving to 0.7 in the second period. In the third period it achieved efficiency based on R&D contracts, which amounted to €570 625, and this was maintained in the last period with a multi-dimensional pattern. IATA-03's evolution is similar; it scored for all three outputs categories, its management is efficient in the first period, due in particular to the large numbers of people trained within the unit (22). It maintains this strategy oriented to becoming a multi-dimensional research group over time, in the last period registering as a comprehensive and efficient group following some less efficient years. In the case of CEBAS-02, its efficiency pattern is similar to IATA-03, but the change in its strategic orientation is more defined than in the previous cases. With an initially efficient performance mainly due to its orientation towards training and science and technology results, and following some inefficient years, in the last period its position improved due to a change in its strategy to include contracts with private institutions: it is ranked second for contracting, with €305 085.

Finally, there is a set of 14 research groups that can be considered *"shooting stars"*, which participated in only one of the four periods under study. Their orientation and efficiency vary, from efficient behaviours, INB-01, to efficiency rates of 0.228 under CRS (0.332 under VRS) by IBMB-1, and 0.341 (0.346) by IMEDEA-01. INB-03's and IMEDEA-01's strategy is to try to produce outputs in all three dimensions, IEG-01 has a clear focus on publishing international papers, while IF-0X and INB-01 (partial orientation) focus on training new graduates, producing PhD theses and publishing results. The IMEDEA (Mediterranean Insitute for Advanced Studies) PRO represents the case of an institution which main research focus (natural resources) is not directly linked to food technology. Hence these results represents the efforts of a reseach group whose research deals with this topic in a collateral way but is able to get funds from the SFTP. Again this technique provides policy makers with valuable information on the future orientation of the programme and its financial scheme for each type in PRO. Based on these results, we would suggest that DEA would be a good instrument for policy managers to use to determine efficient behaviour and formulate policy recommendations. This would enable consistent measurements of consolidated research groups engaged in comprehensive research activities, and contribute to the SFTP's objective of articulating the Innovations System in the Food Technology area.

As our results are based on a standard DEA optimizing procedure, which searches for the most favourable weights, it tends to compare inefficient groups against those DMUs with a higher degree of similarity in their output orientation. From our analysis, IF-03, IG-02 and IIM-01 are benchmarks for a small percentage of research groups because the majority of them do not share their research profile. Particularly, ranked as the most consolidated observations, IF-03, IG-02 and IIM-01 show a comprehensive research mix with large-scale outputs; that does not constitute the representative benchmark for the majority of observations as their activity also includes contracts with private firms. They are clearly producing on a more diversified and larger scale, and are in a league of their own. On the other hand, CEBAS-02 and IQOG-02, which initially are focused on training and science and technology related outputs, and not on private contracts – presenting zero values for that variable (see fn 6 for technical details), would constitute a more useful benchmark, as they represent the research pattern that applies to the majority of the research groups. In fact, in the first period CEBAS-02 (with 43% under CRS and 28% with VRS) and IQOG-02 (70% and 76% respectively) are the most frequent reference for inefficient units. This output orientation is also shared by those research groups considered as benchmarks for the three remaining periods. Note that these results do not invalidate our methodological approach; they simply confirm that detailed examination of the alternative efficient research paths that converge on the production frontier is critical for effective policy recommendations. Our DEA analysis identifies a conscious research orientation towards specialization in a single or partial output dimension, which shows remarkable results based on the relative use of inputs—e.g. trained personnel and/or publication of peer-reviewed articles; however, such an orientation ranks low in terms of promoting and encouraging research that contributes to the articulation of a comprehensive IS within the Spanish food and beverage industry.

Finally, we should discuss the inefficient research groups. As already pointed out, their mean values are constant over time (Table 2), while minimum values have increased over the 12 years. This shows that the SFTP has helped CSIC groups to increase their efficiency orientation. Concerning outputs, in the comprehensive and partial categories we can see a balance between the amounts for efficient and inefficient research groups. Within the specialized category, on the other hand, there are more inefficient than efficient groups, especially in terms of emerging and "shooting star" temporal patterns. However, there is an interesting trend in these inefficient research groups. Overall, inefficient groups are oriented towards a partial perspective in their outputs, especially during the first two periods studied. However, over time, these partially oriented groups show a trend towards becoming multi-dimensional, although they remain inefficient. Therefore, although the SFTP policy may not have helped CSIC research groups to greatly increase their efficiency, it has played a role in orienting them towards multiple outputs[12].

6. Policy implications and conclusions

This study demonstrates policymakers the deviations that exist between the innovation system objectives and the mechanisms (incentive schemes) established to assess research group participation. In particular, the methodology we propose identifies and is able to distinguish research groups' behaviours in terms of research output, which gives support to the design and implementation of the different promotion strategies pursued by the administrative body.

We believe that our efficiency analysis sheds light on the relative success achieved by policy in designing a comprehensive IS, and provides a way of assessing the results and allocating funds for R&D projects according to the specific characteristics of national programmes. This efficiency approach takes into consideration the research group's inputs and outputs to elaborate a helpful picture of how they are performing with the support of public financial and incentive schemes included in a certain policy. This picture is the result of grouping our observations after considering their performance during a period of time. The final result is the characterisation of research groups in terms of their relative strengths (consolidated, emerging or shooting stars) and the short of outputs produced (comprehensive, partial or specialized). This distinction is helpful for policy makers to reorient the financial scheme in order to, on the one hand, foster each sort of group according to its relative strength — providing more accurate financial tools to each category, and, on the other, to redesign the policy as to achieve its main goal regarding the consolidation of a comprehensive IS.

Taking the SFTP as an example, we have analysed to what extent this policy has contributed to fostering the generation of a multidimensional research output mix among research groups, based on one of the objectives of the Programme to induce a change in research strategy from mode I to mode II knowledge production. We adopted a novel approach based on DEA that relies on the generalized distance function proposed by Chavas and Cox (1999), and demonstrated the validity of this methodology for evaluating whether R&D policies are fostering the creation and survival of research groups that perform a comprehensive role within the IS. We characterized different categories of efficient research groups participating in the SFTP, and followed their evolution between 1988 and 1999. We identified: i) groups considered to be *consolidated* and efficient, ii) groups that maintained their relative positions over time by *specializing* in a given output, iii) groups engaging in *partial* research activity that improved their skills and managed to become efficient, and iv) groups that disappeared after being efficient in a single period, i.e. *"shooting stars"*.

We show that well established, consolidated research groups have a greater impact on any IS's objectives through their remarkable output values in all dimensions: their research is more comprehensive than that of new emerging research groups, which has enabled them to sign more contracts with firms and technology centres, and to license their already submitted patents.

[12] In order to measure the relative importance of the slacks on total inefficiency—radial and non-radial, we calculated their relative weight for each output and input—see footnotes 3 and 4. We observe that the highest percentage weights are on outputs variables, which characterize alternative research strategies and whose variability is larger than is the case for inputs. With regard to patents and contracts in particular, we can conclude that slack inefficiency is not negligible, as it exceeds one-third of overall inefficiency in many periods. More information on these calculations can be obtained from the authors upon request.

However, over the time period of our study only a few research groups had reached the critical size needed for them to be considered “mode II knowledge producers”.

From our study we are able to identify those non-aligned research groups’ behaviours with the supporting policy, restricting therefore its success. However, we consider that these behaviours are consistent with the incentive schemes related to the scientific promotion and career structure, which depends on such partial outputs, and is a disincentive for engagement in more comprehensive activities. Such a strategy is also congruent with an infant IS, which needs a critical mass of research groups in order to grow and consolidate over time. To achieve this critical mass, numerous research groups with different abilities and profiles need to be funded despite the fact that only a small percentage will succeed and contribute to the establishment of a benchmark within the system. Such a strategy of seed funding carries a cost in terms of research inefficiency and productivity losses, which decision makers must be aware of. It should be noted that the value of R&D contracts in the 12 year period studied has risen, mainly due to the efforts of a small consolidated set of groups. Therefore, a shift in policy priorities to recognize the importance of training personnel who can then work in industry, and the signing of R&D contracts with firms as a valuable scientific output is recommended in order to reorient activity towards the initial objectives of any policy.

In addition to the multidimensional and partially oriented efficient groups, we found a large set of new research groups with low efficiency levels. These groups have not become more efficient for two reasons: a) they have suffered from a decrease in Programme budget, which in real terms, taking account of inflation, is substantial; and b) they have not been able to raise funds from private firms to compensate —and in case they were able to raise funds, it would be quite probable that their small size would prevent them from ripping the benefits of these partnerships. As a result these new groups led by young researchers from mature research groups have not been able to consolidate their positions, illustrated by the *“shooting stars”* pattern. Their results are insignificant in terms of training and science and technology outputs. However, although the policy overall may not have helped these research groups to increase their efficiency, it has played a role in shifting their orientation from partial towards multiple output production. Therefore, they should receive special attention from the policy managers so that in future they can achieve the desired returns in terms of outputs per unit of invested inputs, and can contribute to the policy’s goal in the medium term. More financial resources and the matching of research groups to business firms will be necessary to change research habits from mode I to mode II knowledge production and contribute to the consolidation of the innovation system in the long run.

The number of comprehensive and efficient research groups compared with those classified as “shooting stars” also reveals that a young innovation system needs to accommodate different research strategies in order to promote the emergence of long-term comprehensive groups. It is understandable, therefore, that the funds allocation scheme followed by the administration body allows for different research strategies which may pursue (or not) the policy’s objective. However, as the optimum policy is utopian, this scheme should vary over time to avoid inefficient “shooting stars” behaviour and encourage a more comprehensively-oriented promotion of knowledge creation that focuses on the needs of the innovation system.

Finally we want to highlight the usefulness of our efficiency approach to the evaluation of research results associated to a public support programme and aimed to research groups and policy makers. Nevertheless we acknowledge several lacks that give room to further improvements in the approach. Some of them deal with inputs and outputs measurement and its attribution since from the available information is not possible to clarify actual dates of outputs production. Others deal with the consideration of environmental and contextual reasons not yet reflected in our approach. In this respect work is in progress as to introduce this sort of information in the efficiency technique which will enrich the analysis and results.

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