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Knowledge production and commercialization from R&D: the pharmaceutical sector

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Abstract

Purpose – The objective of this work is to demonstrate the relationships between the two main processes of research and development (R&D) activities: the knowledge generation phase (KPP) and the knowledge commercialization, or transfer, phase (KCP), in a sector that is intensive in this type of activity, such as the pharmaceutical sector. In addition, within the framework of the general objective of this work, the authors propose two other objectives: (1) make advances in network efficiency measurement models, and (2) determine the factors associated with efficiency in the KPP and in the KCP in companies of the pharmaceutical sector in Spain.

Design/methodology/approach – A Network Data Envelopment Analysis (NDEA) model (Färe and Grosskopf, 2000) with categorical variables (Lee *et al.*, 2020; Yeh and Chang, 2020) has been applied, and a sensitivity analysis of the obtained results has been performed through a DEA model of categorical variables, in accordance with the work of Banker and Morey (1986), to corroborate the results of the proposed model. The sample is made up of 77 companies in the pharmaceutical sector in Spain.

Findings – The results obtained point to a greater efficiency of pharmaceutical companies in the KPP, rather than in the KCP. Furthermore, the study finds that 1) alliances between companies have been the accelerating factors of efficiency in the KCP (but patents have slowed this down the most); 2) the quality of R&D and the number of R&D personnel are the factors that most affect efficiency in the KPP; and 3) the quality of R&D again, the benefits obtained and the position in the market are the factors that most affect efficiency in the KCP.

Originality/value – The authors have not found studies that show whether the efficiency obtained by R&D-intensive companies in the KPP phase is related to better results in terms of efficiency in the KCP phase. No papers have been found that analyse the role of alliances between R&D-intensive companies and patents, as agents that facilitate efficiency in the KCP phase, covering the gap in the research on both problems. Notwithstanding, this work opens up a research path which is related to the improvement of network efficiency models (since it includes categorical variables) and the assessment of the opinions of those who are responsible for R&D departments; it can be applied to decision-making on the aspects to improve efficiency in R&D-intensive companies.

Keywords R&D activities, Efficiency, Pharmaceutical sector, Network DEA

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1. Introduction

The lack of consensus on how to measure the efficiency (as well as the factors that explain efficiency) of R&D in companies that make large investments in knowledge production and transfer activities has become a problem that needs solving.

Various institutions and many researchers have highlighted the need to measure the efficiency of R&D processes, despite the great difficulty that is entailed due to the large number of factors that influence such processes. Seeking efficiency measurements of these activities has occupied much of the available literature on innovation (Karadyi and Ekinci, 2019; Liu *et al.*, 2020; Romasanta *et al.*, 2020; Zuo *et al.*, 2022; Huang, 2023).

Although most approaches consider the R&D system as a single system, in using a deeper approach it can be considered as composed of two sub-processes. According to Chen *et al.* (2018), a knowledge production process (KPP) is responsible for the transformation of inputs that are related to research into knowledge results. In a second stage, Chen *et al.* (2018) recognize a knowledge commercialization process (KCP) that is transformed into knowledge and commercial/monetary results. More specifically, Alnafrah (2021) explains that the knowledge production process (KPP measures the efficiency of the production process of technical and scientific knowledge in any sector. However, the KCP measures the efficiency of the knowledge monetization process, generating the inputs of this process and, at the same time, the outputs of the previous process, which is the KPP.

The motivation of this work arises because we have not found works in the literature that address the problem which pharmaceutical companies have in relating to R&D processes from the perspective of efficiency, as well as the factors that determine R&D, when considering these companies as R&D-intensive companies (Bignami *et al.*, 2020; Xu *et al.*, 2021; MengDie *et al.*, 2023).

Throughout this paper, we aim to demonstrate, from a management point of view, that a higher knowledge production in the KPP does not always have to go hand in hand with a higher knowledge commercialization of that production in the KCP. In relation to the innovation systems theory approach (Edquist, 2013; Sharma *et al.*, 2022), the factors influencing business innovation are key to measurement of the level of organizational efficiency in innovation. Furthermore, Xia (2022) suggests (but does not confirm) that new innovations (either KPP or scientific production) of Chinese pharmaceutical companies can increase productivity (either KCP or marketing of that production), thus being able to accelerate the creation of new benefits while also offering potential for hypothetical growth. In addition, from the point of view of a theory of R&D in the pharmaceutical industry (Scherer, 2010; Arnold *et al.*, 2022; Haschka and Herwartz, 2022), it is necessary to separate the phases of the benefits that are generated by the KCP, and the investments in R&D that are generated by the KPP, although this does not imply that there is a direct relationship between the two phases.

Regarding the methods that are used to measure efficiency in these types of activities, and which are part of the methodology suggested in the present work, Färe and Grosskopf (2000) developed models for measuring network efficiency in organizations, which have been the basis of the Network Data Envelopment Analysis (NDEA) model. Traditional studies regarding DEA (Data Envelopment Analysis) apply to systems as a whole, thus ignoring the functioning of individual processes within a system. The efficiency of the system that is measured in this way represents the overall performance of the processes.

The NDEA model has been used to quantify the efficiency of R&D projects in sectors and companies in various periods and in various phases (Zhou *et al.*, 2019; Mete and Belgin, 2022). Innovation is a complex process whose evaluation requires some treatment and flexibility (Tidd and Bessant, 2020; Erdin and Çağlar, 2023). The NDEA model offers this flexibility from an efficiency point of view, since it allows combining multiple aspects and facets of innovation, thus allowing it to be quantified in multiple periods.

This study has two objectives: firstly, to measure the efficiency of two interconnected phases in the R&D processes: on the one hand KPP, and on the other hand KCP, thus demonstrating whether both processes are related from the perspective of efficiency. For this, we propose a network relationship between the two phases, introducing categorical variables (Karadyi and Ekinci, 2019; Lee *et al.*, 2020; Yeh and Chang, 2020) that are intensified through patents and alliances between companies in the pharmaceutical sector, since it has been shown that these variables influence business results (Nicholson *et al.*, 2003; Gilding *et al.*, 2020). Secondly, we also aim to explain the factors that affect the efficiency of R&D in both phases that are applied in the pharmaceutical sector in Spain, using survey data from 77 companies.

This work focuses on the pharmaceutical sector, as it is one of the most intensive sectors regarding R&D, due to the importance in the proportion of R&D expenses over the sales figures or over the value-added in this sector.

R&D on sales in the pharmaceutical industry has multiplied the sales of manufacturing companies fivefold (Scherer, 2010). According to an OECD (2017) report, although R&D costs per employee have been reduced in recent years, in the pharmaceutical industry they are still more than double those of other industries in Spain. For all of these reasons, the business efficiency of pharmaceutical R&D is a relevant topic in the literature, which covers several complex issues such as its cost and investment in R&D, productivity in R&D, profitability in R&D or the determinants of R&D efficiency (Vernon, 2005; Lakdawalla, 2018; Xia, 2022; Zhong *et al.*, 2022).

This study presents the following structure: a review of the application of efficiency models to R&D activities; a review of the literature on the phases of the KPP and the KCP in R&D; an empirical study applying the NDEA (Färe and Grosskopf, 2000) with categorical variables; a robustness study of the result using the model of Banker and Morey (1986); and, finally, the results, implications and conclusions are presented.

2. Literature review

The efficiency and performance of R&D in companies are difficult to measure. Achieving goals with the least possible use of resources becomes one of the most important problems at the enterprise level. According to Coccia (2001), R&D departments are either efficient or inefficient entities, as they consume resources in order to reach a goal and, in this case, to obtain a new product or scientific advances.

According to Chen *et al.* (2018), a KPP is responsible for the transformation of inputs that are related to research into knowledge results. This multi-stage approach is consistent with several innovation efficiency studies (see, for example, Guan and Chen, 2012; Mavi *et al.*, 2019; Zhou *et al.*, 2019; Mete and Belgin, 2022). In a second stage, Chen *et al.* (2018) recognize a KCP that is transformed into knowledge results and commercial/monetary results. This process also takes place on multiple levels.

Regarding the measurement of efficiency in both R&D processes (KPP and KCP), Guan and Chen (2012) provide another new concept to further enrich research on innovation efficiency. The KPP generates new knowledge and the KCP markets the new knowledge. The two threads, the KPP and the KCP, are relational and interdependent (rather than independent). This means that innovation processes are the output of a first thread (KPP), and the input of a second thread (KCP).

Edquist (2013) affirms, within the Systems of Innovation Approach, that if we wish to describe, understand and explain innovation processes, we must take into account all of the important factors that shape and influence innovations. To achieve this goal and to improve the modelling of innovation processes, it is instructive to study the factors that affect innovation, and their effects on efficiency and/or performance, using two or more related individual sub-processes within the same model.

Recent studies related to efficiency in R&D include the work of Yeh and Chang (2020), which analyses R&D efficiency, while focusing on technological learning, government support and patents as factors to explain efficiency. Wang *et al.* (2020) measured the efficiency of R&D in high-tech companies, while considering R&D as a system. Their work divides R&D activities into two stages, the R&D stage and the marketing stage, while building a high-tech industrial assessment framework of the efficiency of technological innovation.

Regarding the use of the DEA model to obtain the causes of inefficiency of R&D activities, most studies have been carried out within the framework of public research centres (Korhonen *et al.*, 2001; Rhaiem, 2017; Gralka *et al.*, 2019), but few studies have been developed within companies (Yeh and Chang, 2020; Liu *et al.*, 2020).

To our knowledge, there are only a few R&D studies in the body of literature that relate performance and efficiency through the NDEA model, evaluate the suitability of performance (Rickards, 2003) or relate efficiency and performance (Liu and Lu, 2010; Liu *et al.*, 2020; Yeh and Chang, 2020). Traditional studies regarding DEA apply to systems as a whole, ignoring the functioning of individual processes within a system. The efficiency of the system that is measured in this way represents the overall performance of the processes (Färe and Grosskopf, 2000).

Seiford and Zhu (1999) applied the DEA model to calculate the efficiency of each process independently, but Kao and Hwang (2008) developed a relational NDEA model with which to calculate system efficiency, connecting two processes. An interesting result of the relational model is that the efficiency of the system would be formed by the sum of the inefficiencies of each process.

In the body of literature, research examples that have applied DEA have analysed the efficiency of the systems as a whole, while ignoring the internal functioning of a system's production processes. The DEA in a three-stage process measures the efficiency of system processes and their causes, while considering the individual operation of each process in the system structure. The efficiency of each process can be calculated separately, in order to identify the source of inefficiency of a system, which will be the sum of the inefficiencies of the processes that compose it (Kao, 2009).

However, despite the research to date in the body of literature, we have not found any studies that demonstrate whether the efficiency obtained by R&D-intensive companies in the KPP is related to better results, in terms of efficiency in the KCP. For this reason, the innovation of the present work is found, on the one hand, in the study carried out on the efficiency of both R&D processes, analysing the role of alliances between companies and patents as facilitating agents of the efficiency in the KCP, filling the gap in the research on this problem and, on the other hand, the efficiency model used in the pharmaceutical sector (NDEA with categorical variables), since we have found few studies that apply it to intensive sectors in R&D and at the company level.

3. Knowledge production phase (KPP) and knowledge commercialization phase (KCP) of R&D in the pharmaceutical companies

3.1 Knowledge production phase (KPP) in R&D in pharmaceutical companies

Regarding the knowledge production process (KPP) of R&D in the pharmaceutical companies, in the body of literature, the variable that is most used as an input indicator is "R&D expenses", and this is also used to designate the effort made by companies in the development of R&D activities (Yiu *et al.*, 2020). This R&D effort is linked to the innovation results that are achieved by companies, and also to the financial results that are achieved (Grant *et al.*, 2020). Mao *et al.* (2014) also considered as input, the growth of R&D personnel in pharmaceutical companies, with respect to the previous year.

Further, also considered is the fact that in each case a growth rate of investments in positive R&D in a three-year period, both in absolute values and values that are relative to the function of the income of the company (such as the infrastructures that are used in the development of the activities of R&D) plays a decisive role in attaining levels of performance in R&D (Wang *et al.*, 2020; Yiu *et al.*, 2020).

On the other hand, training of human resources in the pharmaceutical companies is among the most influential variables, regarding the efficiency of R&D. The conclusion of the study by Grant *et al.* (2020) is that the efficiency of R&D activities is conditioned by the volume of expenses of R&D, the ability to coordinate human resources and by solving technical problems.

West and Iansiti (2003) affirm that the knowledge of the personnel of the R&D departments, as well as their skills and abilities in the performance of R&D in the companies, depends on the degree of professionalization and training, experience and experimentation. Staff aptitude has also been considered in the literature as one of the conditioning factors that define R&D performance in the pharmaceutical companies (Collinson, 2001). Further, Cruz-Cáceres *et al.* (2013) studied the relationship between innovation and performance, and proposed a new approach to address it by measuring the importance of the skills of pharmaceutical personnel in developing R&D in companies in this sector.

However, the investments and infrastructure in R&D and human resources are also used in the development and implementation of these activities (Cegarra-Navarro *et al.*, 2020; Çağlar and Gürel, 2019; García-Valderrama *et al.*, 2008; García-Valderrama *et al.*, 2009; Mulero-Mendigorri *et al.*, 2016; Yiu *et al.*, 2020; Zahoor and Sahof, 2018).

3.2 Knowledge commercialization process (KCP) in R&D in the pharmaceutical companies

The KCP is related to the final results of R&D in the company's commercialization process that, ultimately, would point to an increase in the profit figure, or an improvement in the economic profitability of the pharmaceutical company. Notwithstanding, it is difficult to demonstrate that the good financial results, which are achieved by the most innovative companies, can be the consequence of a good R&D policy. Hashimoto and Haneda (2008) studied the R&D efficiency of pharmaceutical companies in Japan, and using pharmaceutical sales or operating profit as outputs, they considered that the efficiency frontier shifted over time.

Some of the indicators that are used to measure the efficiency of the knowledge commercialization process (KCP) for R&D in the pharmaceutical sector have been considered as "intermediate variables" of R&D. Some examples would be the development of new products (Gemser and Leenders, 2001), as well as the quality that is achieved in the development of R&D activities (Brennan, 2001). This quality that is obtained will later be reflected in the results which are achieved by the pharmaceutical company, both in terms of profit figures and the improvement of the general management of the company (Tyagi *et al.*, 2018).

Similarly, these inputs, described above, are the outputs of the process prior to the commercialization of R&D. Specifically, they are outputs of the KPP, since they are obtained from investments in R&D, or from the training and skills of human resources, which will lead to the production of knowledge, both in innovation and in the quality of the research that is achieved.

On the other hand, in relation to the commercial benefits that are linked to R&D activities, in the literature that was analysed, we found, among other variables, increases in income from higher sales, market shares or client satisfaction as their most appropriate indicators (Yiu *et al.*, 2020). These variables are considered to be final outputs in these companies.

3.3 Relationship between KPP and KCP: business alliances and patents in the pharmaceutical companies

In this section, we explain why alliances and patents are relevant for R&D-intensive sectors, and more specifically for pharmaceutical companies. Although patents and alliances are two

different concepts, it is considered that their impact on R&D efficiency goes in the same direction, since patents and alliances have a close relationship with the KPP, through the inclusion of new business know-how, and with the KCP, once they are carried out through the monetization of their results. Therefore, the phases have a direct impact, and in the same direction, on the performance of companies in the pharmaceutical sector (Palomeras and Wehrheim, 2021), and we carry out a joint review of both concepts.

The role of alliances and patents in the efficiency of R&D in the pharmaceutical industry in Spain is a difficult item to measure ,and, therefore, it is scarce in the literature (Danzon *et al.*, 2005). There are several reasons stated in the literature regarding why companies can form alliances and patents in this industry and, therefore, why alliances and patents can act as variables that impede R&D efficiency (Kogut, 1988; Castañer and Oliveira, 2020).

Powell and Brantley (1992) state that a single pharmaceutical company will rarely have all the skills and organizational capabilities that are necessary in order to be successful. Given that drug development technology changes rapidly, and knowledge sources are dispersed in many companies, pharmaceutical companies will have strong incentives to establish a series of alliances and patents and, therefore, the need to access new KPPs (Powell *et al.*, 1996; Liu and Lyu, 2020; Nepelski and Van Roy, 2021).

The reasons why pharmaceutical companies agree to establish alliances and patents are (1) to increase their chances of success, (2) increase their know-how or (3) obtain capital by sending a signal to the public and private capital markets that their management and scientific levels are of high quality (Nicholson *et al.*, 2003; Gilding *et al.*, 2020; Liu and Lyu, 2020).

Many conventional models that are based on the input-intermediate-output framework assume that each patent is an intermediate product that may or may not be commercialized (Moon and Lee, 2005). In two-stage DEA models, intermediate outputs from the previous stage do not always enter the next stage. Guan and Chen (2010) considered that the potential patents which have not been commercialized are surplus inputs in the second stage of DEA. Therefore, in the KPP, which is the first phase of the process in the pharmaceutical companies, it is important to consider the patents that result from the generation of knowledge, since this will allow increasing the results in the KCP, which is the second phase (Tyagi *et al.*, 2018; Wang *et al.*, 2020; Yeh and Chang, 2020).

Undoubtedly, another driver of efficiency from the KPP to the KCP is the ability of companies to forge alliances with other companies and with public entities, laboratories or universities. It is proven that those companies which diversify their activity with other partners obtain better levels of innovation, quality and financial results. In this sense, alliances can also be considered as drivers of efficiency between both phases of R&D in these companies (Crosby and Sheery, 2006; García-Valderrama *et al.*, 2008; Liu *et al.*, 2020; Yu *et al.*, 2017).

Other studies (Çağlar and Gürel, 2019; Revuelta-Bordoy *et al.*, 2021) also consider that alliances between companies and patents constitute the true engine of the efficiency of R&D activities, in both the KPP and the KCP.

4. Variables and method

This study has been divided into two analyses: on the one hand, we have determined the efficiency of pharmaceutical companies in Spain by applying the NDEA model (Färe and Grosskopf, 2000), thus establishing two phases in the same model: (1) the knowledge production phase (KPP) of R&D (Division 1 in the model), and (2) the efficiency of the knowledge commercialization phase (KCP) (Division 2 in the model).

On the other hand, we applied a second analysis with a focus on the sensitivity of the obtained results through NDEA, in order to verify that there are no biases in the results. For this purpose, we applied the Banker and Morey (1986) model of categorical variables, employing two independent models: the KPP and the KCP. This second analysis has been carried out in two

independent models, given the impossibility of using the patents and alliances variables as link variables, as it is a model that does not use a network structure. For this reason, both variables are entered as output variables in the KPP, and as input variables in the KCP. This has allowed us to know how NDEA contributes to the efficiency of the companies under analysis in each phase, KPP and KCP, of the R&D, while checking the sensitivity of the results compared to the first network analysis. The objective of using this second study is to contrast the similarities and differences that are found between both results.

In order to obtain the results of both analyses, we used the DEA-Solver-Pro software (Professional Version 15).

4.1 Sample, data and measures of variables

A questionnaire was used, in which respondents were asked to rate each item on a Likert scale from 1 (in total disagreement) to 5 (in total agreement). To obtain a higher response rate, it was decided to use both the traditional postal service and electronic mail to send out the questionnaire. For the latter route, the questionnaire was prepared in HTML format, which allowed us to receive the completed questionnaires promptly. We obtained the data of 77 companies in the pharmaceutical sector in Spain.

For the delivery methods that were used to send out the questionnaire, and the response rate obtained, see Table 1.

Table 2 shows the items and the questionnaire statements that were presented to the pharmaceutical companies. The scale has been validated with a Cronbach's $\alpha = 0.869$.

4.2 Model and data analysis

4.2.1 Network DEA (NDEA) efficiency model. The main contribution to the development of network efficiency measurement models has been made by studies of the NDEA model of Färe and Grosskopf (2000) and Kao (2009). One of the advantages of the DEA model is to allow the individual decision-making units (DMUs) to select the most advantageous weighting factors with which to calculate their efficiency scores. The efficiency values per company are between 0 and 1, with 1 being the maximum efficiency value, and below 1, whereby the company is considered to be inefficient.

NDEA evaluates the efficiencies of multi-divisional organizations. This model solves the comparative overall efficiency of an organization, along with the divisional efficiencies in a unified framework (Färe and Grosskopf, 2000).

We employ the following notations to describe the NDEA model.

n : *The number of DMUs*

K : *The number of divisions* (*stages*)

L : *The set of links*

Delivery method used	Scales (likert 1–5)
Target	679 companies of pharmaceutical products in Spain
Population census	407 companies
No. of responses	77
Respondents	Heads of R&D departments
% of sample	18.91%
Survey	Structured questionnaire administered via Internet and traditional postal

Source(s): Table by authors

Table 1.
Response rate and delivery method

Phases Inputs/ outputs	Items	Scale items Likert scale from 1 (in total disagreement) to 5 (in total agreement)	References
Outputs KCP	Y1	Increase in benefits In the last three years, the profits have increased considerably by the application of the results of the R&D	García-Valderrama *et al.* (2008), Saghaei and Ghasemi (2009), and Zahoor and Sahof (2018)
	Y2	Increase in income: The sales revenues have increased, thanks to the application of the results of the R&D	Kerssens-van Drongelen and Cooke (1997) and Zahoor and Sahof (2018)
	Y3	Improvement of positioning when faced with competitors: The overall positioning of our company against its competitors has improved, thanks to the application of the R&D results	García-Valderrama *et al.* (2008)
	Y4	Increased customer satisfaction and market share: Customer satisfaction has increased thanks to the application of the results of the R&D, and the market share has increased thanks to the application of the results of the R&D	Crosby and Sheery (2006) and Çağlar and Gürel (2019)
Outputs KPP Inputs KCP	S1	Degree of innovation: The innovation in products and in process always originates in R&D	Crosby and Sheery (2006), Çağlar and Gürel (2019), and Wang *et al.* (2020)
	S2	Quality: The R&D activities are always subjected to standards for the measurement of quality, and the standards for quality established for the R&D activities are always achieved	Crosby and Sheery (2006), Çağlar and Gürel (2019), and García-Valderrama *et al.* (2009)
Links Variables (Netwok DEA)	Z1	Degree of appropriation of results (patents). In the last three years, the increase in the number of patents has been very high	Crosby and Sheery (2006), Çağlar and Gürel (2019), and García-Valderrama *et al.* (2009)
	Z2	Alliances in R&D between companies: Opportunities for establishing alliances in R&D with other organizations are always identified	Crosby and Sheery (2006) and Liu *et al.* (2020)
Inputs KPP	X1	Staff capabilities: They have many capabilities (aptitudes and skills)	Crosby and Sheery (2006), Çağlar and Gürel (2019), and García-Valderrama *et al.* (2009)
	X2	Growth of R&D staff for new projects: In the last three years, the number of R&D personnel has increased considerably with respect to the volume of new projects	Crosby and Sheery (2006), García-Valderrama *et al.* (2009), and Leenders and Wierenga (2002)
	X3	Experience of R&D staff: They have much previous experience of R&D in other national companies. They have much previous experience of R&D in other companies, that are foreign	Crosby and Sheery (2006) and García-Valderrama *et al.* (2008)
	X4	Training: Personnel structures of the R&D personnel	Crosby and Sheery (2006), Çağlar and Gürel (2019), García-Valderrama *et al.* (2009)
	X5	R&D effort: In the last three years, the expenditure on R&D has increased considerably, as a proportion of total revenue	Crosby and Sheery (2006), Çağlar and Gürel (2019), García-Valderrama *et al.* (2009), Leenders and Wierenga (2002), and Yiu *et al.* (2020)

Source(s): Table by authors

Table 2.
Preliminary variables

$\boldsymbol{x}_j^k \in R_+^{m_k}$: *Input resources to DMU$_J$ at division k* $(k = 1, K, K)$

$\boldsymbol{y}_j^k \in R_+^{r_k}$: *Output resources to DMU$_J$ at division k* $(k = 1, K, K)$

$\boldsymbol{z}_j^{(k,h)} \in R_+^{l_{(k,h)}}$: *Linking input resources to DMU$_j$ at division h from division k*
$((k.h) \in L)$ = *Linking output products from DMU$_j$ at division k from division h* $((k.h) \in L)$

Where j-th denotes *DMU* $(j = 1, K, n)$. We assume:

$$\boldsymbol{z}_j^{(k,h)} = \mathbf{0}\,(\forall j, h \in S) : \textit{No linking inputs to starting and } \boldsymbol{z}_j^{(k,h)} = \mathbf{0}\,(\forall j, h \in T)$$
$$: \textit{No linking outputs from terminal division.} \tag{1}$$

The production possibility set $\{(\boldsymbol{x}^k, \boldsymbol{y}^k, \boldsymbol{z}^{(k,h)})\}$ is defined by:

$$\boldsymbol{x}^k \geq \sum\nolimits_{j=1}^{n} \boldsymbol{x}_j^k \lambda_j^k (k = 1, K, K)$$
$$\boldsymbol{y}^k \geq \sum\nolimits_{j=1}^{n} \boldsymbol{y}_j^k \lambda_j^k (k = 1, K, K)$$
$$\boldsymbol{z}^{(h,k)} \geq \sum\nolimits_{j=1}^{n} \boldsymbol{z}_j^{(h,k)} \lambda_j^h (\forall (k,h))\ (\textit{as input to } h)$$
$$\boldsymbol{z}^{(h,k)} \geq \sum\nolimits_{j=1}^{n} \boldsymbol{z}_j^{(h,k)} \lambda_j^k (\forall (k,h))\ (\textit{as output from } k)$$
$$\sum\nolimits_{j=1}^{n} \lambda_j^k = 1 (\forall k), \lambda_j^k \geq 0\,(\forall j,k), \tag{2}$$

where $\lambda^k = R_+^n$ is the intensity vector corresponding to division $k\,(k = 1, \mathrm{K}, K)$. DMU_0 $(o = 1, K, n)$ can be represented by:

$$\boldsymbol{x}_o^k = \boldsymbol{X}^k \boldsymbol{\lambda}^k + \boldsymbol{s}_o^{k-}\,(k = 1, \mathrm{K}, K) \boldsymbol{y}_o^k = \boldsymbol{Y}^k \boldsymbol{\lambda}^k - \boldsymbol{s}_o^{k+}\,(k = 1, \mathrm{K}, K)$$
$$\boldsymbol{e}\boldsymbol{\lambda}^k = 1\,(k = 1, \mathrm{K}, K)$$
$$\boldsymbol{\lambda}^k \geq \mathbf{0}, \boldsymbol{s}_o^{k-} \geq \mathbf{0}, \boldsymbol{s}_o^{k+} \geq \mathbf{0}, (\forall k) \tag{3}$$

where:

$$\boldsymbol{X}^k = \left(\boldsymbol{x}_1^k, \mathrm{K}, \boldsymbol{x}_n^k\right) \in R^{m_k \times n}$$
$$\boldsymbol{Y}^k = \left(\boldsymbol{y}_1^k, \mathrm{K}, \boldsymbol{y}_n^k\right) \in R^{r_k \times n} \tag{4}$$

With respect to the linking constraints, we have several options, of which we present the "fixed" link value case. The linking activities are kept unchanged:

$$\boldsymbol{z}_o^{(k,h)} = \boldsymbol{Z}^{(k,h)} \boldsymbol{\lambda}^h\,(\forall (k,h))$$
$$\boldsymbol{z}_o^{(k,h)} = \boldsymbol{Z}^{(k,h)} \boldsymbol{\lambda}^k\,(\forall (k,h)) \tag{5}$$

NDEA model output-oriented constant returns-to-scale model:

$$\frac{1}{t_o^*} = \max \sum\nolimits_{k-1}^{k} w^k \left[1 + \frac{1}{r_k}\left(\sum\nolimits_{r-1}^{r_k} \frac{s_{ro}^{k+}}{y_{ro}^k}\right)\right] \tag{6}$$

Note that, in order to confine all scores within the range [0, 1], we define the efficiency score of division k by:

$$\tau^k = \frac{1}{1 + \frac{1}{r_k}\left(\sum_{r-1}^{r_k} \frac{s_{ro}^{k+}}{y_{ro}^k}\right)} \tag{7}$$

Hence, the overall efficiency τ_o^* is not the weighted arithmetic mean of divisional efficiencies, but, rather, it is the weighted harmonic mean. Thus, usually we have:

$$\tau_o^* \leq \sum_{k=1}^{K} w^k \tau_k \tag{8}$$

Figure 1 graphically represents the measure of efficiency through NDEA, while considering three divisions. Each division consumes an input that gives rise to an output, with a link variable between each division.

4.2.2 Estimation of R&D efficiency in the pharmaceutical sector. Proposal for DEA with network structure (NDEA) and divisional efficiency. In this section we apply the NDEA, thus obtaining both the global efficiency indices (τ^k) by company, and the divisional efficiency index (τ^1 and τ^{k2}), in the NDEA model output-oriented constant returns-to-scale model.

In this study, we use simultaneous measures of general efficiency, and we combine the network structure by means of transfer activities between two phases. Specifically, Figure 2 shows the NDEA model that is proposed in this work.

In the proposed model (Figure 2), we represent how the efficiency of R&D is measured in several interconnected phases, vertically, and where the DMUs are the 77 pharmaceutical companies that are analysed. The vertical network is composed of the input variables in division 1 (knowledge production process, KPP), that will be treated as outputs in division 2 (knowledge commercialization process, KCP).

A KPP (division 1) is responsible for the transformation of inputs that are related to research into knowledge results. This multi-stage approach is consistent with several innovation efficiency studies (Carayannis *et al.*, 2016; Guan and Chen, 2012; Mavi *et al.*, 2019). In a second stage, Chen *et al.* (2018) recognize a knowledge commercialization process that is transformed into knowledge results and commercial/monetary results (division 2).

In our study, the vertical network connects the efficiency of the DMUs that are analysed. Division 1, or KPP, is made up of the input variables: X1, X2, X3, X4 and X5,and the output variables: S1 and S2. In division 2 (KCP), the inputs are: S1 and S2, and the outputs are: Y1, Y2, Y3 and Y4.

The efficiency links, or links between KPP and KCP, or variables from one division to another, is, on the one hand, the patents (Z1) (link 1), and, on the other hand, the alliances (Z2) (link 2).

4.2.3 Sensitivity analysis. Estimation of the efficiency of the KPP and KCP models through the DEA with categorical variables. This second analysis has been carried out in two independent models, given the aforementioned impossibility of using the patents and alliances variables as link variables, as it is a model that does not use a network structure. For this reason, both variables are entered as output variables in the KPP phase, and as input variables in the KCP phase. This has allowed us to know how this contributes to the efficiency of the companies that were analysed in each phase of the R&D generation and transfer process, while checking the sensitivity of the results compared to the first network analysis.

We applied a DEA analysis with categorical variables in each process independently, with the aim of finding the efficiency relationships between the efficiency scores of the two models. Figures 3 and 4 represent the two phases of R&D efficiency. R&D can be measured through categorical variables since there are works, such as that of Karadayi and Ekinci (2019), where a DEA model is used with categorical variables in order to measure R&D in European countries.

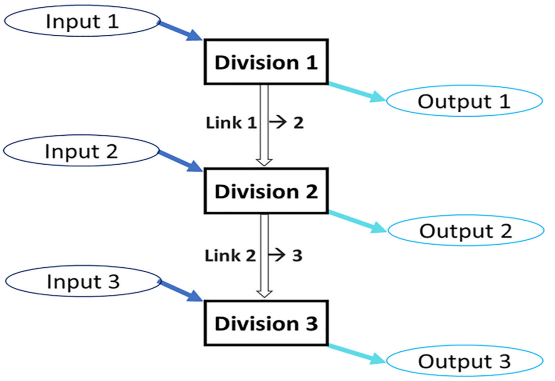


Figure 1.
Network DEA structure

Source(s): Adapted from Färe and Grosskopf (2000)
Figure by authors

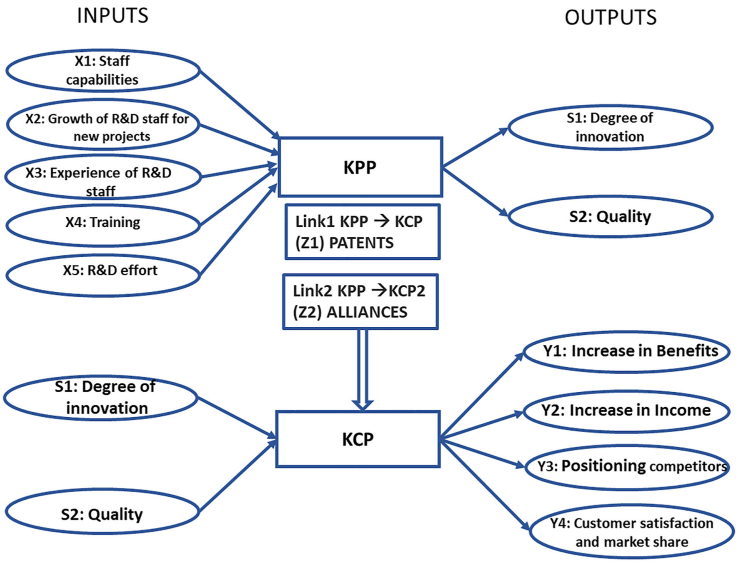
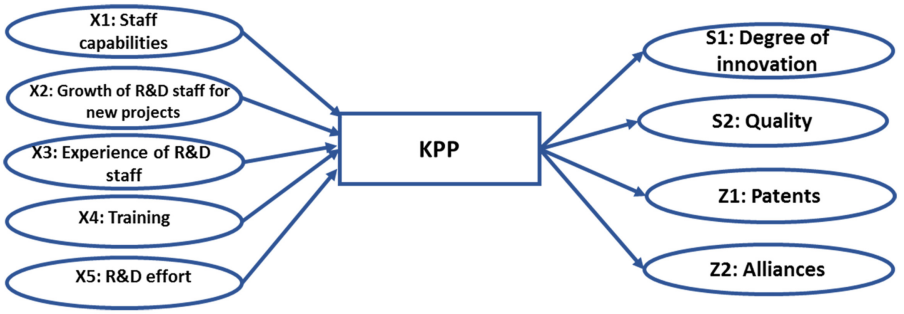


Figure 2.
Proposed model of efficiency of R&D

Source(s): Authors' own elaboration
Figure by authors

The objective is to verify the sensitivity of the results by considering independent efficiency models having categorical variables with three values. The formulation that was followed in the present work (1) is in accordance with what was developed by Banker and Morey (1986), which would lead to the modification of the original DEA model once it is linearized, and (2) considers the dual aspect of Equation 9, with the definition of two categorical variables d^1 and d^2, for three groups, with values zero and one, respectively. These values are assigned, by company, as follows:



Source(s): Authors' own elaboration
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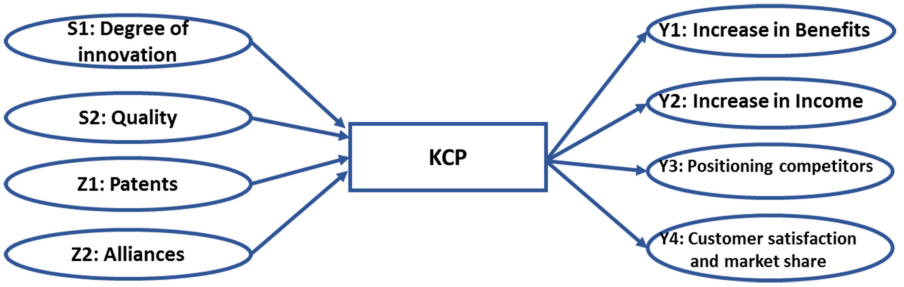
Figure 3.
Structure of the R&D activities in companies in the KPP phase



Source(s): Authors' own elaboration
Figure by authors

Figure 4.
Structure of the R&D activities in companies in the KCP phase

$d^1j = d^2j = 0$, belonging to the group of companies with a score of 1 or 2 on the scale item

$d^1j = 1\,y\,d^2j = 0$, belonging to the group of companies with a score of 3 on the scale item

$d^1j = d^2j = 1$, belonging to the group of companies with a score of 4 or 5 on the scale item

The analytical expression of the Banker and Morey (1986) model corresponds to Equation 9:

$$Min_{w_o}$$

$$w_0 x_{i0} - \sum_{j-1}^{n} x_{ij}\lambda_j \geq 0$$

s.t.

$$\sum_{j-1}^{n} y_{rj}\lambda_j \geq y_{r0},$$

$$\sum\nolimits_{j=1}^{n} \lambda_j d_j^1 \leq d_{j0}^1$$

$$\sum_{j=1}^{n} \lambda_j d_j^2 \leq d_{j0}^2$$

$$r = 1, \ldots, s;\ i = 1, \ldots, m;\ \lambda_j \geq 0, \forall_i, j, r \tag{9}$$

In our study, we use the information that is related to the efficiency or inefficiency scores i (*Wo*) in Equation 9, which will allow us to position the company with respect to the sample. On the other hand, and in order to study the association between the KPP and KCP models of R&D, we analyse the relationship between efficiency ratios corresponding to the different models described, using Spearman's product-moment correlation coefficient.

In addition, we calculate the deviations in inputs and outputs in the NDEA model in the two divisions (KPP and KCP), in order to find out the factors that are generating inefficiency in the pharmaceutical companies.

The structures shown in Figures 3 and 4 allow us to determine the partial efficiency for each of the 2 R&D processes. Specifically, the system would be composed of two models, giving rise to the outputs S_1, S_2, Z_1 and Z_2 (KPP), and Y_1, . . .,Y_4 (KPP).

5. Results

5.1 Network DEA (NDEA) model

In Table 3 we present the descriptive values of the variables that are used in both efficiency models.

Table 4 shows the average global efficiency that was obtained through the NDEA model for the KPP and KCP. The average efficiency of the analysed companies approaches 0.5, which is not a very high efficiency (i.e. let us recall that in the NDEA models, the comparative value of efficiency between companies would be between 0 and 1). It is observed that the average efficiency of the KPP, or R&D production or knowledge phase, is much higher than the following KCP, or R&D commercialization phase.

The above information is seen more clearly when we study the aspects that are to be improved by the companies under analysis. Specifically, Table 5 shows the deviation levels of each of the variables, in each of the phases (KPP and KCP). The higher the level of deviation of the variable, the more the inefficiency levels will increase.

Table 3.
Descriptive statistics of the data of the 77 companies (5-point Likert scale)

	X1	X2	X3	X4	X5	S1	S2	Y1	Y3	Y3	Y4
Average	3.558	3.181	4.04	3.779	3.73	3.73	3.48	3.9	3.25	3.87	3.85
Max	5	5	5	5	5	5	5	5	5	5	5
Min	2	1	1	1	1	1	1	1	1	2	1
St Dev	0.97	0.96	0.83	0.940	0.99	1.03	1.02	0.87	1.3	0.8	0.81

Source(s): Table by authors

Table 4.
Results of the efficiency of the two phases (KPP and KCP)

		Divisional efficiency (NDEA)	
	Overall score	KPP	KCP
Average	0.4725	0.8762	0.3612
Max	1	1	1
Min	0.2892	0.3103	0.169
St Dev	0.1565	0.1512	0.2137

Source(s): Table by authors

Division	KPP							KCP					
Variables	X1	X2	X3	X4	X5	S1	S2	Link1 (Z1)	Link 2 (Z2)	S1	S2	Y1	Y2	Y3	Y4
% Change (KPP and KCP)	−6.08	−8.52	−5.78	−3.96	−4.81	0	39.49		–	0	−8.28	262.39	221.40	271.62	197.97
% Change link KPP and KCP as outputs	–	–	–	–	–	–	–	48.71	0	–	–	–	–	–	–

Source(s): Table by authors

Table 5.
Average projections input/outputs. % change

Table 5 shows that in the KPP phase, most of the inefficient companies are the result of the growth factor in the number of people working in R&D (X2), which is one of the most important changes to be considered by inefficient companies.

Another aspect with which to improve the output of the KPP model by companies that have been inefficient is the quality of R&D (S2), which must be increased in the knowledge generation phase.

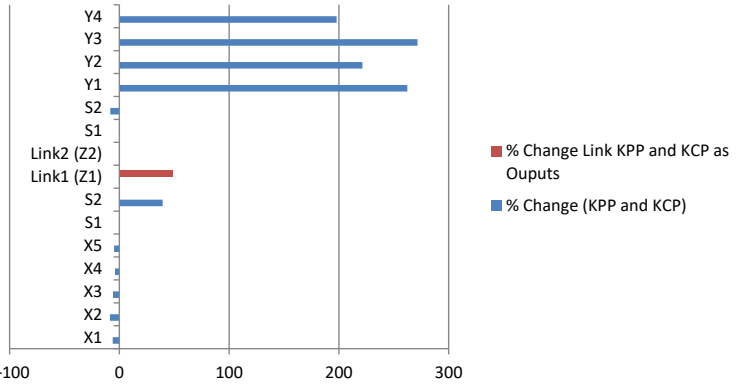
Patents (Z1), as a link that promotes efficiency in the commercialization phase of R&D, has a 48.71% deviation for inefficient companies.

However, in relation to alliances (Z2), Spanish pharmaceutical companies are very efficient, since they have not generated deviations in the model (see Figure 5). One of the latest alliances that was conducted in the pharmaceutical sector has been the alliance between Grifols S.A. (a Spanish multinational pharmaceutical and chemical manufacturer) and the government of Egypt, in order to create the first Asian/African plasma-supply platform (Expansion, 2021).

Finally, in relation to the outputs of KCP, the factors with the greatest deviation and, therefore, those which have generated the highest level of inefficiency, have been the benefits obtained (Y1), with a deviation of 262.39%, and Y3 (positioning in the market), with a deviation of 271.62%. These variables are those that have affected inefficient companies to a greater extent in the commercialization phase, which is due to, among other reasons, the scarcity of the number of patents that are described above.

5.2 Results. Sensitivity analysis of the NDEA model: DEA with categorical variables

As explained above, the objective of this second part of our study has been to carry out a sensitivity analysis of the results obtained in the NDEA model. To do this, we calculate the results while considering the same R&D phases (KPP and KCP), but obtaining the efficiency of each process, and now introducing the variables, patents and alliances, as output variables in the KPP, and as input variables in the KCP, because the Banker and Morey (1986) model does not use link variables. As indicated in section 4.2.3, two categorical variables have been included (d^1j y d^2j) in order to classify the companies into three groups (as explained in section 4.2.3), depending on the response to the item in the questionnaire. The results in percentages on the deviations in each of the inputs and outputs of both phases are presented in Table 6 and Figure 5.



Source(s): Figure by authors

Figure 5.
Change inputs/outputs (%) and links as output (%)

Variables	X1	X2	X3	X4	X5	S1	S2	Z1	Z2	Y1	Y2	Y3	Y4
%Change KPP	−6.04	−7.11	−1.43	−1.69	−7.80	24.58	29.68	28.26	0	–	–	–	–
%Change KCP	–	–	–	–	–	−14.95	−15.35	−9.74	−5.21	224.20	169.09	222.18	173.93

Source(s): Table by authors

Table 6.
% Change in projections input/ output (categorical variables)

As can be seen in Tables 6, in the KPP, the variable that has experienced a greater percentage of deviation in inefficient companies has been X5 (i.e. R&D effort) with 7.80% (i.e. this result specifically differs from what is shown in the previous model), followed by X2 to X5 (i.e. growth of R&D staff for new projects in the last three years). This is, once again, another aspect to be improved by companies that have been inefficient in the KPP model, with a deviation of 7.11%, corroborating the results from the NDEA model. Regarding the R&D effort, Grant *et al.* (2020) find that R&D spending increases the R&D efficiency of biotechnology and pharmaceutical companies in the United States, as well as the global efficiency of companies. Hence, it is recommended that Spanish pharmaceutical companies should increase their levels of investment in R&D.

Regarding the outputs of the KPP phase, the variable S2 (Quality of R&D) is once again the variable that experiences the greatest deviation among the inefficient companies (29.68%), followed by Z1 (patents) with 28.2% of deviation, as has occurred in the NDEA model. The degree of innovation (S1) is, once again, the aspect with the best behaviour in all companies.

Regarding the commercialization phase of R&D (KCP), it is once again S2 (quality) that experiences the greatest deviation (15.35%) as input. In relation to outputs, the largest deviations are in the benefits obtained (Y1), with a deviation of 224.20%, and Y3 (positioning in the market), with a deviation of 222.18%, corroborating the results of the previous NDEA model.

For greater clarity, the results, in percentages, on the deviations in each of the inputs and outputs of both phases are represented in Figure 6.

5.3 Results: sensitivity analysis. Relationship between the results obtained by network DEA (NDEA) and categorical DEA

In determining the degree of robustness of the results that were obtained, we collect the efficiency scores of both analyses in each of the R&D phases: KPP and KCP. Next, the results that were obtained in global efficiency for each of the analyses that were carried out in each phase are presented in Table 7.

The average efficiency, in the categorical variables model and in the NDEA model for the first phase of R&D (i.e. KPP), is approximate in the maximum values (0.8667 and 0.8762, respectively). However, it is further away in the R&D commercialization model (i.e. KCP) (0.5531 and 0.3612, respectively).

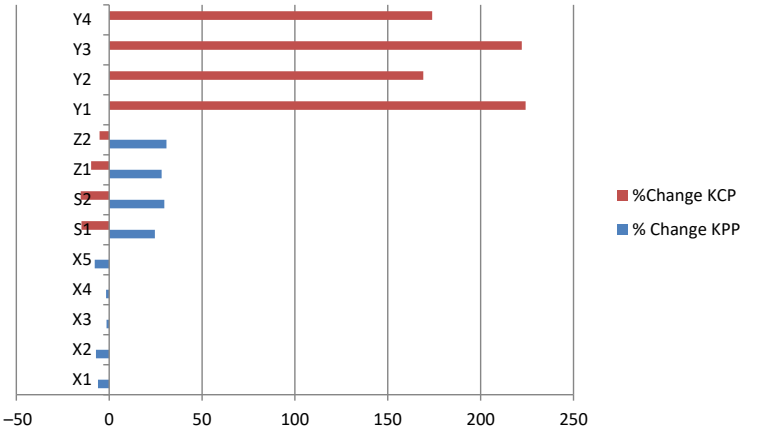


Figure 6.
% Change in projections input/output (categorical variables). KCP and KCP

Source(s): Figure by authors

In order to determine the degree of agreement in the efficiency measure, we calculated and present in Table 8 the degree of correlation in the Spearman's rank correlation coefficient for the rankings obtained by the 77 companies in each of the phases, KPP and KCP, for both studies that were carried out with categorical variables and with NDEA.

In Table 8, we observe that the correlation between the 2 R&D phases (KPP and KCP) in the categorical variables model is 0.97, significant at the 0.01 level. Similarly, the correlation between the position of the companies in the KPP phase of R&D in the categorical variables model and the overall efficiency in NDEA is 0.973, which is a significant value at the 0.01 level, and for the KCP phase, the correlation is 0.994, which is significant at the 0.01 level.

6. Discussion

One of the problems addressed in this work has been the lack of consensus in the literature on how to measure the efficiency of R&D, and the gap in research on the efficiency relationships between the KPP of R&D and the KCP, or transfer phase, of R&D.

Furthermore, the present paper proposes a model for measuring the efficiency of the R&D network with categorical variables, in order to measure the efficiency of R&D in companies that make large investments in KPP and KCP. Another of the problems that is addressed is the determination of the factors that provide greater efficiency in each phase, and whether or not both are related (Chen *et al.*, 2018).

Regarding the principal research question, the contribution of this study is the measurement of R&D performance in two interrelated phases, revealing different levels of efficiency between the KPP and the KCP, or knowledge transfer phase (Zhou *et al.*, 2019; Mete and Belgin, 2022). Our findings show that most R&D-intensive companies, which have been very efficient in the KPP, subsequently fail to be efficient in the KCP. Our work differs from

	Overall score category		Divisional efficiency (NDEA)	
	KPP	KCP	KPP	KCP
Average	0.8667	0.5531	0.8762	0.3612
Max	1	1	1	1
Min	0.4715	0.24	0.3103	0.1690
St Dev	0.1376	0.2665	0.1512	0.2137

Source(s): Table by authors

Table 7. Results of the efficiency of the two phases (KPP and KCP), categorical variables model and NDEA

			Rank1 KPP Category	Rank2 KCP Category	Global network ranking (NDEA)
Spearman's Rho	Rank1 KPP category	Correlation coefficient	1.000	0.970**	0.973**
		Sig. (bilateral)		0.000	0.000
	KCP category	Correlation coefficient		1.000	0.994**
		Sig. (bilateral)			0.000
	Global network ranking NDEA	Correlation coefficient			1.000
		Sig. (bilateral)			

Note(s): **The correlation is significant at the 0.01 level (bilateral)

Source(s): Table by authors

Table 8. Rank correlations for KPP and KCP (categorical and network DEA)

the results obtained by Liu and Lyu (2020), who found that efficiency problems in Chinese pharmaceutical companies stem from the KPP.

In this line, the present work shows that the R&D efficiency measurement model, in a network model with categorical variables, is adequate (Chen *et al.*, 2018; Karadyi and Ekinci, 2019; Lee *et al.*, 2020; Yeh and Chang, 2020). Specifically, based on the context of the development of network efficiency measurement models by Färe and Grosskopf (2000), and incorporating the categorical variables in the form of opinions of individuals who are responsible for the R&D departments of 77 pharmaceutical companies in Spain, our study has provided answers to both research questions, measuring the efficiency of two interconnected phases in the R&D processes: on the one hand, the KPP, and on the other hand, the KCP (Guan and Chen, 2012; Mavi *et al.*, 2019; Zhou *et al.*, 2019; Mete and Belgin, 2022).

Furthermore, existing NDEA models that are focused on R&D performance evaluation are rarely applied at the firm level (Tripathy *et al.*, 2013; Pattnayak and Chadha, 2013; Liu and Lyu, 2020). We have not found studies in the body of literature on efficiency that use both efficiency models (i.e. NDEA with categorical variables) and the Banker and Morey (1986) model of categorical variables as an analysis of the robustness of the results.

The model used in the present work (i.e. NDEA with categorical variables) opens the "black box" of the organization and examines its interior. NDEA sees the interior of a decision-making unit (DMU; i.e. the company) as a network consisting of many divisions (i.e. nodes) that are linked to each other, which is very important in the development of R&D activities.

In this case, in the present study, patents and alliances between companies have been considered as link variables between the two phases, which, to our knowledge, is the first empirical analysis in this research area (i.e. links variables introduced into NDEA models).

Although there are works in the literature on the importance of patents and alliances between companies as generators of higher returns for R&D-intensive companies (Nicholson *et al.*, 2003; Liu and Lyu, 2020; Nepelski and Van Roy, 2021), we have not found studies that use patents and alliances as links between the KPP and KCP of R&D. Further, we have not found studies using network efficiency models and categorical variable models applied to the pharmaceutical sector.

In relation to the links between the two phases, the main factor that has generated inefficiency has been patents (Z1). This result is consistent with the literature that was analysed (Tyagi *et al.*, 2018; Liu and Lyu, 2020; Wang *et al.*, 2020; Yeh and Chang, 2020). According to the Spanish Patent and Trademark Office (OEPM, 2021), the number of national patent applications filed in 2021 was 1,361 compared to 1,483 in 2020, which shows a decrease of 8.2%, and this is especially more pronounced in the pharmaceutical sector, which showed a decrease of 10.2%. As an example, the study by Yeh and Chang (2020) agrees on the result of the decrease in efficiency when it affects the number of patents that are obtained by the company. Therefore, it is recommended that Spanish pharmaceutical companies should increase the number of patents by improving the quality of R&D and the number of R&D personnel, as these are two essential indicators for the creation of new patents (Liu and Lyu, 2020).

With regards to the factors affecting the efficiency of R&D in both phases, our findings contribute to a better understanding of the causes in knowledge-oriented and R&D-intensive companies (Azghandi *et al.*, 2018; Chorniy *et al.*, 2021; Salehi *et al.*, 2020). A two-stage R&D evaluation model adequately classifies efficient organizations and highlights the strengths and weaknesses of each of them (Chen *et al.*, 2018).

With regards to improving the output of the KPP model by companies that have been inefficient is the quality of R&D (S2), which must be increased in the knowledge generation phase, our results coincide with the study by Yiu *et al.* (2020), in which those authors explore

how companies could improve the financial performance of R&D investments through quality management. Those authors suggest that the aforementioned improvement effect through increased quality and efficiency is more pronounced under high operational complexity, conditioned by the intensity of work and geographic diversity. Rather than viewing innovation activities and process management as contradictory functions, they show how improvements in quality and efficiency support companies' R&D investments, thereby generating higher financial returns.

Finally, in relation to the KCP, the input that generates the greatest inefficiency is once again the quality of R&D (S2), and the outputs that have produced the greatest deviation and, therefore, those which have generated the highest level of inefficiency, have been the benefits obtained (Y1) and positioning competitors (Y3). These variables are those that have affected inefficient companies to a greater extent in the commercialization phase, which is due to, among other reasons, the scarcity of the number of patents that are described above. According to Zahoor and Sahof (2018), if a company is not able to make its investments profitable (You *et al.*, 2010; Tyagi *et al.*, 2018), it can have significant problems in terms of profits and liquidity, which would lead to high levels of economic inefficiency.

7. Conclusions and implications

In the present study, we have found that pharmaceutical companies in Spain must improve efficiency, which is higher in the KPP. Therefore, it is noteworthy that pharmaceutical companies have been very innovative, obtaining high efficiency values in the production of knowledge. However, the lowest values in efficiency levels are found in the transfer or commercialization of R&D. These results show that pharmaceutical companies in Spain must aim to maximize the profitability of the investments made in R&D.

Regarding the aspects to be improved by the companies under analysis, in the KPP, most of the inefficient companies have obtained deviations, which are mainly due to the reduced growth in the number of researchers who are working in R&D, which indicates that Spanish pharmaceutical companies are hiring fewer staff for each new project that is carried out. Therefore, it is recommended that those companies should promote a more active recruitment policy. Another aspect that must be increased in the KPP is the quality of R&D levels. To improve this indicator, the number of patents or the number of research projects can be increased.

In this study, it is observed that alliances have played an important role in the efficiency in the production and commercialization phases of R&D (as a link variable in the NDEA model), due to the fact that their levels of deviations have been very low or null. However, it is observed that patents (a variable that has been used in the same way as alliances) have considerable influence on the levels of inefficiency of Spanish pharmaceutical companies. This indicates that a higher level of commercialization of the investments in R&D that are made by these companies is necessary.

Finally, the factors to be improved by the companies under study in the KCP have been: (1) the quality of R&D levels and (2) the profit and the positioning in the pharmaceutical market. This implies that all of the investments that pharmaceutical companies make in R&D do not materialize in high levels of benefits; that is, it is necessary for Spanish pharmaceutical companies to maximize the profitability of their investments. This may be due, among other factors, to the scarcity of patents that are obtained by Spanish pharmaceutical companies.

These results, which are obtained through NDEA, have been corroborated in a DEA model of categorical variables (Banker and Morey, 1986). The coincidence between the results of both models has been very high, exceeding 97% correlation, which confirms the conclusions that have been made in the present study.

In our research, the integration of the two concepts – network concept and categorical variable – in an efficiency measurement framework, is particularly beneficial for its practical application, since it examines efficiency in stages and requires greater discrimination in the results for each business. This study may constitute a starting point for future works to include new variables that allow expanding the study of other factors which may explain new aspects of R&D, such as self-financing, external financing of R&D projects or the profile of R&D project managers and its effects on the performance of R&D in companies in other sectors.

Our findings contribute to the improvement of network efficiency measurement models by incorporating categorical variables.

In addition, we show that this model is suitable for measuring the efficiency of R&D-intensive companies, whose results show that the companies that were studied have been very efficient in the KPP, but are failing to be efficient in the KCP or transfer phase. We find that the accelerating factor for greater efficiency in the KCP has been alliances between companies, with patents being the factor that has slowed down efficiency the most.

As an application of this work, there would be the possibility of it being used by companies to measure the performance of their internal policies, with respect to the development and execution of new research projects, and their relationship with the huge investments that are made in these types of activities. This study is, therefore, defining the framework for analysing the success of companies, from the perspective of achieving their objectives based on the resources and processes that are carried out in increasingly strategic activities, such as R&D.

The above conclusions have an important practical implication; firstly, for the Spanish government in the formulation of policies. The government should increase financial support, allocate special funds for scientific research (in order to recruit more researchers) and support growing small and medium-sized enterprises, especially those with strong technological innovation capabilities in the sector.

In addition, companies must also increase the intensity of investment in R&D and improve their ability to commercialize innovation. We should increase not only government funds, but also corporate and social funds from companies in a joint effort to increase the number of pharmaceutical patent applications. Finally, it would be interesting to continue creating groups of companies through mergers and alliances, with the association of strong companies, to obtain financing, management, technology and other aspects, thus generating synergies, through the complementarity of resources between different companies, the inclusion of various innovative elements and the reduction of the cost and time of innovation.

To our knowledge, the present study does not suffer from any serious limitations. Specifically, it is noteworthy that a limitation of the present study was in the difficulty to find internal data related to R&D activities, since most of the companies we analysed refused to provide such data, which they considered to be confidential. Hence, we prepared a scale (Mulero-Mendigorri *et al.*, 2016) in pharmaceutical companies, and used qualitative variables in the application of the NDEA model. However, we have aimed to correct this limitation by applying the categorical variables model of Banker and Morey (1986).

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