There are sick people around the Ivory Tower: the financing strategy of diabetes research in Mexico

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Abstract

Diabetes is an urgent problem calling for immediate solutions that could help Mexican people to have better living conditions. Scientific research may play a key role in the generation of required solutions. Unfortunately, knowledge application has not been exploited to its maximum potential, limiting its social impact. The aim of this paper is to analyse knowledge production forms and the types of research undertaken, and discuss the reasons behind the existing profile. Our analysis is based on the consideration of knowledge use and the search of fundamental knowledge, as proposed by Stokes (1997). This paper focuses on the specific case of the diabetes knowledge production, and makes use of a database of 303 research projects, applying structural equation modelling techniques to estimate Stokes' analytical framework. We found a bias towards basic knowledge production (Bohr Quadrant), and limited presence of Pasteur and Edison type of research. This reduces applications and could delay or inhibited the perception of STI benefits in such an urgent matter. The nature of incentives of the Mexican research system contributes to this research profile.

Keywords: diabetes research, Mexican Research System, Pasteur Quadrant.

1 Introduction

Health problems have a strong influence in economic and social development. They hinder people's possibilities to enjoy better living conditions. They also imply losses in terms of productive capacities, and represent high costs associated with health care affecting national economies. In Mexico, Diabetes Mellitus has been considered a serious health problem for several years (Salud, 2001), and in 2016 it has been declared national emergency (EE-4-2016). It is a high-cost disease, one of the leading death causes of the country (Barraza-Lloréns et al., 2015), and its incidence shows an increasing trend. Country's health decision-making bodies has declared that both scientific knowledge generation and its application should be oriented to the solution of this important problem (Salud, 2014).

Mexico has been augmenting its health scientific capabilities over time. Today, there is an important knowledge production derived from high-level scientific and technological research carried out in universities, health institutes and institutions, and laboratories of the pharmaceutical industry. As Diabetes is an urgent problem calling for immediate solutions that could help Mexican people to have better living conditions, we would expect, then, that research is oriented towards the generation of those required solutions. Unfortunately, knowledge application has not been exploited to its maximum potential, limiting its social impact (Torres, Jasso, & González, 2014). There is a broad consensus around the necessity of profiting from Science, Technology and Innovation (STI) activities in the health sector (González Block, 2006). Many of the problems we find to make use of STI is rooted in the knowledge generation process (Casas, 2005; Casas & Luna, 2010).

The dependency on public funding for developing STI activities makes it important to understand the different available public mechanisms. We need, therefore, to comprehend changes in the sources and methods used to fund research in Mexico. In the last three decades, new instruments have profoundly affected research activities (Vera-Cruz et al, 2008). However, since new funding schemes were complemented by other policies, there is little empirical evidence about the results that have emerged from different founding instruments and policies (Dutrénit et al., 2010). As in most countries, there has been a tendency to decrease institutional funding and increase the share of competitive funding (CF) in relative terms. These changes have profoundly affected how research is conducted because, as contract theory has shown, no contract can completely specify all the relevant aspects of worker behaviour. Thus, agents only emphasize those aspects of performance that are rewarded and neglect the uncompensated activities (Prendergast, 1999). When it comes to generate knowledge in critical areas, such as healthcare activities, these behaviours might have important impacts.

This paper reviews the case of the diabetes knowledge production in Mexico. The aim is to analyse knowledge production forms and the types of research undertaken, and discuss the reasons behind the existing profile. This analysis is based on the consideration of knowledge use and the search of fundamental knowledge, as proposed by Stokes (1997). We found a bias towards basic knowledge production, which reduce applications and could delay or inhibited the perception of STI benefits in such an urgent matter.

After this introductory section, it follows a description of the public research funding in Mexico. Section 3 discusses the literature review composed by two parts: principal agent's theory and the Pasteur quadrant. Section 4 presents our conceptual model to organize diabetes research projects in Mexico; we outline two hypotheses. Then, section 5 contains the estimation of the empirical model, using Structural Equation Modelling (SEM) techniques. Section 6, discusses the results obtained from this model. Finally, section 7 contains our conclusions.

2 The context: understanding public research financing mechanism in Mexico

The main Mexican agency for STI policy (CONACYT) was created in 1970, hence the institutionalization of STI policy can be dated back to this year. CONACYT has been responsible for promoting STI activities, and became a mediator in a principal–agent relation, where the Mexican government (the principal) pursued its STI- related goals, and the academic community (the agents) sought to fulfill their own interests and needs. CONACYT has responsibilities as both a policy-maker and a funding organization, as many similar agencies that were created in the 1970s and 1980s in Latin America.

The models for financing of scientific research, technological development, and recently innovation changed over time. The linear model was introduced in the 1940s. It holds that results obtained from basic research serve as inputs for applied research, and its output are in turn used for technological development (Bush, 1945). Later on, the 1970s and 1980s were dominated by the science/technology/market linkage model, characterized by sequential but independent stages, which have multiple channels of interaction (Mowery and Rosenberg, 1979). In this model, governments should finance both the traditional research and programs that would support knowledge transfer between researchers and private firms.

The evidence, analysis and discussion of the models evolved, and in the 1980s, the discussion focused on an integrated model in which the different stages - research, development and adoption - could take place in parallel. In the 1990s, this model progressed into the system/network integration model. Here, instead of being an autonomous knowledge generator, the research was intrinsically linked to technological and economic factors. Thus, research activities are nodes of a wide network of knowledge creation and use (Fagerberg, 2005). In the last two models, STI policies attempted to balance technology supply with the needs of the market, promoting the creation of networks, fostering change in research institutions and private firms so that they could better integrate into innovation networks, and strengthening innovative capabilities (Lundvall and Borrás, 2005; Dutrénit *et al*., 2006; Elkins and Keller, 2004; Braun and Guston, 2003; Huffman and Just, 2000).

Even though the analysis of the evolution of incentives for research is beyond the scope of this paper, it deserve to be noted that the volume of external funding received has been an important criterion for researchers to decide what projects of research to undertake (García and Sanz-Menéndez, 2005). In addition, power asymmetry between different research groups, and in particular between basic and applied research, rooted in the first years of existence of CONACyT, generated implicit priorities in resource allocation favourable to basic research that continue to stamp the policy implementation.

In line with the governing objectives of the latter Science, Technology and Innovation Programs (PECyT 2008-2012, and PECiTI 2014-2018), the design of the policy mix included around 60 programs oriented to foster basic and problem-oriented research, regionalization of the activities, research and development (R&D) and innovation activities by the business sector, and formation of human resources.

There are two main programs/instruments to fund scientific research:

- Sectoral funds: these funds operate in conjunction with some Ministries or other government organizations to promote the development and consolidation of STI capabilities according to the strategic needs of each participating sector. There are 31 funds in operation; within those related to basic and applied science are the following:
    - Basic Science fund (CONACYT and the Public Education Ministry (SEP).
    - Sectoral Fund for Health and Social Security Research (CONACYT, the Health Ministry and the two largest public healcare institutions)
    - Sectorial Fund Conacyt-Ministry of Energy/Energy Sustainability (CONACYT and the Ministry of Energy)
    - Sectorial Fund for Water Research and Development (CONACYT and the National water commission)
    - Sectoral Fund for Environmental Research (CONACYT and the Ministry of environment and natural resources)
- Problem-oriented scientific development projects fund: this is a new program oriented to stimulate basic science related to a set of national problems; proposals should propose innovative solutions to national or regional, or obtain results or products that could have a social impact or derive in practical applications using high technology, with the potential to be used for the development of the country. Some of the national problems included in the call are:
    - Integrated water management, water security and water law
    - Mitigation and adaptation to climate change
    - Use and protection of ecosystems and biodiversity
    - Development and use of clean renewable energies
    - Emerging diseases of national importance
    - Combating poverty and food security

For many years, basic science funding was the unique source of financial resources. Because of this, it functioned as an umbrella for different types of research, ranging from very fundamental basic orientation to the most applied ones. From 2003 sectoral funds were designed in order to foster more applied research project developments. A set of sectoral funds were created and, within them, a Basic Science fund. This latter remained as the main funding for science. More recently, in 2013 a problem-oriented fund was put in practice, which look for promoting scientific development oriented towards national problems. This new interesting program still receives a very modest funding. In spite of the efforts to promote applied research, the majority of resources are still destined to basic scientific research, hence it is normal to find a bias towards this kind of research activity.

As a result of this CF funding scheme, CONACYT finds it hard to orient research projects towards a specific public policy orientation or decision. Peer review processes determine which project should be approved, meaning a delegation of resources allocation in the hands of the scientific community. Basic science funding act as an umbrella, in which research projects that combine different levels of applicability and search of fundamental knowledge could be found, although basic research projects may predominate. In other words, basic science funding finances scientific research in a generic way.

When other sectoral funds have a specific orientation, they finance research aimed at addressing sectoral problems. These funds are generated in a CF strategy of the health sector, gender, environment, etc. Funds' orientation and priorities are defined by a technical group of experts. Resources allocated to these funds are, nevertheless, generally very scarce. In this scheme, the sectoral funds should be the main funding for more applied scientific research. However, since only research that responds directly to specific demands is funded, many scientific research aimed at solving other sectoral problems may at a given moment find no place. For instance, not in all cases a diabetes project mandatorily has to be financed by the health sector fund; for it to happen, it is first necessary that diabetes is specified as one of the demands of the health sector in the call for applications of this year.

Summarizing, most of scientific research resources in Mexico tend to be in basic science areas. At a first sight, we might think that government's strategy is to fund only fundamental research. However, in practice it is not the case, because by allocating few resources to applied research financing, it creates pressure on the basic science funds that leads to resource allocation in more applied arenas. Thus, in practice, policy orientation is limited to simply devote a certain amount of resources to scientific research, but without specific orientation. As a consequence, research project funding decision ends up being a bottom up process taken by researchers or research groups.

Another important characteristic of the Mexican STI system is the influence of National Researchers System (NRS) in agents' behaviour. From the NRS, there are strong incentives to promote the generation of new fundamental knowledge. Scientific publications (papers in indexed journal, books and book chapters), human resource formation activities (thesis directions, lectures) and high technology outputs (patents, new devices, trademarks) are the three types of requisites that researchers should accomplish in order to be accepted in the NRS. At the same time, NRS is both a quality certification, which is well appreciated in career promotions and projects' evaluation, and an pecuniary incentive that might account up to 40% of researchers monthly stipend. Therefore, incentives are clearly biased towards the generation of basic knowledge, specially, the one that is internationally recognized.

In a way, we could claim that research funding in Mexico is quite coherent: it allocates resources in terms of CF for basic research projects and incentivize researchers to produce scientific outcomes close to fundamental knowledge production. However, this configuration has an effect in agents' behavior. For this reason, we decided to study the type of research that is produced in Mexico by looking at the individual dynamics.

3 Literature review

Studying diabetes research in Mexico requires a combined strategy. First, we need to understand how research-financing strategies take place in the country. Section 2 revealed that actors tend to behave according to the incentives they find in the system. Second, we will review the principal agent theory and models of scientific research. Third, we will review the Pasteur quadrant: a simple but provoking framework that classifies different type of research according to its usage or search of fundamental knowledge. This aims at finding a way of structuring the type of research produced and its potential to help in the solution of diabetes in Mexico.

3.1 Principal-agent theory, incentives and STI policy

Developed in the context of rational choice and transaction cost theory (Ross, 1973; Williamson, 1975; 1985), the principal–agent theory is increasingly being used to analyse research policy, interpret the interactions between policy and STI, and understand agents' behaviour (Braun and Guston, 2003). This theory deals with a specific social relationship, i.e. delegation in which two actors are involved in an exchange of resources. The principal owns a number of resources but not those appropriated to materialize his interests (Coleman, 1990). Then, he needs the agent, who accepts these resources in exchange of performing something on behalf of the principal.

In terms of STI policy, the government determines to support these activities as a means of achieving certain socio-economic goals. Delegation in this context refers to that, although the government (the principal) has resources, it still needs agents possessing the scientific skills to implement the policy; in other words, the government falls back on scientists to "produce" the knowledge that is required, and provides them with resources for this purpose. STI policy serves to organize the allocation of public funds to scientists in order to get the desired results while ensuring integrity and productivity of research.[1]

Delegation also involves problems. The two most typical problems are associated with collective action derived from the asymmetric information between the principal and the agent about the agent's behaviour: moral hazard and adverse selection[2]. Briefly, "Moral hazard" refers to the situation where the principal lacks sufficient information about the agent's performance to prevent "shirking" or other misbehaviours. The asymmetry of information complicates the principal to ensure and for the agent to demonstrate that research is conducted with integrity and productivity. "Adverse selection" in turn, results

[1] This refers to the integrity of the tasks carried out by scientists and the productivity of these tasks; in other words, the conexion between results and economic effort.

[2] Laffont and Martimort (2002) highlight another type of information problem: "non-verifiability". This occurs when the principal and the agent share ex-post the same information but, no third party and no court of law can observe this information.

from the fact that the principal lacks sufficient information to choose the best agent to carry out the particular tasks that he is otherwise unable to pursue by himself.

The above problems are based on what New Institutional economists call the ‘opportunism’ of actors: they are self-interested and thus seek to maximize their personal welfare (Williamson, 1985)[3]. Differences in the objectives pursued by the agent and the principal become problematic when information about the agent is imperfect. This problem is the essence of incentive questions and calls for a careful reflection on the adequate incentive structures to influence agent’s behaviours, and solve key problems in STI policy such as the integrity and productivity of research, or the choice between alternative types of research.

Whereas contract and close monitoring mechanisms may help to avoid these problems, optimal incentives should still be set and enforced once the principal and the academic researchers agree to work together (Huffman and Just, 2000). Social behaviour however, particularly in small groups, is more complex, norms of behaviour that are culturally inculcated or developed over time play a key role in shaping societies. Private incentives in addition to cultural phenomena motivate agents’ behaviour (Laffont and Martimort, 2002). This is relevant since, as this paper argues, replication of behaviours based on a particular conception on the role of STI in society may make difficult to adjust agents’ performances through renewed STI principles, objectives and policy. Delegation may turn sub-optimal, even unaffordable to achieve the principal’s goals.

Responses to monitoring activities developed by the principal differ among academic researchers, partly because of the ample variety of types and styles of monitoring exerted in different countries, and partly because of the ambiguity in some funding bodies as to what should count as satisfactory fulfilment of an agent’s task. Is it the completion of a given project or, the originality of a work that the principal will subsequently recognize as good? (Morris, 2003)

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[3] Unfortunately, in this piece of research we lack the required information to study in greater detail the problems of adverse selection and moral hazard for the Mexican case: the analysis about changes in the STI policy and their impact on the incentives structure faced by the academic researchers. We therefore assume that such incentives condition possible oportunistic behaviours by the academic community.

In this context, several contributions to the literature criticize the usual dyadic conceptualization of principal–agent relationships, particularly with regards to the governance of such relationship (Braun, 1993; Rip, 1994; Braun and Guston, 2003). In contrast, they offer a theoretical account based on “triadic relationships” among policy-makers, funding agencies –specialized semiautonomous bodies created by the government specifically to act as its agents of STI policy- and scientists. The argument is that funding agencies are sorts of “third party” ensuring the fulfilment of the tasks delegated by the policy-maker as principal, while protecting and promoting the interests of scientists as agents.

A research council would therefore be both agent (in relation to the government) and principal (in relation to the scientists) at once (Braun, 1993; Caswill, 2003, Shove, 2003; van der Meulen, 2003; Morris, 2003). Accordingly, funding policies confront the challenge to strike a balance between maintenance of the autonomy of scientists and the political interest to influence scientific action. In this paper, CONACYT is seen as “third party” between the policy-maker (principal) and the community of academic research (agent).

In this regard, in recent years the mediating role and position of research councils between government and other actors in the STI system –particularly universities and PRC’s- has become more complex in most countries. Research councils have had to address governmental priorities, stakeholders requirements and social needs, induce structural changes in the research base by means of reforming research centres, introduce new funding schemes, promote the revision of research agendas, stricter peer-review based competition for project funding and so on (van der Meulen, 2003; Huffman and Just, 2000). As the Mexican case illustrates however, increased responsibilities have not necessarily been accompanied by the adequate resources for research councils to face the challenge and induce the appropriate incentives to alter the agents’ behaviours.

3.2 A model to frame scientific research: the Pasteur quadrant

This part of the literature review is related to the knowledge production process. If we look at the possibilities of applying knowledge in order to collaborate in the solution of a national problem, such as diabetes, we need to understand how this knowledge is produced.

An alternative is looking at Gibbons et al. (2004)' Mode 1 and Mode 2 description. He organizes knowledge production in terms of the quest of new basic scientific knowledge (Mode 1), versus a problem solving oriented strategy (Mode 2). However, he heuristically configured some specificities of each mode: multidisciplinary, variety of actors involved, and characteristics of the knowledge's main objective. Even though we find this very interesting and provoking, we decide to pursue another avenue related to the Stokes (1997)' Pasteur Quadrant. We think that due to the health research complexity and the characteristics of the research funding in Mexico, this latter approach provides a more interesting tool to understand the structuring of the research in the arena of diabetes.

This paper uses the Stokes's Pasteur Quadrant as the analytical framework. This is a two-dimensional view of knowledge generation and its possible application. It is configured in two axes, i) research motivated by quest for fundamental understanding, without any immediate consideration of use in mind, and ii) research motivated by consideration of use, without any interest for the deeper scientific implications of the findings. This two axes model directly confronts the lineal idea of a one-way road from basic to applied research; following Stokes (1997), works in any part of Stokes' two-dimensional space are needed in any research system.

According to Stokes, the research is subdivided into four quadrants. The first, which he calls Bohr's quadrant, by Niels Bohr's work on the structure of the atom, comprises basic research. The second is called Pasteur's quadrant and encompass what he calls "basic research inspired by the application". The third is named the Edison quadrant; it is the traditional applied research. Finally there is an unnamed quadrant, corresponding to the absence of the two major research locomotives in the Stokes' scheme. In this quadrant would be the investigations that are not motivated neither by the consideration on its use nor by the search of the fundamental understanding.

More into details, as it was argued by Stokes (1997), the work of biologist Louis Pasteur, whose studies of bacteriology were carried out at the behest of the French wine industry, characterizes the work of basic scientists searching for fundamental knowledge who select their questions and methods based on potential relevance to real world problems. Pasteur always undertook an applied study, however he made fundamental contributions to science that spawned the entire field of microbiology and changed the way we view the cause and prevention of disease. Pasteur's quadrant illuminates a path where applied research is not opposed with scientific creativity and rigor, hence he contributed to move away from the basic-versus-applied research logic, and his work suggests the idea of use-inspired basic research. Hence, the Pasteur Quadrant has into mind the Louis Pasteur's work on immunology and vaccination, which both advanced our fundamental understanding of biology and at the same time saved countless lives. In this quadrant, scientists work to both advance scientific theories and methods while addressing practical problems.

The work of the theoretical physicist Niels Bohr typifies the upper-left quadrant: pure, basic research carried out with no practical aim, even though many applications were potentially there. On the lower right is the quadrant of pure applied research, exemplified by the work of inventor Thomas Edison, who restrained his employees from investigating the deeper scientific implications of the findings they made in their pursuit of commercially profitable electrical light. In this sense he was more concerned with practical scientific questions than with the underlying theoretical implications of his discoveries and inventions. In Pasteur's quadrant, the upper right, we find research that both seeks to expand the frontiers of understanding and draws inspiration from practical considerations. In addition to Pasteur and others, Stokes cites here research by John Maynard Keynes and by the Manhattan Project.

The fourth quadrant is not empty, but is occupied, according to Stokes, by 'research that systematically explores particular phenomena without having in view either general explanatory objectives or any applied use to which the results will be put, a conception more at home with the broader German idea of Wissenschaft than it is with French or AngloAmerican ideas of science' (Stokes 1997: 74). In this quadrant, disciplines such as art history can fit, as their focus on specific phenomena, are not primarily searching for the fundamental understandings referred to here, nor are they seeking any kind of practical application. Figure 1 illustrates the Stokes' Pasteur Quadrant.

Figure 1. Stokes' Pasteur Quadrant

Research inspired by:		Considerations about the use?	
		no	yes
Search for fundamental understanding?	yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	no		Pure applied research (Edison)

Source: Stokes (1997)

In his book, Stokes (1997) applies this framework to analyze United States' National Institute of Health (during 1960 and 1970), finding them very successful in fostering Pasteur type research. This was another reason for us to select this approximation for knowledge application in he health sector.

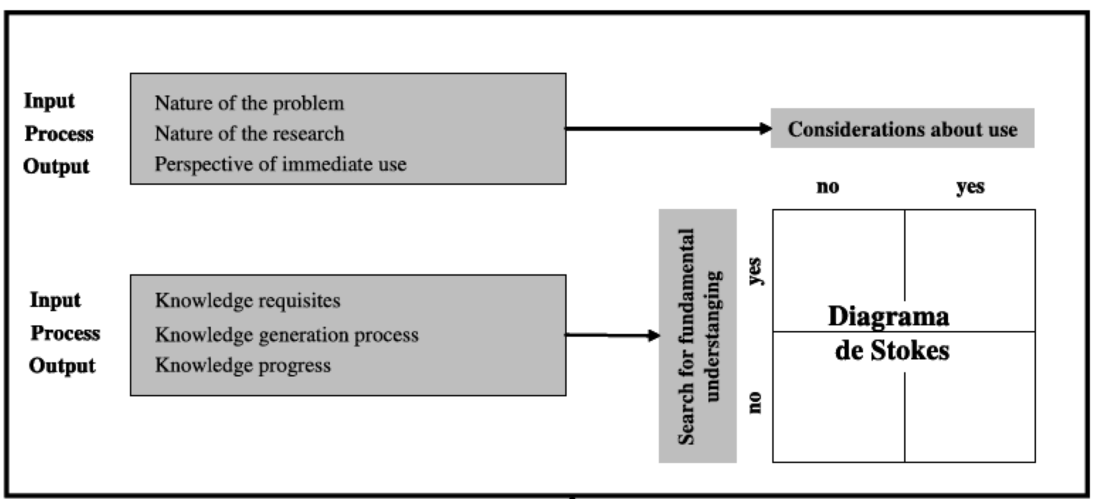
Several works have been inspired by the idea of the Pasteur Quadrant to describe different research systems, research programs, setting a research agenda or classification of journals, such as Ahumada Barona and Miranda Miranda (2003), Simmons et al. (2005), Tsao et al. (2008), Balaram (2008), de Sousa, Zamudio lgami and de Souza Bido (2009), Tijssen (2010) and Cizelj, Kljenak and Tiselj (2013).

4 Conceptual Model and hypothesis

Our conceptual model aims at configuring a Pasteur's Quadrant for diabetes research in Mexico. We base this empirical exercise on de Sousa, Zamudio lgami and de Souza Bido (2009)'s proposal for the analysis of energy research in Brazil. In our case, we investigated a health problem - diabetes. Therefore, we have adapted the original proposal to fit more closely the problems and types of health research. We will represent the main characteristics of diabetes research and understand its possible applications by defining two axes: "Considerations about use" and "Search for fundamental understanding" axis. Both of them are operationalization exercises of Stokes' Pasteur Quadrant.

The first axis analyses whether research is oriented to the application and/or knowledge use. The second axis analyses the contribution of research to fundamental knowledge, which in much of the literature is identified as basic knowledge. The two axes do not seek to qualify the projects according to a specific rank, in turn, they allow us to evidence how the values are distributed in the different quadrants, in order to understand the orientation of the projects and their diversity. As shown in Figure 2, we have followed de Sousa, Zamudio lgami and de Souza Bido (2009) adaptation of the Pasteur quadrant, structuring each axis in terms of input, process and output dimensions.

Figure 2. de Sousa, Zamudio lgami and de Souza Bido (2009)' s adaptation of Pasteur Quadrant



Source: de Sousa, Zamudio lgami and de Souza Bido (2009)

The "Considerations about use" axis refers to concrete use of research activities. In de Sousa, Zamudio lgami and de Souza Bido (2009) proposal, usage is measured with categories that investigate the nature of the problem, the nature of the research, and the perspective of immediate use. The first category - *Problem's nature* - focuses on the definition of research objects, looking at its theoretical or practical emphasis. The second category - *Research's nature* - investigates whether the research process guides future use. Finally, the *Perspective of immediate use* (in our version) looks at projects' potential to identify or include knowledge users.

The other axis, named "Search for fundamental understanding", classifies projects according to their proximity or contributions to fundamental knowledge, which is normally identified as basic knowledge. The first category corresponds to the input dimension, it is called *Knowledge requisites* and denotes the kind of knowledge that needs to be integrated into each project, therefore it refers to disciplinary background of participant researchers profile. The second category is *Knowledge generation* process and refers to the trajectory and development of research projects. Finally, our adaptation of the *Knowledge progress* category differs greatly from de Sousa, Zamudio lgami and de Souza Bido (2009)'s proposal, since it does not start from the idea that there is greater progress when knowledge is basic, but that it establishes progress in relation to the type of object that it could generate.

We propose this stylized model as a tool to organize diabetes research activities in Mexico. We think it might shed light on the chances of having new knowledge applications in the solution of this urgent problem. Anyhow, we cannot draw any inference without having a solid ground to build our conclusions; therefore, the first step of our empirical analysis should be finding evidence to support the utilization of this analytical framework. Our first hypothesis is devoted to the confirmation of the Pasteur Quadrant as a useful tool to describe diabetes research in the country.

> ***Hypothesis 1: Pasteur's quadrant model is useful to represent diabetes research activities in Mexico.***

If we find evidence to support Hypothesis 1, we will be able to investigate another specific question about diabetes research in Mexico. We would like to discern if new generated knowledge is oriented to contribute with concrete solutions for diabetes in the country. If that is the case, we should observe that Pasteur and Edison quadrants are fully populated, as they concentrate the majority of the research projects. However, given the characteristics of public research funding in Mexico described in section 2, we expect to observe an opportunistic behaviour in agents' activities, as discussed in section 3.1. Based on the literature review, we suggest that in the Mexican case, it is the Bohr quadrant the one that concentrates research projects.

> ***Hypothesis 2: There is a bias towards the Bohr quadrant (basic science) in diabetes research in Mexico.***

5 Data and empirical model

5.1 Data: public funded diabetes research projects (2002-2014)

We have constructed and extensive dataset of diabetes research projects funded by CONACYT during the period 2002 – 2014. It contains 303 projects that were approved in CF mechanisms in three funds: Basic Science fund, Sectoral Fund for Health and Social Security Research, and Problem-oriented scientific development projects fund. We have collected descriptive information of each project, making it possible to classify them according to its applicability and search of fundamental knowledge. This information is organized according to de Sousa, Zamudio lgami and de Souza Bido (2009)'s operationalization of Pasteur Quadrant.

In order to assign values for the measurement and location in the quadrants, de Sousa, Zamudio lgami and de Souza Bido (2009) define three categories for each of the axes. These categories are conceived in terms of Input (definition and initial requirements of projects), process (characteristics and development of research) and output (potential research results). For each axis, we define three variables (one per category), and assigned values from 1 to 5 to represent how high a research project ranks according to axis objective: the higher the number, the better the fit. Table 1 shows all the variables defined.

Table 1. Variables definition for the two axes

	"Considerations about use" axis (horizontal)	**"Search for fundamental understanding" axis (vertical)**
Input	Problem's nature	Knowledge requisites
Process	Research's nature	Knowledge generation process
Output	Perspective of immediate use	Knowledge progress

Source: own elaboration

- ***“Considerations about use” axis***

Problems’ nature. Projects’ practical concern is the one that has the highest values, as follows: 1) Totally theoretical, 2) More theoretical than practical, 3) Balance between theoretical and practical, 4) More practical than theoretical, and 5) Totally practical. In the case of diabetes projects, three variables were used to assign these values to the characteristics of the research: the type of research (basic, biomedical, clinical, public health or health systems), discipline or topic (cell and molecular biology or biochemistry, genetics, pathophysiology, nutrition, among others), and knowledge application, a category that describes the expected research output (fundamental study, technique, medical device, intervention). The combination of these variables allowed us to define which projects are more theoretical (eg. basic research + genetics + studies) and which are more practical (eg. health systems + nutrition + interventions).

Research's nature. Its values are constructed considering: 1) Pure basic research, 2) Oriented basic research, 3) Oriented basic research with some scopes of problem solving or practical applications, 4) Applied research to solve problems and / or generate practical applications, and 5) Experimental development about new products, processes, materials, equipment, and systems or their improvements. It is important to point out that all the research projects that were analysed here are oriented by the diabetes theme; however, they are very diverse in terms of proximity to the practical use of knowledge. For values assignment, we combined two criteria: the focus of projects’ discipline (eg., if genetic research is about expression or markers, if nutrition research is about the chemical effect of diets or about behaviours and Lifestyles), and knowledge application objects or research expected outputs.

Perspective of immediate use. The more definition and closeness there is with the users, the higher the figure of its *Perspective of immediate use*. Values were defined as follows: 1) Knowledge users are not identified, 2) There are potential knowledge users, 3) There are specific knowledge user groups, 4) There are specific user knowledge groups and there is a method for knowledge application, and 5) Specific knowledge users are participating in the research project or profiting from research project outcomes. Values were assigned by considering: (i) research expected output, and (ii) a revision of research objectives and available information to determine the closeness with knowledge users.

- ***"Search for fundamental understanding" axis***

This axis contains the greatest adaptations we applied to de Sousa, Zamudio lgami and de Souza Bido (2009)'s model. We have used this model as our guide when using the Pasteur Quadrant's framework, but, we have decide to leave aside the use of "fundamental understanding" as a synonym for basic research. We consider that fundamental knowledge might be expressed not only in scientific but also in technological terms, especially in a case like diabetes research.

Knowledge requisite. de Sousa, Zamudio lgami and de Souza Bido (2009) distinguish between theoretical and practical degrees of the contribution. We have chosen to build values between one-disciplinary research and those that draw on other disciplines. The values are: 1) Knowledge in one specific area, 2) Knowledge in at least two specific knowledge areas, 3) Multidisciplinary knowledge areas, 4) Interdisciplinary knowledge areas and 5) Transdisciplinary knowledge areas. These values were assigned following a qualitative review of the projects, which approached the disciplines involved in its implementation in terms of its uni, multi, inter or transdisciplinary focus.

Knowledge generation. We proposes a research process classification according to their research question. Thus, values are: 1) Generate specific data about a phenomenon - What is a variable specific level?; 2) Specifying phenomenon's analytical dimensions - What should be measured?; 3) Determining causal relationships - Why does it happen?; 4) Exploring association of the phenomena with established knowledge - To what is it related?, and 5) Characterizing and describing the nature of a phenomenon - What is it?. Values were assigned by analysing verbs included in projects' objectives, and they qualified according to the proximity with the aforementioned questions, ranging from 1 to 5. Since a single project can have more than one verb, all research objectives' verbs were assessed and later weighted to obtain average values.

Knowledge progress. This category does not support the idea of knowledge generating greater progress when comes from basic science. Instead, it proposes that progress comes from contributions that imply modifications or renewal of existing knowledge, without using the science-technology tension as the main criterion, but rather as the new-existing tension. Values for this variable are: 1) Support- Confirm already existing scientific or technological knowledge; 2) Minor- Explore relations to already existing scientific or technological knowledge; 3) Moderate - Establishing / transforming new data or new standards to already existing scientific or technological knowledge; 4) Significant- Create a new research line; 5) Extraordinary- Create a new research area or theme. Values were assigned using the knowledge application objects as a first data and a qualitative review of the projects. None of the qualified projects reached the maximum value.

Table 2 shows variables' descriptive summary; we have added short names to each of them (they appear in parenthesis in the table). A quick view on the results is sufficient to observe that diabetes research projects ranks higher in terms of the *Search for fundamental understanding* versus the *Consideration of use*. The empirical analysis will investigate this intuition.

Table 2. Variables' descriptive statistics

Axis	***Variable***	***Mean***	***Standard Deviation***	***Min***	***Max***
Consideration of use	Problem's nature (problemnat)	2.521	1.509	1	5
	Research's nature (researchnat)	2.624	1.504	1	5
	Perspective of immediate use (inmediateuse)	2.508	1.449	1	5
Search for fundamental understanding	Knowledge requisites (krequisites)	3.825	0.9907	2	5
	Knowledge generation process (kgeneration)	3.508	1.032	1	5
	Knowledge progress (koutput1)	4.023	1.408	1	5

Source: own elaboration

5.2 A structural model for diabetes research in Mexico

In order to estimate the conceptual model, we will apply a combination of Structural Equation Modelling (SEM) techniques, namely: Factor Analysis (FA) and Path Analysis (PA).

SEM is a collection of methods that aims at understanding relationships between observed variables and a series of underlying phenomena that are not directly measured. It allows us to analyse different structures of data interaction, by looking at covariates between the included variables. In order to do so, we might focus on the interaction between variables or in the linkages that represent model's structure.

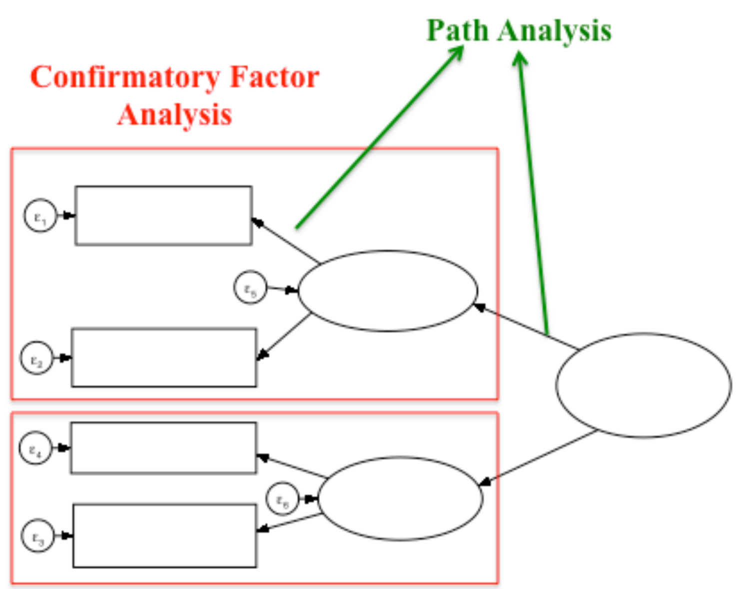
FA is a technique applied as recognition that no all variables can be directly observed. In an empirical problem it might occur that some variables lay in a fore process, related to direct measures but impossible to be explicitly observed. Those unobserved variables are named *latent variables* or *factors*. Description of factors requires disentangling the influences they have on observed variables. In order words, by examining covariation between observed variables, FA presents an estimation of the underlying latent variables.

When different observed variables define a problem, factors could be assessed as a relationship between all variables or between some particular ones. This allows us to test if the proposed constructs influence observed variables in a particular configuration. If that is the case, variable selection process should be part of research design, responding to theoretical bases or to empirical proposals. FA is the name of this special configuration of SEM, in which correlations between the factors are an explicit part of the analysis. With FA, researcher is able to decide a priori whether the factors would correlate or not with particular observed variables and collect them in a matrix of factor correlations (Tacq, 1997). Therefore, it is normally applied when factor structure is known or at least theorized, or when relationships among variables are known. Particularly, in the research design it is possible to impose different types of constraints, such as: correlation between factor pairs, common factors or unique factors that affect specific observed variables.

In the case of PA, we focus on the arrows that link together observed variables and/or factors. PA applies analysis of regression techniques, aiming at a more detailed resolution of the phenomena under investigation. PA permits us to consider chains of association, such as A influencing B, and B in turn affecting C. It examines how an independent variable is statistically related to a dependent variable. Dependency is expressed by connecting two observed variables or factors; which is expressed as an arrow in the diagram (Figure 3). Arrow's source is the independent variable and, consequently, arrow's end is the dependent one.

By combining CFA and PA we might evaluate interaction between variables for models with different complexity levels. By looking at the model fit, we might find evidence that the proposed structure is suitable to describe data interaction. However, it does not imply that other model structures are not suitable as well. This implies that SEM is useful to find feasible combinations of relationship between variables; but it does not represent a definite technique to find *the* unique structure.

Figure 3. Structural Equation Modelling: basic Confirmatory Factor Analysis and Path Analysis



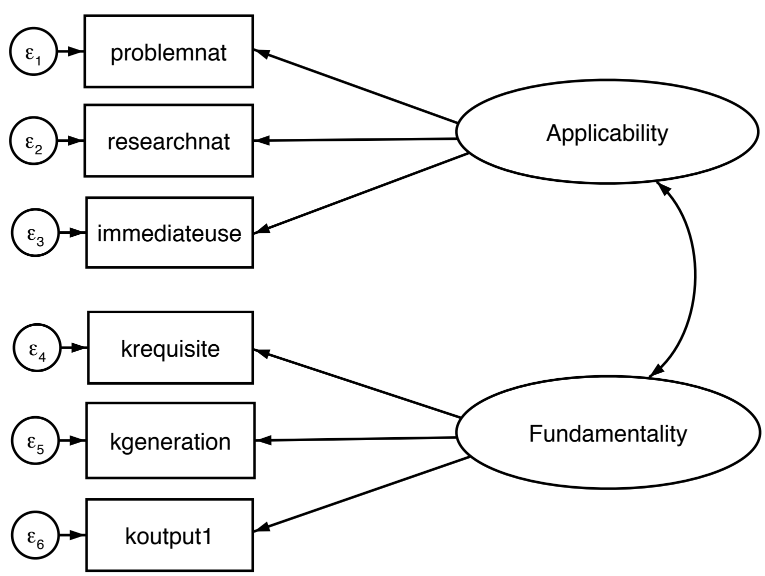
Source: own elaboration

In this document, following de Sousa, Zamudio lgami and de Souza Bido (2009), we propose that diabetes research could be assessed by applying a structural model representation of the Pasteur Quadrant. We have included two latent variables:

Applicability, to express the influence of “consideration of use” axis, and *Fundamentality*, to consider the “Search for fundamental understanding” axis. For each latent variable, we have linked the three observed variables that describe input, process and outputs of research activities. In order to estimate quadrants’ interactions, we have added a bidirectional relation between the latent variables. Figure 4 shows the structure of our stylized model.

If the SEM model holds (Hypothesis 1), we will have empirical support to describe projects according to the two axes and classified diabetes projects accordingly (Hypothesis 2). We argue that our Pasteur Quadrant would be constructed by creating a composite indicator per each axis (containing the three pertinent observed variables) and generating a two ways graph containing projects’ levels of applicability and fundamentality.

Figure 4. SEM representation of Pasteur Quadrant for diabetes research in Mexico



Source: own elaboration

6 Analyses of results

In this section, we will present and discuss the set of results from our empirical analysis. First, we will show SEM's output and the evidence found that suggests its suitability to organize diabetes knowledge production in Mexico. Then we will present our estimation of Stokes' Pasteur Quadrant applied to our case, and its implications in terms of the types of projects that have been publicly funded for diabetes research.

Table 4 shows variables correlation. We observe that variables within the same axis show a positive correlation coefficient, particularly in the case of *Consideration of use,* where correlations are above 0.6. When variables belong to different axes, correlations coefficients are negative. The correlation matrix is consistent with Stokes' model, where there is a compromise between the generation of fundamental knowledge and the possibilities of its application. The only space in which both axes find high levels is Pasteur Quadrant. Therefore, if the SEM holds, we have a first set of evidence suggesting that Pasteur Quadrant for diabetes research in Mexico is weaker than the other quadrants on the model.

Table 3. Model's variables pairwise correlation matrix*

	Problem's nature (problemnat)	Research's nature (researchnat)	Perspective of immediate use (inmediateuse)	Knowledge requisites (krequisites)	Knowledge generation process (kgeneration)	Knowledge progress (koutput1)
Problem's nature (problemnat)	1					
Research's nature (researchnat)	0.8863	1				
Perspective of immediate use (inmediateuse)	0.7494	0.6094	1			
Knowledge requisites (krequisites)	-0.6084	-0.5249	-0.6192	1		
Knowledge generation process (kgeneration)	-0.4067	-0.3222	-0.3992	0.3467	1	
Knowledge progress (koutput1)	-0.6992	-0.7542	-0.4327	0.3641	0.32	1

Source: own elaboration
**All coefficients are significant at 1% confidence level*

We will now introduce results from our SEM representation of Stokes' model. Figure 5 presents a graphical representation of the results, while Table 5 contains detailed results of coefficients and significance levels. Latent variables behave as expected from the correlation matrix. *Fundamentality* has a positive and significant relationship with Knowledge requisites, knowledge generation and outputs. *Applicability* is also positively and significantly related to its three observed variables, and shows higher coefficients than the other axis. Covariance between the latent variables is negative and significant (Table 5): this confirms that there exist a trade-off between the search of fundamental knowledge and the consideration of use in diabetes research projects.

Figure 5. SEM results of Pasteur's Quadrant for diabetes research in Mexico

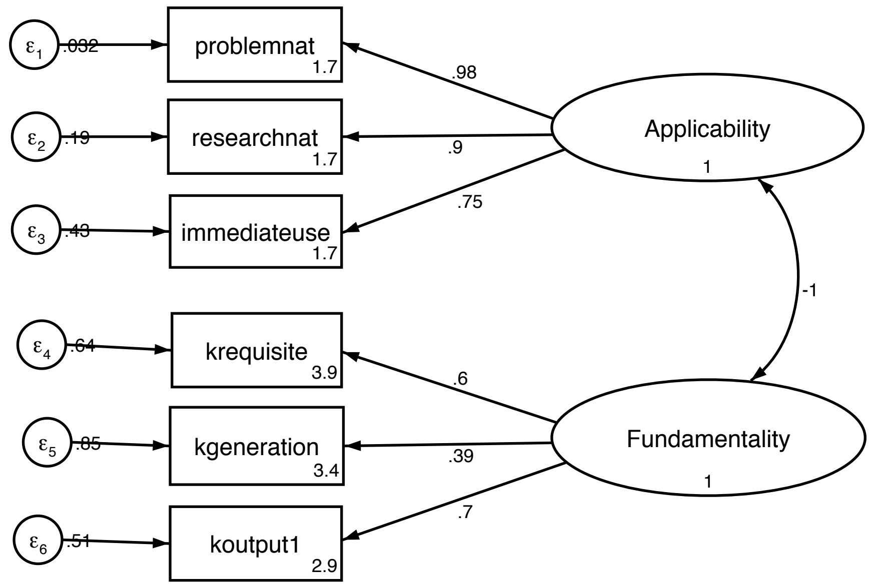


Table 4. Mexican diabetes research: SEM output

Dependent Variable	Independent Variable			Standard Error	Z-Value
Problem's nature (problemnat)	Applicability	B-Coefficient	0.98***	0.01	112.77
		Constant	1.67***	0.09	18.80
Research's nature (researchnat)	Applicability	B-Coefficient	0.9***	0.01	67.24
		Constant	1.75***	0.09	19.14
Perspective of immediate use (inmediateuse)	Applicability	B-Coefficient	0.75***	0.03	29.21
		Constant	1.73***	0.09	19.08
Knowledge requisites (krequisites)	Fundamentality	B-Coefficient	0.6***	0.04	15.23
		Constant	3.87***	0.17	23.12
Knowledge generation process (kgeneration)	Fundamentality	B-Coefficient	0.39***	0.05	7.44
		Constant	3.4***	0.15	22.73
Knowledge progress (koutput1)	Fundamentality	B-Coefficient	0.7***	0.03	20.18
		Constant	2.86***	0.13	22.07
cov(Applicability,Fundamentality)			-1.03***	0.03	-31.68
var(e.problemnat)			0.03	0.02	
var(e.researchnat)			0.19	0.02	
var(e.immediateuse)			0.43	0.04	
var(e.krequisite)			0.64	0.05	
var(e.kgeneration)			0.85	0.04	
var(e.koutput1)			0.51	0.05	

N = 303
Estimation method = Maximum Likelihood
Log Likelihood = -2488.17
LR test of model vs saturated (Chi-Squared)

Finally, Table 6 shows estimations to test model fit to the original data. Based on models' capacity to explain the data generation process (high R2 and high correlations between predicted and observed variables), we find support to propose that the model is useful in our case.

__Table 5. Mexican diabetes research: SEM fit__

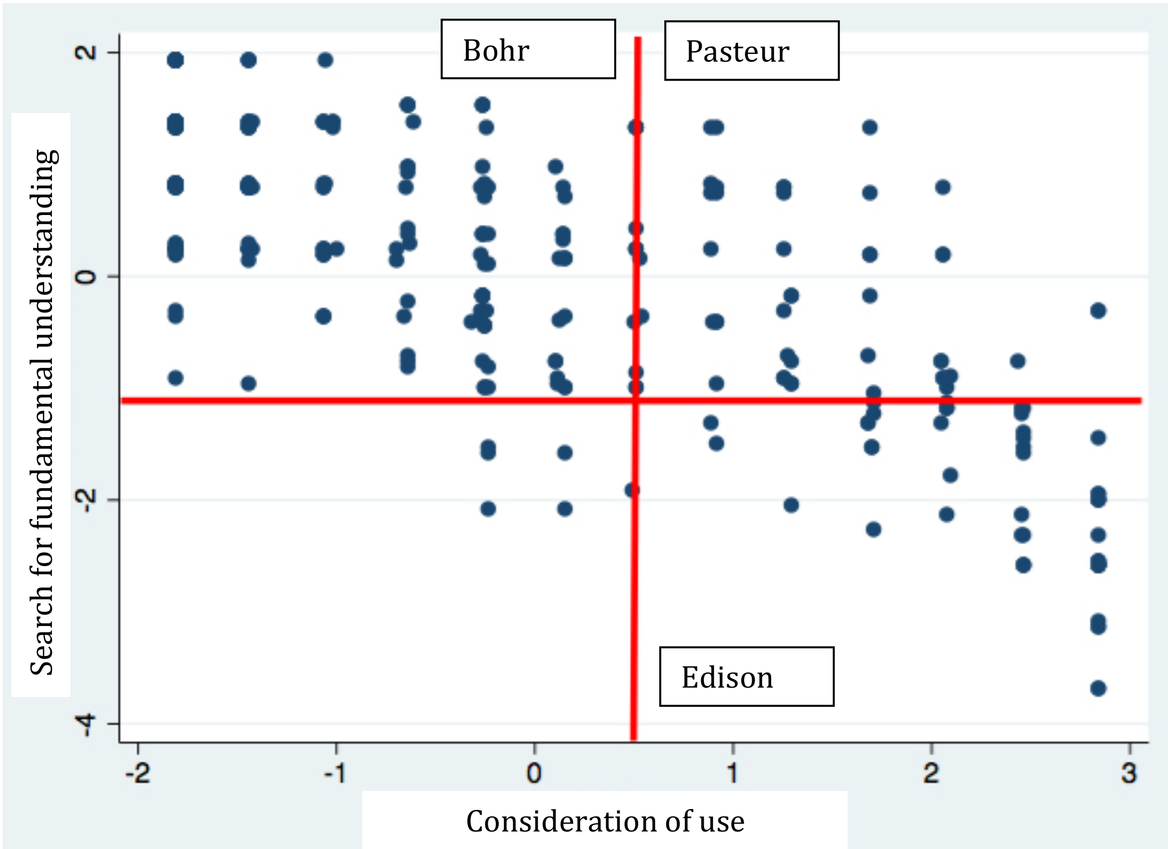
	Variance				
Dependent Variables	**Fitted**	**Predicted**	**Residual**	**R-squared**	**Correlation between Dependent Variables and its Prediction**
Problem's nature (problemnat)	2.27	2.20	0.07	0.97	0.98
Research's nature (researchnat)	2.25	1.83	0.43	0.81	0.90
Perspective of immediate use (inmediateuse)	2.09	1.18	0.91	0.57	0.75
Knowledge requisites (krequisites)	0.98	0.36	0.62	0.36	0.60
Knowledge generation process (kgeneration)	1.06	0.16	0.90	0.15	0.39
Knowledge progress (koutput1)	1.98	0.97	1.01	0.49	0.70
Overall				***0.97***	

SEM's results serve to confirm that Stokes' model is suitable to represent Mexican diabetes research. The proposed structure is statistically significant. Considering this evidence, we will not reject Hypothesis 1: ***Pasteur Quadrant model is useful to represent diabetes research activities in Mexico***. Consequently, we will use Pasteur's Quadrant to categorize diabetes research in Mexico according to its *applicability* and *fundamentality*.

Our version of Pasteur Quadrant was constructed by generating a synthetic indicator (simple average)[4]. The outcome of this exercise is shown in Figure 6. There is a clear concentration of research projects in the Bohr Quadrant. Pasteur and Edison Quadrants are less populated. Therefore, evidence suggests that research projects are not oriented to find useful knowledge applications; they are focused on the generation of fundamental advanced knowledge.

[4] We have also applied a principal component analysis (PCA), which found similar results.

Figure 6. Stokes' Pasteur Quadrant model applied to diabetes research in Mexico



Source: own elaboration

We would like to explore why the search of fundamental knowledge is at the core of diabetes research in Mexico. Diabetes is an urgent problem calling for immediate solutions that could help Mexican people to have better living conditions. We would expect, then, that research is oriented towards the generation of those required solutions. In order to have better understanding, we have codified Stokes' model according to the public fund that have serve as projects' financial source.

Table 7 contains the detail of financed projects by the different funds[5]. Bohr's Quadrant concentrates 61.7% of projects. Because of the predominance of Basic Science fund, this result is not surprising. Nevertheless, we observe that this tendency is still quite high in the

[5] We have also analyzed the amount of financial resources allocated in each quadrant per fund. Results move in the exact same direction as those expressed in Table 7.

other two funds: 48.7% of projects financed by the Sectoral Fund for Health and Social Security Research, and 25.9% of projects financed by the Problem-oriented scientific development projects fund are also located in the Bohr's Quadrant.

Table 6. Projects distributions in Stokes' Pasteur Quadrant applied to diabetes research in Mexico

	Fund							
	Basic Science		**Health Sectoral fund**		**Problem-oriented fund**		**All Funds**	
	# Projects	**%**	**#Projects**	**%**	**# Projects**	**%**	**#Projects**	**%**
Bohr	107	84.9%	73	48.7%	7	25.9%	187	61.7%
Pasteur	6	4.8%	24	16.0%	5	18.5%	35	11.6%
Edison	6	4.8%	48	32.0%	10	37.0%	64	21.1%
NoName	7	5.6%	5	3.3%	5	18.5%	17	5.6%
Total	***126***	***100.0%***	***150***	***100.0%***	***27***	***100.0%***	***303***	***100.0%***

Source: own elaboration

Edison Quadrant comes second, enclosing 21.1% of financed projects. Out of the 64 projects, only six of them were financed by Basic Science fund; most of them were supported by the Health sectoral fund. Projects in this quadrant are normally health interventions, in which existing knowledge is reconfigured in terms of possible applications. Finally, Pasteur Quadrant contains only 11.6% of total funded projects; they were mostly sponsored by the Health sectoral fund. This may represent the major opportunity for Mexican diabetes research. Indeed, as Pasteur Quadrant combines the possibility of using advance knowledge to solve problems, for a national perspective, it might be the source of major potential benefits from STI activities.

The analysis of the results of Pasteur Quadrant of diabetes research provides evidence to avoid Hypothesis 2 rejection: ***There is a bias towards the Bohr quadrant (basic science) in diabetes research in Mexico.*** One question still prevails: why do research projects are oriented towards fundamental knowledge in the case of diabetes in Mexico? We think that it is a problem of incentives. Principal agent's theory (Braun and Guston, 2003) is useful to understand how the way that financial resources are structured poses perverse incentives to researchers in the country. The predominance of the Basic Science Fund and the heavy influence of the NRS in researchers make fundamental knowledge production much more profitable in terms of career (pair recognition, credibility) and economics benefits (resources for research activities and salary incentives) than research oriented for consideration of use.

The problem seems to be twofold; on one hand, the scientific community has a limited participation in the design of public funds structure, so they largely react to the requisites that are outlined in the call for projects from their own perspective, and interpret them to write proposals with greater possibilities of success. On the other hand, projects are approved by CF mechanisms, in which peer review process take the final decision in projects approval, without considering any other participation from outsiders. As a consequence, researchers tend to interpret CF criteria in terms of their own practices, in which basic scientific knowledge has been historically well regarded in detriment of other ways of knowledge production. Autarchic inside the scientific community creates a self-isolation process, in which the consideration of other social needs comes in second place. Model 1 of Gibbons et al. (1994) predominates. At the end of the day, diabetes research in Mexico is oriented to the construction of the Ivory Tower while sick people lay around it.

7 Conclusions and policy recommendations

Diabetes Mellitus is a relevant and urgent national problem in Mexico. We would expect that knowledge production, particularly when is publicly funded, would be oriented towards the generation of useful applications to collaborate in the solution of this disease. Having this in mind, in this paper, we aim at analysing knowledge production in the arena of Diabetes in terms of the consideration of knowledge use and the search of fundamental knowledge, following Stokes' model (1997). We draw on the ideas of Stokes (1997), however, we have followed the proposal of de Sousa, Zamudio lgami and de Souza Bido (2009) in order to operationalize a structural model that could represent Stokes' Diagram for diabetes research in Mexico.

Based on the Pasteur Quadrant built in that way, we organized 303 diabetes projects funded by CONACYT in two axes: *Applicability*, composed by Problem's nature, Research's nature and Perspective of immediate use; and *Fundamentality*, comprising Knowledge requisites, Knowledge generation process and Knowledge progress. This configuration was tested using factor analysis and path analysis, from SEM techniques. We find a reliable model that could serve as a base to describe diabetes research. We proceeded to construct two composite indicators to express in a synthetic way the two axes, and graph them together to generate the representation of project allocations in the Stokes' Diagram.

We found a strong concentration around basic knowledge production, i.e. research that seeks for fundamental knowledge (Bohr Quadrant), in detriment of other knowledge production forms that take into account consideration of knowledge use (Pasteur and Edison Quadrants).

Hence, both Hypotheses will are not rejected: Hypothesis 1: *Pasteur Quadrant model is useful to represent diabetes research activities in Mexico*, and Hypothesis 2: *There is a bias towards the Bohr Quadrant (basic science) in diabetes research in Mexico.*

We argue that this profile of the research is caused by the incentives placed in the Mexican Research system, which is oriented towards the generation of basic knowledge. Researchers' incentives make them work in the construction of Ivory Towers instead of looking at social problems where they might have a greater impact.

The profile of the research in diabetes does not correspond to the need of solutions for the population. This is not enough to help Mexican people to have better living conditions. Even though we do not neglect the importance of having high quality Bohr type of research, this will not bring the solutions that the diagnosed population demands. Hence, more research like Pasteur and Edison types is needed. More interaction between different types of research is also essential to help find those solutions. These results and their interpretation have some policy recommendations. First, incentives should be focused on the reorientation of the research system towards a greater positioning of research and researchers that take into account consideration of knowledge use. This is a major challenge, as the actual incentives structure includes a series of different policies, which makes an impact on both recognition and economic benefits. A first step should be an increase of the financial resources for those more applied sectoral funds and the Problem-oriented scientific development projects fund. This could help to start moving the incentives in the direction of Pasteur and Edition type of research. Second, the project approval process could be also modified to a more democratic process, in which the scientific community could dialogue and find consensus with other social actors, in order to agree on projects' social relevance. Both policy recommendations are in tune with a STI public policy, which include the communities in the policy formulation process.

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