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Effects of a Linear Innovation Policy in Non-linear Innovation Sectors: Empirical Study in Strategic Sectors of the State of Mexico

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Abstract: This article takes up the discussion of the different models of innovation to understand science, technology and innovation policy in Mexico. The main objective of this research is to identify the effects of the innovation policy in Mexico in strategic sectors of the State of Mexico, through public policy instruments focused on encouraging technological innovation in companies in the State of Mexico. Another objective of this study is to add to the development of the theoretical framework of the innovation policy that helps to design better instruments that promote innovation in diverse technological sectors. The main instrument for promoting innovation in companies in Mexico, recognized in the last 20 years, the Innovation Stimulus Program (PEI), is analyzed to find out the impact of a public policy instrument that follows a linear model in companies of strategic sectors of the State of Mexico that follows a non-linear model of innovation. PEI serves companies of different sizes and purposes, it operates under three modalities: INNOVAPYME (aimed at micro, small and medium-sized companies), INNOVATEC (aimed at large companies) and PROINNOVA (companies of any size that present proposals in connection with at least two Higher Education Institutions or Research Centers). For this study, the focus is oriented to companies from strategic sectors of State of Mexico that are dedicated to innovation activities in the areas of the chemical, agro-food, health, automotive, new materials and plastics technology industries, technologies focused on sustainable development, and information technologies. The main strategic sectors of innovation defined in the State of Mexico follow a non-linear model of innovation, but government programs dedicated to encouraging innovation in companies seem to focus on linear innovation processes. Regarding the methodology, quantitative methods are used to know the effect of policy instruments in strategic sectors of the State of Mexico, a microeconomic analysis is supported through the Survey on Innovation and Technological Development (ESIDET) 2017. By knowing the effects of the main instrument of innovation policy in Mexico, it is possible to identify the role of the state government to strengthen these efforts, complement or improve them. The results present some concrete recommendations on the design of public policies to achieve the greatest benefits in investment in STI to promote regional technological innovation in strategic sectors.

Keywords: Science, Technology and Innovation Policies, Linear Model of Innovation, Non-linear Model of Innovation, Strategic Sectors, Empirical Study, PEI, ESIDET, State of Mexico

1. Introduction

Innovation is a key element for the survival, competitiveness and success of companies, it must meet the demands of the market and have an interest in solving needs with innovative products or services. The innovation process carried out by companies differs from the type of product or service they develop. After a long discussion of innovation models and their evolution to the systems perspective [6, 12, 27], it seems that the debate is old and outdated, but the issue remains when innovation policies are designed and implemented with a linear orientation for sectors of more complex innovation. In the formulation of public policies, greater theoretical and conceptual knowledge about the evolution of technological change is necessary to identify the differentiated needs presented by the different technological sectors. The

instrument that was chosen for this study does not have the objective of benefiting specific innovation sectors, but it seeks to know the impact that an instrument of this magnitude has on strategic sectors that follow a non-linear model of innovation. The instrument of public policy of innovation is the Innovation Incentive Program (PEI). The PEI is the technological innovation program for high value-added businesses, pioneering technologies and company competitiveness is a financing instrument that promotes research, technological development and innovation in private companies. The delivery of resources to companies is a co-investment, an incentive for private investment in innovation which also includes the collaboration of research centers and institutions as binding agents.

This research focuses on the State of Mexico, this State has a strategic geographic location and a stable political-social climate; in addition to a high level of logistics development, infrastructure and an outstanding educational system. The general objective of this research is to identify the positive or negative effects of the innovation policy in Mexico in strategic sectors of the State of Mexico, through public policy instruments focused on encouraging technological innovation in companies in Mexico. Another objective of this study is to add to the development of the theoretical framework of the science, technology and innovation (STI) policy that helps to design better instruments that promote innovation in diverse technological sectors.

The justification for this study is to provide elements for understanding the innovation process, through innovation sectors that follow a non-linear innovation model. The intention of this research is that it can be useful for the design and implementation of public policies in strategic sectors and with regional approaches. With the review of the literature, it has been observed that companies that follow non-linear innovation models have greater difficulty in developing innovative products and services due to the particularities presented by the technological sectors to which they belong, so they have specific needs in their processes and require focused support. In this sense, government supports that work in a linear logic of innovation may not consider the specific needs of companies that have non-linear innovation processes, so the following hypothesis is proposed:

H1: A STI government policy that starts from a linear innovation paradigm has significant negative and contradictory effects when applied to support innovation in strategic sectors that do not have linear innovation processes.

The assumptions of this research are the following:

a) Companies from strategic sectors in the State of Mexico have greater difficulty in innovating products, processes and/or technological services due to the specificities in their non-linear innovation process.
b) Innovation promotion programs consider linear innovation processes and therefore the rules of operation and requirements do not consider the times or difficulties that companies in non-linear innovation sectors could present.

The limitations of this study are related to the veracity of the answers by the companies in the ESIDET 2017 survey and the temporality, since for the year in which the survey was published (2017), the information found corresponds to the years 2014, 2015 and 2016. These limitations reduce its ability to generalize, although in a larger study the surveys prior to this year could be used to carry out longitudinal studies. Since it is not the intention of this study, this research uses the most recent survey [5] to answer the research question.

2. Literature Review

2.1. Theoretical Framework of Innovation

The theoretical and analytical framework of the STI policy responds to the technological and innovation changes that constantly arise to face current challenges in all areas of life. That is why the STI policy must consider technological sectors that follow a linear model of innovation in their innovation process and more complex sectors that follow a non-linear model of innovation.

The different generations of innovation models respond to specific times in their emergence. For practical reasons and for the purposes of this study, two types of generic models are considered, linear models and non-linear models of innovation. Linear models can include Rothwell's first and second generation models [20], where “technology push” and “market pull” can be found, as well as the model by stages [21, 25]. While in the non-linear models of innovation are the interactive or mixed models, called by Rothwell as third generation, where the Marquis, Roberts, Rothwell & Zegveld models are found, highlighting the Kline model known as "chain-link-model" [9]. Integrated models can also be found within nonlinear models; Rothwell refers to these models as fourth generation. Another proposal of the integrated models are the models of the Schmidt-Tiedemann Model or model in concomitance. This model stands out because it considers three functional areas of the innovation process: research (basic and applied), technical (technical evaluation, identification of know-how and development needs), and commercial (market research, sales and distribution). It is called concomitance because the three functional areas of the innovation process accompany each other throughout the process with almost continuous interactions [23].

Finally, within the nonlinear models is the network model, considered by Rothwell as a fifth generation model. This network model is the closest approximation to the National Innovation System (NIS) adopted by most countries for the design of public policy.

The innovation systems have several derivations, the best known is the National Innovation System [4, 10, 11, 15, 26], but regional innovation systems can also be found [1-3, 13, 17, 19, 22, 24]. The NIS are an interactive model that promotes innovation processes between institutional agents. Among its main characteristics, it can be found that they are favored by the effects of globalization; the existence of links or relationships between agents, networks and information systems predominates; and includes the conditions of competition,

incentives, continuous learning, use and generation of new technologies. The Regional Innovation Systems study innovation as a regional or systemic phenomenon. They are characterized in that they are based on the concepts of industrial districts, clusters, growth of the regional State, regionalized technological complexes and technopolises. In Regional Systems, innovation can occur from the environment towards the companies or from the internal structure of the companies towards the environment [18].

2.2. Contextual Background

Innovation policies are constantly changing in the global environment, Mexico is no exception, since in each administration new lines of action are proposed regarding the future of science, technology and innovation. It is important to be clear about the role of the State in the face of technological changes, whether it will be a passive entity or a key actor for the development of innovation, as mentioned by Mazzucato [14] when referring to the State not only as a corrector of "market failures", but also as a creator of wealth and engine of innovation.

Regarding the public policy instrument chosen for this study, the Program of Incentives for Research, Technological Development and Innovation (PEI) by its acronym in Spanish, is among the main programs that companies know about in science and technology offered by the federal government. Followed by the SME Fund (recognized by 8,248 companies), the PEI is the second most recognized by companies in Mexico (6,166) [5]. Compared to the SME Fund that focuses exclusively on micro, small and medium-sized companies, the PEI in its three modalities, considers companies of any size and technology sector (See Table 1). Due to the fact that the program serves companies of different sizes and purposes, it operates under three modalities: INNOVAPYME (aimed at micro, small and medium-sized companies), INNOVATEC (aimed at large companies) and PROINNOVA (companies of any size that present proposals in connection with at least two Higher Education Institutions or Research Centers).

Table 1. *Scheme of modality of the Innovation Stimulus Program (PEI).*

Modality of PEI	Features for linking	General requirements to apply
INNOVAPYME (Technological innovation for micro, small and medium enterprises)	Companies can participate with proposals individually or linked to Higher Education Institutes (HEI), Research Centres (RC) or both.	1. Propose investment in infrastructure (physical and human resources) for technology research and development. 2. Consider the creation of new high-value jobs.
INNOVATEC (Technological innovation for large companies)	Companies can participate with proposals individually or linked to HEI, RC or both.	1. Promote articulation productive chains in innovation and technological development activities. 2. Propose investment in infrastructure (physical and human resources) for technology research and development. 3. Consider the creation of new high-value jobs.
PROINNOVA (Innovation-oriented network projects)	Exclusively proposals and projects that are presented in connection with at least two HEIs, or two RCs or one of each.	Preference is given to associations with institutions forerunners in their field knowledge.

Source: Prepared by the author with information from CONACYT.

The PEI was a program that emerged from the recommendations of the OECD. The report highlights the need to improve the supply of support programs for innovative companies, strengthen the link between academia and the private sector, promote the development and mobility of high-value human capital, and increase the regional capacities of the science and technology sector, among other recommendations. In 2009, the PEI emerges as a public policy instrument for innovation that seeks to encourage private investment in innovation and technological development (ITD) activities to strengthen capacities in the business sector, specifically in human resources and physical infrastructure that would increase the country's competitiveness. At the same time that it promoted the articulation between academic institutions and the private sector.

The program remained in force until 2019, presenting successful results in its implementation. Among the most outstanding results is that the program has generated investment in innovation for 2,509.80 million dollars, of which 47% came from public resources and the rest from private resources. Due to changes in the current administration, the PEI stopped operating, without finding a program to replace it with the same results.

The analysis of the PEI, derived from the evaluations carried out, makes it possible to identify the main problems in the design and implementation of the program. In the first place, the program shows problems in transferring resources to the companies immediately to meet the needs of the projects proposed by the companies. Second, the exercise period of the resource tied to the fiscal period. Third, the late submission of final technical and financial reports. Fourth, the Program does not collect information on the characteristics of the companies that are not beneficiaries, nor on the type of projects. Fifth, the Program does not have impact indicators. Other Program implementation problems are associated with the limitation of financial resources, such as the scarcity of resources for a demand that exceeds supply.

This study focuses on companies from strategic sectors in one of the most important states in Mexico, the State of Mexico. This State is one of the most important entities in the country located in the central region of Mexico. The proximity to Mexico City, as well as its growth opportunities, makes it the entity with the largest population in Mexico, 16,992,418 inhabitants [7]. The entity has a contribution to the gross domestic product (GDP) of 8.8% of the national economy [7], second place, after Mexico City. When breaking down the

structure of GDP by group of economic activities, of primary activities, the entity contributes 3.1% [7]. Of secondary activities, the entity contributes 7% of GDP [7], regarding secondary activities without considering oil mining, the State of Mexico contributes 7.8% of GDP. Finally, from tertiary activities, the entity contributes 10.1% of GDP [7].

Regarding companies in the State of Mexico, the micro, small and medium-sized enterprises (MSMEs) represent 95% of the entity's economic units, of which 592,515 are micro (95.5%), 21,453 are small (3.5%) and 4,296 they are median (0.7%) [7]. These data reflect the entity's industrial vocation, especially manufacturing, with trade, real estate and rental services also being of great importance. Despite the economic importance of the State, the entity is in 20th place in the State Competitiveness Index [8]. This places it in the medium-low competitiveness group in its ability to generate, attract and retain talent and investments, which translates into greater productivity and well-being for its inhabitants.

For the purposes of this study, the focus is oriented to companies from strategic sectors of State of Mexico that are dedicated to innovation activities in the areas of the chemical, agro-food, health, automotive, new materials and plastics technology industries, technologies focused on sustainable development, and information technologies. The strategic industrial sectors for the State of Mexico were selected through previous studies carried out by the Secretariat of Economic Development of the State of Mexico and the Council of Science and Technology of State of Mexico (Comecyt).

3. Methodology

This research makes use of quantitative analysis through an empirical study in order to answer the research question: What is the effect of a public innovation policy that follows a linear model in strategic sectors that follow the non-linear innovation model? For this, econometric analysis is used in which a model is proposed that helps understand how companies in strategic sectors of the State of Mexico behave in the face of a program that follows a linear innovation model. The empirical study is based on the survey on Research and Technological Development (ESIDET) 2017 supported by INEGI. This survey is applied to companies, with a universe of 58,947 economic units. The innovation public policy instrument used to exemplify the linear model of innovation is the Innovation Stimulus Program (PEI).

The research design requires macro-specific information and data on companies in strategic sectors of the State of Mexico. To do this, the econometric model allows measuring the innovation of strategic sectors with a non-linear logic and comparing it with sectors that follow a linear model of innovation. This study seeks to understand if the independent variable that is the PEI has an effect or not in non-linear sectors and in linear sectors of innovation.

This paper applies a model of Interactive Effects Regression to perform an analysis of certain interactive effects. This analysis consists of a hierarchical regression with multiplicative terms in order to evaluate the interaction between pairs of variables. With the information from the databases provided by the ESIDET 2017, the following econometric model is built:

$$\text{Inno} = \beta_0 + \beta_1(\text{PEI}) + \beta_2(\text{model\_innov}) + \beta_3(\text{PEI*model\_innov}) + \beta_4(\text{maturity}) + \varepsilon_{...i}$$

Where *Inno* refers to innovation of a product or service from strategic innovation sectors. It is the dependent variable that measures the degree of innovation of companies in strategic sectors of the State of Mexico. *PEI* is an independent and intervening variable that refers to the STI public policy instrument in its three modalities: Proinnova, Innovapyme and Innovatec. It is a dummy variable due to its measurement level. *Model_innov* is an independent variable that measures the innovation sector to which the companies belong (according to the OECD classification by division of activity – 61 divisions). It is a dummy variable due to its measurement level. *PEI (model_innov)* is a variable that measures the interaction of the PEI in non-linear strategic sectors. The strategic sectors of the State of Mexico that follow a non-linear model of innovation are considered the areas of the chemical, agro-food, health, automotive, new materials and plastics technology industries, technologies focused on sustainable development, and information technologies. *Maturity* is used as innovation proxy variable, which is an independent variable that measures the state of maturity of companies according to the years of operation. It is classified into recently created companies (0 - 5 years), young (6 – 25 years) and mature (more than 26 years). It is a categorical variable due to its measurement level.

4. Results

The ESIDET 2017 was carried out on 12,159 companies and 1,045 institutions. With the cleaning of the database and removing the null values, the real size of the sample is 11,904 companies. For the proposed model that covers the regionalism of a specific state (State of Mexico), the sample size was reduced to 135 observations, which comprise the characteristics for the designed model. Table 2 presents the descriptive statistics of the variables of interest, that shows the main parameters of the companies in the State of Mexico.

Regarding the number of innovations carried out by companies, there is an average of 8 innovations per year per company, with a standard deviation of 36.12. This dependent variable reflects the degree of innovation of Mexican companies, regardless of whether they do it on their own or with government or other support, companies maintain constant innovation of their technological products and services.

With the proposed model focused on studying the companies of the State of Mexico, the sample is reduced to 135 companies, of which only 33% of them received support from the PEI, while 67% did not participate in the PEI during the years 2014, 2015 and 2016. In a cross with these data and the size of the companies that participated in the PEI, it is estimated that the size of the companies influences the

participation of a program such as the PEI, since the application and procedures for being able to participate requires certain technical knowledge, specialized personnel and a specific area that operates the technological innovation project. The companies from the State of Mexico that are reflected in the sample are mostly start-ups (65%), followed by young companies (32%) and only a minority can be considered as mature companies (5%). This percentage is reversed in terms of participation in the PEI program, since large companies are the ones that participate the most in PEI programs and small companies are less likely to participate in a PEI.

Table 2. *Descriptive statistics.*

Variables	Frequency	Percent	Number of observation	Mean	Standard deviation
Number of innovation			135	8.72	36.12
Companies					
PEI	45	33.33	135		
Non PEI	90	66.67			
Number of innovations					
PEI	12.87		135	4.42	1.31
Non PEI	7.54			2.27	51.28
Innovation model in strategic sectors					
Linear	95.72	70.79	135	0.56	0.44
Nonlinear	39.43	29.21			
Maturity					
Start-up	87	64.89	135	2.74	0.28
Young	43	31.60			
Mature	5	3.51			

Concerning the most interesting topics for this study, regarding the number of innovations carried out by companies that received support from the PEI, without considering strategic sectors or the companies' innovation model, 12.87 innovations were found per company per year of those that received support. of the PEI, against 7.54 innovations per company per year that did not receive support from the PEI. These data reflect a positive impact of the public policy instrument for innovation in companies in the State of Mexico, since the PEI is a facilitator for the development of technological innovation projects, regardless of whether the company has the capacity to invest in innovation issues.

Finally, it was found that companies from the strategic sectors of the State of Mexico that follow a linear model of innovation represent 71% of the total number of companies studied, while those companies from strategic sectors that follow a non-linear model of innovation add up to a total of 29%. These data provide valuable information on how companies in strategic sectors operate in the State of Mexico. Although most companies follow a linear model of innovation, it is also important to consider the low percentage of companies that are innovating under a non-linear model of innovation. This is because these data can provide information on what companies in strategic sectors that follow a non-linear model of innovation are facing in order to reflect. In other words, due to the difficulties that companies with a non-linear innovation model can present, it is more difficult for them to stand out or survive in the medium and long term, compared to companies that follow linear innovation models, including those in strategic sectors.

Empirical evidence shows that the PEI as a public policy instrument that follows a linear model of innovation has a positive impact on the innovation of companies in the linear sector. The strong impact of PEI is reflected in the number of company innovations (table 3).

Table 3. *Impact of the PEI program on companies in strategic sectors of the State of Mexico.*

	Model of interactive effects (y: number of innovations)
Innovation (dependent variable)	1.42** (0.084)
PEI	0.021* (9.78)
Strategic sector with linear model Non PEI	2.617*** (1.96)
Strategic sector with non-linear model Non PEI	1.56** (8.53)
Strategic sector with linear model with PEI (linear model)	2.87*(4.86)
Strategic sector with non-linear model with PEI (linear model)	2.01** (0.84)
Maturity of companies	1.754* (0.66)
Observations	135
R^2	0.51

Robust standard errors in parenthesis
***p <0.01, **p <0.05, p <0.1.

The results of the model reflect that the innovation (dependent variable) of the companies studied in the sample is 1.42 products of technological innovation, being a significant result. The strategic sectors that follow a linear innovation model develop 2.6 technological innovation products, with a high significance, while the companies in strategic sectors that follow a non-linear innovation model develop 1.56 innovation products. This difference of almost one innovation per year may reflect that companies in strategic sectors that follow a non-linear innovation model

have more difficulty in developing innovative products compared to companies in strategic sectors that follow a linear innovation model.

As a result of the interaction of companies from strategic sectors that follow a linear model of innovation with the PEI, the result is not as differentiated as the previous one (without interaction with the PEI), since they develop 2.87 innovation products, while the companies from strategic sectors that follow a nonlinear model of innovation in interaction with the PEI that follows a linear model of innovation, innovation is 2.01, being a more significant result. With this result, it can be partially verified that the hypothesis that the linear model followed by public innovation policy has negative effects on companies in strategic sectors of the State of Mexico that follow a linear model of innovation. This is because there is a difference between the number of innovations developed by companies in strategic sectors of the State of Mexico that follow a linear model of innovation, compared to those that follow a non-linear model of innovation. The difference shown with the interaction of the PEI is only 0.86, but this result cannot be absolutely justified to the PEI, since other variables can influence this result, such as the size and maturity of the companies. Regarding this variable (maturity of the companies), the model yielded a result of 1,754 innovations per year, with a result of little significance (0.1).

5. Conclusion and Recommendations of Public Policy

The main objective of this study is to answer the following research question: What is the effect of a public innovation policy that follows a linear model in strategic sectors that follow the non-linear innovation model? With the results obtained from the econometric model used in the survey, it was found that the main public policy instrument to encourage innovation in companies has a positive effect on companies in strategic sectors of the State of Mexico that follow a lineal model, not so in companies from strategic sectors of the State of Mexico that follow a non-linear model of innovation.

These results open the line of research to find out what other variables are involved in the innovation of companies in strategic sectors of the State of Mexico, such as the times in the innovation processes of non-linear models, the certainty in investment and the return on investment, or processes and procedures to validate the technologies. At the moment with these results, some recommendations can be made. The first recommendation is that in the design of public innovation policies, the existence of sectors that follow different models of innovation, some more complex than others, should be considered, and that these differences also entail specific needs in the types of support and requirements for their implementation and application. Another recommendation is that innovation policies can be regionalized or focused on specific regions for better results and that they can be operated by Regional Innovation Systems. In the particular case of the State of Mexico, the body in charge of leading the public policy of science, technology and innovation corresponds to the Comecyt, which can focus public policy instruments focused on promoting technological innovation in the region, distinguishing between sectors and models of innovation.

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