The Role of Policy Incentives on the Reproduction of Asymmetries within Nanotechnology Knowledge Networks

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Abstract

We explore new perspectives for analysing knowledge networks, arguing that knowledge networks can no longer be referred to as egalitarian, non-hierarchical, and neutral forms of social organisation. Instead, networks reproduce tensions, asymmetries, and hierarchies linked to Science, Technology, and Innovation Policy (STIP) incentives and incorporate dynamic and multisituated nodes of power.

This paper draws on evidence gathered from a case study on transnational and translocal knowledge networks in nanotechnology, which have central nodes at a public research centre located in Chihuahua (Chihuahua) and its auxiliary branch in Monterrey (Nuevo Leon) in Northern Mexico. We propose that, in order to understand the production of asymmetries in knowledge networks, an incentive policy element must be added to the equation. The latter refer to monetary, symbolic, and material incentives stemming from all arenas where networks interact.

1. Introduction

There is a long-standing tradition of analysing knowledge networks as egalitarian forms of social organisation which are free from tensions and hierarchies (1, 2, 3).

Moreover, network interactions have largely been analysed within restricted geographical spaces such as localities, regions, or sectors. However, there is limited evidence and discussion of the differences and links between translocal, transregional and transnational knowledge networks, particularly when they include South[1] and North nodes.

Although there has been an incresing debate about new ways of understanding networks (4, 5). There is more space for further discussion on how asymmetries are being produced and reproduced in knowledge production networks. Discussing new perspectives for analysing knowledge networks in a global context is a necessity. In this paper we explore the hypothesis that networks reproduce asymmetries as a consequence of constant tensions generated by the incentives linked to Science, Technology, and Innovation Policy (STIP) at different levels of government (local, regional, national). Such networks can be characterized as being hierarchical and asymmetrical in terms of their resources, skills, and flows. This paper argues for the need to distinguish between monetary, symbolic, and material incentives and is organized as follows: Section 2 presents our theoretical assumptions, which are based on Latour's writings on networks (6, 7, 8) and the literature on spaces and policies (9, 10) as a framework to analyse STIP incentives. Section 3 details the data collection strategy and analysis. In section 4, we present the findings of the case study along with the different types of policy incentives and spatial levels where knowledge networks in nanotechnology have emerged. Section 5 discusses the production of asymmetries in networks, based on evidence from transnational and translocal knowledge networks in nanotechnology, as a new framework for analysing South–North interactions for knowledge production. The last section concludes with the analysis of STIP incentives and the production of asymmetries in knowledge networks.

2. Knowledge networks and incentives: theoretical perspectives and connections

The increasing interest in networks related to knowledge and innovation has led to an explosive growth of scholarship inspired by diverging lines of approach. Over time, authors have referred to the concept in different ways: as collaboration networks (11, 12), knowledge networks (13, 14, 15, 16, 17) techno-economic networks (18, 8), innovation networks (19, 20, 21, 22), and production networks (23, 24).

In spite of the great scholarly interest in knowledge networks, several issues have been left unexplored or have only played a minor role in the debate, leaving the following four gaps: 1) there has been an inclination to think of networks as delocalized subjects, unrelated to the political context in which they operate; 2) little discussion has been centred around the creation of nodes of power, tensions and asymmetries in knowledge networks; 3) analysis of transnational knowledge networks between the South and North has been lacking; and 4) there is still little knowledge about the ways in which STIP incentives affect knowledge production in networks in the South. The present study is focused on discussing the latter gap.

Studies within a vast body of literature have analysed knowledge network interaction within the geographical limits of a locality, region or sector (25, 26, 27) but have lacked critical reflection on their global connections. In this paper, we seek to connect three strands of literature: 1) space literature (28, 29, 30, 31), 2) policy incentives literature (32, 33), and 3) knowledge networks (8). Space literature analyses space in terms of relational interactions, in addition to geographical ones, so that the interaction spectrum is broadened beyond geographical constrictions and explored in terms of imaginaries, discourses, identities and material practices (34, 35, 36).

Methodologically speaking, knowledge networks have also been analysed from a structural point of view, focusing on nodes that have greater centrality (number of direct connections) (37, 38, 39). However, this perspective has failed to include discussions on the agency capacity, movements, and strategies of actors as the main sources of power in a network.

In this paper, we discuss an alternative perspective for understanding node formation in networks, building our analysis on Latour's (6) idea that power is executed and in constant motion and that those who connect, translate, enable, and distribute it act as nodes. Following this line of thought, we argue that the formation of nodes is dynamic and mutisituated.[2] Thus, we analyse networks as consisting of connection and movement and not those that were solely enunciated by the researchers, this means that they really work as networks and they were not only called networks.

New knowledge-intensive fields like nanotechnology boost new interactive modes of knowledge production in networks. This results in the reshaping of the way in which knowledge is produced, and changes in mechanisms of STIP, scientific infrastructure, and funding (40, 41, 42, 43, 44).

In this paper, we use the term 'knowledge networks' to refer to interactions among researchers in Public Research Centres (PRCs), universities and companies aiming for knowledge production. We also use the concept knowledge networks in a broader sense, including incentive structures coming from STIP instruments, evaluation processes and policy-making actors involved.

Specifically, incentives are a key concept in this paper. We adopt a spatial perspective to analyse STIP incentives and link the network literature with spatial and state policies related to globalisation (9, 10, 44, 45, 46). This literature stresses the changing spatial policies and challenges to frameworks of transborder regions, global cities, and new subnational actors who are constantly reshaping the policy-making process.

Over time, incentives have been referred to in various ways. In economics, incentives are divided into pecuniary and non-pecuniary (33). Other disciplines, like psychology, have focused on non-monetary incentives and refer to them as intrinsic and extrinsic motivations. Intrinsic motivations are defined as quests for recognition, prestige, reputation, leadership, and power; in turn, extrinsic motivations are seen as economic rewards and awards (32). While in economics and psychology there is an ongoing discussion about monetary and non-monetary incentives (47, 48, 49, 50), and although there is increasing awareness of non-monetary incentives in STIP literature (51), we hold that this still calls for further research in terms of their possible impacts in networks. Thus, the analysis of discourses, imaginaries and their materialities in knowledge networks constitute symbolic and material incentives that have been under-explored. Through inclusion of both symbolic and material incentives, we seek to incorporate the agency and dynamic capacity of actors and the ways in which they affect networks.[3]

For the purposes of this study, we define monetary incentives as the use of public resources at any level of government.[4] Symbolic incentives are, in turn, defined as the use of discourses, the development of a strategy or program which, without direct monetary incentive, incorporates benefits such as prestige, leadership, and kinship. Finally, material incentives are, for our purposes, those monetary or symbolic incentives that have been physically materialised in objects or infrastructure.

3. Methods and data collection

This work is based on a case study of knowledge networks in the field of nanotechnology at the Public Research Centre on Advanced Materials (CIMAV) in Mexico. The CIMAV was created in 1994 and is part of the 27 PRCs of the National Council of Science and Technology (CONACYT), the main Mexican agency promoting science, technology and innovation. The centre is located at the Chihuahua Industrial Complex Park (Chihuahua, Mexico) together with numerous companies. The CIMAV also has an auxiliary branch that is located at the Research and Technological Innovation Park in Monterrey (Nuevo Leon, Mexico), which was created in 2008. Both States are located at the Northern part of Mexico.

The case study method allows us to build an accurate picture of knowledge networks in their particular context and to gain a better understanding of their dynamics and the incentives that affect them. The unit of analysis is the interaction between actors involved in nanotechnology research projects. The study uses a mixed methods approach that combines qualitative information (interviews and documents) with quantitative data (statistics and questionnaires).

The fieldwork was conducted from November 2010 to June 2011 in three different stages. Qualitative data was mainly derived from forty open and semi-structured interviews with actors participating in nanotechnology research projects. Interviewees held research and/or managerial positions at CIMAV, CONACYT, and the Mexican National Research Network in Nanoscience and Nanotechnology. Most of the interviews were recorded, except in those cases where interviewees did not feel comfortable with this.

During the first stage, we conducted pilot interviews to identify projects in which different actors were involved and to collect documents to validate the oral information provided by interviewees. Afterwards, preliminary findings from pilot interviews were combined with selected concepts from the literature to adjust the final script used for conducting a new round of interviews and in the development of a questionnaire.

In the second stage, in-depth interviews were conducted with project coordinators in Chihuahua (Chihuahua, Mexico), Monterrey (Nuevo, Leon, Mexico), and El Paso (Texas, U.S.A.). At the end of each interview with a project's coordinator, respondents were asked to complete the questionnaire to provide quantitative data about knowledge production, dynamics of interaction, flows of knowledge, and incentives affecting the network.

In the third stage, we collected quantitative data concerning articles that are included in the Scopus database. In order to restrict the analysis specifically to the field of nanotechnology, we added the prefix nano* and the CIMAV name in the search query to extract articles for the period 1994 to 2011. With this data, for each of the principal actors we were able to identify with whom they interacted. We are aware of the challenges to methodological approaches with regard to publications and the different methods to improve analytical tools in interdisciplinary fields like nanotechnology (52, 53). Since bibliometrics is not the main method for this paper, we used the triangulation technique to solve the potential limitations of not including all the nanotechnology articles that did not have the prefix nano* in the title. Specifically, we use information from interviews, documents, annual reports of CIMAV, and most important, a list provided by the coordinator of the Nanotechnology Institutional Program of all nanotechnology articles produced at the Center. This triangulation technique was not difficult to implement in our study, since CIMAV is rather a small Center and the database of articles was easy to manage.

Information provided by a key informant was used to validate our findings from qualitative interviews, documents and information gathered. All interviews were fully transcribed.

Both the interviews and documents were examined according to the key concepts of the research (knowledge production, networks, and incentives) and were subsequently coded by means of Atlas.ti. A database was also created, based on all the gathered information containing research projects related to nanotechnology conducted from 1994 to 2011 at CIMAV. The project database comprises 170 projects with a variety of objectives (infrastructure, human research training, publications, and technological development) and actors involved. The project data was then ordered chronologically into tables and matrices of interaction.

We have identified three different circles (patterns) of interaction for producing knowledge within nanotechnology research in CIMAV: articles, projects, and patents. We re-examined the CIMAV networks in line with the following criteria: 1) performance and intensity of interaction of the actors participating in the projects; 2) relevance of a project in relation to the final scientific products of interaction: articles, patents, new projects, technological developments, and technological transfers; and, 3) differences in incentives coming from the particular contexts in which they developed.

Finally, three spatial categories were used to analyse the networks: transnational, transregional, translocal. At the translocal level, the focus was CIMAV's interaction with actors in different localities inside the state of Nuevo Leon (Monterrey, Santa Catarina, San Pedro Garza), where the main projects with companies were conducted. At the transregional level, we looked at interaction between CIMAV and actors located in different states inside Mexico, such as, Chihuahua, Nuevo Leon, and Coahuila. At the transnational level, we considered interaction of CIMAV researchers with actors in different countries, mainly from U.S.A. universities.

4. Nanotechnology at CIMAV: incentives and dynamics of networks

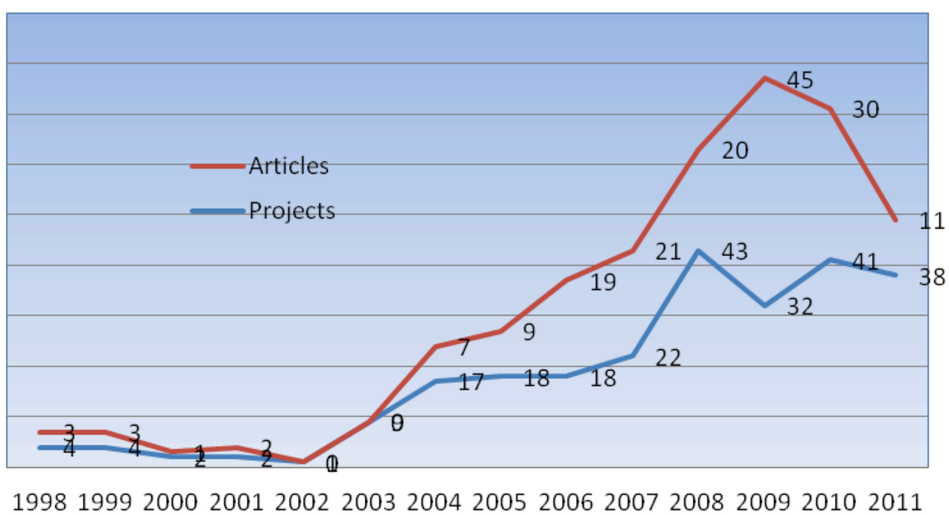
In this section some results of the case study are reported and discussed with regard to the incentives and dynamics of networks in the field of nanotechnology at CIMAV. Some of the main nanotechnology initiatives at CIMAV are highlighted in the following paragraphs as background for discussing the incentives and dynamics of the networks.

In 2004, when a new director took over the direction of CIMAV, nanotechnology was designated a key area with the creation of the Nanotechnology Institutional Program, encompassing the following tasks: 1) promote research activities, human resource training, and links with business; 2) increase researcher mobility; 3) boost networks with leading international institutions; 4) encourage national leadership and international recognition in the field; and 5) attract more public resources.[5]

Following this decision and, as a part of the strategies considered in the Nanotechnology Institutional Program, the director of CIMAV and a group of researchers conducted visits to four universities in the U.S.A.: the University of California (Santa Barbara), the University of Texas (Austin, Dallas, El Paso, and San Antonio), Arizona State University, and the State University of New York (Albany). As a result of the visits, projects were designed and conducted between researchers at CIMAV and researchers at these universities. Subsequently, projects also including Mexican universities and PRCs were arranged.

In 2005, nanoscience curricula were incorporated in postgraduate programs at CIMAV. The year 2008 was important for nanotechnology activities at CIMAV, as the following initiatives were launched: 1) The National Laboratory of Nanotechnology at CIMAV in the Chihuahua headquarters (Chihuahua); 2) CIMAV's new auxiliary branch was opened at the Research and Technological Innovation Park in Monterrey (Nuevo, Leon), where nanotechnology was selected as a key area of interest; and 3) The creation of the Cluster of Nanotechnology and the Nanotechnology Incubator in Monterrey (Nuevo Leon). By 2009, a dual PhD Nanotechnology Program between CIMAV and the University of Texas at Dallas had been created.

Figure 1. Nanotechnology in the making at CIMAV



Source: Own formulation based on Scopus, interviews and database of projects in nanotechnology at CIMAV

Figure 1 shows the increasing impact of the Nanotechnology Institutional Program on the number of articles published and projects conducted by scholars at CIMAV. The projects themselves as well as the publications that resulted from them promoted the development of networks and shaped their dynamics.

CIMAV is one of the main actors in nanotechnology networks in Mexico. From our sample of 170 nanotechnology-related projects carried out at CIMAV during the period

1994-2011, 89 were conducted in interaction with other actors (universities, laboratories, other PRCs, or companies). These projects can be classified according to their structure in the following way: 47.3 per cent basic knowledge, 26.9 per cent applied knowledge, 9.3 per cent without classification, 5.2 per cent technological development, 4.6 per cent infrastructure improvement, 4 per cent creation/strengthening of networks, and 2.3 per cent human resources training.

The structure of the projects shows that over time the creation and promotion of networks has not been a priority nor at CIMAV neither at the federal government. It is just recently that programs that include monetary (few) and non-monetary incentives to promote networks have arisen. The 4 per cent (creation/strengthening of networks) is related to projects that were mainly developed together with U.S. universities; they also the scenario in which asymmetries were produced and reproduced.

Table 1 below summarises the findings of CIMAV's knowledge production interactions.

Insert table 1

At translocal level, CIMAV-Monterrey interacted with 16 companies (large national and transnational companies) placed in different locations of Nuevo Leon (Santa Catarina, San Pedro Garza, and Monterrey). The monetary and material incentives from the Nuevo Leon government, like the Nanotechnology Incubator, were important for the development of this network, as well as CONACYT's Program of Incentives for Innovation (PEI in its Spanish acronym)[6].

In the case of the transregional network, the main and continuous interaction to produce knowledge in nanotechnology has taken place between CIMAV, three PRCs specialized in chemistry and applied knowledge, and one university. CIMAV has been using the Regional Fund instrument[7] to finance applied nanotechnology projects, together with the creation of CIMAV's auxiliary branch in Monterrey. Particularly, the creation of CIMAV-Monterrey encouraged the emergence of the transregional network between CIMAV, Chihuahua (Chihuahua); CIMAV, Monterrey (Nuevo Leon), and other PRCs located in Saltillo (Coahuila). Their interaction has been stable over time and leads to products such as joint projects with companies and peer-reviewed articles. The flows of knowledge between these actors has complemented CIMAV's lack of capacities in specific research lines in chemistry and also improved CIMAV's links to industry.

The transnational network is well connected and involves long-term actors, such as Stanford Synchrotron Laboratory and the University of Texas in their different localities: El Paso, Dallas, Austin, and San Antonio. The interaction taking place within this South-North network had been concentrated around the production of peer-reviewed articles and human resources training. This network has been promoted by local and national monetary incentives, but also local symbolic incentives through the Nanotechnology Institutional Program.

All these actions and projects were the result of incentives associated with different instruments, coordinated at diverse governmental levels. At the local level, producing knowledge in networks through symbolic incentives (Nanotechnology Institutional Program) has been encouraged; monetary incentives promote basic research, human resource training and, to a lesser extent, links to companies. At the regional level, monetary and material incentives have prevailed for promoting links with companies and sparking innovation processes through the Cluster of Nanotechnology and Nanotechnology Incubator. Meanwhile, at the national level the majority of allocated public resources have used instruments that do not reward active formation of networks, but rather have a clear inclination towards the promotion of scientific products to obtain scientific prestige through peer-reviewed articles and human resource training. At the nation level, the main instrument is the National Researchers System, which rewards researchers according to their scientific performance with bonuses amounting to an additional 30 to 40 per cent of their salaries. This instrument, plus other instruments related to basic science and human resources formation, represent 54.5 per cent of the CONACYT budget. Although there are some monetary incentives to link PRCs and universities with companies, they only represent 17 per cent of the budget.[8]

To understand the production of asymmetries associated with STIP at the national level, it should be noted that monetary policy incentives have historically been focused on individual forms of knowledge production, with a strong inclination towards basic research.

Gradually, since 2000, there has been a shift in policy incentives to promote interactive knowledge production and to drive innovation processes. The result has been a significant accumulation of knowledge and skills in scientific activities and less on technology and innovation processes.

The historical asymmetry between the promotion of basic research and the need to foster innovation processes in new fields like nanotechnology has created a constant tension within policy incentives that have led to the creation of two patterns of specialization of researchers at CIMAV, based on their differing types of expertise. On the one hand, there are researchers who produce knowledge individually and have developed contacts with American universities to increase CIMAV's international prestige through joint publication of peer-reviewed articles and human resource training. On the other hand are researchers who are more involved in projects with industry that are interested in generating contacts with American universities so as to learn from experience in transferring and commercialising technology.

The tensions between different types of incentives that reproduce asymmetries related to the national policy incentives also need to be situated at the regional level. The regional government of Chihuahua has promoted *maquiladora*[9] industries and research projects to solve problems related to the state, whereas the government of Nuevo Leon has been promoting innovation processes in networks with monetary as well as material incentives. Meanwhile, at the local level, symbolic incentives have been used for the promotion of networks with leading institutions in nanotechnology, mainly in the U.S.A.

Analysis of the gathered data reveals that the differing types of policy incentives (monetary, symbolic and material) coming from three governmental levels (local, regional and national) produce a constant tension affecting researchers and their performance in networks. Consequently, we argue that these policy incentives also provide a landscape to understand the reproduction of asymmetries in knowledge networks. In the next section we discuss the reproduction of asymmetries, based on evidence from transnational (American universities) and translocal (CIMAV and transnational and national companies) networks.[10]

5. Reproduction of asymmetries in CIMAV's transnational and translocal knowledge network

Traditionally, knowledge networks have been analysed as egalitarian and non-hierarchical forms of social organisation contained within the geographical limitations of a locality, region or sector (13, 15, 54). These dimensions have not, however, been explored in transnational networks or South–North knowledge-production relations. Our data, gathered from a transnational network (CIMAV and the University of Texas at Austin and Dallas, Arizona State University and the State University of New York at Albany, and a translocal network (CIMAV and transnational companies and large Mexican companies), allow us to fill this empirical gap and introduce insights into the debate from an innovative perspective. We stress the tensions and complexity of the relation between the North and the South in producing knowledge.

To analyse South–North relations of knowledge production, we propose using the category of asymmetry because it a) does not entail a negative connotation and b) allows us to visualize the complexity of scientific, technological and innovative processes between the South and the North, which are in a constantly shifting balance. The asymmetries we have documented are mainly in terms of resources, skills, and flows. The following sections analyse these asymmetries.

5.1 Resource and skills asymmetries in the transnational network

Resource asymmetry – both economic and infrastructure related – has been the main one mentioned in CIMAV's transnational nanotechnology network. One researcher at CIMAV conducted projects with the University of Texas at Austin, Arizona State University and the State University of New York between 2006 and 2010. His line of research focused on molecular structures and properties of nanomaterials applied to organic solar panels and electronic devices. During an interview, questions about differences in the capacities and decision making processes within the project were asked. The following is a fragment of the interview:

> Interviewer: In the project, did you always share equally with your partners in the decision-making processes?

Researcher: No, they made slightly more decisions than we did. In fact, they were better equipped, had better financial support, greater ease to travel and all of that, and that sort of made them lead on more decisions than we did.

Interviewer: What types of decisions were more unbalanced?
Researcher: Basically, not in terms of how we should deliver the project, but perhaps more about which direction the project should take.

Interviewer: How did you respond to that?
Researcher: Well, hehehe [laughter], one begins to become a politician, learns to be political. Faced with that, one more or less states his position and, the way to do it wasn't like it would be a confrontation . . . or something like that, but throughout the project, I have felt like they have had more power than we have– more decision-making power, right!

[...]

Interviewer: Do you consider that there are big differences with respect to the formation and skills of the researchers in both countries?

Researcher: Not with regard to the training and intellectual skills or with the people, academics. No, there are no big differences. I believe that when we are discussing, we are at the same level; we are all equally capable. The big differences are financial, when it comes to major access to equipment or possibilities for travel and exchange with other researchers.

They have the possibility to travel because it's easy, or relatively easy, or affordable, we could say, and they have the money for that. . . . Evidently, they have more access to equipment. In my case, for example, we need supercomputers and they share them with us. I can use them from a distance, there's no problem. But other people that need access to other types of equipment, or need to purchase reactive chemicals and that sort of thing, in these cases there are limitations for us and, in that sense, there are inequalities.

At the intellectual level, in intellectual skills and training of students, we are practically the same, practically equal, right (CIMAV researcher, personal communication, April 2011).

This researcher, as well as others at CIMAV that have been involved in transnational network projects, agreed that there were no significant differences between the skills of CIMAV researchers and their counterparts from the U.S.A.

Another researcher, involved in a project with University of Texas at Dallas and the Centre of Research and Advanced Studies of the National Polytechnic Institute – funded by the Air Force Office of Scientific Research – conducted a project with new materials to be used as electrodes in flexible electronic devices. The experience of this researcher reinforces the evidence of the existence of asymmetries of resources with the next quotation:

> Well, the U.S.A. [researchers] have a significantly larger budget than we do, they have access to materials that we don't have here. The materials are more expensive here in Mexico than there. The advantages there are many, it's obvious that their ecosystem will be more productive than ours. [. . .] The work we do here in Mexico is of good quality, but it's very punishing, meaning our deadlines are very different than the deadlines they have.
>
> Plain and simple, the majority of the raw materials that we use to conduct research comes from the U.S.A. or from outside of Mexico, and that implies that delivery times are longer, which implies higher costs. So you can get an idea, whatever I import from the U.S.A. costs me at least 40 per cent more than what it would cost me there; it takes weeks to arrive here, while over there I could have it the next day.
>
> You have to add that we have a smaller budget than they do. Just from that point of view, we are already less competitive, meaning we cannot compete with them. (CIMAV Monterrey researcher, personal communication, May 2011)

Both of these quotations show that asymmetries are been reproduced mainly due to economic and infrastructure resources, rather than skills and capabilities. According to the researchers, there were problems related to funding, bureaucracy, regulations, and paperwork when importing necessary raw materials to Mexico. All of these problems were obstacles in the day-to-day lives of the researchers.

These statements also illustrate the importance of asymmetries for the perception of nodes of power in a network. In this way, laboratories and scientific and technological infrastructure served as artefacts that also contained power and status, and, therefore, led to the formation of authority figures and hierarchies.

5.2 Flows asymmetries in the transnational network

In the category 'flows asymmetries', we consider not only flows of persons, reports, and artefacts, but also discourses, programs and models for commercializing technology that flow asymmetrically from the U.S.A. to Mexico. These flows were materialised in the creation of hierarchical and authority systems, evaluation procedures, programs for commercializing technology and procedures to redesign scientific and technical infrastructure of nanotechnology equipment (e.g. Nanotechnology National Laboratory and Nanotechnology Incubator).[11] A case in point is the translation of the model to commercialise technology from the IC2 Institute of the University of Texas at Austin to the

Research and Technological Innovation Park at Monterrey, where CIMAV's auxiliary branch is located.[12]

We also noticed that asymmetries of flows between Mexico and the U.S.A. were related to the STIP related tensions that are mainly concentrated in the accumulation of capacities for promoting basic research and human resources training. During interviews, we documented problems in the scaling process of pilot test, dislocation of supply and demand of knowledge, as well as problems around the transfer and commercialisation of technology. These asymmetries were the base on which the systems of authority figures were built and linked to the American universities in the transnational network. A senior member of the management team of CIMAV refers to one of these problems in the following quote: 'We carry out high-level basic research, but we don't know how to commercialise it' (Member of CIMAV upper management team, personal communication, January 2011).

Existing flow asymmetries reinforce the evidence for nodes of differing power as well as that these networks produce hierarchies and authority figures. However, these authorities and hierarchies change from one project to the other and from one researcher to the other. That means that the authority figures were not only U.S. researchers, but also Mexican ones, and we were able to document projects where CIMAV performed as the node of power. The following subsection discusses this other side of the hierarchy.

5.3 Balancing the production of asymmetries: CIMAV Monterrey as a critical node for innovation processes in the translocal network

A researcher from CIMAV Monterrey recounted his experience participating in five innovation nanotechnology projects (two of which were in technological development) with two transnational companies and two large Mexican companies. The researcher is young and had conducted those projects in a period of three years, when CIMAV Monterrey was created, from 2008 until 2011 (when the interview was carried out). One of the transnational companies is Tempo[13], dedicated to glass fibre technology and whose main research centre is located in Cincinnati (Ohio). The project significantly improved the properties of a foam polystyrene material that was used by the company and consisted of the modification of nanoparticles that were incorporated in a polystyrene matrix. The innovation consisted in the nanoparticles being chemically dispersed within the matrix. The transnational company and the researcher also went into a follow up project, this time with the participation of the Nanotechnology Incubator in Monterrey, to improve the transfer of this technology. Both projects were funded by CONACYT through the Program of Incentives for Innovation.

The same researcher coordinated a project with another transnational company in the textile sector. This project improved the process of absorption of ultraviolet light through the incorporation of nanoparticles, to prevent the material's degradation from exposure to direct sunlight. The result of the project was a technological development that improved the material's durability by 80 per cent. The researcher illustrates the interaction within the project as follows:

> [T]he projects are dynamic. It is not that I leave it all to you and you figure out how to do it, no. [. . .] Sometimes the planning meetings happen every month. The first month here, the second month there, and so on, or by telephone: "I found this, I saw that the material improved, we meet tomorrow". Or in the opposite [case], one is working and the company is interested: "hey, let's go to the U.S.A., let's measure this". (CIMAV Monterrey researcher, personal communication, May 2011)

The quote shows that the dynamics for interaction within the project consisted of a constant negotiation of perspectives, strategies and ideas in terms of knowledge production. It also reveals that, although some of these companies are located in Mexico, specifically in the translocal network of Nuevo Leon, knowledge-production relations are developed by their headquarters in the U.S.A. Thus, the connections of networks are also relevant, and there is a necessity to explore multiple spatial connections in networks and not only the geographical ones. This testimony demonstrates that even translocal or transregional networks have their global links. Overall, however, the literature on networks has mainly been focused only on local or regional connections (50, 55, 56).

As a part of the accumulation of skills and specialisation of CIMAV researchers in the line of improving the mechanic, electric and chemical properties of materials, the same researcher conducted projects with two large Mexican companies. On the one hand, these were aimed at developing nanostructured silicon sealants for high-performance applications in the automotive industry and, on the other, to increase the durability of paper. The two transnational and one of the two Mexican companies interacted with the Nanotechnology Incubator to transfer the technology. When we asked this researcher about his opinion on STIP incentives, he replied:

> The innovation programs and collaboration between industry and the academy are fine in the sense that a company pays zero pesos[14], practically zero pesos, for a technological development that any other company abroad would have to pay to a university like Austin, Harvard, or whatever, for a development of the magnitude of what is done here.
>
> One classic example: Tempo has a research centre near Cincinnati [Ohio]; they prefer, obviously, to bring more projects to Mexico [. . .], rather than paying another university in Cincinnati. I am familiar with the University of Cincinnati; there are experts in polymers and I know them. They prefer that the project be done in Mexico instead. Why? Simply because of the cost, here the cost would be a fraction of what they could have paid there and with the same quality, or maybe a little higher, of what they would get there. (CIMAV Monterrey researcher, personal communication, May 2011)

This testimony shows evidence of CIMAV Monterrey as critical node for innovative processes that transfers technology to transnational and large Mexican companies. CIMAV Monterrey's role that fostered innovation in companies is explained by the combination of incentives at different levels. First, and most importantly, are the material and monetary incentives from the regional government of Nuevo Leon that were materialised in the Nanotechnology Incubator to promote transfer and commercialisation of technology. These incentives clearly brought a positive balance to the historical focus on basic research and human resource training of the national policy incentives. Second, we observed a slow but positive change in policy incentives at the national level towards the links of PRCs and universities with companies. The Program of Incentives for Innovation was designed in 2009 and was the result of several attempts at redesigning policies to stimulate more of such interactions.

To sum up, based on the evidence presented in this subsection, we argue that CIMAV did not establish a scientific or technological dependency with its U.S counterparts. Instead, the evidence points in the direction of asymmetrical relations, incorporating dynamic nodes that are multisituated and in constant motion from project to project or from a specific line of research to another. For example, CIMAV has changed its role dynamically in the network. In certain projects, CIMAV had an asymmetry of resources, skills, and flows in the transnational network in relation to its U.S. partners whereas, in other projects, like those of the translocal network, its role was more active in fostering innovation processes and technological developments with transnational and large Mexican companies. This process also highlights movements in the hierarchies and asymmetries in these knowledge networks.

Throughout this section, we have linked the movements and changes in these asymmetries, which have resulted from tensions and interactions between the incentives associated with STIP at the different spatial levels. In the next section, we discuss the relation between incentives linked to STIP and asymmetries in knowledge networks.

6. Policy incentives and the production of asymmetries

Based on the interviews, Table 2 summarises the relation between incentives linked to STIP (monetary, symbolic, and material) and the production of asymmetries (resources, flows, and skills) and hierarchies in knowledge networks at CIMAV.

Insert table 2

Table 2 outlines the relations between incentives linked to STIP and the production of asymmetries and hierarchies in knowledge networks at CIMAV.

We consider symbolic incentives to be programs that, without direct monetary incentive, incorporate benefits like prestige, leadership, and/or kinship. In CIMAV's networks, symbolic incentives were institutionalized in the Nanotechnology Institutional Program. The program had two particular tasks: 1) to encourage the making of networks with leading international institutions and 2) to promote national leadership and international recognition in the field. These tasks have, however, produced asymmetries in CIMAV's networks, making visible the power differences between the actors involved.

In table 2 it can be seen that local symbolic incentives are related to asymmetries in resources, flows, and the formation of hierarchies and authorities. For example, according to the interviews, differences in infrastructural, material, and economic resources have led to a reproduction of asymmetries of power and productivity in the knowledge-production process which are also connected to asymmetries in flows and the formation of authority figures. We analyse each asymmetry and its relation to policy incentives in the following paragraphs.

The most evident asymmetry has been the resource asymmetry of scientific and technological infrastructure, due to the fact that the public budget for STIP is asymmetrical between Mexico and the U.S.A. The use and sharing of equipment has influenced the development of networks that include actors with outstanding equipment, such as Stanford Synchrotron Radiation Lightsource, Arizona State University, the State University of New York and the University of Texas at Austin. In Mexico, resource asymmetries are been reproduced by poor material incentives at all levels (local, regional, and national); problems related to the high costs of raw materials; long import processes and insufficient infrastructure for doing research at the nanoscale. We have also observed that CIMAV has developed networks with actors that could provide some sort of solution to these problems, such as those who share their equipment within the transnational network.

The second asymmetry consists of those flows of technology commercialisation models from the University of Texas at Austin that were materialised in regional policy incentives (e.g. Nanotechnology Incubator). An explanation for this asymmetry is that, historically, most of the monetary incentives at the national level and some at the local level in Mexico have been concentrated in basic research and human resource training. Therefore, there is an asymmetry of capacities within Mexican institutions in terms of the technology-transfer process and the involvement of intermediary actors, like bridging institutions. The regional monetary and material incentives of the Nuevo Leon government have balanced the focus of national incentives on basic research and were important for the development of CIMAV's translocal network. They are also the reason why innovation processes have emerged in Monterrey and not Chihuahua. We have identified a clear difference in the structure of incentives between both states. Chihuahua has more of a *maquiladora* incentive structure, whereas Nuevo Leon has historically incentivised industries in key sectors. Lastly, the national monetary incentives of the Program of Incentives for Innovation have been positive in supporting the development of CIMAV's translocal networks with transnational companies and large Mexican companies.

Although researchers at CIMAV agreed on the fact that there were no asymmetries of skills in the transnational network, we were able to reveal that Mexican researchers have highly qualified expertise in basic research and less in the creation and transfer of knowledge. Incentives of the government of Nuevo Leon, such as the creation of the Nanotechnology Incubator, have balanced this asymmetry, accompanied by the interaction with centres at the transregional level, where experiences and contacts could be shared for the purpose of focusing the companies' research interests.

Furthermore, the last row of Table 2 highlights the emergence of hierarchies and authorities in the networks. This emergence is related to the local and national monetary incentives to garner international prestige and local symbolic incentives of the Nanotechnology Institutional Program in promoting networks with international leading international institutions. Additionally, poor material incentives in scientific and technological infrastructure in Mexico can help to explain the development of networks with American universities with outstanding equipment that have led to the formation of authority figures. Thus, hierarchies were created in specific projects or research lines and have contributed to the emergence of nodes of differing power within the networks.

We have analysed asymmetries that are reproduced in networks. Although there are asymmetries that are inevitable, there are others that can be reduced if some policies are implemented. The inevitable asymmetries that are been maintained or reproduced are related to the disparities in economic resources within the networks.

Some policy recommendations that emerge from this study are related to the governance of STI, specifically to reduce the asymmetries in the assignation of public resources to basic research versus innovation processes and the development of networks. There is a necessity to change the incentive structure to researchers, and to incorporate and balance the incentive system to include stimulus in the participation in networks, the development of innovation process, and entrepreneur activities, and not only for publication in international peer review journals.

7. Conclusion: the role of incentives in the knowledge networks

This paper has attempted to enrich the discussion of knowledge networks in two ways. First, it has incorporated analysis not only of monetary incentives, but also symbolic and material incentives from STIP and discussed how their interaction in different spaces has affected the dynamics of networks in Mexico. This is a novel perspective that can contribute to broadening the discussion, which has been mainly centred on monetary incentives (47, 49, 50, 57). Second, the case of the CIMAV knowledge networks has allowed us to contribute to the increasing interest in question the idea of networks as an egalitarian and non-hierarchical form of social organisation. We have presented evidence supporting our argument that there are networks with hierarchies. In our case, hierarchical networks have tended to reproduce asymmetries from STIP incentives associated with their particular governmental levels (local, regional, and national).

Our findings also address the idea that researchers in the South are supposed to do their best to catch up with the North on science and technology issues through the implementation of successful policies and models of knowledge production (58, 59). But we have found evidence suggesting that researchers from one country of the South produced knowledge that has fostered innovation processes in transnational companies. This evidence suggests that the catching up literature has some limitations and that it is necessary to think in new and dynamic perspectives of asymmetrical flows between the North and the South.

Drawing on the postcolonial literature regarding technoscience from the South, which stresses global power mechanisms as a causal factor in North–South relations being intertwined, we discussed the argument promoted by Escobar (60); Castro-Gómez (61); Lander (62); Mignolo (63), and Walsh (64) that the strategies and tensions generated by STIP are local imperatives contributing towards the emergence of authority and hierarchies. Based on the evidence we have gathered, this paper has argued that both local and global mechanisms of power play important roles.

To conclude, we have proposed a new perspective that seeks to reveal the complexity and tensions in knowledge-production in South–North interactions. Our evidence shows CIMAV researchers to be active and dynamic actors, acting as nodes of power in constant motion, while also producing knowledge and scientific discourses about nanotechnology, translating and materialising models of commercialisation of technology, adapting formats and redesigning laboratories, but also reacting to policy incentives tensions and local imperatives. This is how actors deal with policy incentives and asymmetries that develop alongside the knowledge-production process.

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Notes

[1] We understand and use the term South to refer to the complex, multisituated identities, and multiple roles of actors in Mexico. It is not our intention to provide polarized black and white perspectives. We drew on Santos' concept about the South: 'The South as a metaphor with different slopes, the geographic South, the South that also exist in the global geographic North, the imperial South and the anti-imperial South'.

[2] We draw on Richard (65) for the idea of multisituated actors. She describes the power in a network as fluctuating and dispersed points where multiple antagonisms and plural relations of confrontation intersect. The locations are subdivided and multiplied from the 'third world' into the 'first world' and 'first world' into 'third world'.

[3] To get a fresh and deeper understanding about dynamic flows of resources and asymmetries between the North and the South, please also see the concept of reagency in Shrum (66) and Duque et al. (67), which is related to the dynamic and different roles, positions, and identities of social actors.

[4] Incentives coming from private sector are also included since the projects with companies are executed and funded jointly between public sector, private sector, and CIMAV.

[5] The PRCs in Mexico receive public funds for their operations, but they also need to generate their own resources, which may come from public or private national sources or from abroad.

[6] The Program of Incentives for Innovation is an instrument of the STIP, based on direct support for innovation funded by CONACYT, which requires matching funds from companies.

[7] The Regional fund is an instrument of the STIP, targeted towards local demands funded by CONACYT and the 32 states of Mexico. There is one per state.

[8] Information was obtained from the Mexican Scientific and Technological Advisory Forum (FCCyT).

[9] Term used for those companies performing manufacturing operations where factories import material and equipment on a duty-free and tariff-free basis for assembly, processing, or manufacturing. They then export the assembled, processed and/or manufactured products, sometimes back to the raw materials' country of origin. *Maquiladoras* do not tend to carry out research and development.

[10] The translocal network is made up of transnational companies and large Mexican companies that have subsidiary branches in different localities in Nuevo Leon (e.g. Monterrey, Santa Catarina, San Pedro Garza). Although the companies are also global actors, we considered their interaction in the translocal network through CIMAV Monterrey.

[11] The same phenomena of redesigning infrastructure converted to ‘nanotechnology equipment’ took place in the U.S.A., were five of the main centres of nanotechnology are located in military laboratories.

[12] The IC2 Institute is an interdisciplinary research unit of the University of Texas at Austin which works to advance the theory and practice of entrepreneurial wealth creation. The IC2 institute has globally exported its model of commercialisation, named “Technopolis”. For further information visit: http://ic2.utexas.edu/about/

[13] The real name and location of the company was changed so the names of actors involved in the projects can remain anonymous.

[14] The peso is the Mexican currency.