# The Distributed Knowledge Base of the Oil Industry in Venezuela and Private-Public Dynamics

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## 1. Introduction

The research function was generalised in North American universities within the framework of 20th century industrialisation, together with those of preserving and transmitting knowledge in an organisational model for cognitive production that was exported to the entire world. This research function became part and parcel of the conventional wisdom of contemporary technological development (Arora and Rosenberg 1998). It has come to be commonly accepted that the innovation process depends on dynamic links between the production of new knowledge, knowledge transfer, and economic performance. Although these factors are accelerators, there are also a few brakes – finance is one, but so also is research capability. Particularly in developing countries, attempts to restructure higher education to more efficiently and effectively serve as an economic driver have often floundered. The interface between academia and industry, particularly as concerns economic development and national welfare, has remained a difficult and elusive subject (Arvanitis and Villavicencio 1998; Vessuri 1998a, 1995a).

In connection with the public-private dynamics in higher education, we take a particular approach to the subject in this context, by looking into how currently (particularly in contexts of underdevelopment) the public and the private are interconnected, encompassing much broader

sectors of activity beyond higher education with contradictory implications and effects. Different from what happens in many wealthy economies where the university system affords the necessary training to a technically skilled labour force that also carries out the basic research supportive of a country's industrial clusters, universities in developing nations, traditionally hailed as the engines of development and modernisation, have typically had a limited role in the innovation process. Indeed, higher education and the national industry have often remained distant (Vessuri 1995b). Understanding both innovation and higher education in developing country contexts needs concrete analysis and theoretical reflection. To explore these issues in greater detail, this paper looks into the complex relations of knowledge in industry; the legacies of economic and intellectual elites and state power; the encounter of different forms of knowledge carrying unequal social prestige; and the roles of academic research, taking as empirical support the Venezuelan experience in connection with its oil industry.

Our analysis concentrates on five different settings or knowledge domains. The boundaries demarcating them are fuzzy; one will often entail or involve the other. In our presentation we try to show that each reflects an important aspect of the same reality, illuminating a particular dimension. Understanding requires consideration of multiple interactions whose cumulative effect results in peculiar configurations of forces and dimensions. Technical groups and their social environments create stabilised interdependencies that shape further action-including work toward new technology. They may be richer or poorer depending on the variety and density of elements and interactions that characterise them. In some sense this is an exploration of the notion of *technological regime:*

> "The rule -set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems-all of them embedded in institutions and infrastructures. Regimes mediate between specific innovations, as these are conceived, developed and introduced, and overall sociotechnical landscapes. Regimes are outcomes of earlier changes and they structure subsequent change." (Rip and Kemp 1998)

Each knowledge domain highlights specificities of its own, but shares a common basic universe (the oil industry) and a common history. However, as suggested, each inevitably gives only a partial view of that shared reality, while part and parcel of a complex universe of interactions and meaning. The literature on determinants of innovation focuses

strongly on the private-for-profit sector, neglecting other actors and domains involved in the co-evolution of technology and society. Since much analysis of knowledge creation as found in industrialised countries rests on R&D data (particularly intramural R&D carried out by firms) developing countries, whose firms are usually not innovative, are usually described as being 'knowledge poor'. When one finds modern technology in place in the public sector in a developing country it often embodies and expresses knowledge and value choices that, in their use and effects, are enforced upon the recipient host. These impose a greater dependence on further outside knowledge in the form of actual operation, maintenance, and spare parts and simultaneously render local capabilities less relevant and valuable. In our analysis we posit that a public industry that has inherited many features of the former private foreign concessionary companies and a public research establishment that accepts the tacit knowledge dynamics of the corporate culture and technological regime, will most likely determine the ultimate irrelevance of the local knowledge base to the corporate strategy. Before elaborating on this idea, we present the knowledge places examined to make up our argument.

## 2. The knowledge content of the oil industry

*Petróleos de Venezuela, S.A.* (PDVSA) is one of the world's largest energy corporations, whose manufacturing and marketing network encompasses Venezuela, the Caribbean, the United States, and Europe. Before the intense process of merging, alliances, and fusions that globally restructured the oil sector between 1999 and 2001, PDVSA was third largest among international refining industries; today it is the fifth largest oil exporter and eighth producer in the world. The history of this nationalised oil industry is known in general terms, including the technological situation the country faced when nationalisation became effective (CEPET 1989; Brossard 1993). During nationalisation, the great challenge for PDVSA became to acquire commercial legitimacy. Thus it engaged not only in production activities in the areas of petroleum and petrochemistry, but also in technological R&D, education, and training in sectors linked to the energy industry. In the 1990s, to have influence and to be able to compete in the new global environment, PDVSA restructured its business fusing refining with marketing through the creation of a new business (Refining and Marketing). The six existing refineries in

Venezuela[1] that had belonged to three different affiliate companies became integrated under a single refining system in a move within PDVSA international refining circuit (with its eight refineries in the United States, nine in Europe and two in the Caribbean).[2]

In charge of R&D, basic engineering, technological support, and specialised technical services for the national oil industry, its technology affiliate – the Venezuelan Oil Technology Institute (INTEVEP) – became a respected institute, with a staff of almost 2000 persons in the early 1990s, 40% of whom were qualified professionals in strategic disciplines for the industry's business.[3] It has been argued that the *sui generis* features of INTEVEP made it a world class innovative company with little connection with other local institutions or set of firms; this would be one of the features of the Venezuelan experience, emphasising a key limiting aspect with regard to the innovative domestic capacity (Porter 1990). In other words, if long-term ability to translate domestic innovative capability into broadened international competitiveness rests on having strengths in multiple areas, then the existence of only a few fields of expertise will very unlikely produce long term national competitive advantages. This is an additional reason for trying to understand the features of this industry's knowledge base and cultural underpinnings.

If we are dissatisfied with the implicit technological determinism of the 'modern-looking' industry approach to the relationship between innovation and growth – that makes it coterminous with R&D – then we must squarely face the question of the sources and determinants of technically useful knowledge. We need to consider under what circumstances industry decides to invest in the complex of physical and intangible assets that make up a knowledge-intensive approach to production. This is an issue of corporate strategy and control. Recognition of the fact that firms interact with other institutions in a variety of ways leads us to

1 They are: Paraguaná Refining Center, Bajo Grande, El Palito, Puerto La Cruz, San Roque, and Isla.

2 The net margin of refining is the difference between the value of elaborated products and the value of the basket of processed crudes. The first depends to a large extent on the complexity of the refinery, which is determined by the capacity and nature of its plants. The second is given by the kind and quality of the processed crudes, being smaller to the extent that the crudes are heavier. Thus, the greater the complexity of a refinery and the heavier its diet, the larger its net margin.

3 Some 10% had doctoral degrees, 15% were masters and 37% engineers and '*licenciados'*, with 17% of university technicians (*técnicos superiores universitarios*-TSU).

consider two main relevant knowledge bases as far as petroleum is concerned.

The specific knowledge-base of the international oil industry comprises the component available in the oil industry as a whole and the one that is produced and taken care of by the national company. There is also the generally applicable knowledge in Venezuelan society, with emphasis in the academic context and local engineering consulting firms. At the general level of the oil industry, firms in different countries often share scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials, and so on of products. This part of the industrial knowledge base is a body of knowledge and practice that shapes the performance of all operating firms in an industry; it is accessible knowledge which in principle is available to all firms. This knowledge base does not exist in a vacuum, however. In the oil industry, it is developed, maintained, and disseminated by institutions of various kinds, and requires resources (often on a large scale) underlying the existence of a world market for oil and petrochemical technology that accompanies the evolution of organisational learning capabilities.

When the challenges and opportunities for chemical development in Venezuela are mentioned, the shocking news is that out of the 1,300,000 barrels of crude per day that are refined, less than 1% is destined for local industrialisation. This is indicative of the low domestic refining-petrochemical integration and is in clear contrast with elsewhere in the world where a large portion of their chemical business is supported in refinery currents (Rosa et al. 2002).[4] The extensive base of raw materials in natural gas, olefins, methanol, and refinery currents, together with the consumption of chemical products used in every stage of the construction of wells and oil production, offers opportunities to reverse this situation and develop a chemical industry integrated with the oil sector. This would take advantage of abundant raw materials and domestic demand. Indeed, it is possible to take advantage of the state company PDVSA as a lever in two directions for national chemical development: (a) through its demand of chemical products for its oil production opera-

4 The ‘chemical activity’ of the large oil companies, such as TotalFinaElf, ExxonMobil and BP-Amoco, has been a consequence of factors such as power, experience, market, technology, environment, etc. Considering the technology factor, in average, disbursements in research and technological development have represented from 3% to 5% of sales. This has allowed them to mitigate the reduction in earning margins during periods of low prices, affording greater stability to total earnings and optimisation of invested capital.

tions, and (b) as a generator of the basics and/or intermediaries within its business lines, with the aim of promoting a domestic production system.

However, the country has had only limited success in learning to exploit existing processing potential for products of greater added value such as petrochemicals. The development of this sector in Venezuela falls short of expectations. Only recently has a greater awareness of the importance of downstream industrialisation of refinery currents used mainly in the production of fuels developed in products of high added value that may be manufactured directly by third parties or in association with one of PDVSA's affiliates. The main barriers to greater industrialisation have been identified as financial, associated with the fields of manufacture and product development, policy insufficiencies, inadequate juridical and regulatory framework, a limited physical and service infrastructure, and a limited technological absorption capability. The small scale of firms, a lack of integration, deficient technology, long times of execution, high costs of plant construction, etc. are also mentioned. Additionally, reference is made to a persistently limited effort at marketing and sales, which require other capabilities; the country has little knowledge and experience in exports, particularly of technology. Thus, although education is conventionally highlighted as one of the efficacious elements for the achievement of economic and social development, in practice the significance of education and educational tasks in development is very complex and requires the accompaniment of other sources of production to make optimal use of the educated labour force.

The knowledge base of INTEVEP as the technology arm of the oil industry is highly specific to its very specialised features, with some technologies that it understands well and which form the basis of its competitive position. Founded in 1976, it came to have a very good laboratory infrastructure (16,000 $m^2$) with advanced instrumentation and an extensive network of computers and workstations, a technological information centre-library with international databases, a complex of 27 pilot plants and 11 service units for the simulation of processes that allowed solving operational problems of varied complexity, as well as engine benches for testing lubricants and fuels. An 'Experimental Production Centre' in the state of Zulia, comprising an experimental well or field laboratory and a bench of perforation fluids and well cementing allows simulating and reproducing the real conditions of Venezuelan oil wells.[5] Its research areas include heavy and extra-heavy crude exploitation, upgrading and conversion, clean fuel process, exploitation and

5 http://www.pdvsa.com/intevep/espanol/intevep_recur_es.html

drilling technologies, petroleum activities in materials science and environment, industrial use of natural gas, product quality, and specialties and chemicals.[6]

Since this is an industry with reputedly high international standards, it might well be claimed that this should be the most knowledge-intensive sector in the entire economy. However, although much conventional analysis of technological innovation rests on intramural R&D data, it would be mistaken to over-identify knowledge creation with only this kind of activity, for both conceptual and practical reasons. Conceptually, R&D data tends to rest on a view of innovation that overemphasises the discovery of new scientific or technical principles as the point of departure of an innovation process. It sees innovation as a set of development stages originating in research (as a consequence of the alleged prior significance of research behind the use of R&D as a key knowledge indicator).

A different notion, one of learning, has been preferred by some social analysts for a number of reasons. Learning need not necessarily entail discovery of new technical scientific principles, and can equally be based on activities that recombine or adapt existing forms of knowledge (Smith 2002). Many relevant activities are not measured or visualised in R&D data, such as training, market research, design, trial production and tooling up, and IPR costs; R&D appears as just one component of innovation activities, and by no means the largest.[7] This does not deny the importance of R&D, but repositions it in the innovation process as a problem-solving activity rather than an initiating act of discovery. By the same token, it means re-valuing the significance of the contribution of other sources of knowledge. Many of the relevant complexes of instruments and specialised materials as well as the skills and technologies needed to utilise them, lie outside the scope of R&D and even of industry. They can be found in the sciences and in technology/technologist supplying institutions, in the wider circles suggested earlier. These other inputs are supported by little explored, indirect links with universities, research institutes, and supplier companies. This brings us to our second knowledge place – the supplier firms.

6 Among its major results or products is fuel for power generation, processes for heavy crude conversion, environmental bioremediation technology, diverse drilling additives, and fluids. It came to have a portfolio of over 260 technological developments generated throughout almost 30 years of experience in research, development, and technical services. For a socio-historical study of some of these technologies see Vessuri and Canino (1996); Canino (1997).

7 The figures for R&D in INTEVEP varied in time around a proportion that changed from a R&D/service ratio of 70%-30% to one of 30%-70%.

## 3. Supplier firms to the oil industry

If we return to our initial argument that countries in general terms do not achieve outstanding performance by means of isolated firms or sectors, but rather by the grouping of associated sectors that maintain intense co-operation and competition interactions, then the structure of customer-supplier relations appears as a key element in the strategies for creating and consolidating competitive advantages and adding value in productive chains. When there is a close work relation between suppliers and customers, both tend to act in a fast track for the diffusion of firm to firm information. This has a direct effect on innovation and improvement processes throughout the chain, creating a mechanism for the generation and mobilisation of information that allows agents to get the guidelines for resource deployment and the emerging techniques and opportunities at lower transaction costs.

When we turn to Venezuela, we find three different industrial productive structures in the national economy (Pirela 2004). At its core lies a productive structure constituted almost entirely by process industries directly linked to oil production, almost totally in the hands of the State. In principle, their high relative productivity determines a broad access to the most advanced scientific and technological resources and the most sophisticated managerial tools available in the global business world. In this, not only PDVSA is involved but also large foreign corporations active in the country through their local affiliates. Other public oil firms are also involved: large petrochemical firms, power generation, transmission and distribution companies, Guyana's large metallurgical firms, and public services such as water.

A second productive structure, mostly private and made up both by product and process industries, was essentially created with the indirect support of the oil wealth. This structure consists of traditional investment spaces that in general have not demanded high investment levels and are targeted to end – and mass consumption (food; beverages; clothing; textiles; metallurgy, particularly automobiles and auto-parts; and inputs for the construction industry). Industrial policy has traditionally considered only this structure as an object of policy. Indeed this productive structure has been conceived as an alternative rather than as a complement to the oil economy, in the absence of a real interest to knit denser productive processes. Industrial policy was kept apart from anything associated with the industrialising role of the oil industry; this sector has been uncompetitive.

A third productive structure or group of firms, almost totally private and often linked to foreign companies through consortiums, produces

goods and services for the oil and petrochemical industries and process industries in general. These firms have managed to acquire a considerable competitive potential, precisely because of their condition as suppliers to the oil sector. However, this group of firms has been almost totally beyond the scope of industrial policy, while its successes or failures have been related to the effects of market forces or the ups and downs of PDVSA's policies. Even in this case, PDVSA has historically seen any special attention in developing the competitiveness of domestic suppliers as sheer backward protectionism. Added to this is corporate conduct favouring opacity and confidentiality; the result has been placing regular domestic suppliers at a disadvantage vis à vis foreign suppliers. Domestic suppliers have not been able to count on reliable and disaggregated estimates about PDVSA's investment and acquisitions plans except for very general estimates about volumes of investment, generally written in English and first appearing in the large acquisition centres of Texas or Europe.

This sector, producer of goods and services, which attends the domestic demand of the oil industry, is complex and quite atomised. It is formed by several hundred firms, with a great variation in size, activity, geographic location, and source of capital. These are firms producing specialised metal-mechanic manufactures; electric and electronic equipment; engineering consulting and development; support of information and communication technologies; building and assembling; specialised field services, including maintenance and repair; environmental services; assessment of operational technical variables; work safety and health; and many other aspects related to the process industries, whose experience was built to a great extent on the basis of demand from the oil industry and the technical standards imposed by PDVSA (Pirela 2000).

During the 'oil opening' in the second half of the 1990s, expectations were high in this sector; most firms opted for increasing their operational capabilities, getting new partnerships with technology or capital suppliers, and/or by sub-contracting production operations or services.[8] Frustration at not finding an adequate response in PDVSA's high management to incorporate them effectively to the 'growth locomotive' that the 'oil opening' was supposed to be, resulted in what may be described as the worst crisis of the sector during 1998-2003. The in-

8 It has since become clear that although the publicised intention of the so called 'oil opening' was to transform the national oil company into the 'locomotive of the national economy', the international privatist orientation that prevailed left few opportunities to unleash a really national process of technology production.

coherence of PDVSA's behaviour and of the 'oil opening' process with respect to domestic suppliers became evident. The firms' excessive dependence on PDVSA – excluding possibilities of diversification of their customers' portfolio and/or opportunities for exploring new business areas – entailed their extreme vulnerability to the ups and downs of the international oil business, with adverse implications for the investment of fixed capital, plant expansion and technological development. A macroeconomic context that was adverse to the growth of competition by the domestic suppliers of the oil industry and the volatility of oil prices in the international market could only result in the adoption of a conservative behaviour characteristic of a survival strategy by those firms.

Another indication is PDVSA's inability or lack of sufficient trust to produce and make available to its own buying systems, huge databases built over many years of assessment by INTEVEP and the results of contracts with its domestic suppliers. There is no doubt that a database of this sort is strategically valuable for PDVSA and the country, particularly in terms of industrial and technological policy. It may be mentioned that domestic academic institutions such as the Center for Development Studies (CENDES), the Institute of Higher Studies in Administration (IESA), other public and private agencies such as the National Institute of Statistics, the Science Council, PetroLatin, CONINDUSTRIA, Venezuela Competitiva, and others had been working and accumulating data with this orientation for quite some time. What transpires from the relationships between the oil industry and domestic suppliers is that although there has been a local infrastructure for building a considerable amount of equipment and other parts for the industry, PDVSA preferred systematically to buy everything abroad leaving only the design to be done locally at most. Since the design engineering cost is probably 10% of the value of a plant, while a significant amount of money is involved in construction, one begins to understand the function of engineering within PDVSA and its domestic suppliers vis à vis foreign procurement. Its engineers were engineers-administrators who managed contracts without carrying projects through; that was done by consulting firms.

Some analysts argue that a negative view with regard to Venezuelan firms among PDVSA executives had influenced the public opinion matrix (Pirela 2004). Venezuelan society and different governments have traditionally had mistrust as starting point for negotiating with domestic entrepreneurs. Dominant culture does not perceive that the will for profit of an entrepreneur may not only be honest but also positive for development. Be it as it may, the fact is that the foreign firms that participated in the 'oil opening' process were well established corporations in the

world market and most have fostered very broad, complex, and costly programs of supplier development and supply chains in their traditional areas of operation. Some examples are the CRINE program (U.K.) and NORSOK (Norway), where firms such as Shell, British Petroleum, and others also present in Venezuela, participate. Within the setting of the 'oil opening' contracts, issues concerning the supply of domestic goods and services remained as part of the unfulfilled rhetoric, with very little that could effectively serve as an explicit policy of direct incentive to the national component within the process.

It is known that process industries tend to employ few people. This, among other things, produces 'the enclave effect' recognised in underdeveloped economies. However, the combined result of the oil industry with that of its suppliers in the domestic economy could result in a more balanced situation with positive social effects, because the related sectors are labour intensive, employing workers with different levels of qualification. These firms need to grow, since most are too small by international standards and must develop competitive advantages in technology, prices and quality, and delivery conditions. There is potential for hundreds of private firms to be strengthened and acquire a stable competitive capacity and export scale.

## 4. Capabilities and know-how in the communities of practice

Our third setting refers to technological communities of practice. Our evidence comes from refinery operators, that is, technicians attending the needs of the oil plants both in the open air maintenance of a valve and at the console of automated functions within the refinery's control units. In the context of the refinery, the organisation of work involves relationships between different generations (masters and apprentices; old workers and freshmen), institutions (technical colleges, schools, firms, unions) and cultural, social, and political identities that combine tacit and codified knowledge. Observation, imitation, empirical experience, the process of doing together, the exchange of experiences, and the reflection upon what is done constitute the basis of tacit knowledge that is partially converted into codified knowledge through linguistic communication, abstract concepts, formal knowledge, codification, and simulation programs, etc. What we look at in this context is the technology's cognitive locus as embodied in a community of practitioners and the traditions of practice which the community possesses (Constant II 1984).

Oil technical systems have meanings with multiple impacts and serve to establish and systematically sustain asymmetrical power relations. An instance of such asymmetry is expressed in the tensions between procedural manuals (identified with the engineering function) and actual practice (perceived as part of operational experience), according to the different positions in which workers find themselves in the hierarchical oil technical system. There is ambivalence toward such manuals that in theory embody the mode of work within the firm; they are in fact constantly under revision because the daily routine makes evident the presence of failures, errors, and insufficiencies. The main trouble with procedural manuals lies in the difficulties of establishing a correspondence between the generality of the norm and the particularity of practice. The way traditions are built in routine oil technological practice involves the application of general norms to individual and concrete situations, but include the possibility that the individual operator may eventually act in the form of an exception to the rule in singular and contingent situations (Aranciaga n.d.).

The notion of 'efficiency' offers a powerful discursive mechanism in which the consideration that the aim of the firm is to obtain profit from the productive relationship prevails. Efficiency can be translated into order legitimated by the interests of all the stakeholders in the technical system. When there is a distinction between management and operation groups, as in the refinery, it is possible to observe a polarisation of interests where order is imposed. The work organisation is not determined by the strictly technical aspects of the system, but by those in condition of imposing order and those subjected to it. Concrete problems of legitimacy derive from this division of labour between management and operators. It may be evident that operations by means of the procedural manual are ultimately an imposition. Normatively, no worker can escape it despite its recurrent errors, although tacitly he can do it, while in the operation a traditional type of legitimacy prevails.

Domination is defined by the expected obedience of the others. Obedience is the result not only of the power of the oil firm (especially through its capacity of providing employment) but also the result of the belief of operators in the technological function of managers. A contingent event allowed us to put in evidence the structure of domination exerted by management and to revalue the importance of tacit and informal knowledge embodied in the community of practitioners made up of refinery operators. The refinery of Puerto La Cruz was the only one that did not stop operations in the country during the strike of the oil industry aimed to depose the government between December 2002 and February 2003. Keeping the plants functioning allowed insuring the supply of

gasoline to the eastern part of the country during the early stage of the crisis and later to the entire country, significantly contributing to defeat the attempt to paralyse the Venezuelan economy. On this occasion, we were able to look at the *bouleversement* of the work hierarchy explicitly anchored in formal codified knowledge stratification.[9]

The technical operators were unexpectedly ordered by management to stop plant operations between December 2nd and 6th (Canino and Vessuri 2005)[10] in a context in which they feared that they were being passed wrong information by their higher ups who were perceived as sabotaging production. Jumping over the line of command and out of sheer confusion and panic at their responsibility in the handling of operations within the refinery, they started to exchange views and information with their immediate fellow workers and realised that the information they were delivered by the managers was untrue. The international delivery portion in this refinery was also barred in a combined action by management that controlled a number of related activities, with the connivance of the foreign tankers stationed outside the local port. The domestic truck filling station (‘*el llenadero’*) was also barred. The same happened with all the informatics component of the refinery: bills, orders, lists of salary and wage payments, system of health insurance, payments to suppliers, lists of clients, etc. Indeed the five floors of the Management and Service building in the refinery were almost empty. A few people remained working at the piers but none at the port; most operators that remained active were from the refining area.

The decision to continue operations in such irregular conditions implied that the workers from different units that did not join the strike had to work together, eating and sleeping in the same place because in addi-

9 This could be seen in analogy with Garfinkel’s ‘breaching experiment,’ a research procedure that disrupts ordinary action so the analyst may “detect and expose some expectancies that lend commonplace scenes their familiar life-as-usual character, and to relate these to the stable social structures of everyday activities” (Garfinkel 1967). The refinery in question was a relatively small and old facility with a low level of complexity (HHC operations), which because of this probably caused less interest among the leaders of the strike. In the context of a situation of uncertainty, bewilderment, anxiety, and confusion that ensued, there was a breach with the normative order and everyday structures of surveillance, governance, and control were brought into question (Mann et al. 2003).

10 According to formal rules of management, a stoppage in a refinery can only happen either to repair or to enlarge it. In either case it has to be carefully programmed in a very detailed process which involves hiring a lot of people and getting parts and inputs in large quantities that must be available on the spot. A repair and maintenance stoppage was programmed for April 2003.

tion to the lack of staff they had to remain vigilant against the possibility of sabotage. Because the automated systems had been blocked, operations had to be carried out manually and they sought the help of retired personnel and of other staff who had been expelled by the firm and were remembered by their fellow workers for their know-how and experience in operations. Equally workers from contracting companies that operated within PDVSA lent their services in view of the crisis in the refinery in critical areas. The campaign to discredit the workers capacities by local media became a huge psychological pressure. They were frequently frightened at the public visibility they acquired in the emergency; they also started to receive threats against themselves and their family, urging them to abandon their struggle. During the emergency, everyone did everything in what turned to out be in practice an extreme flattening of management. The authority structure was maintained by the presence and action of the people from INTEVEP and technical operators that remained loyal to the company, but they had to rely heavily on the several groups of unskilled workers that helped insure operations and protected the facility against sabotage, in a highly dangerous environment. Some of those people did not even belong to the oil industry but were residents of neighbouring shanty towns who were pro government and politically organised in the so called '*círculos bolivarianos'*.

This experience showed many things. Of interest to our case is that there is also a significant knowledge source for industry in people not usually included in the descriptions of human capital or when talking about the human capabilities of a nation. With this striking example we simply want to call attention to this ignored component of the industrial knowledge base and the importance of recognising it.

## 5. The University Knowledge Domain

We need to understand how and under what circumstances knowledge-creating institutions actually generate and sustain cognitive flows between themselves and into the production system. This is our fifth knowledge domain. The private or non-private nature of science is not an intrinsic property. Degrees of 'appropriability' and rivalry are the outcome of the strategic configurations of the relevant actors and the investments they have already made or are thinking of making. In the co-operation between industry and university the strategies of exchange and pooling of knowledge between partners who dispose of a monopoly over the investments necessary for the use of knowledge makes science ap-

pear as public, while in fact it could be seen as nothing other than a private good shared between several owners, as proposed by Callon (1994).

Through the years, the nationalised Venezuelan oil industry made small, clearly insufficient, steps to develop science and technology resources in the domestic academic context. This seems odd as in view of the nationalisation of the oil industry one would have expected the role of the local research universities to be enhanced. A possible interpretation why this was not the case is that the institutional development policies pursued by the nationalised oil industry were partly responsible for the gap between the high technical levels and work conditions achieved by the corporation in several areas and those prevailing in the rest of the economy and society. INTEVEP's drive to create its own in-house knowledge base turned out to have negative effects as far as shaping up a domestic base of capabilities. An institutional policy for training human resources in the best foreign centres was put in place. When technical human resources began to be locally trained in the country, the oil industry persistently drained valuable professional cadres from the country's institutions of higher education without simultaneously defining an ambitious and consistent long-term national science-technology-management training plan with a strategic vision with regard to the basic source of national wealth.

When PDVSA created its own centre of oil advanced studies (CIED) it sent a clear signal to the public universities that it would invade their traditional spaces to solve its advanced technology problems. The boundary between a 'public' science that disseminates its results and one that assumes their confidentiality is a result of (private) strategic decisions that may lead into a local public good, one possible mode of privatisation. This is particularly the case in connection with public industries that, as far as they are companies, must assume business logic. Even when directed to publicly disseminated science, their support can easily be interpreted as aid for actors who, for strategic reasons (risk sharing, cooperative agreements for the purposes of profiting from complementary assets) have preferred to make a fraction of the knowledge that they produce non-rival and non-exclusive and another portion rival and exclusive.

Initially this inward institutional growth in the oil industry may have been unavoidable to some extent in view of the lack of domestic redundant capacity, which proved so important in the industrialisation of countries such as Germany in mid-19$^{th}$ century (Mendelsohn 1964). But in the long run, this policy weakened the national academic system and with it the very source of local production of knowledge. Distrust and caution vis à vis the demands originating in the public oil sector became

a common feature in the public universities, as had previously occurred with those coming from the foreign private sector. When one asks what the role of the university has been, the answer is not strategic. It has provided basic training to the personnel that joined industry, geologists, geophysicists, chemists, oil engineers, etc., accepting a subordinate position. Why do we say this? Because the oil industry had a human resource development agenda which supposed that people had to take a battery of 'technical' courses to be internally assigned to the different jobs. Only after taking so many courses one was eventually 'channelled', not only technically but also absorbing the corporate culture. Courses were taught by Shell, Exxon, etc., that is, the matrixes of the former concessionary companies.

In connection with the university knowledge domain, we look at two complementary university contexts: the faculty of Engineering and the faculty of Science.

## 5.1 University-Industry Collaboration: Exploration and Production

The situation commented in previous paragraphs is reflected in the Oil School at the Central University. Although it does not have the smallest number of students, it has always had the lowest budget in the engineering faculty, with much reduced physical areas available. With knowledge increasingly a value asset, the school appeared as an institution bogged down with many resistances to change and internal disagreements about how to interpret what being 'committed' to social and economic development meant. Some of the faculty interviewed believed that the interest and good will of PDVSA was crucial to the school's survival and updating. However, this view was clearly not shared by other members of the university community, or by elements in PDVSA and the Ministry of Energy and Mines (MEM). This helps explain the paradoxical weak situation in which these schools have always found themselves in this oil-producing country. The other side of the coin of the mistreatment of universities by the oil industry is attributable to the deep suspicion with which broad segments of the academic community have always seen the association of the university with the oil industry, as something 'impure'.

A special attempt of approximation of the oil industry to the universities occurred in 1998 in the context of the national oil opening program, which was interpreted by some as a re-privatisation of the oil industry. A general cooperation agreement was signed between two PDVSA units (INTEVEP and CIED) and three national universities (UCV, LUZ and UDO) for national strengthening of the Geosciences and Petroleum schools.[12] The underlying reasoning could well be that given the fact that the public university was the nation's critical conscience, giving it a share in the business would convince it to acquiesce. Albeit not very enthusiastically, PDVSA declared its interest to make the university more responsive to the needs of the oil business and its willingness to support academic initiatives with a business orientation, which in principle would lever the self-management of universities and improve academic R&D. However, this program became entangled in the nation's political conflict of the last few years, in which the current government aimed to change the course of the nation and the oil industry. None of the institutions involved was spared. By 2004, the time of our study, the school was once again languishing and mistrust between the national oil industry and the public university school was as high as it had always been (Vessuri and Canino 2004).

To complete the story of the approximation of PDVSA to the three public universities having oil-related programs during the oil opening juncture we have to mention a PDVSA-universities business process model established through the PDVSA-Universities Mixed Firms scheme. This consisted in the establishment of mixed companies for the operation of oil fields of which PDVSA controls 51% and the university 49%.[13] The mixed company scheme was presented as 'a model of integration between university and industry'. Start-up funds were provided by PDVSA as a loan to be repaid as operations progressed.[14] University partners were expected to concentrate in the research and development of technologies for the enhanced exploitation of the fields. Through this deal it was expected that geology, geophysics, and petroleum engineering students would do practical work in the field beyond the knowledge acquired in the classroom. The explicit assumption was that this might not only result in more integral training but could also contribute to raise

12 Interview M. J. Lazo, PDVSA-CIED, 07-06-2001.

13 In the modality of the Third Round Operational Agreements PDVSA-Universities.

14 The fields are Socororo, in Anzoátegui state, operated by PETROUCV, S.A.; Mara East in Zulia state, operated by OLEOLUZ, S.A., and Jobo in Monagas state, by PETROUDO, S.A. Tryptic from PDVSA 'Empresas mixtas PDVSA Universidades', May 2001.

these schools to international standards since teachers and students would be continuously exposed to the real environment of work and business (Olivares 2001).

The agreement also paid special attention to the promotion of the exchange of professionals in key positions, so as to develop operational and managerial skills among academics. Similarly, INTEVEP specialists (PhDs) were to be assigned to key posts in the universities as a way of fostering technological R&D, as well as transferring the industry's experience in integral project management. Students and faculty would be involved in every phase of field development. Faculty exchange between highly recognised programs of national and foreign universities and teacher and student participation in international technical events would be fostered.[15] Within a plan of intensive thesis work, short and longer-term student internships, and promotion programs aligned with the development plan of the allocated fields, INTEVEP was given the responsibility of defining the contents of thesis work and research projects, search for tutors, etc. Technology and Information centres in the universities, and basic R&D in geosciences and petroleum engineering would be strengthened. A field-work semester would be implemented in the disciplines of Geosciences and Petroleum engineering. Finally 'cross-posting' in teaching and research would be promoted within the strategic alliances with service companies, aiming at developing domestic capital through domestic firms of technical consulting and operating companies.

In November 2000 PDVSA signed agreements with the three universities to exploit the fields granted to the mixed firms.[16] Actual operarations began in the PETROUCV business two years later. A thesis produced in the Engineering School largely based on a study carried out by the UCV Oil Consulting Corporation (CORPOMENE), advised the university to admit the high risk levels in the Updated Development Plan of PETROUCV and recommended maintaining a conservative approach under which the materialisation of probable and possible reserves would be progressively gauged. It was estimated that the project would have a 'supported life' of some 10 to 12 years. Although apparently the company was still operational at the level of the university leadership in

15 Interview with Victor Escalona, vice general manager of PETROUCV, S.A. 23-05-2001.

16 The working scheme required knowledge of the processes, application of technology and a level of competence for integrating coordinated teams, relative to four fundamental and six support processes: management of external relations; administration of financial resources, goods and services; coordination of human resources; and prevention and control of active losses.

2004 when this paper was written, the Petroleum school had ceased to have direct interlocutors in its areas of competence, leaving unfulfilled the teaching and research purposes originally envisaged. In the case of Petro-UDO, operations had not started in Oriente University because the university was in no condition to do it and had to hire an external firm.

## 5.2 University-Industry Collaboration: The role of university science

Venezuela has been training scientists in catalysis for the last 35 years; as a result it has a stock of highly qualified personnel. The country has grown a capacity of generating catalytic technologies in connection with refining and satisfying the needs of its oil industry within a wide range of applications. Since this is one of the knowledge fields that has experienced a more continuous effort at building up national capacity in both industry and academy, it is interesting to reconstruct the way relationships between both have evolved.

Catalysis in Venezuela can be traced back to 1964 when the first course was taught in a Venezuelan university. Since then the subject has spread to other academic institutions and is found today in at least 12 institutions of higher education, where groups of different sizes and degrees of consolidation pursue some research activity. The oldest group is the Center of Catalysis at UCV's Chemistry School that was also in the origin of the Catalysis activity at INTEVEP. Some of its members have been actively engaged in contract-research with the industrial technology company at different times (Andréu et al. 2004).

Venezuela publicly funded many of the scholarships to train scientists abroad. International collaboration with French catalysis schools began in the 1970s and became significant in the 1980s when economic crisis curtailed domestic fellowship programs (Arvanitis and Vessuri 2001). Collaboration with the Ibero-American network framed under the CYTED was also instrumental in the development of research capabilities, through its Catalysis and Adsorbents sub-program and the various thematic networks it promoted. Although the main objective of these programs of scientific training and collaboration was articulating research in catalysis to the interests of the oil and petrochemical industry, they basically reinforced academic research, and gave local scientists the opportunity of participating in international research programs. They favoured collaboration with foreign institutions whose international prestige helped validate the work and credibility of the growing domestic catalytic community (Vessuri et al. 2003). University labs in general are conducting good quality research although the lack of large and costly

equipment is among the main shortcomings of academic labs. In the absence of clear signals from the nationalised industry and ignorant of the industrial technological dynamic, academic R&D has proceeded on the theoretical assumption of the needs of the oil industry, making guesses in view of the special nature of its resource base of heavy and extra-heavy crude.

As far as INTEVEP as the technology arm of the oil industry, the hard institutional learning it had undergone of identifying market opportunities and adjusting to rapid changes of course, handling secrecy and confidentiality, the false starts, wrong strategic decisions, a certain arrogance (real or perceived) on the part of affluent INTEVEP staff towards poorer university counterparts, did not favour its interaction with academe. Lack of familiarity in the academic domain with intellectual property arrangements and their implications have deterred industry from working more closely with university researchers. Consequently, in view of the lack of effective demand from industry, a work style developed in universities that lacked competitiveness, had low productivity (according to a recent estimate, 0.30 to 1.0 paper per year depending on whether scientific papers or all publications, including patents,[17] were considered (Vessuri 1998a) and little visibility (since most of the work was published in local and other non-mainstream outlets).

The 1980s were a particularly harmful decade for the academic community, with a recruitment gap because of budget insufficiencies compounded by the retirement of many members of the founding generation of professional researchers. In more recent years things improved somewhat with the emergence of new groups in the province. But in the 1990s established groups had to compete with newer research specialties, under the unwarranted public perception that catalysis already had 'too many' people and had in the past received inordinate public support. Thus cadres of researchers in this field began to get older without being replaced in proportion. This became particularly visible in the case of the largest academic group, the Center of Catalysis at UCV (Vessuri 1998b, Vessuri and Canino 1996, 2002).

In 1997 the largest national concentration in terms of catalysis capability was in INTEVEP with some 50 research staff in the Catalysis section. That year reorganisation was attempted to fuse different groups with the aim of reinforcing the position of the company as technology supplier. A new scheme of work by project and expertise was expected

17 The number of patents developed by INTEVEP in collaboration with universities is less than 5% of the national scientific production in the field of catalysis, much below other production modalities.

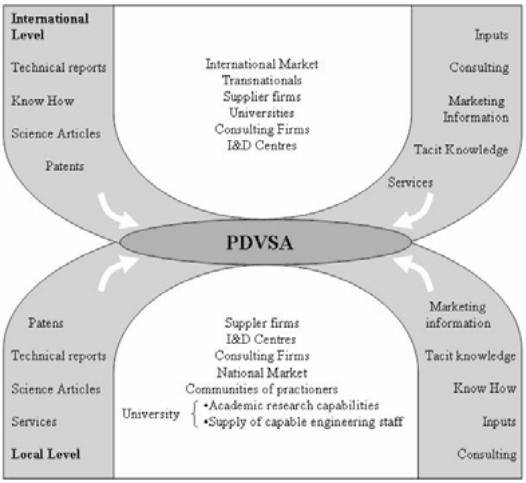
to bring INTEVEP's process engineers and catalytic chemists closer to business opportunities, inducing them to define more concrete projects to be developed by the company in the short and medium term. The strategic decision was to become a technological leader in catalysts and adsorbents, and the preferred supplier of PDVSA in catalytic technologies. This meant organising business units dedicated to customers, diffusion and sales of the product portfolio, and strategic units in charge of developing the knowledge that would be required in the long and short run. The needs of adding value to the resource base made up of mostly heavy and extra-heavy crude, was said to guide the institutional research strategy in an increasingly exacting market. This move was apparently unsuccessful, leading at the time to a great deal of frustration among catalysis researchers, for it meant the disruption and abandonment of research lines and its dilution as a knowledge area within the company. However, we have seen that in the case of the emergency described in section 4, those capacities were put to the test successfully as a consequence of that reorganisation that had forced researchers to visit and get familiar with the operational fields, among other things.

Today the government is aware that it is time to have existing capabilities framed within a national strategy that makes optimal use of existing advanced personnel and foresees its renewal and enlargement in industry, universities, and other research centres in the medium term. Research productivity must be raised; the institutional distribution of individual researchers in the national territory must be revised for the integration of efforts. Among the reasons for inter-group and inter-institutional collaboration are the rising costs of doing research in competitive areas. Current fragmentation and isolation of research groups can be made functional by decentralising tasks and using fruitfully the specific knowledge advantages present in individual laboratories.

A project of a National Program for Chemistry and Catalysis is actively trying to coordinate efforts aiming at application. It seeks better formulae to insure a greater interaction between elements of the national innovation system, including how to link public R&D institutions with the private sector and higher education. A key to this is to focus direct investments in science and technology for long-term economic purposes, useful research in the broad sense that includes basic technology and also basic research. The government's role in promoting the effective use and absorption of technology and knowledge in the economic domain is another key emphasis, as is the recognition that the use of a broad variety of policy tools and incentives (not only in R&D) is a necessity to guarantee an adequate mix.

A joint effort by a carefully designed division of tasks is expected to create social and scientific connections between researchers, leading to greater efficiency and quality. Collaboration may also be stimulated by improved access to communication networks. Networking actively fostered by INTEVEP might result in a stronger coalition and social connection among researchers of both industrial and academic contexts, creating an environment conducive to the development of knowledge activities with the desired speed. Industry must be at the helm in the interaction between the two contexts, causing a strong common drive that will affect all research areas involved. But surely this would not prevent the growth of an enriching collaboration at the horizontal level in the academic community.

*Figure 1: Knowledge base of the Venezuelan Oil Industry*




## 6. Discussion

In the heading of this article we mentioned public-private dynamics. We feel that in their combination we may find a better understanding of the structural features of the problem. We argue that the distributed knowledge base of the oil industry in Venezuela is an aspect of knowledge production that must be considered by the higher education community, although it is qualitatively different from higher education in several important respects. Under the conditions of the public-private dynamics, the required knowledge base becomes a more complex issue, touching on basic dimensions that lead to rethinking education and training. Hence, instead of concentrating only on higher education, we looked at

knowledge activities in five different settings or domains related to the oil industry and started our analysis by considering the industry's general knowledge base, its deployment of scientific and technological capabilities in production, finally looking more specifically into the local sources of useful knowledge.

We examined first the knowledge content of the Venezuelan oil industry-*Petróleos de Venezuela S.A. (PDVSA)* -, by far the largest in the country. We tried to focus on the way it organises relations to the local sources of provision of technical knowledge. The specific division of labour which normally supports a diffuse social contract between corporate management and society is predicated on the idea that there is something special – technology – that is mastered by managers, who are mandated to work on technical progress (and thus insure progress in general), particularly in the case of public companies that are national property. They are given relative autonomy to work on the technology domain as long as they are perceived to be working toward progress. Four-and-a-half years ago a crippling strike (lock-out) led by the upper echelons of the publicly owned oil industry ended in the layoff of about 20,000 workers of this 45,000 or so labour force, including some of the most highly trained local staff. During the strike, they abandoned their posts and ceased to be seen by the majority of the population as working for general societal progress and the public good, and thus became illegitimate in their eyes.

Since then the issues of knowledge structure and capacity-building in this developing nation have acquired renewed saliency. Some people argue that this collective dismissal implies the destruction of the future of the industry and the national economy. By contrast, others observe that not necessarily capacity per se contributes to the public good, and indeed education and educational credentials may come to serve particularistic ends contrary to the public good. Also, this has implied the beginnings of a new exploration of knowledge, not only in terms of allowing for more intense transactions with varying experiences, scale, geography, and other elements. Further, it has disclosed the influence and power of the existing technological regime, which cannot be easily dismantled after it has been put together. Irreversibility (i.e., inflexibility) once achieved, is what makes a technology hard, difficult to change, and a structural factor itself.

But we must also look elsewhere to better grasp the issues at hand: the setting offered by the domestic firms that supply goods and services to the oil industry. We see that these firms act as a transversal segment in the economy, not only serving the oil industry but also providing goods and services or competing with foreign suppliers for a good por-

tion of the other private productive sectors, which are also for the most part process industries, such as CVG, electricity, aqueducts, etc. The productivity differential between the oil industry (including firms directly involved in the exploration, production, exploitation, transport, refining, and commercialisation of hydrocarbons) and the rest of the productive sectors as measured by the total income obtained and the number of workers directly involved in the production of those goods, should not be taken to be one of efficiency, competitiveness, or quality of the management and staff working in one or another productive structure. It may not be stated that one sector is more efficient or more competitive than the other, nor that PDVSA has a better managed productive structure than other institutions. In particular, this can be appreciated in the group of suppliers of goods and services to the oil and petrochemical industry.

What is striking about this industrial segment of oil connected industries is their vulnerability and extreme dependence on PDVSA that has consistently ignored them. The criteria of adequacy and value used in this case have been commented above, showing that non-technical aspects may come to dominate the decision-making process, so that the 'scientific' or technical' quality ends up being distinctly less significant. When all sides have a reflective awareness, contact can be fruitful and creative; but when one side is too weak in relation to the other there is a strong imbalance of power and manipulation and corruption are likely to occur.

With this backdrop, a third knowledge setting was explored. The picture offered by the study of the organisation of workers keeping an oil refinery operational during the 2002-2003 political strike that was aimed at deposing the government offered a valuable perspective for considering changes underway in the knowledge structure and the need of reinterpreting the issue of organisational management. The vertical management line of the oil industry was broken during the strike. The traditional management-imposed work discipline embedded in the corporate culture was turned upside down by the upper echelons of management when they urged lower echelons to halt operations. Appealing to the same corporate discipline and loyalty to the 'national' industry, workers decided to disobey higher orders and maintain operations. Activities in the oil industry continued during the strike, while management and operational responsibility during the emergency were assumed largely by individuals who had an educational background as technicians, leading even to the process being known as the 'IUT-graduates revolution'.

The next knowledge setting explored .was closer to the traditional notions of knowledge production and reproduction, and the relations between higher education and the oil industry. We looked at two knowledge domains: 1) the supply of capable engineering staff in technical fields of mining, petroleum engineering, and geosciences, and 2) the growth of academic research capabilities in the field of catalysis. This situated us in the network of institutions in the public sector whose activities and interactions are supposed to initiate, modify, and diffuse new technologies. Our case study of the training of new professional engineers in the schools of mining and geosciences raises a number of policy considerations including the difficulties to put in place new rationales for advanced training and research, the appropriate mix of universities, inter-disciplinary programs, and inter-institutional programs, as well as the minimum size of a credible national scholarly community. Venezuela is a country whose institutional systems are experiencing substantial changes. We believe that hindsight and modest and fragmented PDVSA attempts before and during the 1990s to articulate the world of academia to that of the oil industry help interpret current events. The prevailing distrust for over half a century between industry and academe should not be interpreted as caused simply by individuals as actors in particular institutions. There is no doubt that some of the present difficulties result from human failings of this or that group of bureaucrats, managers, scientists, engineers, or politicians. However, it is more illuminating to identify structural features of the system in which knowledge is used in production, which lead to situations where ordinary humans make consequential decisions.

Local production and reproduction of formal knowledge must compete with much more powerful structures of traditional and new foreign suppliers of educational and knowledge services to the oil industry, that not only transfer more updated and better quality knowledge but also a wealth of contacts and tacit components that are part of the 'technological culture and regime'. In the strategic approach historically adopted by PDVSA it was unsafe to assume that the relevant knowledge base (be it in the form of skills, information, or services) would be found in domestic public sources, including public universities. These were then left to languish showing little real interest in them. Indeed, coherent with its corporate culture, PDVSA tried to develop its own corporate university (CIED), bypassing the public university system they distrusted.

Our case study of a research community reinforces this basic finding. It allows us to uncover the parallel existence of an academic and an industrial catalytic community sharing similar research interests, in both contexts more inclined toward research than development, and with less

reciprocal interaction than would be desirable, failing to coalesce into a synergistic dynamic to the detriment of both. Standard academic production, research funding, coordination, execution, and evaluation all take place under the umbrella of public research and within public higher education institutions. In this setting, in the absence of a better integration with domestic industry, the academic community has deployed a survival strategy aiming among its best cadres at the articulation with an international establishment that may grant them recognition and credibility. This is an area where different values, norms, and policies play themselves out, providing new insights into the ways in which intellectual landscapes are transformed, and prefiguring battles between public and private ends, institutional aims and scholarly values.

These snapshots show that the domestic knowledge base of the oil industry is internally differentiated. It is distributed across a range of fields, technologies, actors, and industries. By analysing interactions between academic institutions and groups on the one hand, and industry on the other, we described these knowledge settings in terms of their empirical content and particular configurations in different contexts and degrees of control and autonomy. How individuals, organisations and indeed entire nations perceive and respond to the restrictions and opportunities they face are crucial. To make an optimal choice it is first necessary to recognise that the effectiveness of specific forms of collaboration depends on a reasonable reciprocal understanding of the knowledge partners each with its different priorities. Second, it is necessary that they do not find themselves in too unequal power conditions. To be effective, the various actors involved must be capable of articulating and satisfying their particular needs and interests through a 'mediation space' that implies a set of key concerns, expressed in different ways depending on the forms of linking, and where particular aspects of emphasis and strength vary as well. This reinforces the conclusion that it is as much the context as the linkage model that determines institutional capacities in the transfer of knowledge and technology (Webster 1998).

That local actors largely failed to optimise their share and bargaining power might plausibly be related to the tremendous deterioration in the factorial distribution of income experienced by Venezuela during the past 30 years. Rigid production processes are not independent from industry structure. There is enough evidence suggesting that production highly concentrated in a reduced set of industries is likely to exhibit more rigidities than one with a widely diversified base, because a great part of the economy-wide substitution takes the form of substitution among industries. In particular, a broad set of export industries would probably have allowed Venezuela to overcome its problem of low elas-

ticity of substitution. But it is suggestive that high concentration in energy-intensive industries is precisely the specialisation that Venezuela is pushed to by the forces of comparative advantages. In other words, it has been argued that Venezuela's high participation in world trade-given its skewed structure of comparative advantage-may precisely be one of the causes of its low elasticity of substitution (Rodriguez 2004).

Our examples focus attention on different domains with active groups of practitioners with restricted membership and fairly well-defined boundaries. They draw together a diversity of knowledge carriers: researchers, technicians, managers, specialists in industrial property, engineers, skilled and unskilled workers, students, machines, instruments, samples, texts, and orders, all of which circulate among similar collectives. Every element in the collectives that make up the various domains plays an active role, interacting with the others. Problems posed, deciding between giving preference to experience or theory, favouring certain types of explanation, the aversion to or interest in applications, obviously depends on the concrete identity of the elements making up the collective and on the organisation of their interactions. Change the composition of the collective, and you change the content of its production. The variety of knowledge produced and the capacity to shake up networks made irreversible by the market will in part depend on the composition of these collectives. The multiplicity of possible dynamics is enormous.

Rules, practices, cultural forms, and relationships with things all vary from one domain to another. *Diversity* and the *local* are at the heart of science. Science is a public good which must be preserved at all costs because it is a source of variety, depending on a diversity of interests and projects. As clearly argued by Callon (1994) it causes new states of the world to proliferate. Without this source of diversity, the market – with its natural propensity to transform science into a commodity – would be ever more doomed to convergence and irreversibility. By contrast, private science firms up these worlds and makes them habitable. In this sense public and private science appear as complementary despite being distinct; each draws on the other. This definition is independent of the identity of the actors involved. We have found elements of the public and private dynamics in all five domains. A firm that funds diversity by supporting new collectives is producing a public good while the government agency that contributes to a yet stronger linkage between the research it funds and the perfecting of oil technologies is supporting a science that can doubtless be called private.

Paradoxically, since oil nationalisation the dominant trend has been a steady fall in oil's share of GDP. Behind the rising capital share was

an unprecedented collapse in wage rate unaccompanied by a fall in the rate of return to capital. Since a significant amount of GDP takes the form of oil rents, it might be argued that the effective distribution of income would have been influenced by greater progress in the distribution of the state's oil rents. However, this does not seem to have happened in Venezuela. The government redistributive component *par excellence* is wages and salaries. It is significant that the portion of wages and salaries in the government budget fell from nearly half to less than one-fifth over the period studied. Government purchase of goods and services also fell considerably. The factors that experienced the greatest increase were interest payments on internal and external debt, and government subsidies and transfers. The bulk of this last component of government expenditure is made up mainly of subsidies to state-owned enterprises, government-owned financial institutions, and private enterprises.[18]

So, the conventional argument that places the onus of underdevelopment on the educational insufficiencies and lack of general capabilities in developing countries, and its concomitant solution on simply more education and training, can be highly misleading. From what we have found, in the past 30 years the growth of a domestic knowledge base was not really part of the project of development of the nationalised oil industry. Instead of having only one very strong and fully functioning institution in the entire national economy, PDVSA (Vessuri 2005), in a different and more balanced scheme a rich tapestry of knowledge sites and domains would have fed and interacted with the oil industry. Today's general petroleum policy entails, at least at the rhetorical level, aligning PDVSA's business plan to national development concrete purposes. It is envisaged as promoting the maximum participation of the domestic private sector and the formation of domestic capital in the development of oil projects in Venezuela; in particular, it is aimed at the domestic industrialisation of hydrocarbons to significantly improve the export package of crude-products. Such developments would undoubtedly have a positive impact on knowledge supply and demand fostering virtuous cycles of improvement.

18 This, in passing, would agree with the hypothesis that at least since 1983, PDVSA embarked on a strategy to reduce the public oil industry's fiscal obligations through its *internationalisation*, as a mechanism for transferring earnings outside the reach of government (Mommer 2003). That this was the motivation of PDVSA's internationalisation goes a good way toward explaining the extraordinary growth of its international network of refineries and other assets. In 1998, PDVSA defined itself as a world energy corporation dedicated to the business of crude oils, gas, petrochemistry, and carbon, with operations and industrial and service facilities in Venezuela and in over 50 countries.

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