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Abstract

Translating R&D and inventive efforts into a market product is characterized by significant financial skills, and the ability to overcome technical and instititonal barriers. Research into and translation of new technologies such as biotechnology products to the market requires even greater resources. This paper aims to understand the key factors that foster or hinder the complex process of translating R&D efforts into innovative products. Different pathways exist in developed countries such as firm-level efforts, the use of IPs, the spin-off of new firms that develop new products, or a mixture of these. Developing countries differ substantially in the kinds of instruments they use because of their considerably weaker institutional environment and for this reason our framework takes a systemic and institutional perspective. The paper comtributes to this issue by examining systemic institutional barriers to commercializing biotechnology in a develping context within a systems of innovation framework.

Keywords: Biotechnology, commercialization, innovation, Africa, learning and institutions.

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1. Introduction

Investment in scientific research often carries with it an implicit assumption of reaping the fruits of commercial innovation in the form of products and processes. However, the path from the laboratory to the market can be long and expensive and the outcome uncertain. Institutional and structural factors pose significant and sometime unexpected obstacles particularly in a global context with fast changing rules of the game. This is all the more the case in an innovation-driven and science-based sector such as biotechnology, which is characterized by idiosyncratic technical and scientific properties (Traore and Rose, 2005; Gregorio and Shane, 2003). Success in mastering such a technology would therefore require deep-going changes to existing formal and informal institutions that supported traditional scientific research and development (R&D) and commercialization in the past. This places a double burden on developing countries that are still in the process of acquiring scientific and technological capabilities. First they face the challenge of modernizing both the scientific and production structures to deal with the complex requirements of biotechnology and second these countries need to resolve the imperative of new institutions that define the ecology and dynamism of new technologies (Whitley, 2003; Pisano, 1996).

There are four broad features of biotechnology that create discontinuity with extant scientific culture of developing countries. First, biotechnology has its roots deep in basic science and its rise in the west is associated with the activities of "star" scientists, the so-called entrepreneurial scientists (Ben David, 1971; Oliver, 2004). The practice of science in most developing countries is relatively recent, characterized by academic migration, and academic entrepreneurship is hardly common as a result of rigidities in the terms of employment. Second, biotechnology has a strong interdisciplinary content (that fosters strong collaborations within the academic disciplines) and complimentarily, leads to the growth of networks (Powell et al, 1996) that re-defines the nature of inter-firm collaborative structures. Systems of innovation in developing economies are notably weak and beset with systemic disarticulation (Oyelaran-Oyeyinka, 2005; Cassiolato and Lastre, 2004) with poor links between research and industry. Third, new institutions such as venture capital and spin-off companies that cluster around strong research-based universities are rare (Zucker et al, 1998). The last factor relates to a set of informal norms and practices embedded within and

reinforced over the long term by formal institutions such as the attitudes to intellectual property, the propensity to patent research results, and the nature of academic employment that engender little incentive to pursue commercial ventures (Lehrer and Asakawa, 2004).

Among the prominent sources of knowledge within the national system of innovation are industrial firms, private laboratories, universities and public research institutions. While all these organizations have traditionally been sources of commercial technologies, universities and public laboratories are notable sources of inventive activities for knowledge-based new technologies such as biotechnology. Universities have over time been regarded as centres of knowledge creation and products of research that are been increasingly commercialized (Etzkowitz, 1998; Henderson et al, 1998)). In turn inter-organizational collaboration has grown with the private sector relying more on the products of scientific research from universities and public research institutes (Powell et al, 1996). Relatedly, there has been a growing pressure on universities and public research institutes to commercialize research and efforts have been made to understanding the different innovation pathways and what constraints successful inventive activity (Cohen, Nelson and Walsh, 2002).

At the same time, as Laursen and Salter (2004) report in their study of university-industry collaboration, the role of universities in generating knowledge may have been exaggerated. Scholars of innovation system have emphasized the multiplicity of sources of knowledge in the economy and the fact that universities and public research institutes are only one of them. Again, the level of scientific and technological development will condition the roles that different actors (firms, universities, private and public laboratories) will play in the generation, validation and distribution of knowledge. This is due to the idiosyncratic nature of the process of commercialization of research. The process of innovation is path dependent, while its trajectory depends entirely on the context, and the capacities of myriad system actors (Raemer et al, 2003; Kline and Rosenberg, 1986).

Several channels have been identified as important in the literature for translating research efforts to innovative products and processes. These include exchange of information between actors and organizations, technical assistance, cooperative research, licensing and

sale of intellectual property, spin-off of companies from research and hiring of skilled personnel (Traore and Rose, 2003; Reamer et. al, 2003).

The context-specific nature of the process (level of technology and the quality of scientific and technological infrastructure) as well as the nature of institutions (the scientific culture and support systems) can mean that the factors that foster or hinder the translation of research into innovation would differ in developing and developed economies. For instance while patenting has received widespread attention in the literature on commercializing biotechnology in advanced industrialized countries (Henderson et al; Arundel, 2001; Mowery et al, 2001), this is not the case in developing countries. For instance, in a study that investigated the decisions to commercialize new technologies within a large number of research establishments in India, patentability of technology was ranked seventh in importance (Kumar and Jain, 2003). The research on which this paper draws focused on the research activities of a number of universities and public research institutes in Nigeria with the aim to understand the determinants of and barriers to translating research to innovation. Specifically, we try to investigate, within a comparative institutional perspective, the ways in which national trajectories are shaped by historical circumstances. In Africa, universities and public research institutes are controlled and funded largely by governments and we take this as our entry point of inquiry. In other words, in what ways have institutions shaped the observed path of scientific research to the market? Why have there been so few successes in taking inventions to the market in Africa? We take the case of biopharmaceutical system in Nigeria as a case study and our hypothesis simply is that the institutionally determined policy processes have impacted significantly on the ways inventive activities travel/or do not travel from the laboratory to the market.

The paper is divided into seven parts. The next section provides some information on the capacity of universities and public research institutes in the country. Section 3 presents an analytical framework of systemic institutional barriers to innovation efforts, within which the discussions presented in the remaining sections of the paper are structured. We then present an econometric model as well as case studies that illustrate the main propositions of the paper. The final section concludes.

2. The Capacity of Nigerian Universities and Public Research Institutions for Biopharmaceutical Research1

Nigeria's higher education institutions run various programs in the different health and pharmacy disciplines. Among the three categories of tertiary institutions (Universities, Polytechnics, Colleges of Education) only the Universities offer first degree courses in pharmacy. Although pharmacy is a major discipline, it offers a single first degree programme in almost all the Universities with the exception of University of Lagos which also offers a first degree programme in Pharmacology. Programmes that are relevant to Biopharmacy are also taught in Medicine and Veterinary Medicine and are equally offered only in the Universities. These courses like pharmacy at first degree level are single degree programmes. A total of nineteen Universities offer degree programmes in Medical Sciences and five, in Veterinary Medicine. Programmes in the sciences form the bulk of courses that are relevant to the subject discipline and a few of these are offered in the polytechnics, monotechnics and colleges of education as well.

The general objective of pharmaceutical education is "to provide competencies for performing all pharmaceutical services in Nigeria". The course curriculum includes basic sciences and preclinical sciences and professional studies. Basic Sciences refers to courses in the physical and biological sciences as well as mathematics which are pre-requisites for the pre-clinical and professional courses such as Anatomy, Biochemistry, Physiology, Histology, and Microbiology. In Professional Studies and Training, the variety of courses include Biomedical/Pharmaceutical Sciences, Management of Pharmaceutical Sciences and Clinical Pharmaceutical Sciences. This includes clinically applied courses in pharmacy practice based on the pharmaceutical and biomedical sciences, such as biopharmaceutics, pharmacokinetics and pharmacotherapeutics. This also includes supervised training in appropriate in-patient and out-patient environment under the general title of Clinical Pharmacy.

1 The information contained in this section is based on the 2004 survey conducted by the Nigerian National Universities Commission (NUC). They can be found in a report titled: Needs Assessment of the Nigerian Labour Market, NUC, 2004.

The different governments invested relatively heavily in the educational system in Nigeria. The number of Universities in Nigeria increased from one in 1948 to two in 1960, seven in 1970, seventeen in 1980, and thirty-one in 1990 and currently, there are over forty universities.
The Nigerian National Policy on Education placed a strong premium on Science and Technology and states inter alia; a greater proportion of expenditure on university education shall be devoted to Science and Technology, and also provided that not less than 60% of places shall be allocated to science and science-oriented courses in the conventional universities and not less than 80% in the universities of Technology. Several medical colleges, specialist teaching hospitals, science centers, and Research and Development Institutes (RDIs) were built. The private sector established technical and technological training institutes and colleges to produce middle and high-level man-power. However several factors have conspired to truncate the basic objectives of a science policy that sought to build a dynamic science-driven industrial sector.

The military governments over a period of more than three decades invested little on S&T infrastructure and as employment opportunities diminished, many scientists and engineers migrated abroad. The introduction of the Structural Adjustment Programme (SAP) in 1986 led to a dismantling of state-controlled sectors of which the universities and RDIs are a part.

At the same time enrolment in universities grew, a result of the "Universal Primary Education Scheme" which began in 1976 releasing its first products for University admission in 1988.[2] The annual growth rate for the nineties averaged 12%. The mean graduate output for pharmacy as a discipline since the early 1980s is 398 per annum. A total of 187,530 graduates have been trained within the same period in programmes relevant to Biopharmacy.

Public research institutes (hereafter, PRIs) are fully state-funded and devoted to research into the use of local resources with the main objective of adding value through R&D and processing. PRIs have been established for different sectors, namely in agriculture, chemicals, new materials and recently, in space and biotechnology. PRIs have been very important due in

2 The take-off enrolment of 210 was recorded for all disciplines in 1948 for University College Ibadan, the Premier University. This went up to 23, 000 in the six Universities in 1962. By 1996, the total student enrolment figure had risen to 234,581 for 37 Universities and by March 2002 it shot up in excess of 526,780.

part to the weak capacity of private R&D, low level of entrepreneurship that put pressure on PRIs to fill this void. We selected five PRIs for close examination in this study and they are: the Sheda Science and Technology Complex (SHETSCO), National Institute for Pharmaceutical Research and Development (NIPRID), the National Veterinary Research Institute (NVRI), the National Institute for Medical Research (NIMR), and the National Centre for Genetic Resources and Biotechnology (NACGAB).

The areas of focus of the institutes are shown in the Tables 1 and 2 , which equally reveal distinct disciplinary specialization. NAGRAB concentrates exclusively on the preservation of Nigeria's genetic resources (100%), NVRI devotes its attention to animal-based research (90%), NIPRID research is in medicine particularly ethno-medicine (70%); and true to its mandate, SHETSCO's activities span the three areas of bioprocessing: industrial (71.4%), agriculture (57.1) and medical biotechnology (71.4%). SHETSCO's work in bio-processing also includes the development of a gene bank for yeasts. An important focus of the research at the SHETSCO Complex is the transformation of three local staples, namely banana, plantain and cassava using agricultural biotechnology and the work here builds on what the International Institute for Tropical Agriculture (IITA), situated in Ibadan has been doing in order to create superior products through the use of DNA techniques. The institute plans collaboration with the International Agricultural Research Institute (IARI) for staff training on this project. At the time of the survey visit, an expert on banana from the IITA was visiting the SHETSCO Complex. SHETSCO has also been contracted by one of the southern states, the Bayelsa State government to carry out some work on the propagation of local staples using tissue culture.

The pressure to raise additional revenues has forced PRIs and universities to increasingly engage in a variety of activities that supplement their financial allocations from the government. They are in the main, consulting, knowledge transfer to industry through formal and informal channels, and spin-off firms from commercializing research. We sought to know how the different PRIs divide their time in respect of research, which is their primary mandate, and other activities. Apart from SHETSCO, all the institutes are engaged in significant amount of training in addition to research. All the PRIs devote some effort and

time to consultancy, as a way of augmenting their finance, testing and laboratory services, production and contract manufacturing.

There is a lack of systematic data on the extent and depth of biotechnology research within the biopharmaceutical system of innovation. We asked respondents to indicate the broad areas as well as the tools of biotechnology that they presently use and the time and human resources involved. Bioprocess technologies are widely applied at NIPRID and SHETSCO (57.2% and 60% of activity respectively) followed by recombinant DNA in NIPRID and tissue culture in SHETSCO. This confirms some of the earlier but partial survey of biotech activities by Alhassan (2000), which concluded that cell and tissue culture dominates the activities of actors in this system although his study focused only on agricultural biotechnology. This present study shows that while research using cell and tissue culture is relatively widespread, PRIs are also applying bio-processing and DNA techniques although limited by facilities and equipment to a few number of researchers. For instance, NIPRID devotes on average 20% of its resources to aspects of recombinant DNA and 61.3% to molecular diagnostics and less than 20% of financial resources are devoted to cell and tissue culture. This is not surprising given that the mandate of NIPRID is medical biotechnology. SHETSCO on the other hand, has been engaged more in agricultural biotechnology despite the relatively advanced nature of their laboratory. There are two reasons for this. First, the facilities are only partially completed and for most part, scientific facilities in SHETSCO are utilized at less than full capacity due to poor power supply and incomplete equipments. Secondly, there has been a consistent under-funding of SHETSCO as a result of which much of their research activities have been donor-driven. For instance, research activities applying cell and tissue culture to improve plant and crop varieties are being sponsored by USAID and a state government which contracted the Complex to carry out study on micro-propagation of banana for possible mass production.

Table 1: PRIs Area of Focus (%)

Institutions	Industrial research	Agricultural research	Medical Research	Others
1. NAGRAB[3]		100.0		

3 The questionnaire by NAGRAB was filled in by the director of the agency and is the only place where we administered only one questionnaire.

2. NVRI	10.0	90.0	10.0	
3. NIPRD	10.0		70.0	30.0
4. SHETSCO	71.4	57.1	71.4	

Source: Field work (2004)

Table 2: Major Activities of Institutes

Activities → Institutions	Research	Teaching	Consultancy	Production	T&L services	Contract Manu.	Others
NACGRAB	100.0		100.0	100.0	100.0	100.0	
NVRI	90.0	80.0	60.0	70.0	70.0	70.0	10.0
NIPRID	90.0	70.0	60.0	60.0	60.0	60.0	
SHETCO	85.7	14.3	28.6	42.9	42.9	42.9	

Source: Authors survey (2004) ;T&L = Testing and laboratory services

2.1 Institutional Shocks and Emergence of Institutional Inertia4

While organizations may be subjected to strong inertia pressures, lack of perceptible change may not necessarily mean that an organization is stagnating. There could be two possibilities. First, an organization may respond too slowly relative to the changes in the local, national or global contexts. This might well be the case with much of the perceived slow speed of commercialization of inventions in African universities and research institutes. Second, organizations may be subjected to too much and too strong structural inertia relative to their internal capabilities to make on-going changes inadequate.

The academic system in Nigeria inherited habits and norms that tend to be at variance with current global realities such as faster cycles of innovation activities. Again, the system has

4 This section benefits from Oyelaran-Oyeyinka, B.(2006), Learning To Compete in African Industry: Institutions and Technology for Development, UK: Ashgate Publishing.

confronted *dissipative forces* arising in the main from rapid structural reforms for instance that re-focused the attention of universities and PRIs to non-scientific activities that made real substantive changes difficult or impossible. For instance, reform "conditionalities" such as forced budgetary cuts led to widespread closures of universities in Nigeria through strikes and created instability in other levels of the educational sector. Faced with this situation, universities were unable to pay the desired attention to developing necessary knowledge and physical infrastructure that over time suffered decay. Research institutions had to cut back on necessary, but unaffordable imports and technical services all too suddenly due to massive devaluation of local currencies. Subsequent reduction in journal subscription and laboratory facilities resulted in declining standards of research and training. Figures 1 and 2 show the separate cases of declined spending by the Nigerian government on students and the overall picture in SSA.

Figure 1: Government expenditure on education in Nigeria

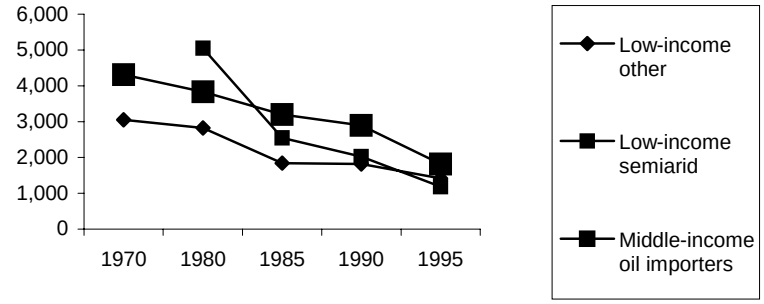
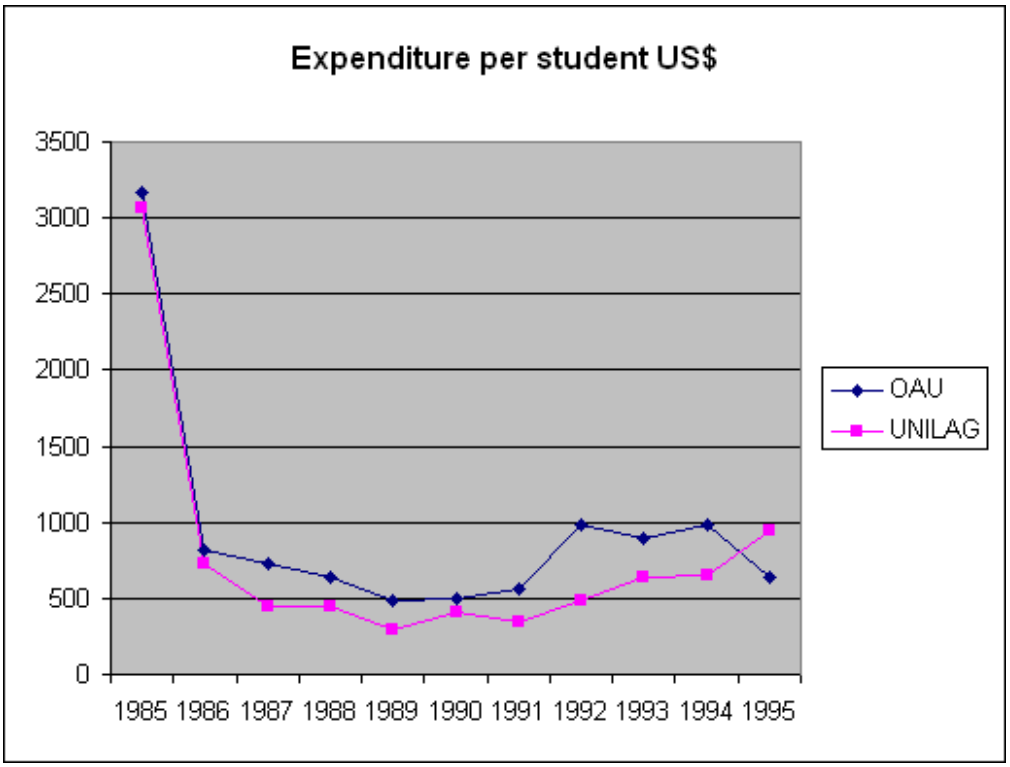


Figure 2: Government Expenditure on Tertiary Education per student in SSA (constant 1990US$)



Commitment to public research can be assessed from the financial allocation to PRIs over time. Table 3 shows the evolution of public expenditure on science and technology in the period of 1980 to 1992 in Nigeria. The peak was 1983 and even at this stage, it was far short of the levels with comparative resource endowment, and less than half the target of 1% R&D as percent of GDP specified by the Lagos Plan of Action. This level of allocation is in fact only indicative because we do not have the breakdown for the different expenditure items such as direct allocation to laboratories and salaries, for instance.

Available resources for S&T investment in other African countries are not different significantly in orders of magnitude. For instance, the expenditure on R&D as percent of GDP for sub-Saharan Africa (SSA) is on average 0.29% (1990 figure), while that of South Africa, the most industrial country in the continent is around 0.6%. Comparatively, the average for Latin America is 0.4%, and East Asia ,2.05%[5].

Table 3: Public Expenditure on Science and Technology in Nigeria (as % of GDP)

1980	1981	1982	1983	1984	1985	1986	1990	1991	1992
0.18	0.41	0.29	0.43	0.13	0.1	0.11	0.08	0.07	0.05

Source: UNESCO Yearbook, 1994

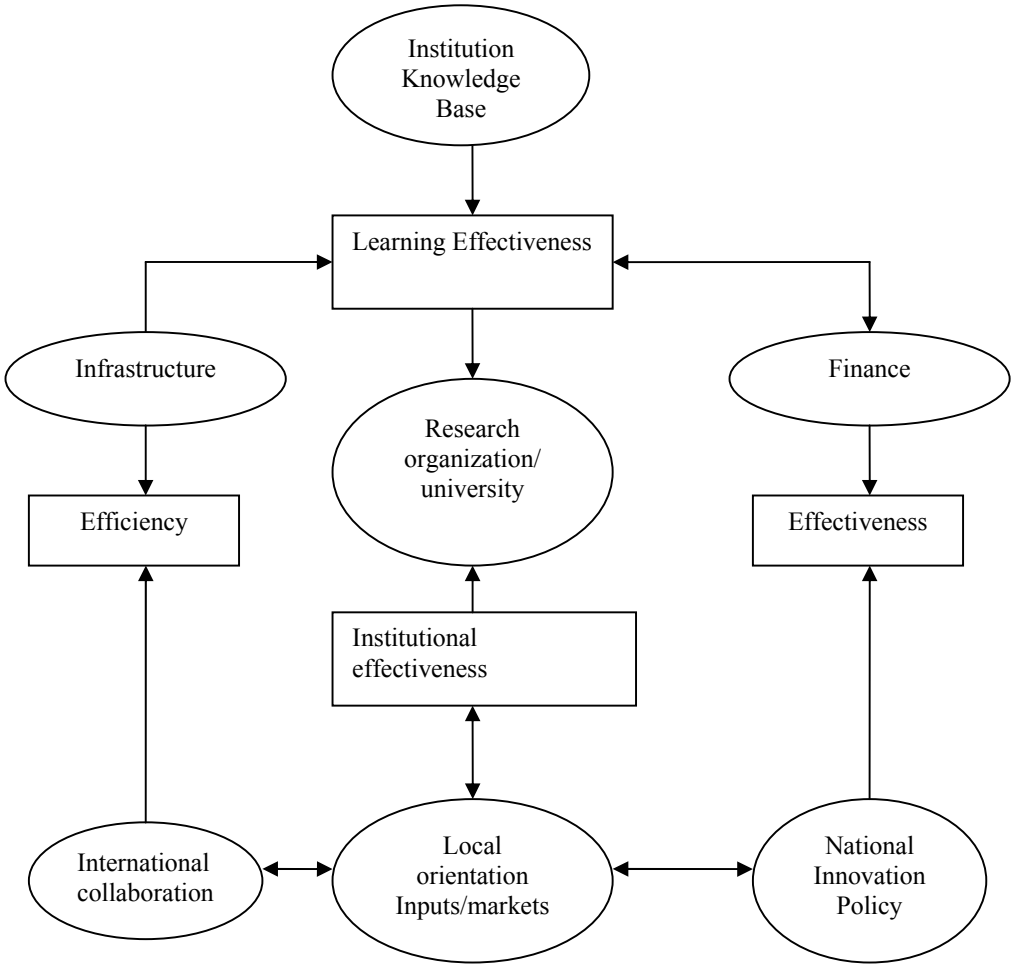
3. Systemic Institutional Barriers and Innovative Efforts: An Analytical framework

The main actors in the biopharmaceutical system of innovation that interact, to collaborate based upon their respective competencies are public research institutions; university departments such as microbiology, botany, pharmacy, medicine and natural sciences, private firms involved in biotechnology; international research institutions; local and indigenous communities; traditional medicine practitioners and hospitals; and, government departments and agencies involved in certification and regulation. A framework is depicted in figure 3.

5 While R&D expenditure gives an indication of research commitment, other measures are required to fully paint a picture of the national innovation capacity such as ratio of scientists and engineers, quality of national laboratories and so on.

The key issues are those of learning efficiency, local orientation, national innovation policy, sources of knowledge exchange and infrastructure.

Figure 3: Analytical Framework



Source: Oyeyinka and Gehl Sampath, 2004

In this framework, the competencies of actors in translating inventions into innovations is linked to four main factors: the role of national innovation policies, learning and learning efficiency of the actors, mechanisms of transferring products and processes into the local market, local and international orientation of actors.

3.1. National Innovation Policies

Innovation policy differs from orthodox science and technology policy in two main respects. First, it seeks above all to promote systemic dynamics within the national economy rather than focusing on one or the other set of actors. Second, it encompasses a wide array of policies that are rooted in the social system in which the policy is operational. The overall objective of innovation policy is to generate systemic efficiency. A considerable number of late followers have attained a high level of per capita income and have succeeded in moving into high-value manufactured export goods such as electronics. A number of systemic instruments have emerged to be crucial in such transitions, including clustering policies, collaborative R&D and science parks (Mathews and Cho 2000; Lall 2001; Amsden 1989; Amsden and Chu 2004; Oyelaran-Oyeyinka and McCormick, 2006). However, much of the successful cases of innovation policy practice are found in East Asia as well as some of the high performing Asian economies, with some Latin American economies notably, Brazil, Argentina, and Chile. The economic performance of these successful latecomers therefore rests in part on their policy-induced, efficient, high-quality technology institutions; highly skilled engineers and professionally managed enterprises, (Amsden, 1989).

African countries have been slower in recognizing the need to address the systemic aspects of policies. The major weakness of the innovation policies of African states has been the neglect of the evolutionary character of technological advance in long-run economic development. While governments have established ministries of science and technology (S&T), most have little interaction with other economic policy ministries and R&D agencies that are in turn isolated from the private sector. This pattern of development inadvertently alienates the policy making machinery from mainstream policy making. Again, the supply-side of knowledge and policy is largely disconnected from the demand side. Governments for instance have set little store on using procurement policy to stimulate demand for innovation. The formulation and implementing of industrial policy is also quite separate from the S&T policy making process. In effect, national technological infrastructure tend to give little support to domestic firms that would benefit from the evolutionary process of technological deepening through learning that is the hallmark of dynamic latecomers. In sum, the legacy of past practices of doing S&T policy, rather than an emphasis on innovation policies, and the weak bureaucratic capacity to manage a modern system of innovation, have combined to severely limit the administrative and institutional capabilities of the African State.

What this means is that innovation systems are shaped by fundamental social processes outside the domain of the firm at the material time.[6] Observed patterns of production and innovation cannot be explained in purely social, economic or technological terms. Innovation systems are rooted within localized learning organizations even in the context of a globalizing learning context. The idiosyncratic character of firms and organizations is developed by the efforts of individual engineers and managers through an evolutionary process, in which the state remains an important coordinator. Since tacit knowledge constitutes an important asset of organizations, firms remain rooted in local socio-economic milieu.

3.2 Technological Learning and Learning Efficiency

According to Dodgson, (1991), "…[f]irms build and supplement their knowledge bases about technologies, products and processes, and develop and improve the broad skills of their work force through various learning processes". Hence learning is crucial to enterprise growth and survival because it is an important avenue for the acquisition of capabilities.

The learning processes and performance of a firm is conditioned significantly by the selection environment, which could be the result of market or non-market selection resulting from the demand and supply conditions in markets, as well as from the institutional and policy context. Selection exerts powerful influence at another level, which is as a determinant of the sources of learning. A learning trajectory as Malerba argues, is a result of the structures of learning which in turn generates the pattern of observed innovation (Malerba, 1982; Metcalfe, 1997), There are diverse sources of learning apart from doing R&D which include learning-by-doing, learning-by-using and learning-by-interacting. Other forms of building up what (Edquist, 2001) called structural capital (knowledge capital controlled at the organization level than by individuals) include training and hiring skilled individuals.
Generally, learning processes are key determinants of innovative activities while institutions are the repositories of knowledge. This is particularly so for tacit, non-codified knowledge at the organizational and firm-level. As North (1996) puts it:

6 The French centralized systems of innovation has its roots in the historical decision by kings seeking means of control and taxation, and the subsequent nation building through a revolution.

> *The speed of economic change is a function of the rate of learning, but the direction of that change is a function of the expected payoffs to acquiring different kinds of knowledge (North, 1996, p. 346; emphasis added).*

In order to develop a new product or process within an organization, firms engage in learning as much through internal R&D and production as through collaborative efforts and competition. There are among others, two broad reasons for this. Firstly, all societies no matter their level of development need to process and use knowledge of one kind or another. This knowledge does not reside only within the organization. As Metcalfe (2003) observes, "…[e]very economy, always and everywhere, is a knowledge economy; for social systems and economies as social systems, could not be arranged otherwise". The second reason is that knowledge growth, validation and transfer is a socially distributed process, mediated by institutions (Lundvall and Johnson, 1994; Metcalfe 2003). However, institutions of knowledge in developing countries are relatively weak and in most cases absent, because small firms, universities and PRIs often lack resources for innovation.

Therefore, understanding the nature and character of a particular national innovation system requires one to examine the processes and efficiency of the learning process within that system. As Lundvall (1992, p. 1) puts it "…[t]he most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning". Systemic cohesion is a key attribute of well functioning system and as such ongoing interactive processes should be able to accommodate the unpredictable, emergent qualities of innovation and new knowledge production. Since much of technological knowledge contains elements of '*tacitness*', making it difficult or very costly to effectively communicate the full range of skills and knowledge required to execute complex tasks, recipients can never hope to obtain all information from codified sources such as blue prints and manuals.

4. Institutions Supporting Knowledge Transfer

Broadly speaking, institutions perform three main tasks, namely, attenuate uncertainty, resolve conflicts and provide incentives (Edquist, 1997). The notions of uncertainty and appropriability are central to the process of innovation. According to (Arrow 1962; Nelson 1959), the key source of technological advance, which is research and development (R&D)

suffers from the twin failures of uncertainty and low appropriability. Firms will under invest in knowledge generation because social rates of return from R&D supersede private returns. The outcomes of inventive activities are inherently uncertain because projects might run into cost and time overruns and commercial outcomes are difficult to predict. Therefore, a firm will place a low premium on a potentially socially useful innovation that, from the judgement of the firm, might be costly, risky, and promise low future returns.

However, institutions, partially due to historical reasons, could constitute systemic institutional barriers to the process of innovation. We consider two broad ways in which this could happen, and they are: institutions that provide a variety of incentives, and institutions that support collaborative learning. Institutions that provide incentives include those established for regulation of the labour market, the terms of employment of university lecturers or employment of scientists in public laboratories. They also include other institutions that are set up to foster organizational learning and establish various infrastructures to commercialize inventions. These include collaborative R&D funds, exchange of personnel and contract research.

The main competencies of the biopharmaceutical innovation system comprise scientific infrastructure, trained personnel, research inputs, such as genetic resources and traditional knowledge. The availability of scientific infrastructure in universities and public research institutes determine the scope for specialization in any or all of the stages of this research, both physical and human capital-related, which are specific for each one of its sub-stages. Trained personnel from various disciplines, some as diverse as physics, informatics and optical sciences are required to facilitate optimal biotechnological innovation, in addition to those in genetics, biochemistry, immunology, cell biology, pharmacy and general medicine (Chiesa and Toletti, 2004).

4.1. Institutions and Innovation Incentives

The dynamics of reward systems and collaboration incentives are an important mechanism that shape the ways inventions are translated to the market although researchers interviewed in our survey tended to rank lack of facilities and research funding as the most critical factor

that affect university performance. Incentive systems tend to develop from more fundamental institutional roots such as labour laws, commercial laws and even a country's constitution. Terms of employment and work environments, both tangible (research and teaching facilities) and intangible (possibilities for institutional collaboration, quality of networks and colleagues) play a pivotal role in retaining skilled professionals. Different countries have different incentives, a good example being the possibility of conferring ownership of patents on individual researchers in German law, thereby granting them intellectual property on their inventions (Giesecke, 2000). As a result, academics have no obligation to share the outcome of research with their employers, and the motivation to file patents is also weakened because individual scientists have to do it on their own. In contrast, the US system facilitates the "Office of Technology Transfer" to assist scientists in the process of finding commercial partners, in return for a share of the royalty. In this wise, the office of technology transfers (OTTs) are operated as profit centres in the US and in the process closer university-industry relations are structured.

There are a number of mechanisms and channels for the effective transfer of knowledge between organizations. The adoption and mastery of a technology requires the acquisition of knowledge about a set of procedures, understanding of why the procedure work and skill in putting them in use. Specifically in the context of academic-industry exchange, several channels have been identified for knowledge transfer and learning, which include publications, mobility of scientists and engineers, informal networks, cooperative R&D, facility sharing, research training (e.g. capacity development at PhD level, international and local exchange of staff), contract research, intellectual property rights (licenses, patents, copyrights), and academic entrepreneurship (Brennenraedts et al, 2006).

Taking a capability view of the organization means that learning efficiency that improves performance will tend to display durability (learning should endure), and appropriability (the ability of a firm to profit from learning) (Peteraf, 1993).

4.2 Institutional Infrastructure Incentives

Translating research to innovation requires a system of knowledge infrastructure of certain quality. It provides the organizational incentive for the long and often complicated process of innovation. Knowledge infrastructure is required at the most basic level of education (training scientists and engineers), as well as at the level of public scientific research and development. These roles are fulfilled by state-based institutions, mainly the universities and PRIs (also known as public research organizations, or PROs). One of the fundamental functions of these institutions is R&D-based learning that creates the absorptive capacity of nations (Teubal, 2001).[7] The state has historically played a leading role in both the early "industrializers" as well as in the more recent dynamic economies such as Taiwan and South Korea (Mowery 2005). For example, the role of universities as a source of trained personnel and streams of scientific and technological knowledge has received considerable attention. Universities are also a facilitator, for example, through the mobility of scientists between university and industry, diffusion of new knowledge, and human capital. In sum, for more than a century, states have recognized and used the institutions of universities and PRIs as a vehicle of catch-up in respective periods, although the roles of the institutions expectedly differ/ evolve with the stage of development. "Institutional differentiation" is required to generate the right kinds of knowledge and skills in an economy, by which Mowery (2005) means the mix of tertiary but non-university establishments such as polytechnics, community colleges and other forms of technical institutes. This mix of institutional structures and the variety of funding arrangements that support them have contributed to the successful response of the system to labour-market demands for skills and knowledge in the developed countries.

4.3 Institutions Promoting Collaborative Learning

The different stages of biopharmaceutical research still engage the same core technologies such as those required for pre-clinical and clinical testing, marketing and manufacturing, remain the same as in the case of traditional drug research (Madhok and Osegowitsch, 2000) despite the changes introduced by biotechnology. Each one of these stages and sub-stages is

7 Teubal considers two mutually reinforcing phases, namely inter-firm learning about R&D (applicable largely to the early innovation phase such as searching for markets and technical information, identifying and generating new projects, learning to screen, evaluate, and choose new projects, and learning to manage the process); and collective learning, which in addition to inter-firm learning, includes managerial and marketing functions that are crucial to the innovation process.

earmarked by specialized actors and competencies, and this underscores the central role of collaboration in biotechnology-based drug research.

Academic-industry collaboration does not just happen. The institutional barriers to natural collaboration are considerable. First, the nature of knowledge generation and transfer between universities and PRIs and industry is complex, highly systemic and context-specific, particularly as a result of the significant but hardly acknowledged tacit content of scientific skills required. Second, there is a wide gap between the motivation, scope and purpose of academic research as opposed to industrial research and production. This complicates the transfer process and restricts the scope for policy incentives (Dasgupta and David, 1994). Third, firms seek external collaboration for purposes of learning because autonomous efforts are costly and innovation outcomes are uncertain. Firms therefore focus on core activities and prefer to specialize, since collaboration releases firms from additional financial commitments, allows them to share risks and spread sunk costs (Bougrain and Haudeville, 2002). However, learning results in new ideas from combining experiences (Hakansson, 1990), while inter-firm cooperation results in the exchange and dissemination of knowledge (Teece et al., 1990).

Fourth, despite the huge investments on public research institutes, they are often ranked low as sources of information. For instance in a study on the topic, only "one third of the firms found the importance of government laboratories to be either moderate or very significant. No firm indicated that the information from universities or government laboratories was crucial for the innovation process". In contrast, over 90% of innovative firms indicated that suppliers of components and materials are at least moderately significant sources of information in Denmark. Similarly, in an earlier study, DeBresson et al. (1998) found that universities and PRIs are cited by only an insignificant number of firms (15%) for collaboration.

Institutional measures are therefore employed to foster academic-industry collaboration. One of this is the grant of p*atent incentives* to researchers which is becoming increasingly common. In the USA, for instance, the Bayh-Doyle Act (1980) was introduced as a means to facilitate technology transfer from universities to industry. The Act allows universities to

retain proprietary rights over invention that were achieved through governmental funding, subject to the condition that the revenues from commercialization of such inventions must be shared with the individual researchers who were the original inventors. This may be a useful incentive, but this path has to be treaded cautiously when one talks of this in a developing country context.

Funding can be used to encourage collaborative research in an effective way. The Japanese government initiated several R&D programmes for biotechnology that had university-industry linkages as a pre-condition for the selection/ funding of research projects in the past two decades. Through these conditions, inter-organizational interactions were promoted (see Hayashi, 2003). Others measures include R&D contracts, reimbursable grants and state R&D procurement (Inzelt, 2004).

5. Data Sources and Variables

The survey employed a multi-method field study approach. We collected a wide variety of data, which include primary, secondary, and consulted with different expert sources in building up the case studies that rely considerably on scientific expertise perception of scientists.

The first tool was a review of existing data sources including policy documents, from the relevant ministries and agencies such as the S&T, agriculture and industry ministries. Information was collected from relatively new agencies such as the SHEDA Science and Technology Complex (SHESTCO). Others are the newly created National Biotechnology Development Agency (NABDA), and older institutions such as International Institute of Tropical Agriculture (IITA), International Livestock Research Institute (ILRI), University departments (microbiology, botany, biotechnology, molecular biology, medicine, among others), and the National Veterinary Research Institute (NVRI), Vom.

The next instrument was a set of semi – structured interviews of leading experts in biotechnology. This exercise was necessary for two reasons. First, it helped to clarify the

structure and content of our framework and secondly, it was used to refine and provide content validation to the survey questionnaire.

We thereafter refined the questionnaire after a pilot test it on a small portion of our sample largely the key informants that we had earlier identified using a list from our contacts of the key institutions that form our samples. We also relied extensively on the Nigeria biotechnology country report that was earlier prepared by NABDA in the process of this study. Broadly we interviewed and serve questionnaires on the following category of actors:

- Public and International Research Institutions;
- University departments such as microbiology, botany, virology, and so on;
- Private firms involved in agriculture biotechnology (crop and livestock);
- International Research Institutions; and
- Local research institutes
- Traditional medicine practitioners and hospitals.
- NGOs
- Representatives of local and indigenous communities

In all, we retrieved 170 questionnaires and carried out face-to-face interviews with over sixty actors, including scientists working in universities, PRIs, firm executives, officers at governmental agencies and doctors/ workers at traditional health institutes and primary health centres.

5.1. The Model

The model hypothesizes a functional relation between innovation activity (the propensity to invent and subsequent translation into a commercial product or process) and a number of explanatory variables that represent the capacity of scientific organizations in which scientists are based. The study based on preliminary interviews focus on product innovation measured in terms of a discrete variable that takes a value of 1 if an organization has been involved in the development its OWN NEW PRODUCT. From our analytical framework, an invention

runs literally a gauntlet of innovation steps and the probability of reaching the market is a function of many factors. Again, we do not make a distinction between the possible changes to processes given that our domain is the scientific laboratory rather than the firm where continuous or incremental technical changes might take on a much more heterogeneous function where innovation to a product will require simultaneous alteration to process. The unit of analysis is the individual scientist.

A probit analysis was undertaken to examine the determinants of probability to innovate in public institutions in Nigeria. Once again, the probit model used enables us to identify the direction of various variables on the likelihood that an institution (University or PRI) undertakes innovation. The model specifying the dependent and independent variables are defined. The propensity to, and the factors that constitute barriers to innovate in Nigeria's universities and PRIs engaged biotechnology research is depicted in the probit model.

$$Ln\frac{p}{1-p} = \qquad B_0 + B_1\sum_{l=1}^{n} X_i$$

Where P = the probability that an institution does innovate. This was based on a simple question simply asked to determine whether an institution had been involved in OWN DEVELOPMENT OF A NEW PRODUCT. X_i's represents the explanatory variables considered.

Dependent Variable: **This is based on observed innovation in an organization**

From the survey data (on universities and PRIs), an organization is regarded as having undertaken innovation if in had been involved in OWN NEW PRODUCT development in the last 3 years. Hence,

Newprod	=	1	If an organization developed a new (own) product in the past 3 yrs
	=	0	Otherwise

Independent Variables

Medresearch	=	1	if an institute participates in medical research
	=	0	Otherwise
Totalpmb	=		Total staff with PHD, Masters and Bachelors in absolute numbers.
Locdisall	=	1	if an institute spends all in research directed towards local disease conditions
	=	0	Otherwise
Locdisall	=	1	if an institute spends 50 % in research directed towards local disease conditions
	=	0	Otherwise
Locdisall	=	1	if an institute spends 25 % in research directed towards local disease conditions
	=	0	Otherwise
Fundgovbn	=	1	If an institute obtains funding from the government
	=	0	Otherwise
Forcollbn	=	1	Strong foreign links
	=	0	Low foreign links
Academiccoll	=	1	Strong academic collaborations
	=	0	weak academic collaborations
Hospitalcoll	=	1	Strong hospital collaborations
	=	0	weak industrial collaborations
Medicprccoll	=	1	Strong medical collaborations
	=	0	weak industrial collaborations

Penvbiotfhi	=	1	If an institute views present biotech environment as very strong
	=	0	Otherwise

Collaboration intensity is derived from response ratings provided in the questionnaire. The benchmark is "3"; that is, if an organization has a rating above "3" collaboration is regarded as strong and below 3 is regarded as weak/low.

The strength of the institutional environment is determined taking into consideration several factors particularly relating to the availability of knowledge infrastructure proxied by Information and Communication Technology (ICT), and physical infrastructure proxied by power and water. The functioning of a good laboratory depends to a large extent on the last two factors(which is often a constraining factor in developing countries) in addition to the basic requirements of reagents and son on. So the average of the three factors is computed and if an institution had above 2 in the rank provided it is taken to mean that it viewed the present environment for biotechnology as strong.

The other institutional factors are finance, collaborative learning (of different kinds), incentive systems to focus on local disease or food problems and the availability of human capital (PhDs and Masters level holders). The progress to the different phases of biotechnology research and commercia;ization is a measure of how much of the gautlet a laboratory ran in the rough road to market.

5.2. Findings

5.2.1. Descriptive Analysis

Tables 4 and 5 show that 67% and 73.5% of universities and PRIs research efforts respectively are focused on screening and laboratory based product development, a finding that shows the dominant activities of the research centres. *H*owever there are variations particularly between the older universities (UI and OAU) in the Southern part of the country with a relatively longer history of research and the newer universities such as FUT based in

the North. More clinical/field trials are being undertaken in the latter universities for two main reasons. They have a more entrenched tradition of research and with this advantage greater number of well known scientists with local and international connections to other research centres. For the aforesaid reason they have been able to attract greater research funds. For instance the WHO malaria research programme is based in the medical science faculty at the UI, a programme that has now been expanded into a regional activity with UI, its hub. *What this means is that commercialization of research results has not proceeded further than the laboratory in many instances.*

Table 6 provides a descriptive explanation of the inventive capabilities of the organizations based on four different variables namely, capacity for new product/process, continuous investment in equipment, capacity to undertake own R&D, and the capacity of the laboratory to undertake biotechnology activity. The four variables relate to the following capabilities measured against a benchmark that the scientists know: skills and knowleddge, financial resources, combined experience and qualification of staff, and scientific infrastructure respectively. The F-test shows statistical significance in three of the variables (except for investment in new laboratory equipment) between the PRIs but they all rate relatively low. The table shows a low rate of investment across the agencies confirming what we found during the interviews and visits to the various organizations.

Table 4: Share of university activity at different stages of the innovation process

Institutions	Screening/secondary screening %	Product/process development %	Clinical/field trials %	Current production %	Total respondents
ABU	22%	15%	4%		13%
FUT	15%	15%	13%	23%	15%
OAU	27%	30%	17%	23%	25%
UI	37%	41%	65%	54%	46%
Total	41 (10%0)	27 (10%0)	23 (100%)	13 (100%)	104 (100%)

N=104

Table 5: Stages of Research and Share of Development Activity in PRIs

Institutions	Screening /secondary screening %	Product/process development %	Clinical/field trials %	Current production %
1. NAGRAB				
2. NVRI	13.6	34.1	30.7	21.6
3. NIPRD	57.6	15.6	12.4	14.4
4. SHETSCO	68.3	31.7		
Total	46.4	27.1	21.5	17.5

Table 6: Capabilities for Process and Product Innovation

Variables	**NVRI**	**NIPRID**	**SHETSCO**	**Total**	**Sig**
New product development	1.700 (.48305)	1.900 (.31623)	1.4286 (.53452)	1.7037 (.46532)	.119 .071
Investment in new equipment	1.100 (.3162)	1.500 (.52705)	1.2857 (.48795)	1.2963 (.46532)	.159 .101
New Process based on in-house R&D	1.200 (.42164)	1.900 (.31623)	1.2857 (.48795)	1.4815 (.50918)	.002 .000
Rating of laboratory facilities	3.50 (.577)	3.67 (.577)	2.25 (.500)	3.09 (.931)	.015 .066

N=109

Table 7: Local Collaboration ratings by universities

	Firms	Universities	PRIs
ABU	1.73	1.65	1.88
FUT	2	1.64	1.99
OAU	3.67	1.93	3.34
UI	3.05	4.01	4.03

1= very low; 5= very strong; N=69

Table 8: Intensity of local and foreign collaboration index (scale 1-5)

Institutions→ Type of collaboration	NAGRAB	NVRI	NIPRID	SHETSCO
Local	2.00	1.80	2.40	2.69
Foreign	3.00	1.40	2.80	2.86

Source: Authors survey

5.2.2. Empirical Results

The results of the estimated probit model are shown in Table 9. Two models were estimated, model 1 and model 2. The diagnostic tests indicate that the models estimated are of good fit; they include Log likelihood, Likelihood ratio LR-Test and Pseudo R^2. There were no multicolinearity or heteroscedasticity detected.

Our interviews show that organizations are judged to be successful on the strength of their ability to solve local problems such as containing disease outbreaks or finding solutions to neglected diseases[8]. We therefore included the scientific effort and intensity of resources devoted to local disease problems as key factors in the models. We examine three levels of local disease investment (at 25%, 50% and 100% levels). The variable is coded: "Locdisall". Model 1 is estimated with the three levels of disease investment which considered the proportion of money directed towards local disease conditions. In model 2, only one level of local disease investment is included. In the first model, four variables are significant and these are: human capital which is a composite of the holders of PhDs, Masters and bachelor holders (Totalpmb), Locdisall, Locdis25 and level of foreign collaboration (Forcollbn). Totalpmb is positive and significant at 10 percent. Locdisall and Forcollbn are both positive and significant at 1 percent. Locdis25 is positive and significant at 5 percent. In model 2, with Locdisall only, government funding (Fundgovbn) became positive and significant at 10 percent. All the other variables remain significant except for Totalpmb which became insignificant. The statistical interpretation of all these results is that the probability of innovation increases with Totalpmb, Locdisall, Locdis25, Forcollbn and Fundgovbn in an organization. All the collaborative variables are not significant.

8 Two notable examples in our study are advances made by the National Veterinary Research Institute (NVRI), an eighty year old organization that has recorded landmark innovations in containing various animal disease outbreaks such as rinderpest not just in Nigeria but across West Africa. The second is the NIPRID which has succeeded in developing a drug for sickle cell anemia, an orphan disease.

Table 9: Probit Analysis with Innovation as the Dependent Variable

Independent Variables	Coefficients Model 1	P-Values	Coefficients Model 2	P-Values
Medresearch	0.163 (0.287)	0.572	0.121 (0.272)	0.656
Totalpmb	0.054 (0.028)	0.056	0.039 (0.027)	0.151
Locdisall	0.865 (0.319)	0.007	0.539 (0.286)	0.060
Locdis50	0.739 (0.494)	0.135	-	-
Locdis25	1.325 (0.522)	0.011	-	-
Fundgovbn	0.430 (0.316)	0.173	0.502 (0.303)	0.097
Forcollbn	0.887 (0.305)	0.004	0.791 (0.293)	0.007
Academiccoll	-0.215 (0.336)	0.523	-0.221 (0.322)	0.493
Hospitalcoll	0.580 (0.376)	0.123	0.553 (0.370)	0.135
Medicpraccoll	-0.388 (0.371)	0.296	-0.228 (0.360)	0.527
Penvbiotfhi	-0.197 (0.372)	0.597	0.006 (0.358)	0.986
Constant	-1.491 (0.315)	0.000	-1.210 (0.278)	0.000
No of Observations	119		119	
LR–Test	37.08 (0.00)		29.00 (0.00)	
Log Likelihood	-61.30		-65.34	
Pseudo R^2	0.23		0.18	

Note: Numbers in parentheses represent standard errors
Source: Computed from UNU-INTECH survey

Table 10 represents results of marginal effects on innovation. The coefficients represent the mean values of marginal effects. All the variables are significant and retained their signs. The interpretation of these variables is that if an organization increases its employment of staff with Ph.D., masters, and bachelors by one unit, it is likely to increase its chance of innovation by 0.02 points (2 %). All the other variables would be interpreted in the same way. For instance a investing in local disease (at different rates) Locdisall, Locdis50,

Locdis25, fostering foreign collaboration (Forcollbn) and increasing funding by government (Fundgovnbn) would have an increment of 0.329, 0.288, 0.48, 0.34 and 0.185 respectively. This could mean that there is considerable potential to improve for all the given variables. For instance, while collaborative variables were in themselves not significant, marginal effects analysis shows that there is scope for increased organizational performance through collaborative learning.

Table 10: Marginal Effects on Innovation

Independent Variables	**Marginal Effects Model 1**	**P-Values**	**Marginal Effects Model 2**	**P-Values**
Medresearch	0.062 (0.109)	0.572	0.046 (0.104)	0.656
Totalpmb	0.020 (0.011)	0.058	0.015 (0.011)	0.154
Locdisall	0.329 (0.116)	0.005	0.208 (0.110)	0.058
Locdis50	0.288 (0.185)	0.119		
Locdis25	0.480 (0.143)	0.001		
Fundgovbn	0.159 (0.111)	0.156	0.185 (0.107)	0.083
Forcollbn	0.340 (0.112)	0.002	0.305 (0.110)	0.006
Academiccoll	-0.082 (0.128)	0.523	-0.085 (0.123)	0.493
Hospitalcoll	0.224 (0.145)	0.122	0.214 (0.143)	0.134
Medicpraccoll	-0.142 (0.130)	0.276	-0.086 (0.133)	0.518
Penvbiotfhi	-0.073 (0.134)	0.587	0.002 (0.137)	0.986

Note: Numbers in parentheses represent standard errors
Source: Computed from UNU-INTECH survey

6. Case Studies

This research explores a set of propositions on what constitutes barriers to translating inventive research and development in biotechnology to innovation in a developing context. A number of structural and institutional variables were included in the multivariate equation used, namely, the types of collaboration, the nature of funding, and the focus of investment.

The analysis underpinned the fact that success in biopharmaceutical research relies on multidisciplinary collaboration between scientists in different scientific fields as well as the creation of new institutions that may previously be alien to the way scientific work is carried out in developing countries. In this section, we present two case studies to illustrate the role of institutions in the in translating inventive efforts to innovation in the biopharmaceutical system of innovation.

6.1. Institutions and Human capital: Federal University of Technology Minna Vaccine development

The study focused on the activities of the Faculty of Biological Sciences headed by a professor with a long experience in animal diseases that proved useful in solving an outbreak of human disease epidemic. The focus of the case study is the Typhoid Fever (TF) vaccine developed by the faculty scientists after a major outbreak of the disease in 1992/94. The potential widespread implications of an unmitigated health disaster prompted the scientists at the Federal University of Technology Minna (FUTM) to seek a solution. In what follows, we narrate the process by which the group developed the vaccine and draw the necessary lessons.

The scientists collected samples from local strains from infected persons and then isolated the organism, which is a standard procedure. But beyond this stage, they lacked the necessary equipment and facilities to proceed further, and therefore, sought external assistance. The samples were sent to a laboratory in Collendale, United Kingdom for characterization of the isolates. They thereafter requested for stock culture and simultaneously prepared stock from local strains. From this, vaccines were developed and they subsequently injected mice, rabbits and monkeys in that order before clinical trials were carried out on humans. At this point, the National Agency for Food and Drugs Control (NAFDAC) was informed and the Agency carried out their own independent assessment but suggested extensive modifications to the facilities and structures at FUTM. This might well be a reflection of the very poor state of the laboratories under which the scientists work.

About 4000 mice were used in the experiment in order to try 68 different types of vaccines and in the process 38 of these were eliminated. The next phase trial on rabbits eliminated all but 3, out of which one was found outstanding. The test outcome proved the superiority of local strains.

The Typhoid vaccine project raises a number of issues, all related to institutional weaknesses. First, getting the research off the ground required considerable individual efforts aided by a confluence of institutional collaboration. The team leader is a virologist who had earlier spent fifteen years at the Natural Veterinary Research Institute (NVRI) before moving to the FUTM to start the microbiology department in 1988 motivated the research. His work at the NVRI was to develop animal vaccines and the competence was brought to bear on the development of TP vaccine for humans. NVRI and NPRID played different but important roles in developing the vaccine.

The second is the funding constraint, an issue that resonated in all our interviews at all the institutions we visited. The process was threatened by poor funding at all phases. Obtaining the requisite laboratory materials and animals required a relatively significant amount of money, given the poor resources of the University. The scientists had no special research funds to draw from and at critical junctures the vaccine development process was saved by sheer serendipitous meeting with some individual and organizational collaboration.

The third was the terms of employment that put the onus for patenting on the individual scientist. The money required was beyond the means of the scientists and the product was patented without assistance from the university. Needless to say, the university has no technology transfer office or any of its variant to help.

Fourth, and more pervasively as far as most institutions are concerned, the facilities for characterizing isolates were missing. It was the chance intervention of UNIPETROL, an oil company that saved the process. The company paid for the transportation of the sample to the laboratory in the United Kingdom where the isolates was characterized.

Finally, although the technique was patented and vaccines were administered to over 2000 persons within the Minna area, nothing much has been done ever since because the investors have no clue as to what next to do. The university as an institution can do very little to produce the vaccines in mass quantities and the scientists themselves are unable to initiate the process. In fact, little is known about this important work, which has been published in a number of local and international journals.

Instead of recognizing and promoting the research potential at the FUTM, massive cuts in public budget to universities, has resulted in reducing the capacity of the institution to do quality research at the institution. The fact that FUTM has little external links and relies almost completely on federal funding to carry out research is reflected in the very poor if not non-existent follow-up efforts to the typhoid fever project.

6.2. NIPRID and Sickle Cell Research

NIPRD has a scientific and technical staff of over 75 personnel comprising pharmacists, clinicians, pharmacologists, clinical pharmacologists, microbiologists, chemists, molecular biologists, pharmacognosists, phytochemists, taxonomists, chemical engineers, immunologists, biochemists, information scientists, computer scientists and instrument technicians. The institute has a company called NIPCO Pharmaceuticals, a drug manufacturing outfit which carries out activities in drug manufacturing, quality control and product research and development.

NIPRD has conducted research and development investigations on the following:
i. Development of pharmaceutical grade starch, glycerin and kaolin using local resources
ii. Production and quality control of pharmaceutical products from medicinal and aromatic plants
iii. Documentation of indigenous medicinal and aromatic plants[9]; and

9 A Nigerian herbal pharmacopoeia was initiated at NIPRID due to the poor statistics on medicinal herbs. In 1990 a documentation exercise resulted in the classification of 650 medicinal plants used largely around the Federal Capital Territory where NIPRID is based. A joint ethobotanical survey of Bauchi State was also carried out jointly with the Abubakar Tafawa balewa University in Bauchi. The framework for the surveys had envisaged a countrywide survey in collaboration with universities based in the local areas in the hope of building a compedium

iv. Screening of indigenous medicinal plant extracts and products used widely in ethnomedicine for the management of sickle cell disorder, HIV/AIDS disease, malaria, diabetes, bacterial and fungal infections, hypertension, epilepsy, asthma, parasitic infections and contraception. In additional to the national compendium, the Institute has undertaken a limited cultivation of plants at their Medicinal Plant Garden to ensure their survival and to maximize the yield of active constituents from the herbs.

The institute has developed collaboration with traditional medicine practitioners, and developed some drugs from indigenous plants namely,

- NIPRISAN is a drug used for the prophylactic management of sickle cell disorder;
- NIPRIPAN is an anti – ulcer preparation developed from Nigerian indigenous herb;
- NIPRIFAN, a highly effective topical anti – fungal agent, was developed from a local plant;

In addition to research activities, NIPRID is engaged in drug production, quality control services, and diagnostic consulting services. As part of these services, it has developed pharmaceutical grade starch from local maize up to the pilot plant stage although commercial production has yet to start. This is an important contribution since the country imports 100% of this grade of starch.

However, it is the landmark research into, and discovery and production of, NIPRISAN, a drug used for the prophylactic management of sickle cell that seems to define the efforts of the Institute thus far. Information on the potency of a local medicinal plant was related to the then chief executive of NIPRID, Professor Charles Wambebe by a traditional healer who also was an Anglican reverend gentleman, and a descendant from a family of traditional healers. NIPRID entered into a formal contractual agreement with the healer after ascertaining his willingness. An important incentive for the healer was the provision in the agreement for the Institute to purchase the raw materials directly from the healer – this enabled him to make substantial earnings. The contractual stipulations also include revenues of 7% to NIPRID and 3% to the healer for all sales of the drug NIPRISAN. NIPRISAN has been developed into both capsule forms and drug syrup granules for pediatric use. Clinical trials of the drug were conducted between 1997 and 2002. At the time of the survey, the process of local certification through the NAFDAC was far advanced but incomplete.

An all-purpose essential oils extraction pilot plant for the production of NIPRISAN and other drugs was funded by the FGN, UNDP/UNIDO in the late 1990s and has been an essential facility despite the frequent power outages and occasional breakdowns due to the lack of spare parts and components. Assisted by UNIDO, the product was patented in 1998 in the United States and initial efforts for production initiated through collaboration with a US-based pharmaceutical firm, Xechem, to which the NIPRISAN production was licensed.

NIPRID has developed a network of collaboration with a number of domestic and international organizations which include the National Institute of Health, United States, Institute of Human Virology, Baltimore, United States (collaborative work on HIV-1 vaccines project); Centre for Disease Control and Prevention (CDC) Atlanta, USA, the Robert Koch Institute, Berlin, Germany; the Council for Scientific and Industrial Research (CSIR), New Delhi, India; Central Drug Research Institute, Lucknow, India and the London School of Hygiene and Tropical Medicine, UK. Locally, NIPRID has collaborative research ventures with all major universities. The Institute has entered into collaborative R&D agreements and consultancy services with various corporate and governmental organizations for the supply of laboratory equipment and financing of specific research projects. For instance, one of the earliest research grants of US$3.5 million was made by the Japanese government for the procurement of research equipment, an exercise that was contracted to the British Crown Agent, London. The UNDP also made a grant of US$1.4 million to NIPRI for the project titled: "Techno-Economic Development of Medicinal and Aromatic Plants for Indistrial Purposes" and followed this up with a supplementary grant of US$ 250,000 in December 1997for the purchase od equipment for the Human Virology and Biotechnology Department. The procurement of the equipment was contracted to UNIDO (Vienna).

NIPRID has had some success but clearly has not realized its promise. The main limitations that have impeded progress for NIPRID, FUTM and the other PRIs and universities visited could be summed up as follows:

- Institutional constraints that lead to poor funding and sebsequent lack of facilities for biotechnology-based research.

- Lack of institutional infrastructure to conclude meaningful partnerships with holders of traditional medicinal knowledge and to contract in states of drug development.

- Lack of regulatory mechanisms to test for efficacy and safety of traditional preparations.

- Institutional rigidities that undermine interaction between universities, public research institutes and agencies that possess the mandate to commercialize drugs based on traditional knowledge, such as NIPRID.

- Lack of private sector interest in drug development**:** presently, most of universites and PRIs research (90%) focuses on screening and secondary screening, with only a last 10% focus on product development activities. Large pharmaceutical firms in Nigeria show little interest and new technology-based firms are yet to fill this gap.

- Lack of governmental aid in conducting research: presently, 90% of their research funds are from international sources, with only 10% from the Nigerian government. The grant money is used to purchase laboratory equipment and chemical agents that are required for conducting research.

- Lack of foreign research collaborations that may help scientific and technological capacity building:

Presently, except for grants, there are no systematic capacity building partnerships with foreign partners despite efforts by various research the teams. Long term commitment by the government will be the more effective solution while grants and aids supplement.

7. Conclusions

In the foregoing analysis, we have employed both qualitative and quantitative approaches to understand the nature of interactions that lead to translating research into innovation. Four major factors condition the competencies of actors in any given system of innovation in

translating inventions into innovations: national innovation policies, learning efficiency of actors, mechanisms available to translate products and processes into the local markets and the innovation orientation of actors. The presence or absence of institutions (or the inadequacy thereof), in turn, are central to how these competencies emerge over time. We have considered two broad ways in which institutions end up constituting systemic institutional barriers to the process of innovation, instead of alleviating them. This is linked to the ability of institutions to provide incentives for innovation and for infrastructural facilities in certain science-based technologies, and the ability of institutions to enable collaborative learning. The lack of such basic-yet-critical endowments can hinder capacity from developing in biopharmaceutical research, despite the fact that there are several pockets of excellence in this area within Nigeria. The paper has used the case of PRI and university capacity to come up with new innovative products and processes to demonstrate this. A variety of variables that play a significant role in promoting innovation in biopharmaceutical research have been considered, and their marginal effects have been calculated.

The data collected in Nigeria confirms our analysis on the factors that cause systemic disarticulation and weak collaboration. All organizations survryed have sought collaboration and those that are presently not doing so, express the desire for both local and international partnerships. They are clearly limited by the systemic factors that do not lay weight on promoting collaboration, lack of interest amongst some/ many sets of actors, like the private sector, and policies that do not view collaboration in a dynamic perspective. Secondly, there is also a lack of institutional incentives. The institutions in which scientists work hardly reward entrepreneurship and there is no motivation to make additional effort beyond publication of academic papers. Most academics do not understand the institution of patents for instance and have had little guide as to what to do to move inventions to the market. Moreover, the sheer weight of infrastructural constraints leaves them with very little energy to think beyond their immediate concerns. The concerns with short term goals was evident and long term commercialization efforts was down the priority list of scientists. It was evident to the research groups that major institutional shifts would be required to change the present habits and practices of the PRIs. While individual researchers are able to carry on working up to a point, the odds rise dramatically as projects demand better facilities, skills

and knowledge that the lone scientist could offer. The lack of infrastructure facilities compounds this issue further. Formal institutional arrangements which we find missing in almost all cases would then be required. This also leads us to conclude that collaborative efforts are inevitable between the different PRIs and with external technical partners. Our interviews show that collaboration has been limited by three main factors, namely, the inability of scientists to move their work beyond the individual organizations; the absence of formal institutions supporting collaboration; and, poor incentive to motivate scientists.

On the question of learning and obstacles to the innovation process, three point seem pertinent. First, an understanding of the process gives an insight into the motives and limits of the organizations capacity. Second, it provides some clue into the nature of the value that an organization is able to add to the natural starting material given that biopharmaceutical remains one of the few activities that tend to follow the linear technology-push model whereby products follow almost directly from invention to prototype to the market, Trott (1998). Third, the nature of activity and the locus of the organization's work in the process may also suggest to the relevance and the perceived importance of the product by the market. For instance, in this study we find that several research projects remain at incipient stages.

Our analysis of the innovation process for biopharmaceutical research within Nigeria reveals specific obstacles at different stages of work that the institutions were engaged in, for three reasons. First, lack of facilities and financing to move the research to the concluding stages. Second, we found situations where significant research results had been collected, with evidence of possible utility of the process and product, but no demand by the end-users[10]. Third, failure to commercialize sometime resulting from institutional rigidity much of which relates to the ways traditional PRIs and universities are set up. There are two issues that recurred in our interviews namely, who initiate the process (the PRI or a firm/entrepreneur?); and what form of formal or informal contract guides the process? In advanced developing and highly industrialized countries, two broad types of formal contract

10 As Jolly, (1997) observed, technologies and for that products and process inventions fail not so much for the skills of the inventor and the lack of market but because no one promotes or get sufficiently interested in them.

are common, which are, academic entrepreneurship, and spin-off companies from public research or universities.[11]

Across the different PRIs, major efforts and resources seem to be concentrated at the early stages of drug development, which is screening and secondary screening (30% to 68.3%). As such there is no statistically significant difference between institutes, meaning that all the PRIs are engaged uniformly in this activity. However, at the next level, which is process/product development/field trial, we find significant difference while only two of the institute, NVRI and NIPRID are involved in production activity. For instance, NIPRID produces the anti- sickle cell drug called Niprisan while NVRI is involved in vaccine production, albeit on a limited basis for regional and national clients. Understandably, SHETSCO being a fairly young establishment is not involved in any form of production.

11 Academic entrepreneurship takes several forms namely; (a) Involvement in large-scale externally funded research, (b) consultancy to earn supplementary income; (c) university-industry research and transfer of technology, (d) patents and trade secrets, and (e) commercialization which might involve holding equity in private enterprises by scientists, see Altonen, M. (1998).

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