Journal of International Development
J. Int. Dev. **22**, 962–977 (2010)
Published online 30 March 2009 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/jid.1560

ROUGH ROAD TO THE MARKET: CONSTRAINED BIOTECHNOLOGY INNOVATION AND ENTREPRENEURSHIP IN NIGERIA AND GHANA

PADMASHREE GEHL SAMPATH[1]* and BANJI OYELARAN-OYEYINKA[2]†
[1] *Open University, Milton Keynes, UK*
[2] *United Nations University-MERIT, Maastricht, The Netherlands*

Abstract: The paper analyses collaborative learning in knowledge generation in biotechnology in two very late follower economies, namely, Nigeria and Ghana in order to compare the innovation and entrepreneurship experiences they present. We suggest that the quality of physical infrastructure, knowledge infrastructure (including appropriate human skills), in addition to institutions and incentives for innovation contribute in large part to observed processes of innovation success. Regardless of whether the initiating step is the incremental design or laboratory-based R&D stage, these factors are critical determinants of commercialisation. We use empirical data from the public sector institutions collected through field level surveys to substantiate these results. Copyright © 2009 John Wiley & Sons, Ltd.

Keywords: biotechnology; latecomer countries; innovation; learning; interlinkages; commercialisation; research

1 INTRODUCTION

This paper focuses on processes of endogenous technological and innovation capacity building in the poorer latecomer countries with the aim to identify factors that determine the successful translation of inventive activities to commercially viable products and processes. It is well known that the path from the laboratory to the market could be long and expensive and the outcome uncertain. Institutional and structural factors pose significant and unexpected obstacles particularly in a global context with fast changing rules of the game. The paper analyses collaborative learning in knowledge generation in two very late

*Correspondence to: Padmashree Gehl Sampath, UK International Innovation and Development, Open University, Walton Hall Milton Keynes, Milton Keynes, MK76AA, UK. E-mail: p.gehlsampath@open.ac.uk
†Professorial fellow.

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corner economies, namely, Nigeria and Ghana in order to compare the innovation and entrepreneurship experiences they present. We suggest that poor flows of knowledge and information and the weaknesses in the creating local linkages are in large part responsible for the weak performance of economic actors (firms and industrial organisations alike).

As with most latecomer countries, the two countries under consideration in this paper have set up several knowledge-related institutions (such as public research institutes and centres of excellence) since the colonial period, however, there has been poignant deterioration due in part to lack of investment in facilities and human capacity development (IFPRI, 2006). For this reason, these organisations have been unable to fulfil the promise that was expected of them at inception particularly in respect of tangible innovations. The quality of physical infrastructure, knowledge infrastructure (including appropriate human skills), in addition to institutions and incentives for innovation contribute in large part to observed processes of innovation success. Regardless of whether the initiating step is the incremental design or laboratory-based R&D stage, these factors are critical determinants of commercialisation. In this paper, therefore, we test three broad propositions, namely

1. Infrastructure (both physical and knowledge) has strong correlation with innovation performance.
2. Collaboration between key agents in the domestic knowledge system has strong correlation with innovation performance.
3. Government policy on innovation has strong correlation with innovation performance.

Using public sector institutions and industry as the basis, the focus of analysis will be on showing how the different physical and scientific infrastructural components interact in the process of knowledge generation, use and transfer and how social institutions, norms and policy frameworks condition these interactions. The analysis aims to identify the principal forms of interaction between different organisations and firms; evaluate the determinants of collaboration particularly the role of public goods and policies and their impact on innovative performance. It points out to an important but neglected reason why inventive efforts tend to get largely buried in the pre-commercial phase in latecomer country contexts: firstly, investing in primary research without extension services that allow for entrepreneurial venues, and characterised by a lack of policy incentives for collaboration between different actors. It sheds light on how policy change could help attenuate this phenomenon. Secondly, the comparative insights that are thrown up from the two-country analysis lend strength to our argument on the relevance of different institutional and historical factors for knowledge generation.

We have chosen to examine biotechnology deliberately. It is a new technology with considerable research payoffs to developing countries but demands the presence of certain *ex-ante* innovation conditions. We define biotechnology not as a sector, but as a new technology with potential for integration into numerous traditional sectors, such as pharmaceuticals, agriculture, environment and industry in general. In this paper, we focus on agricultural biotechnology only.

The rest of the paper is organised as follows. In the next section, we provide the basic hypothesis and the data collection techniques in the two field countries, Nigeria and Ghana. This is followed by case studies and survey results of the biotechnology sector in both countries, with a specific emphasis on collaborative linkages and their impact on innovation and performance and the role of governmental support. The last section presents comparative analyses and concludes. We also use these two cases to highlight the point that institutions for promoting innovation and new technologies have to be strategic in the case

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of latecomer countries. Nigeria and Ghana have only established the barest research facilities in the public sector but are severely lacking strategic policy for private sector initiatives that should capitalise on these research results to produce commercially viable products.

2 DATA AND VARIABLES

Surveys in both countries employed a multi-method approach, consisting of three stages. In the first stage, background reports were prepared to gauge the state of S&T infrastructure for biotechnology research in the country using a review of existing secondary sources on the topic. The second stage consisted of a questionnaire survey that was administered to researchers in universities and public research institutes in Nigeria and Ghana. The third stage comprised face-to-face interviews and select case studies that seek to illustrate important characteristics of the innovation processes as well as the institutional contexts of the actors in both countries. Our units of measurement are the university departments and units within Public Research Institutions (PRIs), or the firms. These included among others, agriculture, chemistry, biology, biotechnology, biochemistry, microbiology and pharmacy.

The Nigerian data were collected during a 2006 survey[1] of universities and three PRIs in Nigeria on aspects of collaborative behaviour within the system of innovation. A total of 210 questionnaires were retrieved out of the 250 administered and face-to-face interviews with over a dozen scientists were carried out. The Ghanaian data were collected as part of a biotechnology survey in 2005 in collaboration with the Centre for Scientific and Industrial Research (CSIR), Ghana. One hundred questionnaires were administered to high-ranking researchers engaged in the development and application of biotechnological techniques in research institutes and universities within the country. Semi-structured questionnaires were complemented by face-to-face interviews with over 20 researchers spread all over Ghana.

3 SYSTEMIC COLLABORATIONS IN NIGERIA: CASE STUDY AND RESULTS OF THE SURVEY

In this section, we start with the presentation of a case of a relatively successful collaboration among key innovation actors for affecting a change to the process brewery technology induced by an economic crisis. This is followed by a statistical and econometric analysis of linkages.

3.1 Case Study: Collaborative Learning and Brewery Technology[2]

The problem of the brewing sector in Nigeria was conceptualised by the government as a failure by private firms to apply extant technical knowledge to the solution of a rising volume of import of an intermediate input, barley malt. Experimental and limited applied

[1]The study was jointly coordinated by the authors and funded in part by the IDRC.
[2]This study was conducted in part in 2002 and revisited for this paper. Aspects of the study were published as Oyelaran-Oyeyinka (2003). "Innovation and Learning by Firms in Nigeria: The Role of Size, Skills and Ownership", *International Journal of Business and Society*, 4:1, pp.1-22.

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research in Nigerian universities and research institutes had already proved that malt from sorghum and grits from maize—both local cereals—could be substituted for barley malt that hitherto was being imported. Government then outrightly banned the import of barley malt, within a given time limit, and at the same time, instituted a regime of incentives for firms willing to undertake the conversion process. From 33 firms, the number of operating firms declined to a dozen in a relatively short time. Only firms that were technologically capable of switching to local cereals survived, with different degrees of production success. We therefore define the problem as the study of the strategic response of firms to an external (to the firm) crisis involving collaborative learning. The three categories of agents and institutions involved in this case were:

- research institutions, universities and technical institutions;
- formal PRIs carrying out research outside the structure of firms and
- private firms in the brewing sector.

3.1.1 Systemic linkage support to develop manufacturing skills

In response to the ban on barley import, firms' innovative efforts included the establishment of hitherto non-existent departments, particularly, R & D as well as the acquisition of new skills. Only firms with the resources and technical support were able to create these departments and attract the requisite manpower. Although, a number of science and engineering faculties in Nigeria's higher institutions had carried out research work on sorghum malting and brewing, they did not possess much beyond sound theoretical knowledge and were able to train firms. Another source of technical training was staff training at the facilities of technical partners, particularly in Germany, The Netherlands and the United Kingdom. Evidently, only those with such partnership were able to tap into this knowledge base. Half the firms surveyed created new departments to cope with materials policy change. All the firms retained existing departments and over 60 per cent of firms employed new skills to cope with the policy change. Nearly all the firms provided training including collaborative capacity development with universities as well.

While some firms established new production lines, some did not, preferring only substantial modification to existing production lines. Over 30 per cent of the firms established new production lines, while the rest of them modified existing lines. Newly established functions by firms include malting sorghum lines and fermentation, sorghum supplementary unit, kettle filter and heater. Modified production lines include mash filter, malt plant, brewing kettle, barley malt line and mash Tun among others.

Apart from production process changes evident in production lines changes, other characteristics also signify different firm level responses to local sourcing of raw materials policy. These include the establishment of own agricultural farms, and the use of contract farmers. However, most of the medium sized firms carried out only minor innovations in the production line, while some established no new production lines. In our interviews, the large firms succeeded in plant modifications largely as a result of strong technical affiliation, competent local skilled engineers and scientists and the ownership stake of partners. Size was decisive to the extent that large firms had the above resources that small and medium firms do not possess.

3.1.2 Ownership and size factors in innovation

Firm characteristics significantly influenced the innovative and collaboration behaviour of firms. Evidence from the survey show that both variables tend to move in opposite direction

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in some cases, and directly in others, and thus evidence is inconclusive. Large- and medium-sized firms tend to have the resources to hire skilled researchers and scientists while MNCs have all the requisite administrative and technical support, including access to local R & D institutes, and thus tend to combine both local and foreign technical relationships. Ownership and size of firms therefore tend to be related to innovation and market performance. Firms with strong and long-standing technical collaboration with foreign MNCs had greater access to technical and financial resources and were able to manage the transition relatively smoothly. However, we found that ownership *per se* was not the issue but the attitude and practices of firms, and they ways in which they deployed the technological assets available to them, in this situation of production crisis. The case study shows that the market leaders had taken certain proactive technical and administrative steps in anticipation of the expected government policy change, among which were:

1. commissioning of product and process centres with active support from technical partners;
2. acquisition of buffer raw materials to see them through the conversion period;
3. establishment of well-equipped laboratories;
4. setting-up of organisations to carry out R&D, cultivation of farms, purchase, transportation, storage and milling of local sorghum and maize and
5. large-scale purchase of raw materials in the open market.

3.2 Survey Results of Systems Linkages in Nigeria

In order to see how far and how well what was observed in the case study holds for the sector at large, we use discrete choice type models (a descriptive as well as a bivariate probit model) to study the determinants of product and process innovation in Nigeria due to the qualitative nature of the data. This allows us to delve deeper into the extent to which process and product innovation are associated with one another, and the factors that influence them. Innovation capacity (to be understood as research capacity of Nigerian universities and PRIs) is measured by the commercialisation of product innovation (technological innovation), and its determinants are investigated using a standard probit model. We use a Bivariate probit to study the determinants of local and foreign collaboration, and to what extent they are correlated. Three types of explanatory variables are used, namely university–industry collaboration variables, learning variables and government variables.

3.2.1 The determinants of research capacity and innovation performance

The performance variable of interest is binary indicating whether an organisation has commercialised product innovations. It is explained in a standard probit model using collaboration and learning variables (see Table 1). Zero means 'no collaboration' while 1 means 'very strong linkage'.

The figure presents descriptive statistics for technological performance and collaboration between various agents who play an important role in research and commercialisation. Most organisations surveyed rate the intensity of collaboration with other universities to be fairly strong, strong or very strong (53.3 per cent), compared to relationships with other types of institutions (e.g. 11.9 per cent with agricultural machinery

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Table 1. Descriptive statistics: collaboration and technological performance

Variable	Mean	(Std. Dev.)	Min.	Max.
Technological performance	0.105	(0.307)	0	1
Col. with res. inst.	0.362	(0.482)	0	1
Col. with farm. ass.	0.376	(0.486)	0	1
Col. with univ.	0.533	(0.500)	0	1
Col. with priv. lab.	0.176	(0.382)	0	1
Col. with ext. agen.	0.295	(0.457)	0	1
Col. with agr. mach.	0.119	(0.325)	0	1
Col. with agr. coop.	0.152	(0.360)	0	1
Col. with seed comp.	0.157	(0.365)	0	1
Col. with others	0.043	(0.203)	0	1
N		210		

Source: Empirical survey by authors, (2006).

suppliers, 15.7 per cent with seed companies and 15.2 per cent with agricultural cooperatives). The estimation results of a standard probit (not reported here) suggest that none of the variables in Table 1 and of the learning variables plays a role in technological performance. Indeed, a standard Wald test with $x^2_{(12)} = 16.26$ and probability value of 0.180 suggest that these variables are jointly not significant in the probit regression. In other words, while universities tend to relate with each other and with research institutes (36.2 per cent), the types of relationships that bring out commercial products are very weak. For example, interaction with seed companies is rated at 15.7 per cent.

3.2.2 Types of collaborations

Both universities and research institutes collaborations can be broadly classified into teaching, research and product development categories. Descriptive statistics of these kinds of collaborations, both with local and foreign partners is reported in Table 1 below. The figure shows the mean results in an interval between 0 (weak) and 1 (strong) where collaborations are measured in binary variables indicating whether an organization has foreign or local collaboration to effect production, in research, teaching, product development, in R&D and in extension services. Hence, any result above 0.5 shows moderate to strong correlation.

Closer scrutiny of the collaborations reveals that more organisations are involved in local collaborations than in foreign collaborations (the mean for foreign collaboration is relatively low compared with local collaboration in research—0.086 versus 0.605 as reported in Table 2). But despite this, the organisations involved in foreign collaborations are more likely to commercialise product innovations than those involved in local collaborations. As Table 2 shows, local collaboration for both product development and R&D are just slightly below average (0.4) but these tend to be not directed towards creating marketable products.

Survey respondents, especially university academics do not conceive their role in entrepreneurial terms while research institutes tend to be better disposed towards getting their research commercialised. However, without exception their efforts are undermined by a host of factors which include not just poor infrastructure but in a more fundamental way socially rooted attitudes and norms that are reinforced by the institutional framework under

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Table 2. Descriptive statistics: types of collaboration in Nigeria

Variable	Mean	(Std. Dev.)	Min.	Max.
Foreign col. in production	0.086	(0.281)	0	1
Foreign col. in research	0.319	(0.467)	0	1
Local col. in research	0.605	(0.49)	0	1
Local col. in teaching	0.176	(0.382)	0	1
Local col. in pdt. dev.	0.414	(0.494)	0	1
Local col. in R&D	0.414	(0.494)	0	1
Local col. in ext. serv.	0.105	(0.105)	0	1
N		210		

Source: Empirical survey by authors, (2006).

which the organisations were set up in the first place. The acceptable and deep-rooted norm seems to be that universities do teaching and research and the private sector firms do product development. The notion that university research should feed systematically into national production has never been promoted and in the extreme, academics have a propensity to view the idea as hostile. The probit estimation results contained in Table 3 below shows other variables that are statistically significant for product development in addition to foreign collaboration. These are collaborations in production to conduct local research and extension services—all of which are positively and significantly correlated to innovation performance. Local collaboration in R&D is however, significant but negative. This helps to capture the poor impact of R&D on collaboration and innovative performance in agricultural biotechnology in Nigeria.

3.3 The Role of Policy in Sectoral Performance

In order to understand the nature of policies that impact upon collaboration incentives as well as the propensity of universities and research institutes to engage in product

Table 3. Probit estimates: the effect of collaboration on innovation performance

Variable	Coefficient	(Std. Err.)
Foreign col. in production	0.925^{*}	(0.396)
Foreign col. in research	0.335	(0.293)
Local col. in research	$0.656^{\dagger}$	(0.361)
Local col. in teaching	0.074	(0.352)
Local col. in pdt. dev.	0.785	(0.517)
Local col. in R&D	-1.125^{*}	(0.564)
Local col. in ext. serv.	$0.658^{\dagger}$	(0.369)
Intercept	-1.992^{**}	(0.302)
N	210	
Log-likelihood	−58.966	
$x^2_{(4)}$	22.945	

Source: Authors survey (2006).
Significance levels: *5%; **1%; †10%.

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Table 4. Bivariate probit estimates: policy impact on collaborations

Variable	Coefficient	(Std. Err.)
Foreign collaboration		
Human capital	0.398*	(0.184)
Gvt. innov. incentive	0.686**	(0.239)
State of power supply	0.973**	(0.351)
State of water supply	−0.539*	(0.271)
Intercept	−0.540**	(0.150)
Local collaboration		
Human capital	0.503**	(0.193)
Gvt. innov. incentive	0.673*	(0.289)
Technical collaboration	0.562**	(0.181)
Intercept	−0.041	(0.167)
Correlation		
p	0.644**	(0.095)
N	210	
Log-likelihood	−230.483	
$x^2_{(26)}$	35.519	

Source: Authors survey (2006).
Significance levels:
*5%; **1%.

development, we employ a bivariate probit model that allows us to estimate the correlation between foreign and local collaboration. We start by estimating a bivariate probit with human capital and all the policy variables as regressors. Using a standard likelihood ratio with $x^2_{(13)} = 18.55$ and probability value of 0.138, we do not reject the restricted model whose estimates are reported in Table 4. These results clearly point to the prominence of three forms of policies for new product/process innovation. First, policies that foster scientific and human capital formation, proxied by human capital, affect positively and significantly both foreign and local collaboration. In other words, organisations with more masters' or doctoral qualifications display the greater the propensity for collaboration and linkages. Second, other governmental innovation incentives, such as sector-specific subsidies, tax rebates, private–public partnership schemes, among others also positively and significantly impact upon local and foreign collaboration. And finally, the physical infrastructure policies, proxied by power and water supply are both significant determinants of collaboration.

The case study on brewery technology shows that collaborative learning between industrial firms, PRIs and with universities was an important activity to realise the technical and organisational change initiated by government policy. Size, manufacturing skills and ownership were decisive factors in the innovation success of firms that survived and prospered under a decidedly turbulent industrial environment. Firm affiliation to foreign technical partners, and multinationals (MNCs) foreign equity in local affiliates were also decisive factors for the success of firms that succeeded. The broader sectoral investigation of the agricultural biotechnology sector confirms these insights: governmental policy and innovation incentives, such as sector-specific subsidies, tax rebates, private–public partnership schemes, among others also positively and significantly impact upon local and foreign collaboration. And finally, the physical infrastructure policies, proxied by power and water supply are both significant determinants of collaboration.

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However, in the case study example, firm-level innovation took several forms: introduction of new processes or products, organisational changes and undertaking of R&D (broadly defined and not limited to basic research). This was the point where universities and public research institutes made the most crucial contributions. These interactions were prompted by two major factors. On the one hand, for certain categories of firms, the *opportunities for change* became a threat to the survival of the firm, for some it was simply a threatening of market leadership, while for others, it signalled exit. Additionally, the government did well in encouraging university–industry linkages through focused meetings and incentives; this behaviour of the state signalled an important support. But at a broader sectoral level, we find that universities and research institutes do not collaborate closely and fruitfully with the enterprise sector due to missing policy and market-based incentives, and thus the success of the case study does not stand replicated at the sectoral level.

Another important lesson that accrues from the comparison of the case study with the empirical data from the rest of the sector is that in the case study, the wholesale adoption and acceptance of the policy was predicated on the number of favourable features and characteristics of policy itself. In other words, the firms found it largely in their own interest to adopt the policy because of the cost, convenience and foreign exchange savings arising from it. Also, the policy provided sufficient lead-time for many of the firms to reorganise many of their production processes in accordance with the requirement of the use of the locally sourced materials. In short, the consonance between government's and firms' objectives assured the success of the materials policy. The main lesson here is that the policy which takes explicit account of the interests of those it affects is more likely to elicit the expected range of responses. Further, the policy itself resulted from a careful determination of what is feasible technologically. Research studies, production using raw materials in a pilot scheme, planting grains (e.g. sorghum and maize), all were done to confirm the feasibility of the local sourcing of raw materials years before the imposition of the ban and hence of the local sourcing of raw materials policy.

The logical planning and design of this policy as well as the consultation between government and the affected sectors of the private sector promoted a fuller understanding of the limit of technical feasibility, the implications for technology acquisition, the availability of local substitute and the financial implications of the policy prior to its implementation. In any case, the thorough understanding of the technical and conceptual processes on the government side made it difficult for government to succumb to pressure for a reversal of that policy. In all, it seems clear that the process of designing and managing this policy exhibited a number of strong features that enhanced its success.

This needs to be replicated at a larger scale for the policies that govern the agricultural biotechnology sector in the country, in order to be able to boost optimal inter-organisational learning and coordination. This will necessarily include policies that target better physical and knowledge infrastructure, as the empirical analysis reveals, but also those that seek to promote partnerships for product development.

4 INNOVATION AND SYSTEMIC COLLABORATION IN GHANA: CASE STUDIES AND SURVEY RESULTS

In Ghana, research institutes are governed by the Council for Scientific and Industrial Research (CSIR). About 10 of the total of 13 research institutes are considered to be

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working on biotechnology-related research and were covered by the survey. The private sector comprises a wide range of producers ranging from subsistence farmers in the rural areas to large-scale industrialists. What distinguishes these actors is their nature of productive activities, the levels of technological sophistication and investment and size; all of which determine the extent to which they adopt and diffuse biotechnology. Crop agricultural research dominates biotechnology research and application in the country, and this is not surprising given that the contribution of agriculture to GDP is about 40 per cent, far more than the other sectors of the economy. In this section, we follow a similar approach as in the Nigerian analysis, namely, begin by providing a successful case study and follow with empirical data from the Ghana's agricultural biotechnology sector.

4.1 Case Study of Cassava Transformation to Export Starch

Starch, an important industrial raw material had a global starch market of about $20 billion in 2004, expected to be growing at about 5 per cent per annum (Office of the PSI on Cassava Starch, 2004). The cassava starch market in particular is estimated to be growing at about 8 per cent per annum globally. Cassava (*Manihot esculenta*) is the backbone for the national strategy for food security of Ghana as an estimated 55 per cent of farming households grow cassava (IFAD, 2004). The innovation process involves several actors—farmers, scientists, investors, policy makers, among others. The roles they play, their relationships, the linkages, habits and practices impact on the dynamism of the innovation process. Several questions arise in analysing the cassava innovation phenomenon. What triggered the diversification of the crop? What are the drivers? Who are the critical actors? What habits and practices have facilitated or impeded innovations? What are the policy challenges? These and other questions will help to answer what factors and actors foster/constrain the road to the market.

The real drive to upscale cassava products to a large-scale industrial production was initiated through a Presidential Special Initiative (PSI) on Cassava Starch in 2001. The policy aimed at fostering cassava industrialisation to connect to key modern sectors is the PSI on Cassava Starch. The PSI aims at launching Ghana on the global starch market exploiting the country's comparative advantage in cassava production. To achieve its objectives, the PSI adopted the strategy of establishing medium scale farmer-owned companies using what is known as the Corporate Village Enterprise (COVE) concept. Each COVE is a limited liability company whose shareholders would be the farmers and other strategic investors. The COVEs are located in the rural areas and serve as poles for industrialisation. The case of the Ayensu Starch Company Limited (ASCo), the first COVE established in 2001, highlights the important roles of the critical actors—the government, researchers, farmers, industrialists—and the respective linkages, to successful innovation. A 20 000 metric ton capacity high-grade native cassava starch plant was commissioned at ASCo, which when operated at full capacity could earn about $4 million in revenue per annum. In 2004, the company processed about 2000 ton of starch and exported to Europe. ASCo has recently signed a contract with Nestle, a multinational dairy food company to supply high quality medium risk cassava starch to Nestle's industries. However, ASCo faces several challenges related to certain dysfunctions in the entire innovation system for cassava starch production and marketing, including farmers' habits and practices, under-capacity utilisation, lack of high-yielding cassava varieties, competition on the international market, politicisation of the project and weak linkages to different

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knowledge bases. These translate into the following specific economic issues that lay bare the weakness of the local system's capacity to promote innovation:

(i) Differential pricing in the local market: There is a significant difference between prices offered at the factory and the local foodstuff market. Whereas the open market offers about \$40–\$45 per ton, the ASCo offers about \$35 per ton (Personal Communication, 2005). Farmers react as rational actors to the fact that factory price is guaranteed and therefore not subject to fluctuations like the open market prices offer higher price advantage. For example, in Thailand starch producing companies purchase cassava between \$19 and \$21 per ton. The firm pays the relatively higher prices (compared to their Thai competitors) in order to secure supply and through price competition with the open market actors. More importantly higher price incentive secures loyalty and builds long-term contractual relationship.

(ii) International price competitiveness: The prices on the international starch market are generally below this price. For example in Denmark the offer price for the starch ASCo produces is only a little over \$200 per ton. Thailand is able to sell at \$22 per kilogram on the international market whereas Ghana has to sell at \$32. Thailand is able to do this because its scale economies are better with daily production of 200 ton per starch plant and there are at least 56 of such plants (Sriroth *et al*., 2000). Ghana has one plant currently operating with daily production of about 65 tons at best.

(iii) Yield as pointer to innovation: Yield differences between Ghana and Thailand illustrates the superiority of technology employed by main competitors such as Thailand. Cost competitiveness is directly linked to the genetic resources available for ASCo's starch industry. The company's operations began with the extension of the cassava variety *Afisiafi*, developed by the Crops Research Institute which proved not to be the ideal variety needed for starch production. The *Afisiafi* variety takes between 15 and 18 months to mature yielding a starch content of between 10 and 21 per cent. The company's competitors in Brazil and Thailand produce with varieties maturing within 9 months and yielding starch content of 27 per cent.

(iv) Weak linkages: Weak linkages between the entrepreneur actors and the scientific community have been a major impediment to dissemination of needed technologies. This point has been discussed at greater length in the next section.

4.2 Econometric Analysis: Systemic Linkages in Ghana

The problems facing ASCo highlight the overall difficulties in the systemic innovation of a traditional food crop to an industrial crop using the present agricultural biotechnology institutions. Apart from the farmers other actors such as scientists and policy makers need to change their modes of operation.

Using empirical data from the 100 questionnaires administered in Ghana's agricultural biotechnology sector, the types of collaboration can be broadly classified into teaching, research and product development. The survey data show that whereas 26 per cent of respondents collaborate in research, only 7 per cent collaborate for both research and product development. This, once again, signifies the low importance given to commercialisation of research results amongst universities and research institutes, and reverberates the ASCo experience.

Contrasting local and foreign collaboration, we find that 84 per cent of those surveyed indicated they had collaboration with local institutions. Much local collaboration can be

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Table 5. Intensity of collaboration

Type (intensity)	Per cent
None	3
Low	12
Average	44
Strong	31
Total	90

Source: Authors survey (2005).

credited to the Agricultural Services Sector Investment Programme (AgSSIP), a World Bank-sponsored programme that began first in 1989 and was called as the National Agricultural Research Project (NARP). The NARP was implemented over a 10-year period and was later replaced by AgSSIP.

Table 5 gives an indication of the intensity of local collaboration, rated from 1 (not strong) to 5 (very strong) by the survey respondents. Only 31 out of 90 respondents consider it to be either strong or very strong, whereas over half of those surveyed (52 per cent) consider it to be average or low or even non-existent. This again shows the limitations of the system, which were illustrated in the case study, where linkages with large-scale industries such as ASCo are the most tenuous compared to linkages with other stakeholders particularly with the farmers, micro-entrepreneurs and small-scale industrialists.

The scientific community comprising among others, six agricultural research institutes of the CSIR and the Faculties of Agriculture of the four public universities have a relatively better defined linkage with the farmer community especially through the extension system of the Ministry of Food and Agriculture. The research institutions have now only set up units for technology transfers, which helps but firms tend to operate without much connection with knowledge bases. ASCo also does have contacts with the scientific community in other areas of its operations. The Water Research Institute carries out laboratory analysis of its water resources—an important part of its quality assurance. ASCo is also working with the Animal Research Institute to produce animal feed from its waste. It is also contemplating producing mushrooms using the cassava peels. The contacts with the CSIR institutions indicate that ASCo recognises the role the institutions can play in its operations. However, there is a difference between contacts and effective linkage. The latter is a more purposive and institutionalised connection, targeted to a specific goal, which invariably facilitates innovation. This has not happened between ASCo and the scientific community.[3]

4.3 The Role of Policy in Sectoral Performance

In order to ascertain the role of the mediating variables, especially policy support in collaboration and resulting new product/ process innovation, Table 6 contains the mean values of rankings of survey respondents on policies that impact positively on innovation in

[3]In analysing Thailand's experience in the cassava starch industry, Sriroth *et al*. (2000) make the point that the transition from small to large-scale production was accompanied by varietal development of root having high starch yield and technological improvement of starch production with shorter processing time and better starch quality. This is perhaps one of the most critical challenges of Ghana's innovative system.

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Table 6. Descriptive statistics for policies

Variable	Mean	(Std. Dev.)	Min.	Max.
Gvt. innov. incentive	0.087	(0.283)	0	1
Skilled manpower	0.663	(0.475)	0	1
Local univ. tech. collaboration	0.457	(0.501)	0	1
R&D inst. tech. collaboration	0.185	(0.390)	0	1
IP protection	0.217	(0.415)	0	1
Quality of IT	0.152	(0.361)	0	1
Venture capital available	0.033	(0.179)	0	1
State of power supply	0.043	(0.205)	0	1
State of water supply	0.087	(0.283)	0	1
Other policies	0.011	(0.104)	0	1
N		92		

Source: Authors survey (2005).

the present environment. Rankings range from 1 (not strong) to 5 (very strong). As Table 6 shows, skilled manpower (0.66) and the incidence of local collaboration among various actors are rated to be of highest importance for biotech research and product commercialisation in the country. Infrastructure facilities such as power supply (0.043), water supply (0.087) and quality of IT (0.152) are all rated very low, denoting the rather poor role they play in enabling biotech research and product commercialisation in the country presently.

This underlines the role played by physical infrastructure, knowledge infrastructure as well as incentives for innovation in the local context, similar to what we found in Nigeria. Other incentives for innovation, such as finances (or the lack thereof), sector-specific subsidies and lack of linkages between research and development activities were all pointed out to be serious constraints by the survey respondents (field interviews).

That the government is a critical actor in the latecomer innovation system has been demonstrated in its instrumental role in the start up of ASCo. The case study demonstrates, howbeit imperfectly, that in Ghana, the innovation of cassava as a commodity to export product has been a result of various interacting initiatives, functions and practices of actors and factors from within and outside the country. Farmers contribute to the process of innovation in terms of the production of the commodity, conservation of genetic resources, the diffusion of the improved varieties, among other things. However, the system of innovation would be enhanced with changes in the habits and practices in networking and communal relationships. The scientists' contribution comes in the form of the improved varieties and the extension into production. However, the dysfunctions in linkages between the scientific community and other key stakeholders such as farmers—more importantly with the industrial sector—have impeded innovation to the extent that is observed in Ghana. The role of government in terms of the policy decisions and implementation and the supportive actions to create a more conducive environment for innovation is critical. Internal policy directions should be towards greater capacity for domestic utilisation of cassava products and for the vital market linkages to be fostered, while still taking measures through increased production and quality assurance to meet competitive demands on the international markets.

In general, pursuing the dual goals of poverty reduction and wealth creation through the industrialisation of cassava presents peculiar developmental challenges, largely of

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conflicting objectives. It showcases the need for a more resilient innovation system with the critical actors showing more ingenuity and responsiveness in their relationships, practices and norms. The government, the scientists and the entrepreneurs are the critical actors who must be more proactive to make the innovation process more dynamic and resilient than it is now.

5 COMPARATIVE INSIGHTS AND SUMMING UP

The paper uses data on agricultural biotechnology sector from two latecomers, Nigeria and Ghana to show the dynamics of innovation by analysing the determinants of collaboration and commercialisation of research results. Our focus was on three major issues: what is the locus of knowledge generation and learning in these systems? What factors affect collaboration and product innovation in the countries? To what extent is the role of policies that directly support innovation, and indirect policies that target human skills and physical infrastructure play a role in creation of innovative activities? The comparative analysis leads us to three sets of results, all of which are very important for policy efforts to enhance innovative performance in a latecomer context.

Closer scrutiny of the factors that determine collaborative efforts and commercialisation of research results in both countries shows that policies both direct and indirect play a pivotal role on what the intrinsic absorptive capacity of the local actors is, and on how they choose to interact and collaborate. Access to knowledge optimally needs to be accompanied by better skills in technology application (which is determined by human and scientific skills formation) but does not automatically lead to research collaborations and results. There are other intangible factors especially attitudinal factors that determine application of knowledge to innovative activities in local contexts in latecomer countries. The social practices and habits of scientists may well be as important as the conducive physical and scientific environment for inventive activities. The following policies are critical:

(a) *Physical infrastructure and networking*: Autonomous telecommunications faculty, such as telephone, fax and internet in the universities falls largely below what may be required for good research and teaching work, getting to know and linking up with similar programmes with other universities and institutions within the country or the rest of the world and for dissemination of research efforts. There is critical shortage of power and water; a situation that calls into question the commitment of governments on research investment.
(b) *Knowledge infrastructure*: High quality research requires equipment and investment in sector specific facilities and laboratories at the national and regional levels. Mostly research equipments are not available, and even laboratories created to facilitate them depend on the availability of foreign grants for their survival. Basic chemicals and reagents are hard to find and graduate students often have to rely on own funding to carry out experiments. Researchers and their initiatives get stunted by lack of funding and the resulting intellectual isolation gets internalised into informal norms and codes of conduct.
(c) *General and specific innovation incentives*: Sectoral policies are important, coordination between sectoral policies, especially those that link research in traditional sectors and new technologies are critical. The comparison between the two countries

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shows failures (albeit of different kinds) on linking their investments into biotech R&D (in the public sector) with the enterprise sector. There are no specific incentives created in the local innovation systems that promote commercialising of research results. Newer and more dynamic policies and incentives are required to bridge the gap between research and production (private sector) activities in these countries.

The paper demonstrates the inadequacy of the orthodox science and technology notions and policies that characterised the early development landscape of developing countries. The focus of the earlier policies was on the supply side (universities and PRIs) as the only loci of knowledge worth promoting with scant concern for the demand side which include customers, suppliers and buyers. Clearly, there are distinct differences between science, technology and innovation policies; as the outcome of our analysis shows, innovation policy takes cognisance of the complexities of the different dimension of the process as well as the interactive learning imperative of all key actors. The broader set of innovation policy objectives is to facilitate interaction between firms of all sizes with all source of knowledge which include but not limited to public and private research institutes. This thinking in terms of systemic frameworks is lacking in the two countries and explains in large part the observed disarticulation in the systems, as our analysis shows. In both countries, we identified three factors why the innovation process remains at the level of pre-commercialisation. 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.[4] Third, failure to commercialise sometime resulting from institutional rigidity much of which relates to the ways traditional universities and research institutes are set up. There are two issues that recurred in our interviews namely, who initiate the process (the university or a firm/entrepreneur?); and what form of formal or informal arrangements guide the process? In frontier countries as well as fast followers, two broad types of formal arrangements are common, depending on whether it is a case of academic entrepreneurship in which case the university actors initiate the process, and spin-off companies from public research or universities or pure private sector initiative, wherein the industry takes the lead.[5] But in latecomer countries, such a separation is usually not possible since all potential channels of interaction that could otherwise provide positive impetus to innovation are constrained. Industry involvement is low, owing to the fact that private sector research is itself in need of basic support such as sources of finance (e.g. venture capital), better infrastructure and technology diffusion activities that could enhance their internal capacity. There is also a historical lack of collaborative interactions between industry and public research. Interactions between the various university departments itself is weak as a result of lack of information and absence of incentives amongst researchers to indulge in joint research. Universities also do not collaborate sufficiently with users of knowledge. In such situations, as our empirical research shows, innovation success often depends on serendipitous accumulation of capabilities or collaboration capacities that remain one-off and unsystematic. The role of incentives, both policy and market-based will be to change this trend into sustainable modes of interactive learning.

[4]As Jolly (1997) correctly observed, technologies for 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.
[5]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) commercialisation which might involve holding equity in private enterprises by scientists, see Altonen (1998).

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