ISTAfrica
IST-Africa 2013 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2013
ISBN: 978-1-905824-38-0

Surveying National Systems of Innovation (NSI) Using Free Open Source Software (FOSS): The Case of Ghana

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Abstract: In today's global knowledge-based economy, knowledge, its creation, accumulation and distribution, through institutions of human, organizational and social capital, plays an increasingly crucial role as the key factor in innovation and economic development. The production, distribution and processing of knowledge (especially scientific and technological) is increasingly performed within the domain of computational information and communication technologies (ICTs). Even though there is an asymmetric distribution of ICT resources, particularly between developed and developing countries the emergence of Free Open Source Software (FOSS) is a means to bridge the 'digital divide'. This paper examines the use of FOSS for mapping and measuring the National System of Innovation (NSI) in Ghana and generating evidence based policy. Findings indicate the value of FOSS in mapping and measuring for evidence based policy and the crucial role of ICT in the NSI.

Keywords: Free Open Source Software (FOSS), Knowledge transfer, Knowledge accumulation, National Systems of Innovation (NSI), Ghana, Developing Countries

1. Introduction

The dynamics of the global knowledge-based economy requires participation articulated by knowledge, its production, accumulation and distribution through organizational capital [1] as well as institutions of human and social capital. Organizational capital and the management of the stocks and flows of knowledge play an increasingly crucial role as a key economic factor [2][3]. Since the 1950's the ability of policy makers and economists to explain fully the determinants of, and growth rates for, Western Industrialised Economies in terms of traditional production factors land, labour, and capital has become increasingly problematic. [4][5]. The 'residual' [6][7] has been explained in terms of: upgrading of the labour force; surplus generated by externalities and interaction effects; and the increasing role of knowledge in the economy [8]. To underscore the increasingly strategic economic role of knowledge Lastres et al. (2005) [9] present three interrelated arguments. Firstly, "the proportion of labour that handles tangible goods has become smaller than the proportion engaged in the production, distribution and processing of knowledge"; secondly, "the share of codified knowledge and information in the value of many products and services is significantly increasing"; and finally, "knowledge-intensive activities are rapidly growing" [10]. This production, distribution and processing of knowledge (especially scientific and technological), manifest ultimately in the global factory [11], is increasingly performed within the domain of computational ICT. The key dimension of the knowledge-based global economy is the NSI of respective countries and their comparative effectiveness and efficiency.

This paper emphasizes the importance of ICT, particularly FOSS in measuring the NSI main actors' perspectives and interactions—as development assets—within Ghana as a valid means to implement effectively national targets of innovation, science and technology policy.

Designing policy for social institutions to absorb, retain, advance, distribute and sustain knowledge becomes vital to a nation's global economic positioning. However, this process of design poses serious challenges. "In addition to understanding the importance of codified and tacit knowledge, it is also important for governments concerned with competitiveness to efficiently utilize policy instruments and internal resources (economic agents and institutions) if they are to achieve competitive advantage" [12]. Arguably the most powerful framework that enables this process of design is the NSI. The definition of NSI is varied and a good overview of its conceptual evolution is provided by Freeman (1995) [13]. We embrace the definition by Lundval (1992) as 'the elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge ... and are either located within or rooted inside the borders of a nation state' [14]. To this succinct definition we add an additional dimension of organizational capital, from the definition of Bartels et al. (2012), which is "the envelope of conforming policies as well as private and public institutional relations, and their coherent social and capital formations, that determine the vector of technological change, learning and application in the national economy" [15]. Through these definitions the importance of the non-recursive relationship between knowledge, institutional relations and policy becomes clear.

Given the definition that alludes to the 'envelope' of conforming policies, there are two specific factors excluded from the traditional framing of NSI, particularly in the context of developing countries, which we include in our model and analysis, namely the effects of diffused information and communication technologies (ICTs) and arbitrageurs. Through the spread of digital information and ICTs new modes of development have evolved [16][17]. Our conceptualization of ICT in NSI is not based solely on the concept of access, but the work of Hilbert et al., (2010) [18] who view the digital divide as being attributable to asymmetries in storage, the ability to compute and transmit digital information; to contextualize not just the quantity of hardware but also the corresponding performance in relation to all three NSI actors namely; Government; Knowledge-Based institutions (KBIs, universities, think tanks, public and private research institutions); and industry [19]. Within the developing country context the three actors are perceived to hold relatively traditional and separate roles, with little or no overlap in functional relationships typified by "entrepreneurial academics, academic industrialists, and business strategy in government" [20]. This is evidenced by the lack of bodies such as technology transfer or licensing offices within universities, or the widespread intermediating role of venture capitalists. Therefore, access to the necessary financial and information resources would lead to the need for independent institutions, namely arbitrageurs. Figure 1 illustrates this more inclusive concept which we propose formally as a 'Triple-Helix type 4' model, where the dimensions of diffused ICT and arbitrageurs[1][21][22][23][24][25][26][27] which are normally missing from the traditional framing of NSI have been included.

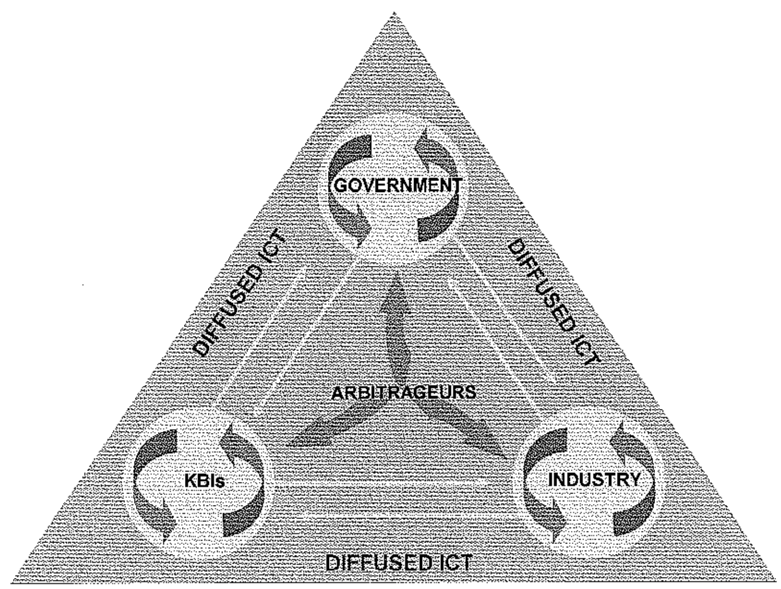

Fig. 1

As indicated by Leydersdorff and Ektowitz (1996) [28], the characteristics of NSI—that is, the distribution, density, strength and quality of interactions between government, KBIs and industry—are critical determinants of efficiency and effectiveness in the creation of stocks of, and dissemination of, tacit and codified knowledge.

It should also be understood that "policy is a part of the system, and it has outcomes and impacts, just as a new technology or business process does" [29]. From a developing country perspective there are good and better ways to develop policy, but above all, it is important to "avoid copying the latest policy fashion" [30]. Thus, informed policy requires an empirical understanding of the characteristics of the actors within a system, their inter- and intra-relational dynamics and their individual utilities. This can only be achieved through effective systemic mapping and measurement of NSI using ICT. This is a complex affair that requires efficient deployment of limited resources (finances and human capital).

The aim of this paper is to highlight the crucial importance of ICT, particularly FOSS in the mapping and measurement of the actors' perspectives and interactions—as development assets—within the NSI of Ghana; consequently providing a strong basis for validly developing policy to achieve effectively national targets of innovation, science and technology policy.

[1] Arbitrageurs (venture capitalists and knowledge brokers) are of "crucial importance as the innovation process requires internal and external knowledge which has led to the emergence of new business models and new types of companies. As such, knowledge brokers and venture capitalists fill this gap through the provision of links, knowledge sources and even technical knowledge so that firms can improve their performance in terms of survival rate as well as accelerate and increase the effectiveness of their innovation processes (Zook., 2003; Hargadon., 1998; Baygan,. and Freudenberg 2000). Their resource allocation role is based on the assessment of advantages in information asymmetries (Williamson., 1969; 1971; 1973)" (Koria et al., 2012., pp.7). In the Triple Helix Type 4 it is posited that the arbitrageur interacts, primarily as an inter-mediator, with Industry, KBIs and Government and not only provides the necessary financial, legal and information inputs to the system but also, when appropriate, assumes equity position, mentoring and other investor roles.

The rest of this paper is organized as follows. Section 2 of the paper addresses the difficulties of data collection particularly in a developing country context and highlights the importance of FOSS. Section 3 presents a summary of data collection in the case of the Ghana National System of Innovation (GNSI) Survey. Section 4 looks at the results gained from the GNSI Survey and relates them to the use of FOSS and ICT. Section 5 concludes with policy recommendations and areas of further research.

2. Free Open Sourced Software and Data collection

At the most elementary level, "evidence based policy making refers to the notion that policy intervention and direction are underpinned by an understanding of how things develop" [31]. In order to facilitate this there is the need for mapping and measurement and hence effective data collection. Essentially there are two basic forms of data collection, namely, interviews and self-administered questionnaires [32]. Both forms are complex communication and information processes which require careful consideration of a multitude of parameters, including: nature and scope of the enquiry; availability of financial resources; availability of time; access to necessary manpower; degree of accuracy required, type of collection method to be used [33] as well as issues of statistical reliability and validity.

Traditionally methods of data collection and knowledge codification have involved mail, face-to-face, and telephone based approaches. The main issues that arise across all three data collection methods are the relative and comparative cost, coverage, and quality of response. These issues are comprehensively covered by Koria et al (2012) [34]. However, the emergence and proliferation of the "new techno-economic paradigm, centred on information and communication technologies (ICT), have accelerated and deepened both the codification of knowledge and the spread of information" [35], as well as the overall quality of data acquisition and response to surveys.

As highlighted above, a country's ability to access information and knowledge are key factors in developing economic competitiveness and being able to engage globally. In particular, in the creation, dissemination, accumulation and application of information and knowledge, ICT is the main conduit facilitating this process [36]. Regrettably, "there is an uneven distribution of this resource, which directly impacts on developing countries' capacity to fully participate in today's global information economy" [37]. This visible "digital divide" is partly due to the minimal availability of ICT access in developing countries as compared to developed countries. "Limited resources in developing countries, Africa in particular, act as a barrier to investment in expensive communication infrastructure, applications and hardware. Many countries are more concerned with basic economic priorities as housing, water and energy. Bridging the digital divide through digital inclusion may provide a possible means to make globalisation work for the poor" [38].

FOSS presents a significant part of the access solution for developing countries to adopt affordable software applications thus facilitating the bridging of the digital divide. FOSS by its constitution – non-rivalry and non-excludability [39] – acts as a public good. The consumption of a non-rival good by one consumer does not decrease its utility for another consumer. FOSS programs can be copied and distributed at near zero costs without the application losing its quality. Non-excludability is defined as the characteristic, which makes it difficult or impossible to charge people for the use of a good. The distribution of the source code of FOSS underlines this characteristic. "According to its proponents, [free], open source software development has the capacity to compete successfully, and perhaps in many cases, displace, traditional commercial development methods [40][41]".

Conversely there arises the issue of sustainability as, according to public choice theory, FOSS developers would cease to invest time and expertise in developing programs [42] that could otherwise be used by free riders and the FOSS movement would unravel, and contributions would cease. However in practice, there are few grounds to assume this outcome as FOSS projects are growing around the globe in both business and academic communities [43]. For example, there are long running FOSS projects such as GNU/Linux [44], Apache or even the internet browser Mozilla's Firefox [45]. This brings up the question of why talented programmers would offer their expertise for free and also why developing countries would actively participate and contribute to FOSS distribution and development.

It has been noted that there is a positive correlation between the growth of a FOSS developer base and the innovative capacities of an economy [46]. Therefore FOSS has the inherent capacity for development of local nascent capacity by fueling innovation through knowledge transfer. With this in mind there needs to be a rethinking of the use of proprietary software by developing countries, as this may not be the optimal strategy for technological or human resource development.

3. Methodology Used for Ghana National System of Innovation Survey

A full description of the methodological approach to mapping and measuring the GNSI is beyond the scope of this paper. However, a detailed description can be found in Koria and Köszegi (2011) [47], Koria et al (2012) [48]. For the intents and purposes of this paper the salient points pertaining to the methodology are as follows:

- the most senior contingent of policy makers from government[2], medium and high technology industry[3], knowledge-based institutions (universities, public and private research institutes, think tanks)[4], and arbitrageurs[5] were identified;
- the survey approach was perceptions based using Likert scales [49][50][51]; and
- an innovative web based approach to data collection was utilised;

It should be noted that maximizing the response rate is crucial to achieve good survey results. With this in mind the elevated response rate attained in the survey is a direct product of the innovative ICT based approach to data collection, is addressed in the following section.

4. Results and Discussion

Considering the challenges of surveying in general, and particularly in developing countries, the methodological results of the GNSI survey are very encouraging. The sample population is composed of senior persons within the hierarchy of Government, KBIs, Medium- and High-Tech Industry (MHTI) and Arbitrageurs, and the rate of response from such a group is expected, at best, about 32% [52]. For the GNSI survey a universe of 558 respondents was identified. From this, due to changes in contact information and inability to access current information and inactive email addresses, a convenient sample of 444 was obtained. The convenient sample was surveyed for a period of 6 months[6], the end result being a total number of 234 responses (52.7%). This figure is considerably higher than the aforementioned expected

[2] Minister and Deputy Minister.
[3] CEOs and Directors.
[4] Deans and heads of faculty.
[5] Directors.
[6] The risk of the survey becoming longitudinal is low as the rate of institutional change within Ghana is low.

response rate of 32%[7]. Table 1 below indicates the respective universes, convenient samples and responses obtained for each group of actors using FOSS.

Table 1 - Universes, Convenient Samples and Responses

Actor	Universe	Convenient sample	Responses	Response Rate (%)
Government Policy Makers	260	166	39	33.6
MHT Industry	120	87	60	68.9
Knowledge-Based Institutions	182	175	129	73.3
Arbitrageurs (Venture Capitalists/Knowledge Brokers)	16	16	6	37.5
All actors	**578**	**444**	234	52.7[8]

It should be noted that, in the case of the GNSI survey, the survey is the data base because of the unique properties of FOSS Lime Survey. As responses are remotely completed they are automatically translated into the database, therefore attributing a high level of fidelity to the responses as error from data transcription is avoided.

In terms of validity: i) the level of internal and construct validity is high as variables were extracted from a comprehensive review of NSI literature and subject to expert peer review; ii) due to the elevated response rate the external validity, or the generalizability, of the results is also high; and iii) an elevated degree of face validity is achieved as the FOSS Lime Survey tool facilitates accurate, efficient and reliable mapping and measurement.

The key factor in the resulting statistical reliability and validity of the GNSI survey[9], in addition to the NSI variables, is the (ICT) FOSS Lime Survey application. Within this context of measurement for policy craft the role of ICT becomes clear.

In order to reinforce the crucial role of ICT within the Triple-Helix Type 4 model ICT variables were incorporated into the measurement of the effectiveness and efficiency of the GNSI. The areas of analysis that reflect the ICT dimension of NSI with respect to systemic innovation and innovativeness in Ghana are namely: (i) Factor barriers to innovation and innovativeness[10]; (ii) availability of policy instruments and success; and (iii) Factors to policy success[11], indicate the crucial role of ICT. A comprehensive indication of the variables used in the analysis can be found in UNIDO 2013 [53].

With respect to Factor barriers to innovation and innovativeness Table 2 below indicates that for all respondents the most significant Factor barrier is <Skills-ICT Capability / Capacity > and explains meritoriously[12][54] 33.524% of the total variance in the data and hence the population. This Factor is responsible for 61.6% and 57.8% of the variance of the variables

[7] The ability to remotely prompt respondents and the non invasive manner in which the survey was conducted using Lime Survey considerably bolstered the response rate.

[8] In surveys directed towards senior management the general response rate is at 30%. See Harzing, A.W., 2006. Response Styles in Cross-National Survey Research. A 26-country Study. The International Journal of Cross Cultural Management, 6(2), pp. 243-266

[9] Statistical results are reported at or above the 95% Confidence Level.

[10] Principal Component Factoring with Factor Loading Cut-off 0.55, Oblique Rotation and reporting the Structure Matrix. Factor Loading Cut-off means that unless the Factor accounts for 30.25% or more of the variance of the variable, the variable does not load on the Factor. Extracted Factors explain at least 50% of the Total Cumulative Variance in the data.

[11] Principal Component Factoring with Factor Loading Cut-off 0.55, Oblique Rotation and reporting the Structure Matrix. Factor Loading Cut-off means that unless the Factor accounts for 30.25% or more of the variance of the variable, the variable does not load on the Factor. Extracted Factors explain at least 50% of the Total Cumulative Variance in the data.

[12] Kaiser H. F., 1974, An Index of Factorial Simplicity, Psychometrika, Vol. 39, No. 1, pp. 31-36, p. 35, March.

'Rate of Access to ICT' and 'ICT Capacity' respectively (in the data and hence the population). A measure of the significance of this first Factor, and the (ICT) variables it influences, is that it is 3.5 times, 4.0 times and 4.8 times as powerful as the other three Factors respectively; and it accounts for more of the total variance explained than the other three factors put together.

Table 2 – Factors for All Respondents

All Respondents (ALL)									
Factor Number	Name of Factor	Variables	Factor Loading	Cronbach's Alpha	Total Variance Explained (TVE)	KMO	Bartlett's Test of Sphericity		
							Chi Squared	Df	Significance
1	Skills-ITC Capability/Capacity	• Quality of technically trained manpower • Rate of access to ICT • ICT capacity • Lack of technically trained man-power	0.797 0.785 0.760 0.695	0.833	33.524	0.577	1,625.579	136	0.000
2	Unsophisticated Markets*	• Lack of demanding customers • Lack of innovative customers • Lack of competition*	0.697 0.639 0.682	0.752	8.671				
3	Deficient Fiscal Policy	• Lack of finance • Lack of explicit policy support	0.770 0.737	0.698	8.437				
4	Reduced Organisational Risks	• Excessive perceived economic risk • Organisational rigidities • Hierarchical organisations • Restrictive public/governmental regulations	-0.809 -0.723 -0.675 -0.653	0.757	7.037				
				Cumulative Total (CTVE)	58.669				

For each group of NSI actor respondents, the fourth most significant Factor barrier to innovation and innovativeness (see table 3) is oriented to ICT and are namely: <Constrained ICT Stocks & Flows> for Government; <ICT-Skills Incapacity/Incapability> for MHTI; <ICT Stocks & Flows> for KBIs. In each case the potential benefits of FOSS are clear, as indicated by the government of the United Kingdom in a recent report on intellectual property rights and international development [55]. The main recommendations are that developing countries and donors should review their policy for the procurement of computer software, with greater attention being paid to the benefits of low cost and open source software [56]. The impacts of adopting such an approach would: firstly, facilitate the flow of ICT stocks by increasing access through a reduction in the dependence on costly proprietary software [57]; secondly, FOSS would act as a conduit to bolster indigenous ICT skills and capacity through access to source code [58], and creating an environment conducive to learning [59].

Table 3 - Factor Barriers and Variance of ICT Variables

Respondents	Factor Barrier[13]	ICT Variables[14]	Factor Loading	% of Variance
Government	Constrained ICT Stocks & Flows	• Rate of Access to ICT • ICT Capacity	-0.809 -0.799	65.5 63.8
MHTI	ICT-Skills Incapacity/Incapability	• Rate of Access to ICT • ICT Capacity	-0.854 -0.752	72.9 56.6
KBIs	ICT Stocks & Flows	• ICT Capacity • Rate of Access to ICT	0.890 0.856	79.2 73.3

Another level of analysis undertaken with respect to the GNSI was the availability of policy instruments and their relative success in promoting innovation. The result of this was an indication that, at the 95% confidence level, 63.8% of all respondents indicate that 'ICT Access' as a policy is not successful. For Government and KBI respondents the figures are 69.3% and 62.1% respectively [60]. On examination of the factors to policy success

[13] Kaiser-Meyer-Olkin (KMO) Measures of Sampling Adequacy range from 0.551 to 0.786, The Bartlett's Test of Sphericity are all significant at 0.000.

[14] The Cronbach's Alpha reliabilities range from 0.818 to 0.925.

<Standards-Based Regulatory Support>[15] for All actors, <ICT Infrastructure Support>[16] for Government, <Labour Skills Flow> [17]for MHTI and <ICT Infrastructure Support>[18] for KBIs influence the variable 'ICT Access'. High levels of variance in the variable 'ICT Access' is accounted for by these factors except for in the case of MHTI (see table 4).

What this indicates is that 'ICT Access' is important to policy success for each actor but, at varying levels depending on the actor perspective. As previously indicated in the analysis of barriers to innovation and innovativeness, ICT access in the form of FOSS can be used in differing ways to address different issues. Standards for example, can be addressed through targeted policy, as in the case of the Government of India's Policy on Open Standards for e-Governance which promotes technology choice, and avoids vendor lock-in [61]. More specifically Clause 4.1.2 ensures that standards do not discriminate against open source [62]. Additionally, "unrestricted access to the source code, [and] an environment of unlimited experimentation and tinkering, collaboration and interaction with a community of programmers, coders and users around the world provides a fertile ground for learning and ICT skills development. This in turn fosters an environment where local products and infrastructure can be developed. The case in point being the the development of solutions in local languages which are often deemed commercially unviable [63][64]

Table 4 - Factor Success and Variance of ICT Variables

Respondents	Factor to Success[19]	ICT Variables[20]	Factor Loading	% of Variance
All	Standards-Based Regulatory Support	• ICT Access	0.649	42.1
Government	ICT Infrastructure Support	• ICT Access	0.945	89.3
MHTI	Labour Skills Flow	• ICT Access	-0.420	17.6
KBIs	ICT Infrastructure Support	• ICT Access	-0.870	75.7

The above results, in the context of our Triple-Helix Type 4 model (Figure 1), demonstrate the crucial role of ICT in NSI. In the case of Ghana, not only do Factors, as barriers to innovation and policy success, account for high amounts of variance in ICT variables (with the exception of the assessment by MHTI[21][65]) but ICT policy instruments are not successful.

These findings evoke two major requirements for policy in resource constrained economies. First, ICT infrastructure needs higher levels of investment in installed capacity. Secondly, the restricted 'policy space' regarding proprietary software can be successfully overcome by exploiting FOSS. This is so for Ghana and developing countries in general (notwithstanding issues of storage and computing capacity), and Sub-Saharan Africa in particular.

[15] Factor number 2 out of 2.
[16] Factor number 2 out of 3.
[17] Factor number 3 out of 3.
[18] Factor number 3 out of 3.
[19] Kaiser-Meyer-Olkin (KMO) Measures of Sampling Adequacy range from 0.797 to 0.936, The Bartlett's Test of Sphericity are all significant at 0.000.
[20] The Cronbach's Alpha reliabilities range from 0.846 to 0.926.
[21] This is probable due to the fact that although Ghana is ranked low in the Network Readiness Index 2012, 97 out of 142 (World Economic Forum, The Global Information Technology Report 2012: Living in a Hyperconnected World, Eds., Dutta S., Bilbao-Ososio B.,, 2012, Geneva), MHTI is well connected.

5. Policy Recommendations and Concluding Remarks

Policy for enhancing the role of innovation, science and technology, in terms of knowledge that drives performance as well as application across the economy, is crucial for national economic development and industrial competitiveness. However, reliable policy craft (mapping, measurement, analysis and control) and operable and valid policy instruments (performance requirements, regulations, fiscal and monetary incentives) continue to elude, to a large extent, developing countries in general and least developed countries in particular. The reasons for this range from sheer institutional capacity constraints, budgetary limitations and inappropriate priorities to the lack of know-how by the policy making community and the problematics of corruption, managerial utility and perverse incentives. While these challenges may not be tractable simultaneously, developing country policy makers can make relatively easy choices to alleviate their problems of inadequate policy craft and unsuitable policy instruments.

The first is the adoption of longitudinal mapping, measurement, analysis and control of the variables of innovation, science and technology policy in terms of NSI. This enables policy to be evidence-based. The consequences of misinformed and incorrectly targeted policy is confirmed by the mapping of the Canadian innovation system, in that only certain human resource groups were targeted by programmes and policy which subsequently resulted in creating serious gaps [66]

Secondly, recognizing the crucial role of computational ICT (internet access, storage capacity and processing capability) in the health of the national economy, ICT infrastructure needs to be prioritized in developing country government budgetary expenditures. This progressively provides an effective and efficient medium in which the accumulation of knowledge, its diffusion and spatial distribution, through the economic institutions of human, organizational and social capital, can take place.

Thirdly, in terms of late-comer advantages and learning, the use of FOSS (such as Lime Survey) for longitudinal mapping, measurement, analysis and control of NSI variables provides all the value of a public good to the developing country without legacy, proprietary and sunk costs. The question of who should lead in making such choices comes to the fore. Clearly, given the strategic value of NSI, computational ICT, and innovation, science and technology in the economy, it falls to governments to lead. This can be accomplished judiciously in a number of ways namely: (i) compiling and maintaining a database of FOSS; (ii) by example in using FOSS within government work; (iii) incentivizing KBIs to employ FOSS in their research and policy work, and in government awarded contracts; (iv) requiring the application of FOSS in tendering for government contracts; and (v) ensuring that the intellectual property rights regime is compatible with the computational ICT infrastructure and exploitation of FOSS.

Lastly, the NSI mapping and measuring methodology herein described has been operationalized successfully for policy purposes in the case of Ghana (2011) and seven EMEs (2007). This track-record provides high levels of confidence for the operation to be replicated in Kenya (currently underway) and in Tanzania, and the East Africa Community (EAC)[22].

[22] Currently UNIDO, in response to official requests from the Governments of Kenya, Tanzania and the EAC, is performing the mapping and measurement of the Kenya National System of Innovation. That for Tanzania and EAC are expected to be initiated in 2013.

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