A study of technological capability among product based telecom start-ups in India: Role of knowledge, learning and bricolage

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Abstract

Present work explores the development of new products among telecom start-ups in India. This paper weaves together threads of literature including innovation, bricolage, learning and knowledge acquisition and technological capability. We employ a qualitative research method and works through the data collected from seven independent start-ups. Our work proposes a process model for the evolution of technological capability as a result of complex interplay between existing knowledge, bricolage, new knowledge acquisition, and combinative capabilities. Paper further identifies gap focused learning and market focused learning as the two dominant learning mechanisms and also develops a conceptualization for studying architecture among the telecom related firms.

Keywords: New product development; Bricolage; Learning; Technological capability.

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1. Introduction:

Extant research has shown technology based new ventures play a significant role in the development of economy (Schumpeter, 1934, 1942; Wagner, 1994; Tether and Massini, 1998; Brixy and Kohaut, 1999) however, it is also well established that such start-ups face greater obstacles in their quest towards success with a substantial number failing to make the mark (Reynolds and Miller, 1992; Carter, Gartner and Reynolds, 1996). Existing literature offers little insight about; how the technological start-ups develop their products; introduce their products in market (commercialize) and what skills and resources are vital in the process.

Our primary theoretical contribution is to bring together diverse threads from strategic management literature i.e., resource-based view, innovation, architectural knowledge and its interplay with bricolage. Based on the above we propose a process based framework for creation of technological capability among the start-ups. Technology capability is a prime candidate that helps in commercialization in a technology based start-up and therefore is a source of competitive advantage. Our work thus contributes to theory development related to architectural knowledge, technological capability and its various dimensions among start-ups in a high-tech (telecom) context.

Before we move further, it needs to be clarified why our focus is on product based start-ups and why we focus on telecom as a context. In India, telecom sector has registered consistent growth of 20% (CAGR) during 2002-2012[1]. This growth coupled with rapid technological changes and changing customer preferences led to several business opportunities and as a result several telecom related start-ups sprung up across the country. However, majority of such start-ups have a services outlook as they have spun off from the Information Technology (IT) sector of India. Popular literature often reports that with price advantage facing fast deterioration; high intensity completion from other

[1] http://www.thehindubusinessline.com/features/eworld/indian-telecom-the-perfect-storm/article4313100.ece accessed as on 3rd March 2014

countries catching up; existing Indian IT services firms have been stagnating with lower than expected growth with no clear way forward. They have still not established themselves as product developers although it offers better margins and higher growth rate. Risk associated is presumed high even though Indian telecom equipment imports alone are expected to grow in double digits and projected to touch USD 30 billion[2] (by 2020). Since there is opportunity within the telecom sector and a few start-ups are engaged in product development so sector offers a conducive setting for studying product development related technological capabilities among Indian firms.

The rest of the paper is organized as follows. We begin with literature review and some basic conceptualization; we then discuss our methodology towards developing our analysis framework. We then present detailed analysis based on our case studies to understand and establish the interplay of architectural knowledge with bricolage as technological capability and further drill into architectural knowledge to understand its sub-components. We end the paper with limitations, and managerial implications of our work within conclusion.

2. Literature review:

Resource-based-view (RBV) and technological capability:

RBV views firms as bundles of resources and capabilities. RBV has been extensively used to explain the differences between performances of firms in same sectors which are attributed to idiosyncratic or tacit internal capabilities. It establishes that heterogeneity among the firms is due to valuable, rare, inimitable, and non-substitutable resources and these together bestow a sustainable competitive advantage to the firms (Amit and Shoemaker, 1993; Barney, 1991; Wernerfelt, 1984; Peteraf, 1993). Existing conceptual and empirical work has established that the development of capabilities is difficult, time consuming, expensive and risky because the outcomes may be uncertain (Dierickx and Cool, 1989; Helfat, 2000; Karim and Mitchell, 2000). For capabilities to be relevant to managers and researchers, measures of these capabilities need to be developed at the firm level, and therefore measuring different organizational capabilities has become an

[2] Source TEMA website, http://aycasonicsindia.com/pdf/ESDM%20Policy%20Initiatives%20by%20Govt.%20of%20India,%20May%202013.pdf accessed on 6th March 2014

integral part of research efforts (Henderson and Cockburn, 1994; Kim, 1999; Deeds et al, 2000; Upadhyayula et al., 2006). Technological capabilities too are a part of various other organizational capabilities and in this work we focus on technological capability only.

Over the years scholars have looked at technological capabilities in different ways. Conceptually, Bell and Pavitt (1993) define technological capabilities as the resources needed to generate and manage technological change, including skills, knowledge and experience, and institutional structures and linkages. Dosi and Teece (1993) added a more operational perspective when they defined technological capability as the ability to develop and design products and processes, and to operate facilities effectively. Prencipe (2000) has operationalized technological capability as breadth and depth of technology, with breadth referring to the diverse technological fields in which the firm is active and the depth dimension dealing with two different levels of component design (context being engine control systems in aircraft industry). On similar lines, Patel and Pavitt (1997) conclude that technological capabilities among large firms are multi-field, highly differentiated and stable, and rate of search is influenced by principal product and home country. Among important works focusing on technological capability in a specific industry, Figueiredo (2002) has studied Brazilian steel manufacturers and Afuah (2002) has studied the pharmaceutical industry. Industry focused scholarly work establishes complexity, path dependence and the fungibility of technological capabilities. Although rich in various ways this thread lacks finer details of how a technological capability can be conceptualized and operationalized. Existing literature is also not precise with regard to how technological capabilities evolve or develop.

Innovation and bricolage perspective:

From within the wide innovation literature we invoke the concept of architectural innovation first proposed by Henderson and Clark (1990). The authors argue linking various components differently without changing the core design to achieve requisite end result is innovative. This resulting innovation also forms the basis of competitive advantage to the firms. Various authors have defined architecture as modules, combination of modules and interfaces (Ulhrich, 1995; Baldwin and Clark, 2000; Fixson, 2005). As per Baldwin and Clark (2006), MIT, Engineering Systems Department defines architecture as “an abstract description of entities of system and their relationship”.

Irrespective of definition there is general agreement about superior architectural knowledge being a source of innovation as it enables firms with better understanding to experiment and work around existing bottlenecks to gain competitive advantage. Or in other words we can say that successful architectural innovation which leads to competitive advantage is the result of technological capability of the firm. So it is the technological capability that is behind innovation and also contributes strongly to commercial success.

In general innovation literature argues that in a situation of penury of generic resources and skills; innovations might happen through complex combinations of existing resources (Garud and Karnoe, 2003; Miner et al., 2001; Green et al., 2003; Olson et al., 1995; Schoonhoven et al., 1990, Baker and Nelson, 2005). Baker and Nelson (2005) and Senyard et al., (2009) reintroduced the idea of bricolage (Levi-Strauss, 1967) and extended its definition from simply "making do", to "making do by applying combinations of the resources at hand to new problems and opportunities". Another very important aspect of bricolage is selectivity (Baker and Nelson, 2005), in fact non-selective bricolage might be detrimental to an entrepreneurial firm. Afuah (2002) too in his work has included combination/re-combination of components, linkages between the components, methods, processes and techniques to offer products with desirable characteristics as a part of technological capability. Danneels (2002; 2007) emphasizes on leveraging of technological competence[3] and customer competence to develop new products which also enables renewing existing competence of the firms. Above thread thus borrows from RBV and presents bricolage as the primary driver of innovation and more so in case of entrepreneurial firms. Clearly, technological capability through a process of interaction between architectural knowledge and bricolage leads to architectural innovation among resource constrained start-ups. But how exactly does this interplay between bricolage and technological knowledge and resources enables development of new products is still not well understood.

[3] In present work we consider competence and capability as interchangeable

Measurement of technological capabilities:

Most scholarly work on technology capability is primarily focused on established firms and has operationalized the technological/R&D capabilities in terms of citations, patents, R&D labour, R&D expenditure to establish the important link between technological capability of the firm and firm performance (Deeds et al., 2000; Henderson and Clark, 1994; Yeoh and Roth, 1999; Tsai, 2004; Lee et al., 1999). But all such parameters including patents, citations and R&D spend are inadequate in the context of Indian and other start-up companies in the developing countries as start-ups in such places are not as patent intensive as their counterparts in developed counties. Often such start-ups are hard pressed for finances and they actually see patenting as cumbersome and resource intensive process during the early days. Patel and Pavitt (1997) have pointed out additional limitations of patent and citation based research on technological capabilities such as external technology linkages not getting addressed, tacit component of technology which may actually form the inimitable and valuable component not getting addressed and lastly software related capabilities not getting captured through patents and citations. Moreover, in a start-up firm expenditure is essentially on the development work and in this scenario R&D expenditure cannot be separated from development related expenditure. So there is a need for identifying better measures for technological capability among the start-ups which could also be potentially useful for the established firms.

To summarize, still existing literature does not present any framework to identify and measure technological capability in a given context and this represents a grey area in the literature. Moreover, there has been no work on telecom sector which involves a complex interplay of software and hardware knowledge to reach an end product. Specifically, we are looking to answer the following research questions through this work,

1) How does architectural knowledge manifest itself as a technological capability among the product based start-ups? How does it interact with bricolage to produce this capability?
2) Can architectural capability among product based start-ups be conceptualized into a measurable/tractable unit?

3. Method

Research design:

We choose multiple case-study based inductive approach to answer the questions posed by us based on the following;

a) Extant literature has unanimously established that capabilities are strongly connected to the context (Grant, 1996; Teece et al., 1997; Eisenhardt and Martin, 2000). In order to unravel capabilities among start-ups it is important to understand the context and case study as a method enables better understanding of the context.

b) Scholars in the field (Teece et al., 1997; Eisenhardt and Martin, 2000; Montealegre, 2002; Pan et al., 2006) have called for longitudinal case based studies to better understand capability related research questions.

c) Case based study is ideally suited to answer questions related to process inquiry as well as answering in depth explorative how and why kind of questions (Eisenhardt, 1989; Yin, 1994; Eisenhardt and Graebner, 2007).

Choice of cases or sampling is critical for multiple case based studies. For the purpose Miles and Huberman (1994); Pettigrew (1988) and Eisenhardt (1989) have advocated maximum variation or polar sample as an aid in developing more robust and generalizable theory. Another important issue in case based research is the number of cases and it has been recommended (Eisenhardt, 1989; Eisenhardt and Graebner, 2007) that usually four cases upwards is a good number for theory development if dealt with in a rigorous and detailed manner. Based on above guidelines we choose seven firms based on fundamental differences in terms of specific observable parameters (see table 1)[4]. Among the studied start-ups, one of the companies (C3) is no longer in existence and had to be closed down due to various business reasons even before we started our work. This company is of special significance in our work as it could help us in identifying many divergent patterns amongst the other firms.

[4] Refer Appendix-I for more details about research design and data collection related issues.

Table-1 Details of Firms under Study

(Under mentioned details capture the snapshot of firms at the time of data collection during 2008-09)

	Company Name						
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Location	Bengaluru	Chennai	Mumbai	Bengaluru	Bengaluru	Chennai	Bengaluru
Birth Year	2005	2000	2002	2004	2002	2001	2007
Founders' education and prior experience	Both had Post graduate degrees in technology. Both were first generation entrepreneurs without any prior start-up experience. The founders worked for well-known telecom related companies which included exposure to both hardware as well as software.	Both had Post graduate degrees in management; one founder was also a graduate from (IIT[5]) Bombay. Both were first generation entrepreneurs without any prior start-up experience. One founder had prior experience working for well-known software MNC and then for an Indian ISP in various capacities.	All founders possessed Post graduate degree or above in engineering from premier institutions. First founder was an experienced faculty member at IIT with years of consulting experience. Second founder was running a successful family owned business related to manufacturing CPE. The third co-founder had about 2 years of experience in software development.	Both had Post graduate degrees in management and graduation in technology. Both founding members were first generation entrepreneurs without any prior start-up experience. The founders worked in telecom software division for well-known software companies and also worked for a telecom start-up in both technical and managerial positions prior to starting up.	Both founders were engineering graduates with 2-3 year experience in telecom division of Indian software MNC. Both were first generation entrepreneurs.	Both the founders were PhD in respective engineering disciplines from prestigious universities abroad apart from being IIT graduates. Both were engaged in teaching at one of the IIT, and were known for creating several successful start-up telecom and software companies. Both were first generation entrepreneurs.	Founders were a group of seven engineering graduates with varied experience in software and telecom industry. All were first generation entrepreneurs although they had worked together in an earlier start-up related to telecom and networking.
Technology	WiMax (wireless)	Voice over Internet Protocol (VoIP)	Circuit emulation over Ethernet	Bluetooth (wireless)	SMS-C and Assorted mobile VAS	Network management infrastructure	Voice recognition for mobile VAS
Area of operation	Equipment Development	Platform Development	Equipment Development	Platform Development	Platform Development	Platform Development	Platform Development
Product Novelty	Small base station using the chipset developed by Wavesat	Specific software to enable ISP/TSP[7] to offer VoIP services. The	Working to develop a multi-service interface that could use the existing	Bluetooth based product to convert community centers into Bluetooth	Earliest SMS-C development for CDMA networks in	Comprehensive remote network management product for assessment and	Replacing interactive voice response by pressing keys to

[5] Indian Institute of Technology

	(semiconductor manufacturer) for their CPE[6]. The base station could be mounted on a tower or house top for broadband access.	pivotal innovation was the development of soft switch which de-coupled application server and front end.	infrastructure but provide data, voice and video capabilities with Ethernet at the core of the network.	enabled zones for promotion and advertising over existing mobile handsets.	India, also earliest Location Based Service developed	control of large networks including reporting tools	verbal mode using voice recognition
Hardware/software	Hardware intensive	Software intensive	Hardware intensive	Software intensive	Software intensive	Software intensive	Software intensive
Incubation	No	IIT Madras (TeNeT[8] group)	IIT Bombay (SINE[9])	No	No	IIT Madras (TeNeT group)	No
Venture Capital investment	No	Yes	Yes	Yes	Yes	Yes	Yes
Customers (all B2B) (Tech Vs Non tech)	ISP/TSP (Tech)	ISP/TSP (Tech)	ISP/TSP (Tech)	Community center, retail malls (Non tech)	ISP/TSP (Tech)	ISP/TSP (Tech)	ISP/TSP and other enterprises (Tech)
Patent Status (Granted/Pending/not Applied)	Yes (Pending)	Not Applied	Yes (Granted)	Yes (Pending)	Not Applied	Not Applied	Not Applied
Average employee strength	30	30	30	50	50	75	20
Success/Failed	Success	Success	Failed	Success	Success	Success	Success

[7] Internet Service Providers/ Telecom Service Providers
[6] Customer Premises Equipment
[8] Telecommunications and Computer Networks Group
[9] Society for Innovation and Entrepreneurship

We begin with our initial framework that we present in the next section but our ultimate aim would be to develop a parsimonious framework by weaving together the existing concepts besides coming up with a measure for architectural design related technological capability. As a part of cross case analysis we dwell deeper into the process of design activity among the firms to unearth patterns regarding their interaction of architectural knowledge with bricolage process; which did educate us about a way to conceptualize development of technological capabilities. This enabled development of conceptual clusters which subsequently were sharpened iteratively by using memos. Memos were utilized to present emergent themes which were further explored and discussed before we could reach any definitive point in our work. From the perspective of presentation we move back and forth between data and theory like it is the standard practice in most works on theory building (Daneels, 2007; Eisenhardt, 1989). We present evidence in the form of quotes and examples from case studies to back up our arguments.

However, it needs to be mentioned here that a limitation of the above process is that it has the danger of suffering from entrepreneur's bias towards certain skills or activities as they might be overemphasized in hindsight. We wave tried to minimize the bias by talking to most members of the founding teams and getting their opinions as well thereby achieving triangulation. In cases where this has not been possible we have taken a call based on our understanding of the context.

4. Initial Analysis Framework:

Based on our review of extant literature and our context; for the present work we define technological capabilities as *a collection of skills, resources, routines or processes that enable a start-up to design and develop the desired product and thereby bestow competitive advantage (through cost, scale or fulfilling a special need)* . In order to identify the technological capabilities we utilize the framework by Aeron and Jain (2011). This has also been indirectly emphasized in the previous work in the domain that; just a presence of certain activity cannot make it a capability but certain level of excellence or maturity has to be achieved with respect to the process of the activity and its outcomes (Helfat and Peteraf, 2003; Winter, 2003; Helfat et al., 2007; Schreyogg and Kliesch-Eberl, 2007). Process based maturity for start-ups is difficult to adjudge as most processes are still evolving and in flux, so primarily outcome based maturity is what would aid in identifying a technological capability in a start-up. Summarizing the above discussion; important attributes of any activity that help in identifying technological capability are that the activity should have,

a. Been performed well, consistently leading to competitive advantage (Helfat and Peteraf, 2003; Winter, 2003). So activity should be one that might have made critical contribution to the commercialization and revenue generation process.
b. Evolved into identifiable routines overtime (Nelson and Winter, 1982) or resulted in creation, modification or extension in terms of outcome (Helfat et al., 2007).

In addition from our theoretical understanding of bricolage (Baker and Nelson, 2005; Garud and Karnoe, 2003; Kogut and Zander, 1992; Miner et al., 2001; Salunke et al., 2011), we can say that the process may be in the form of combination or recombination; enabling exploitation of many different capabilities (combinative capabilities) resulting in creation, modification or extension (Helfat et al., 2007) of existing paradigms. So we look for specific instances that bring out the above mentioned points.

5. Analysis:

We intend to highlight the design related activities among start-ups in order to understand how they go about the process of developing technological capabilities for designing new products within their constraints. We primarily intend to understand from a theoretical perspective how architectural knowledge and bricolage interact to play a role in the process.

Towards a process framework of technology capability:

All the start-ups we studied were engaged in developing products wherein the basic functionality had been in existence since some time in some form or the other. However, the uniqueness of the start-ups emanated from creating a completely new product; extending the existing technology to a new and relatively unexplored market or adopting/modifying existing products for usage in a new context with significant customization.

For example, C1 developed a lower capacity, compact WiMax BS for local/individual usage at a time when base stations were perceived as only mass scale, expensive equipment in India (extension and modification). C2 was engaged in developing ready to use VoIP software infrastructure for service providers in India (modification). The table below summarizes the creation, modification or extension of product by the firms under study.

Table 2: Overview of firm classification

Company	Create	Modify	Extend
C1	No	Yes	Yes
C2	No	Yes	No
C3	Yes	Yes	Yes
C4	No	No	Yes
C5	No	Yes	Yes
C6	No	Yes	No
C7	No	Yes	Yes

For product design, understanding of the telecom domain played a major role. It also requires complete familiarization with existing designs as well as their constraints in terms of limitations and existing problems. From a bricolage perspective we see that the firms were trying to utilize the existing resources in order to develop new products. Prior literature distinguishes between necessity-based-bricolage (Desa and Basu, 2013; Duymedijan and Rȕling, 2010; Simon, 1957) which is "satisficing"; and ideational bricolage (Desa and Basu, 2013; Carstensen, 2011; Kumar et al., 2011; Mair and Marti, 2009; Seelos et al., 2010; Louridas, 1999) which could be a design philosophy with firms intentionally using existing or discarded resources. Our evidence shows the presence of both necessity based and ideational bricolage among the firms that we studied. In addition across all firms we could observe instances and examples of material, skill, and labour bricolage (Baker and Nelson, 2005). Rich evidence from firms under study have been presented in the table below.

Table 3: Citing evidence for material, labour and skill bricolage

Company	Context	Cited Vignettes/Examples
C1, C4	Material bricolage	"We have created our own architecture by which we said, we are going to pick and choose hardware available in the market put our software on it and that's how we are going to ride on the volumes that somebody else picks up and therefore we are able to substantially lower the price of the Base Station". "We had components and we added to their ideas, in fact our proposition is we have the components, we know the market and that should help us reduce the risk and cost associated with any development. So it is their idea, basic idea was theirs but components were all ours."
C2, C5	Skill bricolage	"The same team was doing development and support, because there were live customers. So the same team is also attending to all those problems and building further". "It was on a completely Motorola environment. It was coding for them but it was on a new product and it was something which I had not done earlier. Earlier I was working on the network side but now I moved to the mobile handset side on a mobile program".
C3 and C6	Labour bricolage	Initial days a lot of work was accomplished by students of IIT where the companies were being incubated and the entrepreneurial teams comprised professors on sabbatical.

The above mentioned bricolage stage together with combinative capabilities (which forms second stage of bricolage) is aimed towards creation, modification or extension, which are manifestation of technological capability. But to reach such a stage the firms were faced with a knowledge gap which was overcome through learning (March, 1991; Nonaka, 1994; Gavetti and Levinthal, 2000). This learning was different in differing instances for example the knowledge gap for creation required a different form of learning vis-à-vis either modification or extension.

For the case of C3 which was involved in "creating" a new product knowledge gap was rather huge although the entrepreneurs were highly trained and had access to IIT Bombay in terms of learning resources. Given the product complexity the amount of exploration and involvement of the technical team was very high. According to one of the co-founders and a senior developer at C3,

"We were developing state of the art hardware, complete with NMS and MDU's etc, a complete system not some software alone. …. Also all this requires a very high quality execution team. … the nitty gritty of the details you have to go through it, I did not know all the details to the last detail but actually my team members like XXXXX, they were also quite well versed with this, so they were also very competent people really so that also helped to some extent".

"There were other complexities; the uplink was VDSL in the first version of MDU. So with VDSL the chip sets were new and not many people had used it so [had to learn it for further development]".

"The use of public domain SNMP codes and he wrote all the assembly language stuff, that was one of the toughest challenges that we faced, getting it on the foot and make it work on the micro controller, the SNMP agent was something that was really original that was done here".

"We used to look in to the web site of the vendors, newsletters, vendors also used to come, we kept reading and discussing features, we kept looking for if this is the feature we need which chip supports this feature, it was a very involving exercise."

"It [information] really also came from the experience and domain knowledge of the people. Actually I was very fortunate to have some of the brightest people, they were really very competent. They were very good employees and always knew where to look for information. It was like research to some extent. Even though they were not experienced there maturity level was matching those of the experienced people. ..Sometimes they were doubtful about whether they were doing the right thing or not."

Based on above cited vignettes, we label the learning requirement for "creation" kind of products as "explorative" learning. Specific characteristics of "exploratory" learning were that the team had no set ideas or fixed direction and was completely self-driven. The team had to go through not just standard documents and text books but also technical journal articles to be able to develop functionality. Moreover, the focus was on development from scratch in most cases as is evident from above cited quotes about SNMP. Lastly, given the product to be developed was one of a kind so the technical team was always in a learning mode with high uncertainty around the final design and structure of the product. "Explorative" learning was found to be absent from "modification" and "extension" kind of products.

In addition to above, in "creation" we could identify and label two other forms of learning, "Gap focused" learning and "Market focused" learning. We were able to identify both gap focused learning as well as market focused learning for firms that were identified as engaging in modification but for firms engaged in extension only; we could identify just gap focused learning.

Market focused learning deals with reworking and customizing a product through multiple interactions with the market forces including but not limited to domain experts, customers, dealers or vendors. Gap focused learning deals with highly specific technical knowledge being acquired for the purpose of completing the product. In gap focused learning; search for knowledge is highly selective and aimed towards fulfilling existing shortcomings towards completion of final product. In a majority of our firms gap focused learning was related to acquiring knowledge about standards in place for specific technologies like WiMax or VoIP or Bluetooth etc.

Both gap focused and market focused learning display rich evidence of interaction with social networks and so we can say that both implicitly include a component of relationship based learning within them (Salunke et al., 2012). Also, both market focused and gap focused learning represent much more guided knowledge acquisition processes vis-à-vis explorative learning which proceeds with minimal guidance and therefore the intensity of search is much higher in the latter. Below we present instances/examples from firms under study as evidence of market focused and gap focused learning.

Table 4: Citing evidence for various learning types

Company	Market focused	Gap focused
C1	"On regular basis we get ideas about where we are going wrong, what features he [customers] needs more urgently, what he needs a little late, so we talk to him, bargain with him. So I think we are more and more becoming a company of product engineering, taking marketing requirements into the product development".	"Reading the standard was helpful in a way to understand how the [WiMax] protocol works and how the things should be done but finally you need to apply your experience in those things [design]".
C2	"Earlier for everything we had a one line solutions – for example we thought we will hire space from data centers but slowly things fell in place. We realized we could design the service and sell it to service providers who already had an infrastructure, subscribers etc". "We got feedback in every aspect of its running, in fact we were only focusing on the switch and soft phone but when we started to sell people asked them how do they bill for its usage".	"I was actually going through the VoIP things [material], how to fit this in to that, you can say that the Internet was the only source for me. I hooked myself on that, followed it and thus updated my knowledge about all this". "It is internalized in our environment, here is no formal training or anything but essentially the group as a whole they read up the things, there is a small presentation and we sit together and discuss what is it that needs to be done, what are the packets that need to shot out at what time, what is the basic thing so that is how the things are taken up".
C3	"So customer interaction actually led to our articulating the kind of product that was really required. That was because of customer requirements which were conveyed to us by the marketing team".	"When we started this company MEF and their standards were not formalized but over the years the forum was formed and they started standardizing their activities and we also started tracking it so eventually we had put this goal that we will have to comply with these standards".
C4	NA	"See Bluetooth stack is not something that we are inventing its already there and we know that in our stack these are the components which are not there we need to

		develop it so there is a roadmap for it when we did it, the initial roadmap only has basic components and later on there were other things that we wanted to, that was pre-decided….of course there are various things that we have done for instance a device for recognition. For us to be successful there are various things that have to be done and one is identifying the device and making sure that the right content is delivered to the firm".
C5	"So we realized that there was no SMS for CDMA in India and we got to know that this was something that we could do. No one was developing it, no one knew much about it and we smelled an opportunity there".	"It was the Internet and discussion…We were reading actually at least one year back onwards, we had documents about CDMA".
C6	"We moved from providing network management to enterprises for their heterogeneous networks to proving it for telecom service providers". "I think the senior management felt that there is a need for such an organization that focuses on Indian market and provides customized solution –that is the key offering - we do not sell you what we have but what you need. Pre-dominantly the team is focusing on making frameworks – so that it is possible to customize to the next level".	
C7	"See they wanted to reduce cost and one of our common contacts said this is something to look at. Then they called us, then they discussed with us, these are our problems and how could you help, then we jointly came out with this is what we can do".	"There is a difference between audio songs and video songs, so if you try to use TV for voice recognition it will not work; we realized video songs were a bit slower. Since you cannot know from where the song is been played, we have implemented a logic that first checks it with the original song, then reduces the speed of the song and then checks it and it one of the most important developments".

Once the above mentioned knowledge gaps are identified, next we see combination of knowledge and skills that culminates in outcomes namely creation, modification or extension. This combination is part of second stage of bricolage which succeeds the learning process and thus enables technological capability to evolve which we identify in the form of product (create, modify and extend). As suggested by extant literature (Yli-Renko et al., 2001; Ethiraj et al., 2005, March, 1991), firms needed to assimilate and integrate their existing knowledge with knowledge acquired from external sources, make requisite improvements/adaptation (Kiel, 2004) to the acquired knowledge for realizing the products. This required combinative capabilities (Kogut and Zander, 1992) to come forth and play a part in effectively utilizing the existing resources which is another example of bricolage. This is in accordance with existing theory where bricolage is looked at as a platform that enables combining of existing resources to create new value without the resource being withdrawn from the original source as was pointed out by Baker and Nelson, (2005). However, unlike Baker and Nelson's (2005) findings we see that bricolage did result in innovative solutions and designs which supports work by Gundry et al., (2011); Phillips and Tracey, (2007).

The technological capability which manifest itself as the final product enables the firm to commercialize and therefore earn revenues and as we argued in the previous section, for a start-up revenue generating activity is a source of competitive advantage. Based on above discussion we propose the following process model (see figure-1).

Existing literature (Barney, 1991; March, 1991; Grant, 1996; Teece et al., 1997; Eisenhardt and Martin, 2000) has been consistent in bringing forth the role of tacit knowledge and causal ambiguity or idiosyncraticity (Lippman and Rumelt, 1982; Dierickx and Cool, 1989; Reed and DeFillippi, 1990) in the capabilities of the firms. Bricolage too, involves idiosyncratic combinations of resources. In technological capability we see an existence of significant tacit knowledge dimension because most standards that were implemented by firms were not readily imitable by even leading firms in the domain. This corroborates that our results are in agreement with the existing paradigms of capability framework. So we can conclude that the evolution of technological capability was a result of complex interplay between bricolage, existing knowledge and knowledge brought forth by learning among the start-ups.

Next we develop a conceptualization for architectural design that would enable better assessment of IT/telecom related products.

Conceptualizing architecture:

Below we identify and present three distinct design levels with the aid of instances/examples from our case descriptions for understanding overall architectural design. The three design levels are the *concept level, component level and interface level* design. Concept level deals with idea and top level view of the product, component level and interface design look into further detailed aspects of components and their integration into a functioning product.

Concept level design: Concept level design represents the detailed top level idea of the product identified as opportunity by the entrepreneurs. In other words, it is the most basic and feasible abstraction of the product design by the team. During concept level design, the design team identifies the roles of major components (both hardware and software) that need to be brought together to achieve desired end functionality or final output. Although none of the product concept was a breakthrough in the scientific sense, it did represent a change from those in the existing designs[10] in the market. In other words the firms were engaged either in bringing a change in operating paradigm (extension and/or modification) or in creating a new concept within specific constraints to achieve the requisite functionality.

From a measurement perspective we propose that for describing a concept level design change, the product should either be completely new to world, a new scientific development altogether (the fundamental principle behind the product should change, a new functionality) or the operating paradigm needs to change (same functionality as before but in a novel way) such that it was never conceived in the product family previously. Change in configuration, by affecting existing overall modularity of the product or drastic scalability changes for specific contexts are also considered a part of concept level design.

Component level design: This occurs at a more granular level wherein each major part identified in the concept level design is taken up for detailed design. It could be an incremental improvement in existing component or a component which is not being used for the specific purpose could be adapted for use in the upcoming product leading to cascading changes elsewhere. Important aspects of component level design are segregation of strategic and non-strategic components; knowledge regarding functions of individual components and their interactions; familiarity with various off the shelf components available in the market. The above activities enable the start-up to focus its

[10] Existing design stands for those designs which were being used in family of products that were similar to the ones being conceived by the start-ups under study in terms of functionality

energies towards identified strategic components to bring about any improvement/modification within the components.

In case of hardware dominated products, the choice of chipset determines the further design of hardware circuit and other functional components. The choice of software platforms to be used in the development is also made during component level design. Design of specific algorithms for improving the performance of telecom related products such as jitter control; buffer control etc is accomplished as a part of software component design. Additionally, software design related to graphic user interface as well as the network management systems is also decided during the component level design. Apart from software and hardware individually, design has to be worked out for the development of embedded software which enables interaction between the hardware components and this is a very complex activity.

Table-5: Component level changes made by firms under study

Parameter	Firms that show evidence
Major change across components	All firms
Changes due to chip set	C1, C3
Customized choice of software and hardware platforms	All firms
Internal design of hardware circuits	C3
Internal design of embedded components	C3
Internal design of telecom specific algorithms	All firms
Internal design of graphic user interface and network management component	C1, C3, C6

Interface design: The third component of architectural design is the way interface between various components of the product is conceptualized. The product by virtue of its interface design may be strongly coupled or loosely coupled impacting its modularity. Interpreting standards is a critical activity as most external interfaces have to be standardized to enable interconnection with a plethora of third party equipment. Internal interfaces between components are also based on various protocols which on improper interpretation may impact the overall performance of the product. The main activity that needs to be accomplished is the choice of appropriate protocols for the interfacing with other components or products.

Table 6: Instances of protocol development by some firms under study

Firm	Protocol worked upon
C1	designed its versions of protocols between the base station and the network management system
C2	worked on H.323 and SIP, Radius
C3	SNMP agent and compliance with MEF formats
C4	worked on object exchange protocols (OBEX)
C5	CDMA

Also most of the firms designed their own complete protocol suites for the products. In certain situations the existing protocols or standards may not be best suited or might be proprietary. In such cases either a protocol may need to be re-conceptualized from scratch guided by the existing protocols or the existing protocol may need to be enhanced or modified to serve the purpose like C2 had to design its proprietary NAT traversal method. Based on above discussion we propose following conceptualization for architectural design of any telecom related product.

Table 7, Components of architectural design of the product

Architectural design	SD	D	N	A	SA
a) Concept level design • Is there a change in functionality with respect to existing products • Is there a change in operating paradigm (w.r.t.) existing design • Is there a change in configuration from existing design					
b) Component level design • Has majority of components undergone change • Is extent of change from dominant design significant (due to chipset) • Has customized choice of hardware and software platforms been made • Has design of most hardware circuits been supervised in-house • Has design of embedded components been supervised in-house • Has design of telecom specific algorithms been undertaken in-house • Has the design of GUI and network management system been developed in-house.					

Architectural design	SD	D	N	A	SA
c) Interface design • Has Interface standardization (external and internal) been achieved • Is the Interface flexible • Has design of protocol suite been supervised in-house • Is there any protocol enhancement					

On comparing our conceptualization of product architecture with existing literature, we see that it is similar in intent to that conceptualized in Ulrich (1995) and Fixson and Park (2008) but at the same time enables extension to products that that have both hardware and software parts within them. Hence it is more useful for IT/telecom or embedded products as compared to pure mechanical products.

6. Conclusion:

Our work contributes to both theory and practice in many ways. From a theoretical standpoint our work brings together innovation, bricolage and RBV literature to answer questions related to technological capability evolution and bricolage leading to innovation among start-ups thereby contributing to various threads of strategic management literature in the process. We also present a process model for the evolution of technological capability linking together bricolage, learning as well as combinative capabilities. Our approach has promising implications for future work focusing on understanding evolution of capabilities as well as studying strategic innovations among the firms.

From managerial practice perspective insights from product development among start-ups might aid similar activities across established firms, enabling them in adopting lean and more cost effective techniques. We also contribute by proposing a scheme to understand product architecture which is agnostic to product being software or hardware. We also bring forth that the technological capabilities among start-ups lies in enabling a product or service that further aids in revenue generation unlike and an established firms where capabilities manifest in the form of maturation of a specific skill and high level of routinization. Our work forms an important link in the technological capability evolution related work and thereby complements existing work on established firms.

Through this work we have presented a snapshot of product based telecom start-ups and their issues in India but it can be speculated that on investigation in similar settings across other developing counties similar issues may emerge. Also we would like to mention that although our context was telecom but our process of technological capability evolution can be extended to other high-tech start-ups in different settings such as bio-tech or pharmaceutical sector. Our conceptualization of architectural design could be used as an instrument for assessing innovativeness of any new design which could further inform measurement of technological capabilities in future research in this area. Another interesting area of future research could be interaction of different organizational capabilities and their impact on one another as well as on the firm performance. On a broad level work on technology entrepreneurship in India is still in infancy and we hope our work motivates more work in this area.

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APPENDIX-I

Details of Research design:

We identified 16 companies within the telecom sector (through entrepreneur network) operating in different domains such as voice over Internet Protocol (VoIP) platform development, technology platform for offering value added services and equipment manufacturers. To fulfill our objectives we were looking at the firms with following attributes. The companies had to be product companies looking to sell their end product to either telecom/Internet service providers or other enterprises and none of them was to be purely a services based company. Since we were interested in understanding technological capabilities leading to commercialization, we needed early stage firms which already had customers and were in the market for at least a year. A time window of 3-4 years from inception of the firm was considered adequate as beyond that the firm moves to a growth stage. The companies had to have their registered corporate head offices in India. The reason for the above filter was that companies started out of India would face a different external environment in terms of the ability to raise capital as well as the risk appetite of the entrepreneurs and investors as compared to those based in US or UK. The companies had to be independent and not promoted by any large diversified conglomerate as a company promoted by such group would be a diversification move rather than a start-up.

We sent letters to all the 16 identified companies obtained from their respective websites and sent mails to them identifying ourselves and explaining the purpose of our work. We requested each of the companies to let us have a session with each of the co-founders to understand and assess the evolution of their firms over the years. Of the 16 firms five chose not to respond and four were found to be services oriented firms.

Data Collection:

Our data collection was spread over a year wherein we conducted 2-3 rounds of interviews across the four firms. Since we were studying start-ups (max team size 30, min team size 16) the founding members formed primary respondents as they are most well informed about each activity in the firm. In first round we interviewed the founders in all firms separately and our interview questions (semi-structured) were focused on technological trajectory followed by the firm and associated decision making (interview duration varied from 45 mins to 2 hours). Subsequently in second or third round we also talked to senior managers apart from founding members wherever need was felt for the same (about 3-4 members in each firm were interviewed). We also collected company related documents (product details, meeting details, e-mails etc.) which helped in triangulation of collected data. We also interviewed five external experts (both from industry and academia put together) to enhance our understanding about the telecom start-ups and issues faced by such firms. Once data was collected the interviews were transcribed verbatim (300 pages) and converted to case histories. The case histories so prepared were sent to respective firms for their approval in establishing an authentic description of chain of events before further analysis.

Figure1. Process model of technological capability evolution leading to competitive advantage