Citation:
Kunamaneni, S (2017) Low-Cost Innovation Capability development in Emerging and Transition countries: An Institutional Perspective. In: International Conference on Frugal Innovation for Sustainable Global Development, 07 November 2017 - 08 November 2017, Leiden (Netherlands).

Link to Leeds Beckett Repository record:
https://eprints.leedsbeckett.ac.uk/id/eprint/5836/

Document Version:
Conference or Workshop Item (Published Version)

The aim of the Leeds Beckett Repository is to provide open access to our research, as required by funder policies and permitted by publishers and copyright law.

The Leeds Beckett repository holds a wide range of publications, each of which has been checked for copyright and the relevant embargo period has been applied by the Research Services team.

We operate on a standard take-down policy. If you are the author or publisher of an output and you would like it removed from the repository, please contact us and we will investigate on a case-by-case basis.

Each thesis in the repository has been cleared where necessary by the author for third party copyright. If you would like a thesis to be removed from the repository or believe there is an issue with copyright, please contact us on openaccess@leedsbeckett.ac.uk and we will investigate on a case-by-case basis.

International Conference

Frugal Innovation for Sustainable Global Development

Museum Volkenkunde, Leiden
7 - 8 November 2017

Centre for Frugal Innovation in Africa
www.cfia.nl

SESSION 3: Frugal Innovation & Society
Suneel Kunamaneni

Low-Cost Innovation Capability development in Emerging and Transition countries: An Institutional Perspective

Universiteit Leiden
The Netherlands

TU Delft
Delft University of Technology

Erasmus University Rotterdam

Low-Cost Innovation Capability development in Emerging and Transition countries: An Institutional Perspective

Abstract

The past decade has seen an increase in the extent of research focused on low-cost innovation in emerging and transition countries (ETC). However most studies focus on defining and differentiating the various innovation terminologies (good-enough, frugal, cost etc.) and in general offer a market based view of how firms develop low-cost innovations in response to consumer needs and affordability constraints (demand side), rather than attempting to understand 'how' firms may also come to develop such innovation capabilities as a result of institutional factors related to public-science system, labour and finance (supply side). The analysis in this paper is structured around low-cost innovation in rechargeable batteries in China and point-of-use water purification in India, and draws upon strategies at the Chinese firm BYD and Indian firm Tata respectively. Our analysis shows that a.) Institutional structuring of public science R&D and weak engagement with industry, b.) 'diffusion oriented policies' related to producing technical labour, and c.) a weak venture capital finance system, are important drivers for firms in ETCs to focus on low-cost technological innovation capabilities.

Keywords: Low cost Innovation, Emerging markets, Innovation system, Innovation capabilities

1. Introduction

Management researchers have devoted considerable attention to the drivers of new product innovation and its impact on firm performance (Chesbrough, 1999; Teece, 1986; Tylecote & Ramirez, 2006). However research on innovation capabilities and strategies is largely based on the institutional structures of the developed west. Considerably less attention has been devoted to the study of innovation in Emerging and Transition Countries (ETCs) (Crescenzi, et al., 2012; Ayyagari, et al., 2011). This is despite the fact that competitiveness of firms and regions in a globalizing economy rests on their ability to continuously develop, accumulate and exploit transnational capabilities (Ghoshal & Bartlett, 1988; Cooke & Morgan, 1998).

The majority of Customers in ETCs are very price sensitive and have very different requirements to developed countries in terms of product and service requirements. Developing low-cost and good-enough innovation requires different strategies to premium products for western markets. Williamson (2010) introduced the idea of 'Cost innovation' as solutions that offer similar functionalities to Western products at lower cost. An often cited example of cost innovation is rechargeable lithium-ion batteries made by the Chinese firm BYD which was able to reduce the production costs by 70% by using a semi-automated process (Quan & Sanderson, 2013). Another popular concept is 'Frugal Innovation' (Radjou, et al., 2012; Bound & Thornton, 2012), which is not a re-engineered solution like BYDs semi-automated process, but a product or service that may be quite disruptive because firms offering them are not competing merely against a traditional rival but also against "non-consumption" since the potential customer might not have the financial means or access to the necessary infrastructure for using it. Indian firm Tata's 'Swach' water purifier that can remove

99% of disease causing bacteria is often cited as an example of frugal innovation (Tiwari & Herstatt, 2012). It was offered at a price point keeping in mind the affordability constraints of the 'bottom of the pyramid' income group. A fuse on the product indicated beforehand to the consumer when the filter was near its end of life, giving enough time to replace the filter, hence solving the accessibility constraint.

Despite the increasing attention on low-cost innovation in ETCs (Prahalad, 2006; Zeng & Williamson, 2007; Brown & Hegel, 2005; Govindarajan & Ramamurti, 2011; Radjou, et al., 2012; Prahalad & Mashelkar, 2010), the existing literature is weak on the institutional antecedents of low-cost innovation. Most studies focus on the demand side in relation to customer affordability and accessibility. Ernst, et al. (2015) claim to draw on institutional theory to explain three antecedents of affordable value innovation -bricolage (creative combination of scarce existing resources to develop new solutions), local-embeddedness of a firm and product standardization. Their study however tends towards pragmatism as it explains how firms overcome institutional constraints rather than understanding how the structure of institutions in itself may encourage firms to develop distinctive low-cost innovation capabilities. We argue that such a market-led approach on low-cost innovation puts a strong emphasis upon the need for 'quick' adjustments in reaction to an uncertain environment, rather than improving the efficiency of institutions. This research therefore emphasises the key features of institutions that shape low-cost innovation competencies.

This research will primarily look at technology oriented innovation because technology development has a strong impact on national innovation policies. Most of the scientific and technical knowledge still exists in the triad countries (United States, Western Europe and Japan) and technology development in ETC's continues to rely on transfer of knowledge and expertise from the industrially advanced economies, moreover it is often inappropriate to the needs of low income consumers (Kaplinsky, et al., 2009). Archibugi and Pietrobelli (2003) also argue that the transfer of foreign technology per se has a negligible impact on learning unless accompanied by local innovation policies to promote learning, skills and technological capabilities. Therefore this study aims to analyse the relevance of technology innovation within the socio-economic condition it is embedded in, because policies that are only aimed at catching up with the developed west are unlikely to meet the needs of most people in ETC's.

The rest of the paper is organised as follows. In section 2, we discuss the theoretical and empirical background of the study. The methodological issues related to using archival data are presented in section 3. In section 4, we provide a detailed analysis of low cost innovation in rechargeable batteries in China and point-of-use water purification in India. Our analysis will draw upon firm-level strategies at BYD in China and Tata in India. In section 5, we conclude that the structuring of institutions plays a critical role in ETC firms innovation strategies, and offer thoughts for future research on sectoral innovation across countries.

2. Institutions and Innovation Capabilities

The potential market size of ETCs has attracted management scholars and thinkers to investigate and analyse their role in globalization of technology and innovation. Ever since Vernon (1966) first proposed the product life-cycle theory, industrially advanced countries have been the focus of innovation diffusion studies. According to this classic notion, new products and technologies are first developed and launched in developed countries, and only later introduced and commercialized in less developed countries when they have become increasingly mature, out-of-date, and obsolete in the developed market.

The large market potential of ETCs has led to increasing competition among firms fighting for a share of the pie (Iyer, et al., 2006; Gadiesh, et al., 2007). However, despite a growing middle class in ETC's, especially in Asia, most consumers still cannot afford western consumption and are often constrained by other bottlenecks, such as poor public and private infrastructure or limited service availability. As a result, firms have started to develop market-specific local innovations that are characterized by high value at low cost, and potentially disruptive. The rising demand for low–cost products among the aspiring consumers of the developing world will drive an enormous global market for low–cost, high–quality products.

The emergence of a hub for low-cost innovations possibly suggests a "lead market" role for ETC's (Tiwari & Herstatt, 2012; Herstatt & Tiwari, 2017). However, lead markets, as understood today, are associated with economically developed countries characterized by high per capita income, great customer sophistication and high quality infrastructure. Tiwari and Herstatt (2012) propose that lead markets can also emerge in ETC's because market attractiveness (e.g. high demand volume, export advantage) and technological capabilities can offset many other resource and institutional constraints. The generally low customer sophistication is thus balanced by innovator sophistication to design cost effective, "good enough" solutions that can meet the needs and aspirations of consumers in a highly competitive market. This implies that firms need access to a competent and sufficiently large technical base with in-depth knowledge of the targeted consumers ("social capital"). However Tiwari and Herstatt do not consider how the structuring of institutions may also lead firms to develop low-cost technological capabilities and unique innovation strategies to satisfy the lead market potential. The lead market idea is focused on competition as the most important element to push innovation. However development issues such as access to clean water at low-cost cannot be solved simply by competitive strategies to fill institutional voids, because such solutions require firms to have an innovation model that supports them in identifying specific solvable problems and proposing possible modes of participation within the current institutional set-up. The current study therefore deepens our understanding of how institutions in ETCs interact with firm-level strategies, and explains how firms come to develop unique low-cost innovation capabilities.

The idea of a National Innovation Systems (NIS) is often used to understand how national institutions contribute to generation and diffusion of new technologies, and how government and firms negotiate policies to influence the innovation process (Metcalfe, 1995). The key components of innovation systems include firms of different types, public and private research organisations, education and vocational training institutions, financial institutions, business associations, research consortia etc. (Whitley (2002), Whitley (2007, pg. 75)).

Although technological 'catch-up' and economic development have always been central to the NIS concept (Lundwall, 2007), the idea was conceived on institutional characteristics in developed countries (e.g. Japan, USA, Germany, Sweden) with ETC's largely absent from discussions in early literature. However, later the NIS concept was applied to the newly industrialised countries of the east (e.g. South Korea, Taiwan, and Singapore) and countries of Latin America (e.g. Mexico and Argentina), and more recently, been applied to the transition countries in eastern Europe, emerging powers of India, China, and South Africa, and more limitedly to less developed countries in Sub- Saharan Africa and elsewhere (Metcalfe & Ramlogan, 2008; Balzat & Hanusch, 2004).

Gu (1999) suggests that technology catch-up with the west, based on industrial models of the west and capital from the west is the best way to augment the innovation system in ETC's. Though "imitation" catch-up activities may be considered as innovations since their adoption involves adaptations to the local context (Dutz, 2016) and may also positively correlate with new-technology development (Zhang & Zhou, 2016), ultimately ETC's must implement an Innovation policy that is most appropriate for their country's unique socio-economic structure. While 'best practices' implemented in developed and recently industrialised countries such as Korea can offer useful guidance, a 'one size fits all' solution is unlikely to align with the local context (Crescenzi and Rodríguez-Pose, 2012; Niosi, 2010). However National innovation systems may be weakening as different countries and also different regions within the same country may have advantages in different sectors, thus requiring different logics. Also key features and characteristics of institutional frameworks governing finance, labour and public science systems encourage firms to develop innovative competencies in different ways, and so generate different types of technology innovation in different societies (Whitley, 2007, pg. 191). Bhatti and Ventresca (2013) argue that, in addition to resource constraints faced by firms upstream of their value chain in order to innovate and affordability constraints downstream in meeting the needs of the base of the pyramid, firms are challenged by complex institutional contexts or institutional voids characterised by the lack of institutional facilities, norms, and regulations needed for a well-functioning economy. This is because of constraints on the limited capacity of governments in ETC's to pursue various issues at a time. While such institutional features generally limit business activity by increasing transaction costs and therefore represent a hurdle for MNC and entrepreneurs (Soni & Krishnan, 2014), they may encourage development of new innovative competencies. Institutions can indeed facilitate innovation if firms have an adaptive ability that allows them to react to and play a more active role in overcoming any institutional constraints by taking over certain functions of institutions (Greeven, 2013). Bhatti and Ventresca do not analyse how key features, of institutions can encourage firms to develop organisational capabilities suitable for low-cost innovation. Moreover the development of specific ways of innovating depends not only on the strength of institutions, but also on the complementarity of key institutions. Complementarity entails that the comparative advantage of a region or country depends upon the extent to which institutions are compatible with one another (Bruno, 2000). For example, a robust venture capital market is dependent upon the existence of clear rules governing intellectual property rights (Fenn, et al., 1995). Because of institutional complementarity, different kinds of learning, cooperation and competition take place under different institutional settings (Whitley, 2007, pg. 84). Therefore both the strength of institutions and extent of complementarity lead to certain firm strategies and organisational forms to become prevalent.

Strategic cost-innovation in high-tech firms that is primarily a result of efficient management of low-cost labour may not be perceived as genuine technological innovation capabilities (Zheng & Wang, 2012). Moreover any Innovation is likely to be process innovation, new techniques that lower production costs. As we shall see later in the case of rechargeable batteries made by BYD, the lower costs were a result of both low-cost labour and process improvements. Also low to medium technology innovation for the bottom-of-pyramid, though market disruptive, could be a result of incremental improvements to existing technology and not a result of radical technology development (Agnihotri, 2015). In the case of Tata's Swach water purifier, the technology development is arguably incremental, as it involved a new technique for treating an existing water filter made of rice husk ash with silver nanoparticles that have antimicrobial properties. As such, Swach did not involve the development of radically new materials. However radical technological innovation is an important driver of the growth, success, and wealth of firms and nations (Tellis, et al., 2009). (Li, et al. (2017) suggest that because high resource consumption and high uncertainty are two of the most critical challenges for radical technological breakthroughs, for firms in ETCs that are characterized by significant resource deficiency and high contextual uncertainty, it becomes necessary that they adopt resource acquisition and resource accumulation for effectively managing their resource portfolios, and also embrace resource flexibility and coordination flexibility for effectively managing their contextual uncertainties. However a resource based view (RBV) of firm considered in isolation from the institutional environment, specifically the nature of the public science system and engagement of firms with them, cannot fully explain how firms develop their technological capabilities and form their innovation strategies. Moreover it is important to understand the relevance of radical innovation in the context of the 'distinctive' low-cost capabilities and routines in ETC firms. We argue that uncertainties and costs could be minimized if institutions not only enable firms to make their own technology accumulation, but also facilitate access to radical technologies and skills in the public science system.

Summing up, the work on low-cost innovation has thus far been enriched by many empirical case studies but awaits further theoretical analyses. Although several studies have attempted to integrate institutional theory to explain low-cost innovation, I believe that none explain how firms come to develop such 'capabilities'. Strategies promulgated for developed countries may not be appropriate for ETC's that provide a socio-economic context for how institutions in transition and market constraints such as affordability and accessibility, provide opportunities for emergence of new organisational and technological capabilities. Previous research has elaborated on the 'market based' view of low-cost innovations captured in the various terminologies such as 'Good-enough', 'Trickle-up', 'Blow-back' innovation etc. (Zedtwitz, et al., 2015). Drawing on an institutional perspective, this study argues that low-cost innovation capabilities are profoundly influenced by the structuring of institutions.

3. Methodology

This research looks at innovations within two technological domains: Rechargeable Batteries and Point of Use (PoU) Water purification, and draw on two successful low-cost innovations launched in an ETC context – BYD's rechargeable Lithium-ion batteries in China launched in 1995 and Tata's 'Swach' water purifier launched in India in 2009. I compare the two innovations with current and potentially radical technology developments in respective countries within the same sector, and analyse what if any impact institutional changes have had on the nature of innovation capabilities. BYD's process innovation in manufacturing Lithium-Ion batteries is compared with developments in a new advanced performance and potentially low-cost radical battery technology namely Sodium-Carbon dioxide batteries at China's Nankai University. Tatas Swach water purifier is compared with more advanced nano-materials innovation from Indian Institute of Technology Madras (IITM) capable of meeting more complex water purification challenges at low-cost. The analysis is primarily based on extensive secondary archival data from interview quotes in mass media and case studies from credible sources. Interview quotes in mass media are accepted as credible only if they can be verified using other secondary data or where possible using direct interviews. Qualitative evidence is not used to build theory but rather to provide examples that reflect various features and characteristics of institutions and markets.

	Type of Data	**Period**
BYD's low-cost innovation on Lithium-Ion battery production	Interviews with founder and CEO in Two Press Articles.	2009-2010
	Quotes of founder and CEO in three Case Studies	2006-2013
	Quotes of various senior management in a conference proceeding: *Asian Business & Management Special Issue and Conference 2016* (Interviews in the article were conducted by Chinese media agency CCTV)	2017
Sodium-Carbon dioxide batteries from Nankai university	Quotes from various senior government officials in magazine *Nature Outlook*	2016
	Quotes of inventor and comment of another scientific expert in magazine *Chemistry World*	2016
Tata Swach water Purifier	Interviews with various senior managers at Tata in Six mass media sources	2009-2012
	Direct Interview with the previous technology lead – Prof. Murali Sastry	2017

IITM Advanced Nano-Materials for water purification	Interviews with inventor and team in four mass media sources	2007-2016
	Interviews with inventor and team in three internet media sources	2014-2016
	Quotes of inventor in magazine *Scientific American*	2013
	Direct Interview with inventor – Prof. T. Pradeep	2017

3.1 Rechargeable Batteries: "Process Re-engineering" v. "New Materials"

Background

BYD Co. of China was founded in 1995 by Wang Chuanfu, a chemist and government scientist to manufacture rechargeable batteries, when the battery market in China was huge, but dominated by Japanese imports at very high prices. By 2009, the company occupied 10% of global market share for lithium ion batteries and was the second largest lithium-ion battery supplier for mobile phones in the world (Shirouzu, 2009).

A significant competitive advantage of the company is its low cost structure. This was achieved by replacing expensive machinery with a semi-automated line and cheap local labour. The custom-built semi-automated line cost a fraction at US $3 million compared to $100 million for a fully automated line. Since labour costs were very low then in China, it helped BYD with significantly lower overall manufacturing costs. In 1998, BYD could sell one lithium-ion battery at US $3, whereas Japanese manufacturers charged US $8 for a similar quality battery (Quan & Sanderson, 2013).

However waste rates were between 20 and 30% whereas an automated production line in Japan would have a waste rate of about 5 % (Dongmei, et al., 2010). BYD still enjoyed 60% gross margin for each battery. The R&D strategy of BYD's case is more than just process simplification because they had to re-design the entire production line based on the limited resources they could leverage (e.g. cheap labour). Although their production process is less sophisticated than their Japanese counterparts, BYD still had strict product quality controls in order to compete with their competitors. Lithium-Ion battery market has grown exponentially since the mid 1990s (Vulcan, 2008; Clark, 2016), and today BYD occupies 25% of the market share (Lux Research, 2017).

Though Initially BYD had to depend on external suppliers, the acquisitions of nearly 200 companies and their integration into BYD has allowed it to focus on internal capability development along the entire value chain. As almost two-thirds of the engineers working on battery technology are dedicated to process design, the assembly lines are also developed internally. This further reduced the price of batteries. As a consequence, from delivering initially batteries for mobile cell phones, BYD was able to quickly diversify into producing many mobile components for major companies like Siemens, Nokia and Motorola. Within a short span of time BYD had developed strong product innovation as well as process engineering capabilities as core competences.

Chinas diffusion oriented labour policy and low-cost 'Process Innovation'

BYD's entry and gaining a share from Japanese rivals in a high growth market for Lithium-ion batteries is normally attributed to it developing new low cost 'process' innovation capabilities. Such low cost capabilities were made possible due to the composition of its labour institution, i.e. availability of a huge pool of low cost-high quality labour for R&D in addition to low cost unskilled labour for its manufacturing operations. Further, BYD efficiently manages its highly skilled human resources (Quan & Sanderson, 2013). The many thousands of graduates recruited each year from the best Chinese universities are systematically trained and go through a job rotation programme. It was especially easy to find good talent in the early days because of the lack of job opportunities for graduates. To retain good talent, BYD provides plenty of promotion opportunities and stock options as well. Employment has increased exponentially since BYD was founded, from about 20 employees in 1995, a few hundred in 1997, to little more than 10,000 in year 2000, to more than 150,000 today. Thus BYD's innovation capabilities emerge from a strategic approach to managing and training its human capital. Importantly, BYD developed its own internal R&D and manufacturing capabilities with little links into the public science system. In general the cooperation between universities and enterprises remains weak in China and firms do not have mechanisms to effectively absorb universities' research output (Boeing, et al., 2016). Zheng (2014) however argues that the key factors for Chinese firms to be technologically innovative are more internally driven, in alignment with the resource-based and competency-based strategic perspective. High technology Chinese firms focus heavily on developing internal assets such as technology champions, entrepreneurship, organisational structural reform, learning and knowledge creation, as well as building strong financial base (i.e., utilising stock market listings to generate capital for growth and expansion).

In the early 1980's China was introducing major institutional and policy changes affecting its technological learning system. During this time it was heavily dependent on foreign education and technology transfer (Xie & White, 2006). Chinese universities focused on producing engineers and scientists than on training them to do advanced research, hence the government had to sponsor Chinese students to pursue higher education abroad, especially USA. The 1990s saw major policies in advanced manufacturing and quality systems, however Chinese firms relied on MNC's for technological know-how. Therefore China's 'diffusion' oriented policies in the 1980s and 1990s did not encourage close long-term links between domestic firms and local university researchers and the engagement was usually limited to solving short-term problems. However the weak science-industry link was balanced by a large pool of highly skilled graduates (strong labour institutions) in enhancing firms capabilities, especially in particular sectors such as in Electronics. This combination of particular features of institutional systems could have driven BYD to work closely with customers, instead of the public science system, to develop innovation competencies in low cost-high quality batteries. For example during BYDs early years, Motorola sent its engineers to work on-site and closely with BYD engineers to improve the quality of its batteries. Six months later, BYD earned the six-sigma certification, an international badge of quality Motorola itself invented (Fishman, 2005, pg. 215). By relying on existing technological knowledge around Lithium-ion batteries, and collaborating with customers in building firm specific know-how in low cost process innovation and in developing new organisational routines in quality, BYD was able to outdo its Japanese rivals. Thus the local labour composition and weak university-industry interaction encouraged the integration of existing know-how with support from key customers, leading to re-engineering the production process from a largely automated to a semi-automated method. One could however argue that a re-engineered 'process' innovation strategy would limit the ability of BYD to move into new technological domains, as the innovation is incremental in nature, rather than being something new and radical. Interestingly BYD has diversified into other industry sectors such as automotive and lighting, however its growth in these sectors is still a result of its production capabilities around its core technological knowledge in batteries. For. Example, the DENZA electric car manufactured by a 50:50 joint venture between BYD and Daimler Mercedes (BYD Daimler New Technology Co., Ltd. or BDNT in short), combines Daimler's engineering expertise as a worldwide leader in safety technology and quality excellence with BYD's low-cost battery technology. Thus from venturing into new end sectors such as automobiles and externally sourcing technological knowledge in these sectors, BYD in effect reinforced and augmented its distinctive capabilities in low-cost innovation around its original core technological domain i.e. batteries.

Can Chinas new high-tech policy ensure low-cost ?

Though Chinese firms have largely followed an incremental innovation strategy aimed at reducing costs, the weakening of such a strategy due to competition from countries in ASEAN, saw the Chinese government focus on endogenous innovation in the last 10 years (Gu, et al., 2016) including the establishment of about 38 collaborative innovation centres (CICs) across the country since 2012 (McGilvray, 2016). An important potentially radical nano-technology was a sodium–carbon dioxide battery coming out of the CIC in Chemical Science and Engineering (CICCSE) at Nankai University in 2015. In principle, these batteries are more energy efficient than lithium-ion batteries, as well as 'cheaper' because of the abundance of sodium and carbon dioxide (Kramer, 2016). Because 'diffusion oriented' Science policy that is closely linked to current problems is unlikely to encourage strong connections between industry and researchers in public science institutions around 'pre-competitive' fundamental research on remote topics that seeks to explain general phenomena, one would hope that high technology research centres like CICCSE would enhance the National Innovation capacity for more radical research. However industrial interaction between CICCSE and industry (Lithium ion Battery developer Lishen and electronics manufacturer Samsung) has also simultaneously continued in improving current technology around Lithium batteries, presumably because the new Sodium-Carbon dioxide technology is not yet commercial, and translating it into practical benefit is not trivial. ‘Pre-competitive’ research can result in radical technologies, however when research in universities and other public research organisations is facilitated and coordinated by government around its public objectives and mission, and not a consequence of strategic R&D investments by autonomous firms (as was the case of Bell labs, RCA, Xerox PARC and Fairchild semiconductor in the United States), technology development will tend to be restricted to a few priority areas of economic interest for the government rather than being ‘generic’ (Whitley, 2007; pg. 70). Therefore though China’s high-tech research, whose costs are mostly borne by the government as in the case of CIC’s, may lead to newer technologies, however when government policy is focused on current priority economic sectors and industrial engagement is largely around solving current problems within those sectors, the primary emphasis in Chinese firms Innovation strategy will be tweaking existing technologies, and not much research effort around developing “new to the world” scientific ideas and technologies (Gupta & Wang, 2016; Williamson & Yin, 2014). Taking the example of Sodium-Carbon dioxide batteries, though they can theoretically store ten times more charge for the same weight, and use cheaper and more abundant materials, i.e. Sodium and the freely available Carbon dioxide in the air, commercialisation may be challenging because it will be difficult for firms to acquire radically new skills to scale such technologies to also realize low production costs if they follow a rather passive approach to working with public-science institutes by restricting to incremental improvements to current technologies. Further, in addition to recruiting recent graduates emerging from higher education such as seen in the case of BYD, firms may have to focus on recruiting leading scientists and highly experienced researchers who have spent significant time in public-science institutions even after their PhDs, in order to commercialise radical technologies that carry a significant level of technical and economic uncertainty, especially in the early stages.

3.2 Point of Use (PoU) Water Purification: “Design trade-offs” v. “New Materials”

Background

In India, access to improved water supply and sanitation remains insufficient. Poor quality of drinking water leads to various diseases and high death rate. The ‘Point-of-use’ Water purifier market in India was dominated for a long time until late 2000 by Aquaguard from Eureka Forbes with a price between Rs 5000 (~ US $80) and Rs 10,000 (~ US $160), which was not affordable to most Indian families. Efforts were made by various companies to build affordable water purifiers, e.g. Hindustan Unilever’s PureIt water purifier. But PureIt ran on battery (electricity) and it cost around Rs 1,800 (~ US $ 30, battery included).

In response to the affordability constraints of low income consumers, Tata therefore developed the “Swach” filter system that uses silver nano particles infused in rice husk ash (RHA), runs on zero electricity, and was reportedly claimed as the world’s cheapest household water purification system. RHA reduces the turbidity or cloudiness of the water entering the filter and removes most of the toxic organic impurities, whereas the silver nanoparticles kill 99% of disease causing bacteria.

Developed by Tata Chemicals with help from Tata Research, Design and Development Centre (TRDDC) and Titan Industries, Tata Swach came in two variants, priced at Rs 749 (~ US $12) and Rs 999 (~ US $16), at a time when most other purifiers cost more than Rs 2,000.

When it was launched in December 2009, Tata Chemicals had earmarked an investment of Rs 1 billion (~ US $ 1.6 million) over five years for producing, developing and launching more water purifiers. Rather than just rely on large scale commercials and ads, Tata uses affordable and thereby innovative media so that the cost does not trickle down to consumers who have to pay for it. Tata Swach campaigns through an army of foot soldiers with one mission – education and demonstrations carried out house to house, and exploits the extensive sales and distribution network of other Tata group companies such as Tata Salt (Press Trust of India, 2010) and Rallis (Kinetz, 2010), an agrochemical subsidiary of Tata group. It also uses the access base of its rural resource centre – Tata Kisan Sansar (Kinetz, 2010), a farm services business run by Tata chemicals. In addition, it coordinates with NGOs such as the Hawaii children's foundation to distribute filters in villages (Tata Chemicals Limited, 2011).

No simple conventional technology exists that addresses multiple water quality problems such as bacterial and heavy metal contamination together or Heavy metals, turbidity, pesticides and salinity together (Lakshmi K, et al., 2011). However consumers strongly disliked chemical additives (e.g., chlorine tablets) for water purification, and preferred filters (Poulos, et al., 2012). Consumers considered filters to be superior to other forms of treatment because they are 'perceived' to treat water completely, and when storage of the product incorporates a storage container, it protects water from dust and hands. Tata Swach Silver Nanotechnology provided a strong market potential in providing cost effective solution to drinking water quality problems in developing countries.

Despite the existence of a favourable market and supporting factors such as strong country specificity of distribution networks, technologies such as Swach, although effective and relatively easy to use, had its own adoption challenges. For instance, though the filters can be bought from grocery stores, purify 3,000 litres and last six months for a family of five, and cost less than a rupee per day per family, timely accessibility of filters would be a key determinant in rural India with poor transport and retail infrastructure. However, a key innovation, the Tata Swach 'Fuse', indicates the capacity remaining in the filter, giving householders time to buy a replacement, and automatically shuts it off once the purifying admixture is exhausted. The fuse is thus an important factor in timely product accessibility.

India's weak public-science commercialisation mechanisms and low-cost 'Design with Trade-offs'

Though better technology, and timely accessibility of accessories such as filters, are likely to be important determinants of PoU water treatment product adoption (Null, et al., 2012), most evidence suggests that price considerations dominate the other elements (Ashraf, et al., 2010; Miguel, et al., 2009). Therefore Tata Swach's success is mostly due to trade-offs between product attributes and price acceptable for a potentially large lead-market. Though the basic product removed 99% bacteria and many organic impurities, it is unable to remove inorganic impurities, particularly Fluoride and metal ions such as Arsenic. However, it still allowed significant gains to consumer within their affordability limits compared to previous consumption of unfiltered water. Such ‘design’ capabilities could be a result of India’s focus on developing simpler low-risk technological solutions in areas of immediate concern such as clean drinking water, healthcare and energy (Bhattacharya, et al., 2012). Moreover, India has built a robust innovation climate around ‘resource-constrained’ innovations for addressing pressing global problems in clean water (Bhati, 2013). Further, in relation to nanotechnology, India’s present status of research and development is still not comparable to developed countries such as US, UK and Germany. Advanced and more radical nanotechnology innovation requires institutional complementarities between a strong ‘mission’ oriented public-science system and the existence of a strong venture finance system to commercialise high risk nanotechnologies with a long gestation period. However, the weak interaction between public science institutions and firms in India, compounded by the lack of skills to commercialise scientific output may have led to a focus on low-cost low risk technologies in both public-science institutions and firms (Ali & Sinha, 2014). In addition, both Nanotechnology policy and venture capital mechanisms are in their infancy. These factors may be responsible for lack of industry and venture capital (VC) participation in more advanced high-risk nanotechnology R&D. Therefore it is likely that weak university-industry links, a weak venture capital financing system, and a pressing need to meet basic needs of people led to a focus on a simpler low-risk silver nanotechnology based solution in Tata Swach. It also makes sense for industry to ensure that low-risk technology research is exploited, because commercial successes of low-cost solutions could help catalyse public research institutions and corporate R&D units to subsequently collaborate and innovate around more advanced technologies in the future, and also help strengthen the capital market for technology commercialisation.

The initial ideas that led to the development of Swach were infact initiated by Prof. PC Kapoor at a public science institution, ‘Indian Institute of Technology Kanpur (IITK)’ in the 1980s. After his retirement he continued his work at Tata’s research arm ‘TRDDC’ where a rudimentary device ‘Sujal’ was developed in late 1990s using Rice husk ash (RHA) and pebbles. Though Sujal wasn’t commercially successful because of its inability to remove many bacteria, it provided an important CSR (Corporate Social responsibility) image to Tata when it distributed them during the 2004 Indian Ocean Tsunami. The project was revived in 2006, and it took two years for the development of Swach when Tata Chemicals at their Innovation centre found the right chemistry to bind silver nano-particles with significant antibacterial properties to RHA. Interestingly the Chief Scientific Officer of Tata Chemicals Prof. Murali Sastry had also moved in from a public science institution, the ‘National Chemical Laboratory’. Overall the development journey of even a low-cost water purification device points to a weak commercialisation mechanism of public science during the period. The initial science that had emerged from a public science institution was not commercialised by it. Tata independently developed the ‘Swach’ purifier by developing organisational routines for embedding tacit knowledge brought in by researchers who previously worked at public science institutions.

Can advanced nano-materials with high technological uncertainty compete on low-cost ?

Tata’s competitor, Eureka Forbes however licensed a nanotechnology intellectual property on a new ‘material’ from another public-science institution ‘Indian Institute of Technology Madras (IITM)’ in 2004 in order to remove pesticides. Though it had introduced the technology in some of its products, and claimed to be the first nanotechnology based water filter, the products were not targeted for base of pyramid income groups, because the production could not be scaled to bring down the costs. Moreover the filter was used as a retrofit on its existing products to additionally remove pesticides. Subsequently IITM created a spin-off business ‘InnoNano Research’ (INR) in 2008 to produce a nanofilter based on the new materials it had been developing to capture ions like arsenic, iron and fluorides, and effectively kill microorganisms, and also make affordable water filters for base of pyramid that can tackle complex water problems. The main investigator at IITM, Prof. Pradeep, has received support from the governments Department of Science and Technology (DST) towards his research. Moreover the DSTs Nano-mission supported a ‘Thematic unit of excellence in Water purification’. However the commercialisation journey required retaining of student researchers trained in the labs in order to drive the venture activity. Some of the initial success came as a result of commissioning by the districts of Nadia and Murshidabad in the Indian state of West Bengal, to fit filters to community water pumps to remove arsenic. West Bengal has now commissioned fitting of 2000 community filters for serving 600,000 people. The Indian government has now requested all states to implement the filters where arsenic poisoning is an issue. The real success came in 2016 when a US based venture capital firm Nanoholdings plc acquired InnoNano for $18mn (Rs 1.2 bn) and formed a separate company headquartered in Singapore, ‘Safewater Nano pte’, to globally commercialise its water purifier that can effectively tackle complex water problems and remove metal ions, fluorides and bacteria without requiring any electricity. Nanoholdings plc had also previously for four years supported InnoNano’s global patenting activity before the acquisition.

IITM was able to somewhat monopolise on ‘new materials’ research for water purification, because state funded research in India, especially in ‘basic R&D’, is mostly allocated to a handful of elite research universities and institutes. In the best public science institutions such as the various IIT's in India, they not only recruit the best academic staff and students, but the academic staff are likely to remain in them for most of their scientific careers because of their ability to attract resources and funding for research due to the elite status of their institutions. Interestingly, elite research institutions such as the IITs were created with on-campus housing to support research staff careers. However, when public science-industry links are weak and local venture finance mechanisms are also weak, mechanisms that are not highly competitive in distributing public funds to researchers in public science organisations may not encourage research efficiency in finding novel yet lowest-cost technological solutions in the shorter term for pressing issues such as access to clean water. According to Prof. Murali Sastry, "issues around accessibility and distribution of funding not only exists for lab research, but also in the government's various recent venture funding mechanisms (including soft-loans) for scaling-up scientific output. This ecosystem is evolving with the emergence of VC and Angel Investor firms."

Interestingly, though the team at IITM initially received funding for pilot studies to test the product, lack of necessary venture finance during seed stages of commercialisation and industry support for scale up hindered the speed of commercialisation. This is presumably because the commercial prospects of inventing completely 'New' materials are uncertain and take longer time, unlike Tata's effort to find the right chemistry to bind silver nano to RHA in an existing rudimentary device. It took the team nearly 13 years since the research efforts started in 2003 and almost 8 years since InnoNano was created in 2008 to receive any venture backing. Further, the PoU water purification market is very competitive in India, and the lack of uptake by the incumbent players may be due to both the technical and market uncertainty of 'new materials'. Even for incumbent firms such as Tata and Eureka Forbes, resolving technological uncertainty requires a high level of investment over a long period of time because of pilot plants and process innovation required to meet economies of scale. Moreover in a highly competitive PoU water market, trialability will require a full working system and even then consumers may not be able to easily observe the new technology as regards its universal attributes to remove metal ions, fluorides and microorganisms. Moreover despite its universal attributes, targeting many different developing country markets may require different designs because of different consumer attitudes and design familiarity. Thus given the long gestation period of advanced nanomaterials R&D, it may not be possible to deliver the water purification system at low-cost for consumers without significant investment and being patient about a long period for return on investment. Further, unlike the case of the rudimentary Sujal device that needed an incremental nanotechnology solution and where Tata recruited experienced academic researchers, firms rarely have an interest in actively engaging with academic researchers conducting generic research with potentially radical outcomes given the risks involved. According to Prof. Pradeep, “though firms who earlier came to me for a short 3 month problem solving project are willing to commit now for 5 years and also fund 20-30% of equipment costs, this is not true across the system and limited to very few academics”. However, the appetite of firms to recruit senior researchers from academic institutions is weak, and moreover if they have to recruit them even for incremental solutions such as in the case of Tata, it indicates a weak absorptive capacity of firms and this could also explain the lack of active engagement with academic researchers working in more remote areas.

4. Conclusions and Further Research

China’s ‘Diffusion oriented’ policy of producing ‘Engineers’ and ‘Scientists’, and largely state facilitated and coordinated public R&D, with weak links into industry, resulted in autonomous firms such as BYD developing distinctive capabilities in low-cost process innovation by exploiting the technological skills of its engineers and scientists along with support from key clients and partners. Even if public-science institutions are engaged with industry, unless firms make strategic R&D investments and recruit leading researchers from universities, engagement is likely to be in solving current problems within the priority sectors, rather than in ‘generic’ and ‘pre-competitive’ areas even though they hold potential for newer and higher performance technologies at lower cost.

In the case of India, a weak absorptive capacity of firms to engage with ‘generic’ and ‘pre-competitive’ research were factors in internal development of incremental low-cost technological solutions as in the case of Tata Swach. Even such incremental developments needed recruiting leading scientists from public science institutions. Moreover a weak venture capital system implied a long gestation period for high risk research as in the case of IITM. However, if one assumes that developmental issues around clean water necessitate shorter term solutions, it is questionable whether distribution of public funds to a handful of elite research institutions in remote areas, and hence a lack of research competition can provide the lowest-cost solutions.

Both the cases illustrate that the nature of the public science system plays a critical role in firms low-cost incremental innovations. However though the public-science system may engage in more remote and ‘pre-competitive’ research, with the potential for radical technologies with better performance and lower costs, the current structure of institutions does not encourage their commercial development. Arguably, institutional changes are resisted more than technological changes. One would therefore anticipate that the more pervasive and radical are technological changes, the more significant will be changes in public science institutions and engagement with industry, thus readjusting the entire innovation system to a new form of developing and diffusing technologies (Lastres, 1994)

The existing and largely market based understanding of 'low-cost' innovation does not adequately mirror the more complex reality on institutional drivers. The results of this study would therefore be useful to both policy makers and firms. For e.g., in addition to firms taking advantage of market potential of low-cost innovations globally, regional and national policies should also support firms in developing linkages with the public science system. Our research did not look at how different institutional set-ups can lead to varied types of capabilities within the same industry. Future research could therefore look at how low-cost innovation in sub-sectors within the same industry vary across different institutions

5. Acknowledgements

I wish to thank ……

References

Agnihotri, A., 2015. Low-cost innovation in emerging markets. *Journal of Strategic Marketing,* 23(5), pp. 399-411.

Ali, A. & Sinha, K., 2014. Exploring the Opportunities and Challenges in Nanotechnology Innovation in India. *Journal of Social Science for Policy Implications,* 2(2), pp. 227-251.

Archibugi, D. & Pietrobelli, C., 2003. The globalisation of technology and its implications for developing countries Windows of opportunity or further burden ?. *Technological Forecasting & Social Change,* Volume 70, pp. 861-883.

Ashraf, N., Berry, J. & Shapro, J. M., 2010. Can Higher Prices Stimulate Product Use?. *American Economic Review,* Volume 100, pp. 2383-2413.

Ayyagari, M., Demirguc-Kunt, A. & Maksimovic, V., 2011. Firm Innovation in Emerging Markets: The Role of Finance, Governance, and Competition. *Journal of Financial and Quantitative Analysis,* 46(6), pp. 1545-1580.

Balzat, M. & Hanusch, H., 2004. Recent trends in the research on national innovation systems. *J Evol Econ,* Volume 14, pp. 197-210.

Bhati, M., 2013. *Innovation Ecosystem of Nano Water Research in India: Step Towards Basic Research to Commercialization.* Chon Buri, Pure and Applied Chemistry International Conference.

Bhattacharya, S., S. & Bhati, M., 2012. China and India: The two new players in the nanotechnology race. *Scientometrics,* Volume 93, pp. 59-87.

Bhatti, Y. & Ventresca, M., 2013. *How can 'frugal innovation' be conceptualized?.* [Online]
Available at: Available at SSRN: http://ssrn.com/abstract=2203552
[Accessed 14 March 2015].

Boeing, P., Mueller, E. & Sandner, P., 2016. China's R&D explosion—Analyzing productivity effects across ownership types and over time. *Research Policy,* 45(1), pp. 159-176.

Bound, K. & Thornton, I., 2012. *Our Frugal Future: Lessons from Indias Innovation System,* London: NESTA.

Brown, J. S. & Hegel, J., 2005. Innovation blowback: Disruptive management practices from Asia.. *The mcKinsey Quarterly*, pp. 35-45.

Bruno, A., 2000. Institutional complementarity and diversity of social systems of innovation and production. *Review of International Political Economy,* 7(4), pp. 645-687.

Chesbrough, H., 1999. The organizational impact of technological change: A comparative theory of national institutional factors. *Industrial and Corporate Change,* 8(3), pp. 447-485.

Clark, R., 2016. *The exponential growth of the Lithium-ion battery market and its impact on Graphite supply..* Shenzen, International Lithium and Graphite Conference.

Cooke, P. & Morgan, K., 1998. *The Associational Economy: Firms, Regions, and Innovation.* Oxford: OUP.

Crescenzi, R., Rodriguez-Pose, A. & Storper, M., 2012. The territorial dynamics of innovation in China and India. *Journal of Economic Geography,* Volume 12, pp. 1055-1085.

Dongmei, L., Binbin, Y., Yanyan, F. & Duan, W., 2010. *How Manufacturing's Mockingbird Sings.* [Online]

Available at: http://english.caixin.com/2010-02-10/100117245.html
[Accessed 04 Jan 2016].

Dutz, M. A., 2016. Catch-Up Innovation and Shared Prosperity. In: J. Haar & R. Ernst, eds. *Innovation in Emerging Markets.* London: Palgrave MacMillan, pp. 253-270.

Ernst, H. et al., 2015. The Antecedents and Consequences of Affordable Value Innovations for Emerging Markets. *Journal of Product Innovation Management,* 32(1), pp. 65-79.

Fenn, G. W., Liang, N. & Prowse, S., 1995. *The economics of the private equity market,* Washington: Board of Governors of the Federal Reserve System (US).

Fishman, T., 2005. *China Inc.: How the rise of the next superpower challenges America and the world.* New York: Simon and Schuster.

Gadiesh, O., Leung, P. & Vestring, T., 2007. The battle for China's good-enough market. *Harvard Business Review,* 85(9), pp. 80-89.

Ghoshal, S. & Bartlett, C., 1988. Creation, adoption, and diffusion of innovations by subsidiaries of multinational corporations. *Journal of International Business Studies,* 19(3), pp. 365-388.

Govindarajan, V. & Ramamurti, R., 2011. Reverse innovation, emerging markets, and global strategy. *Global Strategy Journal,* 1(2-4), pp. 191-205.

Greeven, M., 2013. Sources of Institutional Capability for Innovation in China's catching up Economy. In: L. Al-Hakim, ed. *Quality Innovation: Knowledge, Theory, and Practices: Knowledge, Theory, and Practices.* s.l.:IGI Global, pp. 406-417.

Gupta, A. & Wang, H., 2016. *Innovation, How China's Government Helps and Hinders.* [Online] Available at: https://hbr.org/2016/11/how-chinas-government-helps-and-hinders-innovation
[Accessed 01 September 2017].

Gu, S., 1999. *Implications of National Innovation Systems for Developing Countries: Managing Change and Complexity in Economic Development',,* Maastricht: UNU-INTECH.

Gu, S., Serger, S. S. & Lundvall, B.-A., 2016. China's innovation system: ten years on. *Innovation: Organisation & Management,* 18(4), pp. 441-448.

Herstatt, C. & Tiwari, R. eds., 2017. *Lead Market India: Key Elements and Corporate Perspectives for Frugal Innovations.* s.l.:Springer International Publishing.

Iyer, G., LaPlaca, P. & Sharma, A., 2006. Innovation and new product introductions in emerging markets: Strategic recommendations for the Indian market. *Industrial Marketing Management,* 35(3), pp. 373-382.

Kaplinsky, R. et al., 2009. Below the radar: what does innovation in emerging economies have to offer other low-income economies?. *International Journal of Technology Management and Sustainable Development,* 8(3), pp. 177-197.

Kinetz, E., 2010. *India's Tata Group Launches Inexpensive Water Purifier,* New York: Huffington Post.

Kramer, K., 2016. *Rechargeable first for promising battery tech,* s.l.: s.n.

Lakshmi K, V., Nagrath, K. & Jha, A., 2011. *Access to Safe Water: Approaches for Nanotechnology Benefits to Reach the bottom of the Pyramid,* New Delhi: Project report to UK DFID, May 2011. Development Alternatives Group..

Lastres, H. M. M., 1994. *The Advanced Materials Revolution and The Japanese System of Innovation.* London: The MacMillan Press .

Lim, C., Han, S. & Ito, H., 2013. Capability building through innovation for unserved lower end mega markets. *Technovation,* 33(12), pp. 391-404.

Li, Y., Li, P. P., Wang, H. & Ma, Y., 2017. How Do Resource Structuring and Strategic Flexibility Interact to Shape Radical Innovation?. *Journal of Product Innovation Management,* 34(4), pp. 471-491.

Lundwall, B.-A., 2007. National innovation systems—analytical concept and development. *Industry & Innovation,* 14(1), pp. 95-119.

Lux Research, 2017. *Quality Over Quantity: The Complex Case Behind Present and Future Li-Ion Battery Manufacturing.* [Online]
Available at: http://blog.luxresearchinc.com/blog/2017/01/quality-over-quantity-the-complex-case-behind-present-and-future-li-ion-battery-manufacturing/
[Accessed 29 June 2017].

McGilvray, A., 2016. China: High-tech transformation. *Nature,* 537(7618), pp. S8-S9.

Metcalfe, S., 1995. Technology systems and technology policy in an evolutionary framework. *Cambridge Journal of Economics,* 19(1), pp. 25-46.

Metcalfe, S. & Ramlogan, R., 2008. Innovation systems and the competitive process in developing economies. *The Quarterly Review of Economics and Finance,* 48(2), pp. 433-446.

Miguel, E. et al., 2009. Making water safe: Price, persuasion, peers, Promoters, or Product Design?. *Unpublished (Harvard University).*

Mossingers, J., 2015. *innovation - Make it Smart and Frugal.* [Online]
Available at: http://www.thehindubusinessline.com/opinion/innovation-make-it-smart-and-frugal/article6839616.ece
[Accessed 29 Dec 2015].

Niosi, J., 2010. Rethinking science, technology and innovation (STI) institutions in developing countries. *Innovation: Management, Policy & Practice,* 12(3), pp. 250-268.

Null, C. et al., 2012. *Willingness to Pay for cleaner water in less developed countries: systematic review of experimental evidence,* New Delhi: International Initiative for Impact Evaluation.

Poulos, C. et al., 2012. Consumer preferences for household water treatment products in Andhra Pradesh, India. *Social Science & Medicine,* Volume 75, pp. 738-746.

Prahalad, C. K., 2006. *The Fortune at the Bottom of the Pyramid.* New Jersey: Pearson Prentice Hall.

Prahalad, C. K. & Mashelkar, R. A., 2010. Innovation's holy grail. *Harvard Business Review,* 88(7/8), pp. 132-141.

Press Trust of India, 2010. *Tata Chem aims to sell 1 mn Swach,* New Delhi: Business Standard.

Quan, X. I. & Sanderson, J., 2013. *A case study on the Chinese way of innovation.* Beijing, IEEE Innovation Conference (SIIC).

Radjou, N., Prabhu, J. & Ahuja, S., 2012. *Jugaad Innovation.* San Francisco: Jossey-Bass.

Shirouzu, N., 2009. Technology levels playing field in race to market electric car. *Wall Street Journal,* Volume 12.

Soni, P. & Krishnan, R. T., 2014. Frugal Innovation: Aligning theory, practice and public policy. *Journal of Indian Business Research ,* 6(1), pp. 29-47.

Srivastava, V., 2015. Will Make in India Initiative boost Innovation?. *Indian Management*, Feb, pp. 42-45.

Tata Chemicals Limited, 2011. *Tata Chemicals distributes Tata Swach purifiers in villages and schools of Babrala, Uttar Pradesh.* [Online]
Available at: http://www.tatachemicals.com/media/releases/201101jan/20110130.htm
[Accessed 03 December 2015].

Teece, D., 1986. Profiting from Technolgical Innovation: Implications for Integration, Collaboration, Licensing and Public Policy. *Research Policy,* 15(6), pp. 285-305.

Tellis, G. J., Prabhu, J. C. & Chandy, R. K., 2009. Radical Innovation Across Nations: The Preeminence of Corporate Culture. *Journal of Marketing,* Volume 73, pp. 3-23.

Tiwari, R. & Herstatt, C., 2012. Assessing India's lead market potential for cost effective Innovations. *Journal of Indian Business Research,* 4(2), pp. 97-115.

Tylecote, A. & Ramirez, P., 2006. Corporate governance and innovation: The UK compared to the US. *Research Policy,* Volume 35, pp. 160-180.

Vernon, R., 1966. International Investment and International Trade in the Product Cycle. *The Quarterly Journal of Economics,* 80(2), pp. 190-207.

Vulcan, T., 2008. *The Battle Of The Batteries.* [Online]
Available at: http://www.etf.com/sections/features-and-news/1292-the-battle-of-the-batteries?nopaging=1
[Accessed 2017 June 2017].

Whitley, R., 2002. Developing innovative competences: the role of institutional frameworks. *Industrial and Corporate Change,* 11(3), pp. 497-528.

Whitley, R., 2007. *Business Systems and Organisational Capabilities.* Oxford: OUP.

Williamson, P., 2010. Cost Innovation: Preparing for a 'Value-for-Money' Revolution. *Long Range Planning,* Volume 43, pp. 343-353.

Williamson, P. J. & Yin, E., 2014. Accelerated Innovation: The New Challenge From China. *MIT Sloan Management Review,* 55(4), p. 27.

Xie, W. & White, S., 2006. Imiitation to Creation: The Critical Yet Uncertain Transition for Chinese Firms. *Journal of Technology Management in China,* 1(3), pp. 229-242.

Zedtwitz, M. v., Corsi, S., Soberg, P. V. & Frega, R., 2015. A Typology of Reverse Innovation. *J PROD INNOV MANAG,* 32(1), pp. 12-28.

Zeng, M. & Williamson, P. J., 2007. *Dragons at Your door: How Chinese Cost Innovation is Disrupting Global Competition.* Boston, MA: Harvard University Press .

Zeschky, M., Winterhalter, S. & Gassman, O., 2014. From Cost to Frugal and Reverse Innovation: Mapping the Field and Implications for Global Competitiveness. *Research-Technology Management,* 57(4), pp. 20-27.

Zhang, G. & Zhou, J., 2016. The effects of forward and reverse engineering on firm innovation performance in the stages of technology catch-up: An empirical study on China. *Technological Forecating and Social Change,* Volume 104, pp. 212-222.

Zheng, C., 2014. The inner circle of technology innovation: A case study of two Chinese firms. *Technological Forecasting & Social Change,* Volume 82, pp. 140-148.

Zheng, C. & Wang, B. X., 2012. Innovatibe or imitative? Technology firms in China. *Prometheus,* 30(2), pp. 169-178.