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Abstract

Recently, electric vehicles (EV) production and markets have been growing and auto makers are producing their products, continuing development and improving portfolios to match the needs of consumers. This paper is devoted to the analysis of the evolution of different aspects, concepts and strategies of frugal innovation, then the development of EVs from a historical perspective and finally an overview is given of the different types of EVs developed in this paper. In other research done on Frgal Innovation the different challenges of facing EVs are described and analyzed. In recent years, there has been a growing awareness among companies of the need to innovate with limited resources. The main goal of the article is to demonstrate how

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** Professor, Department of International Liberal Arts and Graduate School of Humanities and Social Sciences, Fukuoka Women's University.

the frugal innovations of EVs refers to innovative EV components, such as motors, bodies, tires, batteries, infrastructure and electricity, that are developed and deployed with minimal resources to meet the needs of their markets.

Keywords : Electric vehicles, Frugal Innovation, low cost,

1. Introduction

The term innovation has been used more and more frequently since the innovation theory was formed. Researchers, academics, policymakers, business specialists, and management consultants from all kinds of disciplines have been analyzing not only scientific and technologically based concepts but also non-scientific and metaphorical concepts across a variety of industrial fields. With increasing global business competition and the continuing development of new products, there has been a growing interest in the role of innovation within companies which has prompted many theoreticians to return to the Schumpeter innovation theory(1). This theory basically states that innovation drives the development, growth and prosperity of a company in the long run (Schumpeter 1934; Fagerberg 2003). Companies and organizations use many different approaches to innovation formulation to achieve their goals and mission.

Since the Schumpeterian interpretation, technical change has been defined as “a(n) historic and irreversible change in the method of production of things” and “creative destruction” (*Economist*, 2012). In the second half of the twentieth century the concept of innovation started to spread over the different fields of science and social science. Innovation is not only the “creation of something new” but also a solution

to a broad range of problems. Many definitions of innovation attempt to define an innovation, contain information regarding how an innovation is created, and what a strategy is expected to achieve. There are so many different kinds of innovation, such as disruptive innovation[(2)]; cost innovation; production innovation; design innovation; process innovation; marketing innovation; reverse innovation[(3)], open innovation[(4)], jugaad innovation[(5)], frugal innovation; good-enough innovation and others. All of these innovations are mostly related to the same strategies of designing, and developing both products and processes for minimum cost, and offering customers opportunities to consume affordable products and services suited to customers' needs. In order to analyze these common characteristics of innovation, it will be necessary to discuss innovation diversity. Innovation diversity involves various forms of innovations, which are all dynamic in character in the sense that they have (an) economic impact and evolve over time.

The study aims at exploring the concept of frugal innovation and evaluating whether, it has been adopted in the Electric Vehicles (EVs) field. Moreover, the intent is to identify which kinds of potential advantages and challenges should need to be faced when choosing frugal innovation strategies. As regards to its basic goal, the study attempts to enrich the existing empirical evidence because few studies about the topic have been conducted to date. The discussion of this paper is organized as follows: Section 2, Strategies of Frugal Innovation; Section 3, Electric Vehicles; Section 4, Prospects for Future Markets; and Section 5, Conclusion.

2. Strategies of Frugal Innovation

The goal of any company is to make a profit through the production of high quality products, high-tech, low cost and customer satisfaction.

Due to the lack of resources and environmental concerns (materials, energy, capital and time), needed to achieve this goal, companies need to minimize resources through efficiency, skill, technology, R&D, and innovation. It is very difficult to make a profit by only engaging in new product development necessary. There may be better alternatives to innovation (Milton, 1982, 7-8). Frugal innovation is an example of an alternatives that can be used to reduce production materials and achieve cost reductions. There are many strategies a company can use to innovate a new product. Innovation occurs through the 'competitive race' in local and global markets. To lead in the global market, companies need to compete in the areas of cost, design, and quality. EV producers need to consider frugal innovation for emerging and developed markets of middle class customers, that is, those people who are able to afford EVs.

1） Frugal Innovation

In recent years, a number of theoretical works (Table 1) about frugal innovation have been published (e.g. Tiwari and Herstatt 2012; Basu *et al*. 2013; Radjou *et al*. 2013; Zeschky *et al*. 2014; Ostraszewska and Tylec 2014; Angot & Plé 2015; George *et al* 2012). The field has thus been rather well covered, and at present frugal innovation has emerged in particular to do more with less, although it is still outside the mainstream of innovation technology.

Frugal innovation is a phenomenon that has become important for both practice and theory in many industries including the automobile industry. The concept of frugal innovation has become paradigm for innovation and technology management. In 2012, The Universe Foundation, as part of a larger project on "frugal" solutions, has conducted extensive research on the *Jugaad* concept, including visits and discus-

sions with a number of the leading Indian companies that deliberately aim to create low-cost solutions. Frugal innovations have also been gaining in importance in practical and academic discourse during recent years (Bhatti & Ventresca, 2013). Frugal in the literal sense means sparing, thrifty, or "characterized by or reflecting economy in the use of resources" (Merriam Webster 2011) and "simple and plain and costing little" (Oxford Dictionariesy 2011). In India it is explained in Hindi by the term *jugaad*, *Shanzhai* in Chinese (The Economist, 2010), and in Japanese the term 'setsuyaku' or 'frugal' is an adjective that denotes characteristics of being "economical in use or expenditure; prudently saving or sparing; not wasteful; entailing little expense; requiring few resources" (Tiwari *et al*., 2016).

Technological strategy means the development of some new product, a new process, and with less materials. Consequently, certain structural elements might be made more compactly or in some other advantageous way.

The cost, availability and reliability of a new product will be factors influencing affordibility. At present the important goals of EV producers are; to produce cost-effective products, batteries, infrastructure, also, the electricity used to power the vehicles has to be generated by electricity that comes from others sources. The frugal innovative approach is an approach which will help producers achieve to reduced production materials.

In the context of markets, automakers are giving customers opportunities to consume affordable products and services suited to those customers' needs. Economic growth and social changes can also create market opportunities. However, there is still uncertainty over how electric vehicles will affect the industry and they (EVs) will become a key part of the mainstream market. The rapidly escalating price of

gasoline has created opportunities for energy conserving products like EVs.

Table 1: Definitions of Frugal Innovation at Different Levels

Conceptual Definition (Institutional perspective)	・Frugal innovation is viewed as a purposeful systematic change on how development can be best achieved within specific social contexts. This contributes to it developing as a new field (Bhatti, *et al.,* 2018). ・Frugal innovations are "good-enough, affordable products that meet the needs of resource-constrained consumers" (Zeschky *et al.,* 2011). Frugal innovation is "an art of overcoming harsh constraints by improvising an effective solution using limited resources" (Radjou *et al.,* 2012).
Theoretical Definition (Process-related perspective)	・Frugal innovation is viewed as a set of tasks or actions to redesign products and services and reconfigure value chains to improve efficiency and create value for inclusive markets (Bhatti, *et al.,* 2018). Frugal innovations are "cheap, robust in harsh environments, easy to use and repair, and made of used and local materials" (Douglas, 2013) ・Frugal innovation is "a product, service or a solution that emerges despite financial, human, technological and other resource constraints, and where the final outcome is less pricey than competitive offerings (if available) and which meets the needs of those customers who otherwise remain un-served" (Simula *et al.,* 2015). ・Frugal innovations are "new or significantly improved products (both goods and services), processes, or marketing and organizational methods that seek to minimize the use of material and financial resources in the complete value chain (development, manufacturing, distribution, consumption, and disposal) with the objective of significantly reducing the total cost of ownership and/or usage while fulfilling or even exceeding certain pre-defined criteria of acceptable quality standards" (Knorringai *et al.,* 2016). ・Frugal innovations "seek to create attractive value propositions for their targeted customer groups by focusing on core functionalities and thus minimizing the use of material and financial resources in the complete value chain. They substantially reduce the cost of usage and/or ownership while fulfilling or even exceeding prescribed quality standards" (Tiwari *et al.,* 2016).
Operational Definition (Functional perspective)	・Frugal innovation focuses on how the outcomes are used and for what purpose. For instance it may mean to satisfy unmet needs (user driven), become more efficient (efficiency driven), solve social problems (social driven) or solve wicked problems for underserved markets (challenge driven) (Bhatti, *et al.,* 2018). Frugal innovation involves means and ends to do more with less for many (Bhatti, *et al.,* 2018). ・Frugal innovation is "an innovation that redefines business models, reconfigures value chains and redesigns products to use resources in different ways and create more inclusive markets by serving users with affordability constraints, often in a scalable and sustainable manner" (Bhatti, 2012). ・Frugal innovation "involves (re) designing products, services or systems to significantly cut costs, without sacrificing user value, so as to reach a mass customer base, especially in low-income settings" (Rao, 2013). ・Frugal innovation "reflects products, services, technologies or (organizational) processes that do not compromise on necessary quality, reliability or safety standards but can enable significant cost reductions by, for example, making use of state-of-the-art technologies, inventive analogies and accessing open global innovation networks". (Tiwari and Herstatt, 2017b). ・Frugal innovation refers to "the systematic innovation processes that had been adopted in order to develop high-end low-cost technology products for underdeveloped and developing economies, which are demanding in terms of features of the products and/or services offered but are also demanding in terms of the price" (Ojha, 2014).

Source: Bhatti, *et al*.,2018, 180, Harpreet and Sandeep, 2016,website.

To do more with less through 'frugal activities', means the ability to develop high quality products and create more business and social value while minimizing resources. Frugal innovation is a breakthrough in technological innovations, which can lead to sustainable development that saves valuable resources and energy. Frugal innovations in automobiles will mainly be focused in the areas of friction reduction for improving fuel efficiency of engines, emission reduction, light weighting and recyclability. This is driven by the need to not only improve fuel efficiency and become cost-competitive, but also to address the newer stringent emission norms, and the advancement of the auto industry. However, product development for frugal innovations should be done close to the market with a clear understanding of customers needs and constraints. One of its most often used frugal innovation definitions is the process of reducing the complexity and production costs of a product in a scalable and sustainable manner. It can be achieved through redesigning products, implementing new business models, and re-configuring value chains (use of proven parts, leverage of the local supply chain etc.), although ultimately consumers should always be the beneficiaries of such a development.

Basu *et al*. (2013) stated that "Frugal Innovation is a design innovation process in which the needs and the circumstances of citizens in the developing world are put first in order to develop appropriate, adaptable, affordable, and accessible services and products for emerging markets." According to Radjou, *et al*. (2012, 45) frugal innovation relies on six principles: "*1. Find opportunities in a context of adversity and transform constraints into opportunities, 2. Do more with less, 3. Think and act with agility, 4. Aim for simplicity, 5. Involve the marginal population, and 6. Follow your heart*" (Radjou, *et al*., 2012, 45). Tiwari and Herstatt (2012) define frugal innovations as new or

significantly improved products (both goods and services), processes, or marketing and organizational methods that seek to minimize the use of material and financial resources in the complete value chain (development, manufacturing, distribution, consumption, and disposal) with the objective of reducing the cost of ownership while fulfilling or even exceeding certain pre-defined criteria of acceptable quality standards (Tiwari, *et al*., 2017a). Weyrauch and Herstatt (2017) stated three criteria for frugal innovation: substantial cost reduction, concentration on core functionalities, and optimized performance level.

In 2006, Carlos Ghosn, Chairman and Director of Renault-Nissan, introduced "frugal engineering" as “achieving more with fewer resources” (*The Economist, 2010*), (This reference is written below so probably not needed here too) and described frugal innovations as products that are “stripped down to their bare essentials”, “take the needs of poor consumers as a starting point” (*The Economist, 2010*).

Zeschky *et al*. (2014) also analyzed different resource constrained innovation types. In the analysis, they distinguish between frugal innovation, good-enough innovation, and cost innovation, conceptualizing the distinctions between them. They classify frugal innovation via the criteria technical novelty and market novelty. In their view, frugal innovation has a higher technical novelty and a higher market novelty than good-enough innovation and cost innovation. Also, in their conceptualization, cost innovation means the same for less, good-enough innovation means tailored for less, and frugal innovation means new for less. Ostraszewska and Tylec (2015) use a similar conceptualization, with the criteria the same for less, adapted for less, and new for less to distinguish between cost innovation, good-enough innovation, and frugal innovation. The core characteristics of a frugal innovation are engineering simplicity as the use of raw materials and other resources

needs to be minimized, which results in lower manufacturing cost (Rao, 2013).

Angot & Plé (2015) argue that frugal innovation includes four main characteristics: affordability, good performance, sustainability, and usability. George *et al* (2012, 1) define frugal innovation as "innovative, low-cost and high-quality products and business models originating in developing countries and exportable to other developing countries or even the developed world". This definition is quite similar to that of Japanese production strategies which are explained as follows.

2） Japanese Production Style of Frugal Strategies

The fundamental philosophy of Japanese production management are productivity, quality and customer satisfaction. Toyota and Nissan in the years after World War II revealed an over-riding concern with “small-lot” production management which seemed to be frugal. There are some expressions like ‘*muda*’ (6) or unnecessary, ‘*seri*’ or sort out, “just-in-time” (JIT). In business terms, the Japanese word ‘*setsuyaku*’ which means to do more while having less, or to do more with a lack of resources. Low cost automation, and ‘lean’, (Ohno, 1978), are also terms used in connection to frugal innovation strategies.

By building on the JIT foundation, lean manufacturing concepts place an added focus on efficiency by seeking ways to produce measurable value for customers. With this emphasis on enhancing customer value, lean manufacturers are driven to produce something of value for the customer in every step of the production process. In terms of a fit with responsiveness, just-in-time (JIT) or lean production (Monden, 1983) is well placed, since its persistent focus on lead-time reduction and customer value seems apposite within the debate about responsiveness, as Hines (1998, 911) argues:

The Toyota Production System is, simply put, a method of shortening the time it takes to convert customer orders into vehicle deliveries. In order to achieve this the entire sequence from order to delivery is arranged in a single, continuous flow with continuous efforts made in terms of shortening the sequence and making it flow more smoothly.

There is an important term used in production management, *kaizen*, which means improvement, continuous improvement, involving everyone in the organization from top management, to managers then to supervisors, and to workers. The implementation of *kaizen* principles have been viewed as one of the key factors to Japanese competitive success. (Imai, 2012) so *kaizen* principles emphasize problem-awareness and provide clues to identifying problems. When identified, problems must be solved, so *kaizen* is also a problem-solving process. In *kaizen* philosophy, the aim is to eliminate the seven types of waste caused by overproduction, waiting, transportation, unnecessary stock, vover processing, motion, and defective parts. It is very clear that *kaizen* principles and frugal innovation principles both have the same goals. Frugal innovation is an approach to innovation which is based on the principle of simplification–finding solutions to a problem which solve the problem but without adding unnecessary costs or adding unwanted functions.

Japanese auto makers have also tried to decrease costs and produce with less resources. The goal is to cut back on redundant designs and parts and share common components between different cars in response to the lean production model. It is a strategy to share frugally, using parts such engines, brake systems, and energy or fuel systems, among multiple car models to reduce the number of parts and to improve the efficiency of the R&D expenses and capital investment (Imai, 2017, 139). Shared common component parts are increasing among Nissan's

'Common Module Family' (CMF), and Toyota's 'Toyota New Global Architecture (TNGA) (Imai, 2017, 139). Frugal innovation refers to 'the design and development of products and services with price rather than features as the starting point, while also focusing on the end product and value offered, rather than high-end sophistication. Frugal innovations have to address the accessibility of new technologies in particular because the ultimate purpose of frugal technologies have to lead to solutions concerning cost, resources and waste of production in a companies. However, frugal innovation must devise novel approaches to exploit new technology, which are also important to individual companies, because it becomes crucial to potential for expansion and future profits.

3．Electric Vehicles

Since the beginning of the 21st century, EVs have again been attracting a great deal of attention worldwide. In fact, EVs were invented in the 1830s, before internal combustion engine vehicles (ICEVs) or gasoline vehicles, were manufactured in the U.S.A, England, Germany, and France (Chan, 2007). According to Westbrook, from 1900 to 1910 was the golden age of EVs. Then, due to the development of ICEVs and expanding demand EVs started to lose its market (Westbrook, 2007,16). High prices were the reason for the decline in the demand for EVs. The average price of an EV was $1750 while the Model T (gasoline vehicle) could be bought for only $550 in 1912 (Westbrook, 2007,18), and gasoline prices were low. However, by the end of the 20th century, energy security concerns, environmental concerns and regulations became drivers of this renewed interest in EVs. As a result, a new revolutionary innovation appeared in the late 1990s: invented hybrid technology, which combined the internal combustion

engine with an electric motor. Japanese automaker Toyota made the Prius, the first mass produced hybrid electric vehicle (HEV), which was launched successfully in Japan in 1997. Shortly after, in 1999, the Honda Insight was launched in both the United States and Japan. These two vehicles pioneered the hybrid vehicle concept, and led to a shift in the market perception of alternative fuel vehicles. By 2000, interest in electric-drive vehicles took off in Asia, Europe and America.

Production and markets have been growing and auto makers are producing their products, and developing and innovating to match the needs of consumers. In the context of markets, automakers are putting more emphasis on customers opportunities to consume affordable products and services suited to customers' needs. Battery technology has also certainly improved. Development is being done on battery technology to improve performance while ensuring that batteries are lightweight, compact, and affordable. Across the international EV market, different countries have different characteristics. The EV markets in China, France and Norway are primarily composed of battery electric vehicles (BEVs). The Netherlands has the largest share of PHEVs at 88 percent of total vehicles. Canada, America and Japan, have a fairly even distribution of PHEVs, BEVs and HEVs (IEA, 2017, website). At present the important goals of EV producing companies are to produce (more) cost-effective products, batteries, and infrastructure, because the electricity used to power the vehicles has to be generated from different sources.

1） Technology and Types of Electric Vehicles

With the innovation of technology there has been development of new models, an increasing amount of high-tech and the latest EVs put on markets. In terms of structure, the automobile is a very complex

product. It is made up of a large number of parts, which are produced by several different industries. Peter Druker famously called the automobile industry “the industry of industries” more than 70 years ago (Druker, 1946), which was no idle statement when one considers that the average vehicle has in excess of 30,000 components and component parts.

(1) Technology

As mentioned above, the automobile is a complex product with many thousands of parts. The total number of individual parts including nuts and bolts ranges between 20,000 and 30,000 (Table 2). It is basically a product made of over a ton of steel, however through modern technology and innovation the use of plastic and aluminum parts has increased. Until now, automobile technology has advanced in a comparatively stable manner. In the same way, despite the large amount of electronics being introduced to automobiles in recent years, the automobile is nevertheless a “machine”. EVs are powered by electricity with a large, rechargeable battery, an electric motor, a controller that sends electricity to the motor from the driver’s

Table 2: Parts Assumption of a ICEV and an EV

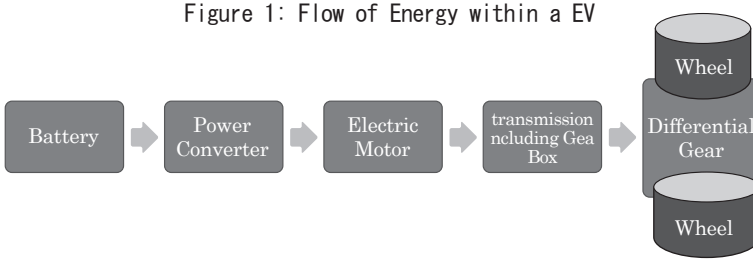
Component Parts	Component ratio of ICEVs	Necessary Parts in ICEVs	Unnecessary Parts in EVs
Engine parts	23	6,900	6,900
Drive, transmission, operation parts	19	5,700	2,100
Suspension, braking parts	15	4,500	0
Body components	15	4,500	0
Electrical component and parts	10	3,000	2,100
Other parts	18	5,400	0
Total	100	30,000	11,100

Sources: Ministry of Economy, Trade and Industry (2010), June. Website

accelerator pedal, and a charging system. The electric motor gets its power from a controller and the controller gets its power from a rechargeable battery.

According to Chan (2002), an EV can be considered a system incorporating three different sub-systems; an energy source, propulsion and (an) auxiliary. The energy source subsystem includes the source, its refueling system and energy management system. The propulsion system is the heart of an EV, and the electric motor sits right in the core of the system. The motor converts electrical energy that it gets from the battery into mechanical energy which enables the vehicle to move (Figure 1). The auxiliary subsystem is comprised of (an) auxiliary power supply, temperature control system and the power steering unit (Chan, 2002, 247-275).

Figure 1: Flow of Energy within a EV

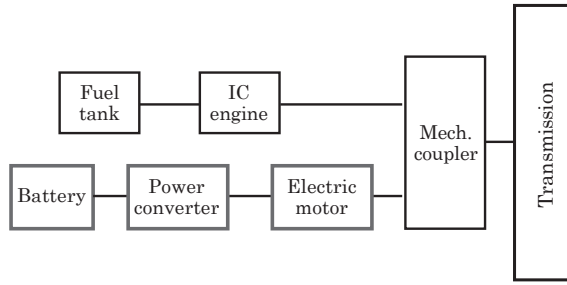


Source: Compiled from Westbrook, 2007, 145.

The electric motor of an EV is the primary source of propulsion in hybrid, range-extended, battery and fuel cell electric vehicles. The hybrid vehicle (HV) is powered by both a gasoline engine and an electric motor (figure 2). Four main parts make up the EV, the potentiometer, batteries, direct current (DC) controller, and motor. Usually, DC electricity is fed into a DC or alternating current (AC) inverter where it is converted to AC electricity and this AC electricity is connected to a

AC motor. EVs today have built in battery chargers and all that is required to recharge is a long extension cord and plug into a regular 110 volt home outlet.

Figure 2: Flow of Energy within a Hybrid Electric Drive Train



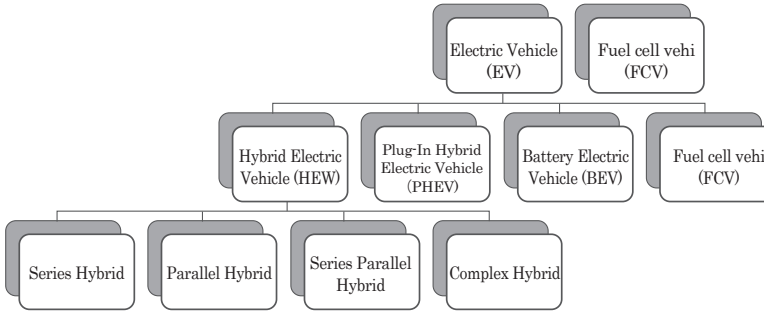
Source: Compiled from Westbrook, 2007, 145

HEVs can only use gasoline as fuel, but they utilize a small battery pack and electric motor to improve fuel efficiency, mostly through regenerative braking, engine downsizing, engine shutoff at idle, and power management. PHEVs are similar to HEVs except they can be plugged into an electrical outlet to charge the battery pack.

(2) Types of Electric Vehicles

EVs are classified as depicted in Figure 3, namely; EVs which include gasoline-powered hybrid electric vehicles (HEVs) as well as several plug-in vehicle technologies, plug-in hybrid vehicles (PHEVs), battery electric vehicles (BEVs), and low-speed electric vehicles (LSEVs)[(7)]. IEA has also classified, electric cars to include battery-electric, plug-in hybrid electric, and fuel cell electric passenger light-duty vehicles (PLDVs)[(8)]. They are commonly referred to as BEVs, PHEVs, and FCEVs (IEA, 2017, website). The fuel cell vehicle (FCV)[(9)].

Figure 3: Type of Electric Vehicles



Source: Compiled from Westbrook, 2007,

2） Challenges for Electric Vehicle Makers

The prices of materials, goods and commodities necessary for the production of EVs, such as oil, steel, copper, aluminum and others, have been skyrocketing. As mentioned above, there are many different types and sizes of EVs. An electric motor has continuous torque and has different properties than a gasoline engine. Most EVs are much heavier than they look, due to the weight of the batteries. According to the METI (Ministry of Economy, Trade and Industry, website) the weight concern an EV is 2.1 tons which battery weight is 550 kg that contributing 26 percent. In general, an EV weighs from 300kg to 600kg heavier than a gasoline vehicle. This means that an EV weighs about 800kg and can travel at between 50km and 90km per hour (METI, website).

As mentioned above, EVs are dependent on batteries. Batteries are the main problem, because of the high cost, shorter possible driving distances, longer charging times, and the need for infrastructure such as charging stations. Access to recharging is not always available outside the home. These problems are directly related to power supply

system (that is batteries). The most expensive part of any EV is the battery and battery management system. Battery costs, which account for up to 25 percent of an EV's price, were predicted to fall from above US$1,000 per kilowatt-hour in 2007, to US$383 in 2015 and to US$200 in 2020 (Accenture, 2016, website). In addition, battery prices, which were about $1,000 per kilowatt hour, declined to $500 per kilowatt hour in 2010, and to $250 per kilowatt hour in 2016 (IEA, 2017 website).

EVs share many other issues with conventional cars too. Both require roads, parking areas and other infrastructure, which is especially a problem in cities. EVs are an important part of the sustainable passenger transportation of the future. But unfortunately many people still associate EVs with high prices, have uncertainties about life-span of batteries and a concern that the EV will not be able to fulfill the needs of a regular car user. This makes it hard for the electric vehicle consumer, despite the cars low running cost and potential environmental advantage, to compete with traditional cars when it is time for the family to buy a new car.

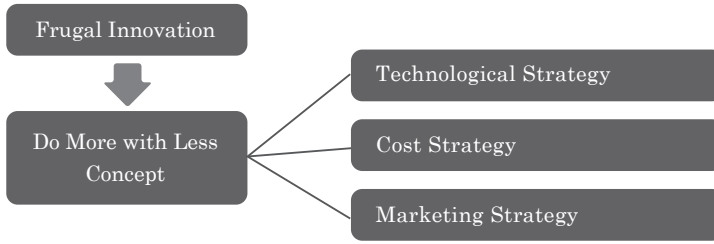
EVs also have limited performance capability when compared to gasoline-powered vehicles. Moreover, the lower price and available ability of gasoline, as well as the EVs' high initial costs, together with a lack of infrastructure and the high cost of batteries further negatively influence or effect customer choice. The governments of many countries have been encouraging customers to purchase more EVs. For this purpose there are intensive programs offered by governments whereby subsidies are given for the purchase of such vehicles. Furthermore, governments also provided billions of dollars towards the R&D of advanced technology, innovation and introduce policies that encourage EVs deployment. While there has been no

international treaty on EVs, there appears to be a worldwide commitment to the commercialization of them.

3) Adoptation of Frugal Innovation Strategies

Despite the many challenges facing proponents of EVs, virtually every car-maker in every country in the world is innovating to solve the problems associated with EVs. This is occurring with assistance from national governments and there will be many more opportunities in the future. The EV represents the culmination of numerous technology achievements, from design to engineering, to consumer adoption, so the demand for EVs will presumably continue. Frugal based on three main strategies; first is a technological approach, which reduces materials using efficient technology, second is a cost cutting approach which offers affordable prices, and third is a marketing approach for 'middle class' [10] customers, in both emerging and developed markets, with the concept of "do more with less" (Figure 4). "Mass production mass consumption" or "more for more" business models of a company, backed by huge R&D budgets and closed organizational structures, are not designed to serve the needs of cost-conscious and eco-aware consumers seeking more and better for less.

Figure 4: Approach of Frugal Innovation



Source: Compiled by author

EV production and markets have been growing rapidly since the 2000s. At present the important goals producers need to achieve are cost-effective products, (much) cheaper batteries, and increased and improved infrastructure and services. In recent years, there has been a growing awareness among companies of innovating with limited resources(11). Under these circumstances, frugal innovations are becoming popular due to lower costs and no frills production (*The Economist, 2010*).

Frugal technology innovators are taking advantage of developments in areas such as batteries, parts, and more to greatly reduce production costs and improve EV affordability worldwide. Thus, EV production strategies consider, and include, frugal innovation in the design of batteries and chargers to lower production costs. As noted above, the EV market is also driven by government support in the form of subsidies, grants, and tax rebates in almost all countries in the world. Improving charging infrastructure, increasing vehicle range, and reducing cost of batteries have fueled the demand for EVs.

Technological diffusion differs when incumbent technology and frugal technology are both produced by the same company versus when the incumbent technology and frugal technology are from different companies. Adaptation possibilities of a frugal technology strategy in any organization can be frightening. Frugal innovation is not a distinctly new phenomenon or process. Industry might use the tools and techniques to set frugal innovation goals and priorities that match their company's unique culture and needs. Frugal innovations of EVs refers to innovative EV components, such as motors, bodies, tires, batteries, and electricity, that are developed and deployed with minimal resources to meet the needs of their markets. Automotive light-weighting is a strategic opportunity which auto manufacturers must

explore further, as demand and prices for fuel will tend to move upwards in the future.

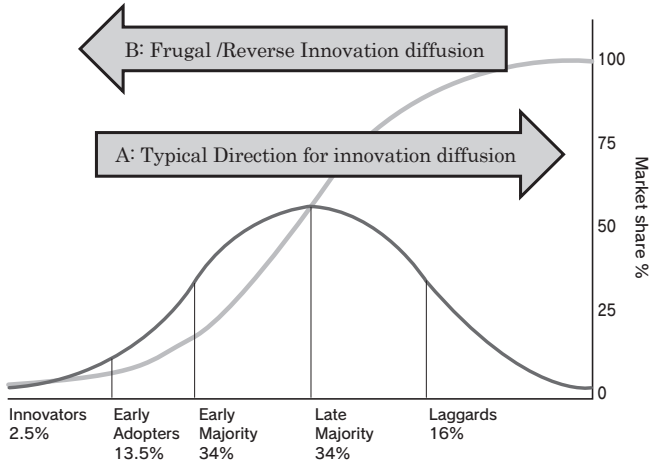
In innovation diffusion theory Rogers (2003) idea that frugal innovation might from the outset target late majority or laggard customers challenges the diffusion and adoption curve (Bhatti, *et al*.,2018, 214). Recent studies analyzing the frugal innovation process is operating in emerging markets of which may diffuse to developed markets. Diffusion of frugal innovation warrants investigation since their diffusion starts from low-income countries, contrary to conventional models of innovation diffusion, which presuppose high-end markets start. Diffusion refers to a process "in which an innovation is communicated through certain channels over time among the members of social system and spreads in a market (Rogers, 2003, 221). Rogers' model [(12)], has presented in the existing literature regarding diffusion of innovation (Benedetto, 2015, 1-5). However, these models are manned for conventional innovations. Figure 5 illustrates the adoption and outcomes of frugal innovation. The principal goal of frugal innovation is to 'do more with less', to use less materials, to lessen costs and to make profits whilst making an effort to avoid failure. In figure 5, A wealthy and early adopters to lower income and laggard adopters, to B: lower income and laggard or late majority adopters to wealthier and sophisticated early adopters or innovators (Bhatti, *et al*.,2018, 214). Companies have to make correct decisions and not adopt frugality in production development efforts that can result in failure. However, whenever a decision is made to adopt frugality in the development of a particular product, there is some risk but the effort associated with frugal innovation should bring about success and profit.

Frugal innovation focuses on reducing the cost, volume, and weight of batteries, while simultaneously improving the vehicle batteries' performance and ability. As mentioned above, the cost of batteries has

been dropping, also, frugal innovation goals in this and other areas together with commercializing advanced energy storage technologies, will allow more people to purchase EVs.

One solution to weight reduction is to make body components of lighter materials like carbon fibre-reinforced plastic (CFRP) or polymer. Another method of reducing vehicle weight is by reducing the weight of the wiring harness in the car, the third heaviest component after the chassis and the engine. By eliminating heavy, shielded cabling, automotive manufacturers can reduce cabling weight by up to 30 percent and connectivity costs by up to 80 percent.

Figure 5: Reverse Diffusion of Frugal Innovation in the Rogers Diffusion Curve



Source: Bhatti, *et al*.,2018, 215, and Rogers, 2003, 210.

Frugal innovation has its roots in frugal engineering, a term first coined in 2006 by Carlos Ghosn, the CEO of Renault-Nissan, to describe the achievement of Tata Motors, in India. The system is minimizes

packaging concerns by simply replacing the alternator. Materials used in products of a vehicles are a major source of cost and waste, at the start and throughout a product's life cycle. For example, a vehicle's fuel efficiency depends on its weight, and therefore it's the materials of which a part or parts are constructed. As a result, carmakers are increasingly employing "light weighting", which is the use of lighter yet stronger materials.

Initially, the concept of frugal engineering was raised by Renault stating that frugal innovations could be a great opportunity for successful business in emerging markets by integrating the resourceful mindset of ingenious Indian engineers into the product development processes (Sehgal *et al*. 2010; Radjou 2014). In 2004, Renault launched Logan, an affordable, robust, and well-designed car priced at 5,000 euros (retails for US$10,000). The Logan has become Renault's cash cow across recession-hit European markets as well as in many emerging economies. But Ghosn wants to do more. Under Ghosn's leadership, Renault-Nissan has proactively adopted frugal engineering and the underlying *jugaad* mindset and established itself as a major global manufacturer of both low-cost vehicles as well as EVs, two of the fastest growing segments in the global automotive market.

According to Accenture (2014), the BMW i3's maximum electric range is 160 km, using a conventional power point. The car's battery can be charged within 6-8 hours and less than 30 minutes are needed when charging at fast charging stations. The auto-body of the BMW i3 is made of carbon, an expensive material which is about five times lighter than steel. The BMW i8 drive train and chassis are aluminum, which reduces the weight by 30 percent compared with steel and the passenger cabin is almost entirely carbon fiber. The instrument panel sits in a lighter, magnesium frame. As a result, the BMW i8 weighs

1,490 kg, which is in line with conventional sports cars, despite its heavy battery (Radjou and Prabhu, 2015, 4).

Developing affordable batteries offering long driving range is the biggest challenge to increasing sales of plug-in electric vehicles. Batteries for these vehicles differ substantially from traditional lead-acid batteries used in internal combustion engine vehicles: they are larger, heavier, more expensive, and have safety considerations that mandate use of electronically controlled cooling systems. Various chemistries can be applied to frugal innovation, with lithium-ion appearing the most feasible approach at the present time.

The lithium-ion battery supply chain, includes companies that: mine and refine lithium; produce components, chemicals, and electronics; and assemble these components into battery cells and then into battery packs. Auto manufacturers design their vehicles to work with specific batteries, and provide proprietary cooling and other technologies before placing batteries in vehicles (Bill, 2013).

According to the IEA (2015), Japan, South Korea, Germany and China have producing the most significant technological advances in batteries. The top ten leaders in the development of battery production are from these countries. Five are Japanese ompanies, AESC, Mitsubishi/GS Yuasa, Hitachi, Panasonic and Toshiba. Two are South Korean, LG Chem and Samsung SDI. There is also one joint venture company between Germany and South Korea, SK Continental E-Motion. BYD is the only Chinese firm among the top ten.

4．Prospects for Future Markets

EVs eliminates many maintenance hassles. Overall, maintenance costs[(13)] for EVs are lower than ICEs because there are 11,100 fewer parts in EVs (Table 1), and therefore fewer mechanisms that need

maintaining. On average, the annual maintenance costs are about a third less for EVs than their petrol-powered counterparts (Delucchi & Lipman, 2001). Fuel costs can vary considerably for both petrol and EVs depending on region and vehicle efficiency. However, the average cost of driving 160 kms in an EV is a quarter of the average price to drive 160 kms in a gas-powered car (Union of Concerned Scientists, 2013)[(14)] . The difference in fueling costs can amount to an annual fuel savings of $750 - $1,200 for EV owners, but it can also lead to big expenses and to a burden on the environment.

The narrowing cost gap between EVs and ICEs suggests that as EV sales keep growing to the 2020s, governments of various countries will need to gradually revise their approach to EV support, phasing out incentives in cases where EVs and PHEVs actually rival ICE costs. The EV market surpassed 2 million units in 2016 after crossing the 1 million vehicle threshold in 2015 worldwide. Even though EV sales are growing, the numbers are still low, the total number of passenger cars sold in 2014 being only 0.08 percent. Despite continuous growth in the EV market, annual growth rates have been decreasing since 2011 (IEA, 2017, website). To expand EV markets, the Paris Declaration on Electro-Mobility and Climate Change and Call to Action, announced at COP21, expressed the intention to exceed globally the threshold of 100 million electric cars and 400 million electric two-wheelers by 2030 (UNFCCC, 2015). In recent years, more and more governments are involved in Electric Vehicles Initiative (EVI) activities (IEA, 2017, website). As a result, electric car deployment seem to confirm which positive signals indicating a good chance that the electric car stock will range between 9 million and 20 million by 2020 and between 40 million and 70 million by 2025 (IEA, 2017, website). Think tanker McKinsey points out that the automotive revenue base is expected to expand drastically; between

2015 and 2030 it is projected to expand by 100 percent and grow to over $6 trillion. This growth will not come from vehicle sales, but as a result of new business models, such as shared mobility and services.

The aged generation has been increasing in Europe, America, Japan, and also China. Aged people have, amongst other things, physical limitations. These rapidly ageing customers will demand easily accessible and more affordable EVs. There are already 130 million people aged over 50 in the EU, by 2020 one in two EU adults will be over this age, and by 2050 one-fifth of the American and Japanese populations will be 65 or older. This ageing generation represents a huge 'silver market' who will demand appropriate, adaptable, affordable, and accessible services and products. The solutions will come through corporate R&D teams who will need to change and shift their technology, innovations and models accordingly to the market demand(s). The economy will almost double from $7.1 trillion in 2015 to $13.5 trillion by 2032 (Radjou and Prabhu, 2015, 194).

GM came up with the Chevrolet Volt in 2007, a vehicle that would drive on battery power; Tesla Motors came up with the luxury model Tesla Roadster and, in 2010, Nissan Leaf introduced the first Asian mass produced EV. The Mitsubishi iMieV is the first EV that sold more than 10,000 units in 2011. The Prius Model from Toyota is another successful innovation, which totaled 3 million units (sold) in 2013. The Asian region has started to expand the market for EVs (Table 3). In terms of the development of its EV industry, Asia has now pulled ahead of other countries, into a leadership position, and growing industrialization in China, India, Indonesia, Malaysia and several other countries ASEAN[(15)] in the Asia Pacific is likely to contribute to the further growth of EV markets. In 2016 automobile sales including EVs, in 18 Asian countries, totaled 42.64 million units, which was the

first time to exceed 40 million units. China had the highest number of vehicle sales at 28.03 million units, Japan 4.97 million units and India 3.71 million units (Fourin, 2017a, 270-275).

Table 3: Trend of Electric Vehicles (BEV and PHEV) in Some Asian Countries and the USA (Units: 1,000)

Country	Type	2010	2011	2012	2013	2014	2015	2016
China	Stock	1.91	6.98	16.88	32.22	105.39	312.77	648.77
	Registrations	1.43	5.07	9.90	15.34	73.17	207.38	336.00
	Market Share(%)	0.01	0.04	0.06	0.09	0.38	0.99	1.37
America	Stock	3.77	21.50	74.74	171.44	290.22	404.09	563.71
	Registrations	1.19	17.73	53.24	96.70	118.78	113.87	159.62
	Market Share(%)	0.01	0.17	0.44	0.75	0.74	0.67	0.91
Japan	Stock	3.52	16.14	40.58	69.46	101.74	126.40	151.25
	Registrations	2.44	12.62	24.44	28.88	32.29	24.65	24.85
	Market Share(%)	0.06	0.35	0.53	0.63	0.68	0.58	0.59
South Korea	Stock	0.06	0.34	0.85	1.45	2.76	5.95	11.21
	Registrations	0.06	0.27	0.51	0.60	1.31	3.19	5.26
	Market Share(%)	-	0.02	0.04	0.05	0.09	0.21	0.34
World	Stock	16.81	64.58	182.64	388.07	715.39	1262.61	2014.22
	Registrations	6.78	47.58	118.06	203.66	323.42	547.12	753.17
	Market Share(%)	0.01	0.10	0.23	0.38	0.54	0.85	1.10

Source: IEA, 2017, website

Having said that, EVs have remained a relatively small market. The market is still concentrated in a limited number of countries. Of the total sales of world market, 95 percent are taking place in just 10 countries[16]. Accenture (2016) investigated 14 selected markets[17] with respect to their EV 'Market Attractiveness'. In addition, the IEA (2017) reported that in 2016, China became the largest EV market in Asia, with about a third of the world market. With more than 200 million electric two-wheelers, 3 to 4 million low-speed electric vehicles (LSEVs) and more than 300 thousand electric buses running in China. The high economic growth in Asian countries has been a major reason for the increasing demand for EVs. The Asia Pacific has already become

the world's largest automobile market, and although total EVs sales are not high when compared with conventional vehicles, sales and production are increasing steadily.

5．Conclusion

The theoretical conceptualization of frugal innovation in this paper began with historical precedents and then moved to current contexts in which the innovation is practiced. As a process, frugal innovation provides technological solutions through few resources. It provides a means to practice innovation in a manner different from the standard innovation approach predominantly practiced in more developed contexts. There is potential to demonstrate that frugal innovation is an innovation process which leverages limited resources, cost reduce, affordability and appropriate performance of automobile as well as EVs.

From a current perspective, an analysis of the golden age of the EV sector has been done, and it could be said, that it is coming again. In the market context of a product, service, practice and technological process need to be considered a part of frugal innovation in EV. The frugal aspect involves solving needs without being stymied by affordability, resource, or institutional constraints. The practice of frugal is useful all over the world given austerity, the ageing population of many countries, customer affordability (particularly in the middle classes), and infrastructure concerns. Efforts to advance EVs should also aim, along with frugal innovation and technological developments, to improve consumers' familiarity with EV technology and thus promote EVs to mainstream status for. Future research should be directed at more in-depth case studies analyzing company's performances in local and foreign markets. Finally, trends and ways of future development have been providing a clear picture of this sector and the areas in need

of further research.

Endnotes

(1) Schumpeter include (1) developing a new product through creative activities; (2) the introduction of a new production method; (3) the development of a new market; (4) the acquisition of a new resource (or source of supply thereof); and (5) organizational reform. In addition, he states that the destruction of existing values and creation of new values (creative destruction) by entrepreneurs is the source of economic growth (GOJ, 2006 White Paper on Science and Technology).

(2) According to the Clayton Christensen Institute for Disruptive Innovation, the "theory explains the phenomenon by which an innovation transforms an existing market or sector by introducing simplicity, convenience, accessibility, and affordability where complication and high cost are the status quo. Initially, a disruptive innovation is formed in a niche market that may appear unattractive or inconsequential to industry incumbents, but eventually the new product or idea completely redefines the industry."

(3) A frugal innovation initially designed for emerging markets may sometimes also find its way to industrialized countries, but then, it is called a reverse innovation "at its core, reverse innovation describes solutions adopted first in poorer, emerging nations that subsequently and disruptively find a market in richer, developed nations." (Govindarajan *et al*. 2012).

(4) The concept of open innovation was introduced by Chesbrough in 2003. During the past decade, many firms have stimulated their employees toward openness and encouraged them to interact with external environments to find ideas to improve products, processes and services (Chesbrough, 2003).

(5) *Jugaad* is an innovation concept from the Indian countryside that describes a phenomenon of innovative solutions created in absence of systematical processes and resources. *Jugaad* is Hindi and means a clever solution, an improvised fix made out of the things that one finds in a scarce environment (Radjou, 2014; Rosca et al., 2016, p. 4).

(6) *Muda* of overproduction, *muda* of waiting, *muda* of conveyance, *muda* of processing, *muda* of inventory, *muda* of motion, *muda* of producing defects (Imai, 2017, 134).

(7) LSEVs are a particular subset of BEVs that use older technologies, such as lead acid batteries, and sell at lower prices, often around US$5,000 or less.

These vehicles are typically micro-vehicles that have maximum speeds of less than 80 kph and limited ranges of around 50-80 kms. They are also sometimes referred to as neighborhood EVs.

(8) PLDVs include passenger cars and passenger light trucks but exclude two-wheelers, three-wheelers, and low-speed or low power four-wheeled vehicles.

(9) The by-product of hydrogen and oxygen reaction is simply pure water, which renders FCVs emission-free and consequently an environmentally friendly technology (Gulhane *et al*., 2006). Despite some controversy over the reasons, which range from the lack of a hydrogen infrastructure, absence of a technological breakthrough in hydrogen technology, to very high cost production of FCVs (Honda FCX Clarity, an FCV most close to market, costs circa 1 million USD, clearly not an attractive pricing), as a matter of fact these vehicles do not seem an option anymore (Bakker, 2010).

(10) According to a World Bank Report, the world's Middle Income Countries (MICs), which are defined as having a per capita gross national income of US$1,026 to $12,475 (2011) are a diverse group by size, population, and income level. Middle income countries are home to five of the world's seven billion people and 73 percent of the world's poor people. At the same time, middle income countries represent about one third of global GDP and are major engines of global growth. (Loayza, N., *et. al*., 2012, World Bank, website).

(11) The innovation technologies explored in this study clean energy solutions also includes nuclear, efficient natural gas, clean coal, and energy efficiency. Understanding all of these innovation pathways and their potential contributions to the future electric power system can inform the development of integrated portfolio scenarios. Innovation focuses on the extent to which electricity needs can be supplied by renewable energy sources, including biomass, geothermal, hydropower, solar, and wind.

(12) Rogers defined diffusion as the process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system (Rogers, 2003,11). Diffusion researchers believe that a population can be broken down into five different segments, based on their propensity to adopt a specific innovation: innovators, early adopters, early majorities, late majorities and laggards. Rogers went as far as assigning precise notional percentages for each segment: Innovators: 2.5 percent, Early Adopters: 13.5 percent, Early majority: 34 percent, Late majority 34 percent, Laggards 16 percent (Rogers, 2003, 282).

(13) Vehicle costs can be divided into two categories, capital costs and long-term costs. Capital costs means the purchase price, and long-term costs consist of fueling and maintenance costs.

(14) Comparing a 2013 Nissan LEAF charged at the national average residential electricity rate, with a compact gasoline car fueled at $3.65/gallon and fuel economy of 35 km/gallon. Assuming 24,000 km driven annually, 55 percent city, 45 percent highway, the estimated annual operating cost of a new Camry was $4,332, while the annual operating cost for a new LEAF was estimated to be $2,680 (IEA, 2017, website).

(15) Among ASEAN-10, seven countries have exceeded a per capita income of UD$ 2000-3000, which has contributed to motorization in ASEAN countries (Fourin, 2017b,2-9). According to the IMF, the population of South East Asian countries is 645 million and with a combined GDP is USD2.7 trillion, and the average per capita GDP is an estimated US$4,200.(IMF, October 2017 estimates).

(16) China, America, Japan, Canada Norway, the United Kingdom, France, Germany, the Netherlands and Sweden.

(17) Brazil, Canada, China, France, Germany, India, Japan, the Netherlands, Norway, Russia, South Korea, Sweden, United Kingdom, and the United States.

References

Accenture (2016), “Electric Vehicle Market Attractiveness Unraveling Challenges and Opportunities” www.accenture.com.

Accenture, (2014), “The Electric Vehicle Challenge Electric Vehicle Growth in an Evolving Market Dependent on Seven Success Factors”, www. accenture. com

Angot, J., & Plé, L. (2015), “Serving poor people in rich countries: the bottom-of-the-pyramid business model solution”, *Journal of Business Strategy, 36*(2), 3-15.

Bakker, S. (2010), “The Car Industry and the Blow-Out of the Hydrogen Hype”, *Energy Policy*, Vol.38, 6540-6544.

Basu, R. R., Banerjee, P. M. and Sweeny, E. G. (2013), “Frugal Innovation: Core Competencies to Address Global Sustainability”, *Journal*

of Management for Global Sustainability, 2, 63-82.

Benedetto, C.A. Di (2015), "Diffusion of innovation", *Wiley Encycl*. Manage, 13, 1-5.

Bhatti, Yasser, Basu, Radha, Ramaswami, Barron, David and Ventresca, Marc, J. (2018), *Frugal Innovation Models Means Methods*, Cambridge, UK.

Bill Canis, (2013), "Battery Manufacturing for Hybrid and Electric Vehicles: Policy Issues", *Congressional Research Service*, www. crs. gov

Bound, K. & Thornton, I. (2012), *Our Frugal Future: Lessons from India's Innovation System*, London, NESTA.

Chan, C. C. (2002), "The state of the art of electric and hybrid vehicles," in Proceedings of the IEEE, vol. 90, no. 2, February, 247-275.

Chan, C. C. (2007), "The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles", *Proceedings of the IEEE*, Vol.95, No.4, April, 704-718.

Chesbrough, H.W. (2003), "The era of open innovation", *MIT Sloan Management Review*, Vol. 44, No. 3, 35-41.

Delucchi, M., & Lipman, T. (2001), *An analysis of the retail and lifecycle cost of battery-powered electric vehicles*, University of California, Institute of Transportation Studies.

Douglas, T. S. (2013), "Contextual innovation and social engagement: From impact factor to impact", *South African Journal of Science*, Vol. 10. Nos. 3/4, 1-20.

Drucker, P. (1946), *The Concept of the Corporation*, John Day, New York, NY.

Economist, (2012), Schumpeter: Asian innovation. Frugal ideas are spreading from East to West. Mar 24th 2012. http://www.economist.com/node/21551028

Economist, (2010), "The power to disrupt", Vol. 395, Issue 8678, 16-18.

Economist, (2010), Woolridge, A. The world turned upside down. A special report on innovation in emerging markets. April 15. http://www.economist.com/node/15879369.

Fagerberg, J. (2003), "Schumpeter and the revival of evolutionary economics: An appraisal of the literature", *Journal of Evolutionary Economics* 13, 125–59.

Fourin, (2017a), *Seikai Jidousha toukei nenkan* Fourin.

Fourin, (2017b), *ASEAN Jidousha Sangyou*, Fourin.

George, G., McGahan, A. M., & Prabhu, J. (2012), "Innovation for Inclusive Growth: Towards a Theoretical Framework and a Research Agenda", *Journal of Management Studies*, 49(4): 661-683.

Govindarajan, V.J. & Trimble, C. (2012), *Reverse innovation: Create far from home, win everywhere*, Harvard Business Press.

Harpreet Singh Bedi and Sandeep Vij (2016) "Antecedents and Consequences of Frugal Innovation: A Conceptual Model", *Researchgate*, November.
https://www.researchgate.net/publication/311456008

Hines, P. (1998), "Benchmarking Toyota's supply chain: Japan vs UK", *Long Range Planning*, Vol. 31 No. 6, 911-918.

IEA (International Energy Agency), *Global EV outlook*, https://www.iea.org/

Imai, Masaali, (2012), *Gemba Kaizen: A Commonsense Approach to a Continuous Improvement Strategy, Second Edition,* McGraw-Hill Education, New York.

Imai, Noriyuki, (2017), " Front Loading; Key Concept of Stratrgy for Business Innovation in Japanese Automobile", *Management of Innovation Strategy in Japanese Companies*, World Scientific Publishing, Singapore.

Knorringa, P., Pesa, I., Leliveld, A., and Van Beers, C. (2016), "Frugal innovation and development: Aides or adversaries?" *The European Journal of Development Research*, Vol. 28, No. 2, 143-153.

Loayza, N., *et.al*., (2012), "Do Middle Classes Bring Institutional Reforms?", Policy Research Working Paper 6015, World Bank, Washington, D.C.

McKinsey, (2017), "The automotive revolution is speeding up" https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-automotive-revolution-is-speeding-up

Merriam Webster Dictionary, (2011), http://www.merriam-webster.com/dictionary/frugal

Monden, Y. (1983), *The Toyota Production System*, Productivity Press, Portland, OR.

Milton D., Rosenau, (1982), Innovation Managing the Development of Profitable New Products, Lifetime Learning Publications, Belmont, California, USA.

Ojha, A. K. (2014), "MNCs in India: focus on frugal innovation", *Journal of Indian Business Research*, Vol. 6, No. 1, 4-28.

Ohno, Taichi (1978), *Toyota seisan hoshiki*, Tokyo:Diamondo.

Ostraszewska, Z., & Tylec, A. (2015), "Reverse innovation—how it works", *International Journal of Business and Management,* 3(1), 57–74.

Oxford Dictionary (2011), http://oxforddictionaries.com/definition/frugal

Radjou, Navi, and Prabhu, Jaideep,(2015),*Frugal Innovation How to Do More with Less*, Public Affairs, New York.

Radjou, Navi, Prabhu, Jaideep. and Ahuja, Simone, (2012), *Jugaad Innovation -- Think Frugal, Be Flexible, Generate Breakthrough Growth*. Jossey-Bass, USA.

Rao, B. C. (2013), “How disruptive is frugal?”, *Technology in Society*, 35(1), 65-73.

Rogers, Everett, M. (2003), *Diffusion of innovations*, 5th edn. Free Press, New York.

Schumpeter, J. (1934), *The theory of economic development. Cambridge*, MA: Harvard University Press.

Sehgal, V., Dehoff, K. and Panneer, G. (2010), In *Strategy + Business*, Vol. Summer, Issue 59, 1-5.

Simula, H., Hossain, M. and Halme, M. (2015), "Frugal and reverse innovations - quo vadis?" *Current Science*, Vol. 109, No. 5, 1-6.

Tiwari, R. and Herstatt, C. (2012), “Frugal Innovations for the ‘Unserved’ Customer: An Assessment of India’s Attractiveness as a Lead Market for Cost-effective Products”.
Working Paper No. 69. Hamburg: Hamburg University of Technology. http://www.tuhh.de/tim/downloads/arbeit spapiere/Working_Paper_69

Tiwari, R. and Herstatt, C. (2014), *Aiming Big with Small Cars: Emergence of a Lead Market in India*, Heidelberg: Springer.

Tiwari, R. and Kalogerakis, K. (2017a), ‘Assessing Innovation Capabilities in India’s Auto Component Industry’, Paper Presented at the Conference R&D Management; Leuven, Belgium.

Tiwari, R., Fischer, L. and Kalogerakis, K. (2017b), ‘Frugal innovation in Germany: A qualitative analysis of potential socio-economic impacts’, Working paper No. 96. Hamburg, Institute for Technology and Innovation Management, Hamburg University of Technology.

Toyota, “Hydrogen Fuel Cell Car Toyota Mirai” https://ssl.toyota.com/mirai/fcv.html

UNFCCC (United Nations Framework Convention on Climate Change), (2015), “Paris declaration on electro-mobility and climate change & call to action”,

http://newsroom.unfccc.int/media/521376/paris-electro-mobility-declaration.pdf.

Westbrook, H. Michael, (2007), *The Electric Car Development and future of battery, hybrid and fuel-cell cars*, The Institution of Engineering and Technology, UK.

Weyrauch, T. and Herstatt, C. (2017), "What is frugal innovation? Three defining criteria", *Journal of frugal innovation*, Vol. 2, No. 1, 1.

WB, (2013), *Economic Mobility and the Rise of the Latin American Middle Class*, Washington DC.

Zeschky, M., Winterhalter, S., & Gassmann, O. (2014), "From cost to frugal and reverse innovation: mapping the field and implications for global competitiveness", *Research-Technology Management*, 57(4), 20–27.

Zeschky, M., Widenmayer, B. and Gassmann, O. (2011), "Frugal innovation in emerging markets," *Research-Technology Management*, Vol. 54, No. 4, 38-45.