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Integrated vs. add-on: A multidimensional conceptualisation of technology obsolescence

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ABSTRACT

In the past two decades, technology obsolescence has become an increasingly common feature of the global economy, often precipitated by new technological breakthroughs and innovations. Although a number of companies persist with obsolete technologies until disaster strikes, our understanding of the dynamics of technology obsolescence and why some firms persist with obsolete technologies remains largely underexplored. This conceptual paper seeks to fills these gaps in our understanding by developing a four-domain framework to explicate the dynamics of technologies' obsolescence, which takes into account the components in determining different types of obsolescence. The framework articulates two types of life-cycle match and two types of life-cycle mismatch. The article also contributes to the literature by delineating an integrated framework of firm-specific and market-based factors which account for some firms' persistence with obsolete technologies. Amassing and utilising the latest information to update their technologies can help firms enhance their competitiveness. The wider implications of the analysis for public policy and directions for future research are examined.

1. Introduction

Historically, it has often taken product recalls, tragedies and monumental losses to bring to the fore the existence of obsolete technologies within companies and industries (Gidadhubli, 2000; Gupta and Wilemon, 1990; Luo, 2008; Shein, 2011; The Economist, 2014; see also Hora et al., 2011). In a world of increasing global integration and competition, technological breakthroughs and innovations have destroyed the competences of many firms as well as accelerated the demise of old technologies in both industrialised and industrialising nations (Adner, 2002; Afuah, 2009; Amankwah-Amoah, 2015a, 2016c; Fawcett and Waller, 2014; Pourakbar et al., 2012a, 2012b; Schilling, 2013).

Reflecting on these varying realities, some scholars have emphasised that the adoption of modern technology can help to minimise errors and defects, reduce costs, improve efficiency and innovativeness, and above all deliver sustainable competitive advantage (Afuah, 2009; Powell and Dent-Micallef, 1997). Buoyed by technological advancements, many firms have sought to improve their competitiveness by eliminating obsolete technologies, routines and processes (Bartels et al., 2012). In spite of this, some companies persist with using obsolete technologies (see also Cooper, 2004). Such persistence may stem from high switching cost, but our understanding of the wider issue remains underexplored (see Bartels et al., 2012).

Recent streams of scholarly works have emphasised that the obsolescence problem is "*going to get worse, not better*" during the 21st century (Bradley and Guerrero, 2009; Pourakbar et al., 2012b; Sandborn, 2007a). Indeed, around 3% of the global pool of electronic components becomes obsolete every month (Sandborn, 2007b). In spite of the growing body of research on obsolescence and the potential benefits of discarding obsolete technologies (Feng et al., 2007), there remains limited understanding of the dynamics of technology obsolescence and why some firms persist with an obsolete technology (see Bartels et al., 2012; Sandborn, 2007b).

Against this backdrop, the main objective of this paper is to explicate the dynamics of technology obsolescence. Our secondary objective is to examine why some firms persist with obsolete technologies. The issue of technology obsolescence is particularly important given that undetected obsolete technologies can lead to errors and product recalls, and thereby undermining the reputation and competitiveness of the focal firm (Luo, 2008). The study offers several contributions to technology, operations management and strategy research.

First, although the existing streams of research have reinvigorated our understanding of technology obsolescence (Rivera and Lallmahomed, 2016; Sandborn, 2007a, 2015; Torresen and Lovland, 2007), a shortcoming is the relative lack of a comprehensive conceptual model to account for the dynamics. The study deepens our understanding of technology obsolescence (Pecht and Humphrey, 2008; Sandborn, 2003) by

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developing a unified framework which encompasses and takes into account the state of the products as well as the components in determining different types of obsolescence. The study further extends prior research by explicating and specifying the different ways in which a product can come to be declared obsolete by the end users.

In addition, although technological development per se has garnered rich streams of academic research (see Afuah, 2009), there remains a lack of clarity about the issue of persistence with outmoded technologies. By delineating firm-specific and market-based factors which account for such persistence, the paper provides in-depth insight into how firms come to reach such decisions.

In developing the multi-dimensional framework, we begin by providing a brief review of the literature on obsolescence. Next, we pull together the multiple streams of research on the subject to develop a four-domain framework to account for the various facets and different types of technology obsolescence. This is followed by explanations of the features of the four quadrants. Finally, the directions for future research and implications are examined.

2. Technology obsolescence: definitions and scope

Technology in this context refers to tools, devices and body of knowledge that mediates between inputs and outputs, and creates new products or services (Rosenberg, 1972; Tushman and Anderson, 1986). Technology can be conceptualised to include methods, techniques, equipment and devices (Dosi, 1984). One line of research has conceptualised products to include software, hardware and firmware, which are all subjected to threats of obsolescence (Bartels et al., 2012).

Broadly speaking, there are different types of obsolescence. First, there is voluntary and involuntary obsolescence. Involuntary obsolescence occurs irrespective of whether the customer or the manufacturer necessarily wants to alter the product (Bartels et al., 2012). Voluntary occurs when the user or manufacturer allows the technology to die out. It can be attributed to its high inefficiency and high maintenance cost. There is also expected obsolescence, where the focal firm is aware of the time support service is to be discontinued or the machine becomes obsolete. Unexpected obsolescence refers to sudden changes in the position of the original manufacturer, e.g. declared bankrupt or issued with notices of impending closure or end of production. This then forces the focal firm to seek alternative sources of supply.

Paralleling the above body of knowledge, some scholars have defined obsolescence as the degree to which an employee lacks the current knowledge or technological acumen required to deliver expected performance (Amankwah-Amoah, 2015b; Aryee, 1991; Sandborn and Prabhakar, 2015). From an engineering standpoint, the skills of engineers, electronic components and software are all subject to risk of obsolescence (Aryee, 1991; Wallis, 2010). Table 1 provides a sample of definitions of obsolescence used in management, operations and strategy literature. The table also illustrates the multitude of interpretations of the term.

Broadly speaking, obsolescence occurs when a particular technology is considered less effective in addressing its current and future needs/problems of affirm relative to other technologies currently available and/or utilised by other firms (Cooper, 2004). Put differently, technological obsolescence occurs when the functional qualities of a product are inferior relative to newer versions of the same product (Cooper, 2004). It can also occur when devices and software become non-procurable from the original producer/manufacturer/supplier (Bartels et al., 2012). Some of the unique features of obsolete technologies include high failure and error rates, continuous breakdowns and repairs, increasing product recall associated with the technology, and high cost of operations and manpower (see Hitt and Schmidt, 1998). Table 2 summarises a range of technologies/products that have been considered obsolete.

There is also perceived obsolescence. This is where the users or customers of a product are persuaded to replace a functional product and/or its component because it is seen to be no longer fashionable or suitable (Bailey 2013: 366; Zhang et al., 2012). Indeed, the introduction of a new version of a product buttressed by effective advertisement and promotion can persuade users that the old version has lost its appeal and attractiveness, and therefore needed to be replaced (Rivera and Lallmahomed, 2016). Such approach can help to ensure sustained consumption and contribute to the profitability of the producers. One example of planned obsolescence can be traced to the Phoebus cartel (1924–1939) formed to control the light bulbs market by limiting the lifespan of light bulbs to 1000 h (Kessler and Brendel, 2016; Rivera and Lallmahomed, 2016).This distorted market competition.

Technology obsolescence can be viewed as the outcome of a "*mismatch between the life cycles of products and the technologies they incorporate*" (Feldman and Sandborn 2007: 2). Following similar logic, Feng et al. (2007: 1) defined it as a mismatch "*between electronic part*

Table 1
List of "obsolete" products/technologies.

Types	Nature of evolution/modernisation process	Current status
Cassette	• Superseded by the compact disk and other storage devices. It was found to be unreliable and possessed limited ability to store large data.	• Can be purchased from aftermarket sources.
CD players	• Evolved and built in to other technologies.	• In use in underdeveloped markets and countries.
Floppy disk	• It was a cutting-edge technology of the 1980s but has since been found to be inefficient, costly and unreliable, prompting many users to switch.	• Can be purchased from aftermarket sources and used by some government agencies in both developed and developing economies.
Fax machines	• Many users have found e-mails to be much cheaper and more convenient to use relative to fax machines.	• Can be purchased from aftermarket sources.
Telex machine	• Users have shrunk and some countries have not developed the infrastructure to support its operation.	• Can be purchased from aftermarket sources.
Landline telephones	• Many developed countries have leapfrogged to the latest technology and built facilities for mobile networks.	• In decline but still in use.
MP3 players	• Many users have switched to alternatives including using mobile phones.	• In decline but still in use.
CD-ROMs	• Emergence of more reliable and high-capacity storage devices has encouraged many users to switch.	• In decline but still in use.
Typewriter	• Superseded by the PC and keyboard which is more efficient and effective.	• Can be purchased from aftermarket sources.
DVD	• Superseded by streaming services such as Netflix, Hulu, Apple's iTunes Store and Amazon Instant Video. Cloud-based storage options have also emerged and are growing.	• Still in use.
Public phone booth	• Its function has been subsumed by the emergence and development of mobile phones.	• Still in use but usage rate has declined.
VHS	• DVD/Blu-Ray discs emerged with superior quality and multimedia functionality relative to VHS.	• Can be purchased from specialised stores.

Data sources: synthesised from: Amankwah-Amoah, 2016c; Bartels et al., 2012; Grobart, 2012; Pollack, 1990; Smith, 2013; Stonington, 2015.

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Table 2
Definitions and types of obsolescence.

Type	Definitions
Systemic obsolescence	It encompasses "altering the system in which the product is used to make it more difficult to use, or by cancelling maintenance services for the product" (Rivera and Lallmahomed 2016: 120).
Diminishing Manufacturing Sources and Material Shortages (DMSMS)	It refers to the "loss of the ability to procure required materials, parts, or technology" (Bartels et al. 2012: 4).
Functional obsolescence	It occurs when the specific requirements for the product have been changed, rendering the product's current function and performance outdated (Bartels et al., 2012).
Logistical	This is where the focal firm is unable to procure the components or materials to deliver continuous service/support the operations of the technology (Feldman and Sandborn, 2007).
"Inventory obsolescence"	This refers to where "inventories of parts become obsolete because the system they were being saved for changes such that the inventories are no longer required" (Sandborn 2007a: 2).
Managerial obsolescence	Diminish value of individuals' human capital in the face of environmental shifts (Aryee, 1991).
"Involuntary" obsolescence	This occurs when "products are forced to change by circumstances that are beyond their control" (Sandborn 2007a: 2).
Planned obsolescence/built-in obsolescence	Planned obsolescence refers to a deliberate attempt to curtail the lifespan of a product (Cooper, 2004; Packard, 1960).
"Psychological" obsolescence	This occurs where "a product that is still sound in terms of quality or performance becomes 'worn out' in our minds because a styling or other change makes it seem less desirable" (Packard 1960: 58–59; Cooper 2004: 424).
Economic obsolescence	When economic factors cause a product to be considered obsolete or waste (Cooper, 2004). End user attributes little or no value to the product.

procurement lifecycles and the lifecycles of the products". Building on these two definitions, it can be deduced that technology obsolescence entails life cycles of the parts/components incorporated into the product/system and the product itself. By electronic components or parts, we are referring to features such as integrated circuits and discrete passive components (Feng et al., 2007; Sandborn, 2007a).

One of Dell's products, the Dell Inspiron Notebook Computer, helps to illustrate the points here. The product entails multiple components encompassing battery, cooling fan, modem, hard disk drive, motherboard, memory, Intel microprocessor, keyboard and LCD display (Cavusgil et al., 2012; Friedman, 2007). The components and product are all subject to threat of obsolescence. Our central contention here is that match or mismatch between the product and components ultimately leads to different degrees and types of technology obsolescence. Therefore, interdependence is a central concept in that the function of products partly depends on the functionality of the components in the product.

Researchers investigating obsolescence have noted that some parts included in many products have their own life cycles, which must be taken into consideration when examining technology obsolescence (see Bradley and Guerrero, 2009). Besides, many products/systems are made with electronic parts which have a significantly shorter lifespan than the product they support (Bartels et al., 2012; Sandborn, 2015).

Electronic products such as monitors, printers, mobile phones and laptops tend to have relatively short lifespans compared to military aircraft, avionics systems and power grids which require decades of support services and high levels of investment and follow-on development (Feldman and Sandborn, 2007). Accordingly, life cycle mismatch (Solomon et al., 2000) occurs when the parts can become obsolete before the product's life cycle comes to an end and vice versa (Bradley and Guerrero, 2009). Indeed, some products entail multiple components which become obsolete sequentially over a protracted period (Bradley and Guerrero, 2009). Therefore, inability to obtain and replace parts could render a machine or product obsolete.

Anchored in the above is the notion that the value of a product partly depends on the components. Most hardware components (e.g. aircraft, missiles, networking equipment) consist of physical components such as transistors, gears, motors, etc., whereas software consists of objects and modules (Kossiakoff et al., 2011). Whilst hardware might be limited by power and accuracy, software tends to have no inherent limits on the functionality (Kossiakoff et al., 2011). In an attempt to differentiate the concept and provide analytical clarity, we limit the conceptual analysis to mainly products, machines and systems. Before going further on this, we turn our attention to the process of technology obsolescence to guide the conceptualisation.

2.1. An integrated process perspective of technology obsolescence

Obsolescence unfolds over time and entails multiple stages and events (Sandborn et al., 2011; Underwood et al., 2014). Conventional wisdom holds that as a new generation of technology emerges with superior features and functionality, the predecessor technology which is inefficient and ineffective at performing tasks becomes obsolete in its wake (Afuah, 2000, 2001). The essence of the argument here is that the speed and accuracy of the latest technology often means that consumers, firms and users are left with limited options other than to switch to the modern technology to accrue the benefits (Gomes, 2008). Recognising the disadvantages of old technologies relative to latest versions, some users/firms are forced to switch to superior technologies which then begin the process of decline leading to discontinuity.

Researchers investigating technological developments have emphasised that the technology obsolescence process commences when original manufacturers issue product or part discontinuance notices alerting firms and end users that termination is imminent (Sandborn et al., 2011). Some component suppliers also issue product change notifications to signal their intent to discontinue a product, whilst others do not (Husey, 2001). Indeed, it is not uncommon for electronic parts to be discontinued by the original manufacturer without warning (Bradley and Guerrero, 2008). These discontinuance notices are not only applicable to hardware; many companies have also alerted users of terminations of software.

The costs involved and resource requirements of some products may rise to a level that it serves as a dis-incentive to existing manufacturers which then forces them to switch to more profitable alternatives (Hitt and Schmidt, 1998). The issuing of notices can then trigger lifetime buys/final order components as users seek to extend the life of their technology before they are eventually rendered obsolete or phased out (Feng et al., 2007). Some microchip manufacturing firms also provide last-time buy alerts one year prior to the production termination (Pourakbar et al., 2012b). The discontinuation of support services by the manufacturer may accelerate the switch over to the new technology or speed up the obsolescence of the old technology.

In the wake of the changing competitive landscape and emergence of new firms with latest technologies, many organisations are forced to modernise their technologies and upgrade their expertise to help them maintain or improve their competitiveness (Amankwah-Amoah and Durugbo, 2016; Guiltinan, 2009). The process of technology obsolescence entails multiple decision points by a focal firm, as shown in Fig. 1. To sum up, obsolescence can occur during design development and post-production phases (Underwood et al., 2014).

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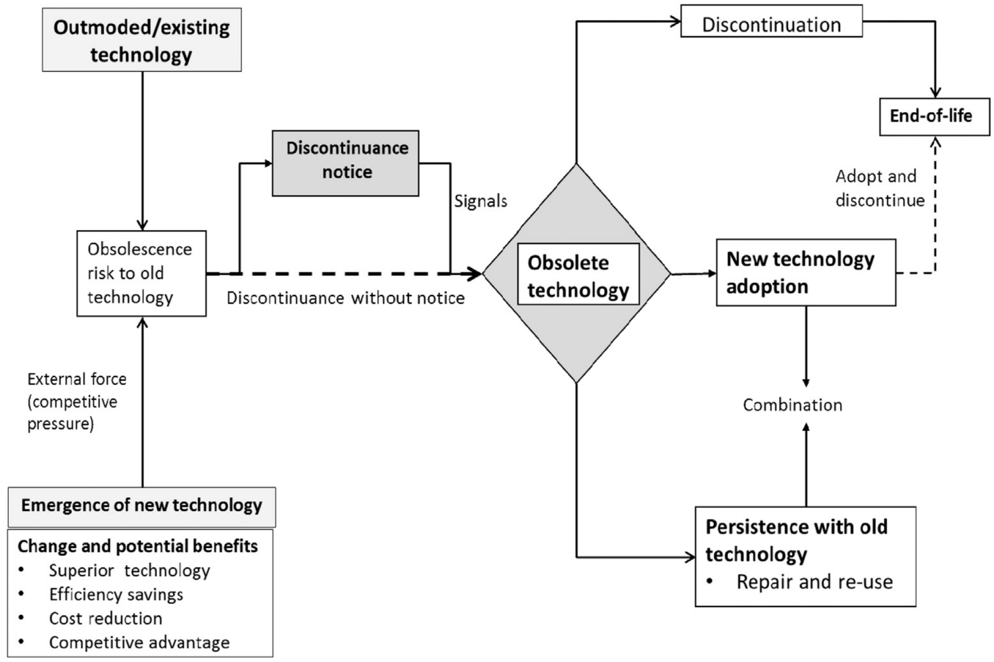

Fig. 1. Intersections of technology change and technology persistence.

3. Towards a typology of technology obsolescence

To develop a comprehensive framework of technology obsolescence, we identified the life cycle of a product (i.e. long or short lifespan) and life cycle of a product's components (i.e. long or short life cycle). Crossing these pillars produces the 2×2 matrix of technology obsolescence, representing the relationship between life cycle of a product and life cycle of a product's components/parts.

The four-quadrant framework articulates various dynamics and the nature of obsolescence, as portrayed schematically in Fig. 2. This produces life cycle matches and mismatches as key dimensions of technology obsolescence. Life cycle mismatch refers to a situation where "*the life cycle of a product does not coincide with the life cycles of the parts used in that product*" (Bradley and Guerrero 2008: 497). These are broadly "in-process dynamics of technology obsolescence" which ultimately lead to discontinuance of the technology and its usage.

3.1. Quadrant I: life-cycle match (short-life products with short-life parts)

Quadrant I demonstrates a situation where the product and its components both have a shorter lifespan. The risk that a component will become obsolete before the product is eliminated. As technological advancements surge across industrial sectors, shortening product life cycles have become more pronounced (Bradley and Guerrero, 2008; Calantone et al., 2010). Two of the unique features of this quadrant are design for limited repairs and built-in obsolescence. Design for limited repairs refers to products designed and built to be non-repairable such as single-use cameras/disposable cameras (Adolphson, 2004). Often the cost of repair far exceeds the price of new products, which contributes to the tendency to dispose of rather than repair them (Guiltinan, 2009; McCollough, 2007).

Another related feature of this is "death dating", where a product is designed to last a particular time period (Slade, 2006). For decades, this has been a standard practice for some appliances. For instance, portable radios were designed at some point in history to last for a mere three years (Guiltinan, 2009). Built-in or planned obsolescence refers to products that are "*designed to have uneconomically short lives, with the intention of forcing consumers to repurchase too frequently*" (Fishman et al., 1993: 361). By creating products such as machines and appliances with a limited lifespan, technology-oriented companies or manufacturers create conditions which lead to higher future demand for the products (Hennies and Stamminger, 2016; Rivera and Lallmahomed, 2016). Indeed, the limited life span of such products can also stimulate replacement buying and thereby contributes to higher profitability of the manufacturers (Slade, 2006).

In the contemporary competitive business landscape, built-in obsolescence has become a strategy for firms to accrue higher profit (Orbach, 2004). By adopting a strategy of shortening products' lifespan, additional e-waste is likely to be generated which would then requires stakeholders' involvement to manage and mitigate the environmental effects (Amankwah-Amoah, 2016a, 2016b). On the other hand, planned obsolescence can create a need for firms to continuously innovate and produce an improved product (Fishman et al., 1993).

3.2. Quadrant II: life-cycle mismatch (short-life products with long-life parts)

Quadrant II displays a situation where the components last longer than the products. Perhaps one of the most striking characteristics of this quadrant is that government actions through environmental and safety requirements can render an existing product obsolete, but the parts can be used and re-used in other products (Pobiak et al., 2014). This often occurs when government regulation within a particular jurisdiction leads to the alteration of standards, specifications and even processes for making a product, thereby forcing the manufacturers to alter their process or even discard old machines. For instance, when the Restriction on Hazardous Substances (RoHS) legislation was introduced in 2006, it led to a complete "wipe out" of some products (Wallis, 2010). Indeed, new regulatory regimes or directives requiring higher standards and new designs can render existing technologies obsolete (see Bartels et al., 2012).

Another feature is functional obsolescence which occurs when the specific requirements for the product have been changed, rendering the product's current function and performance outdated (Bartels et al., 2012). Regulatory changes may also lead to a situation where the suppliers and manufacturers are required to phase out older materials or obsolete technology to meet new requirements (Howard, 2002). For example, the European Commission's Directives on the

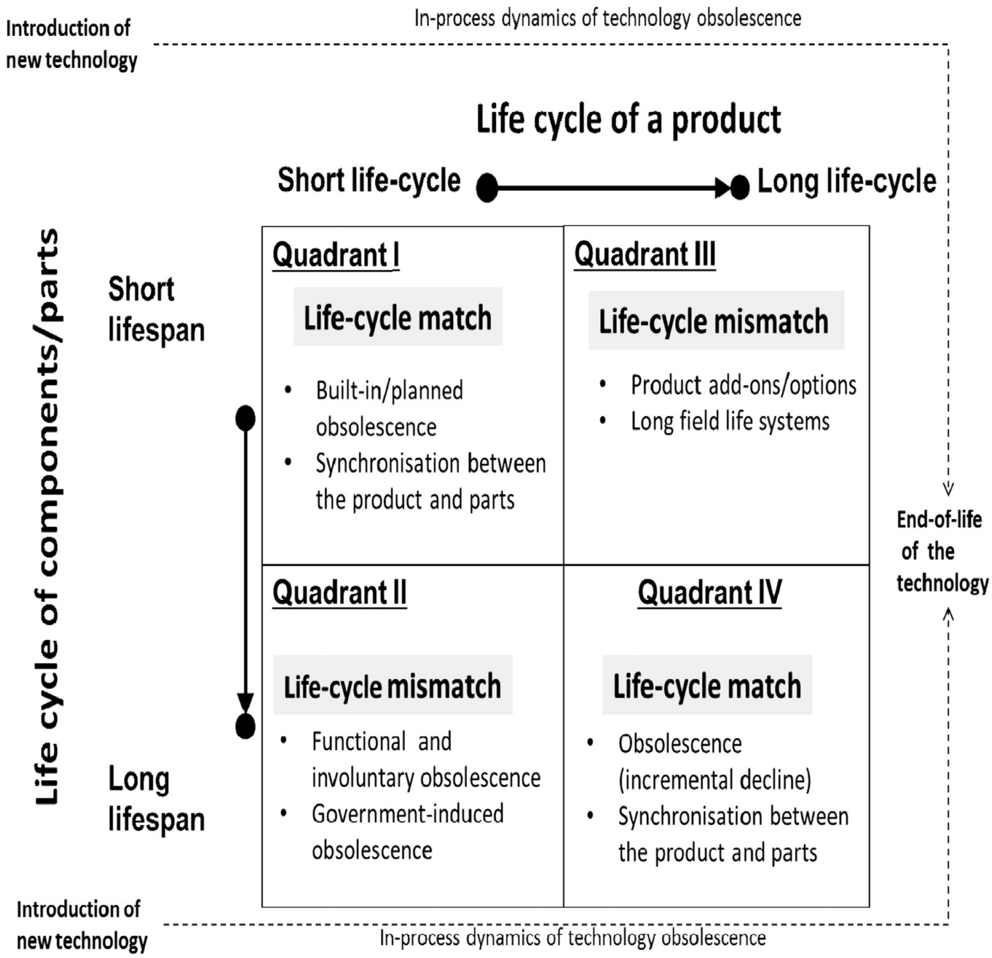

Fig. 2. A typology of technology obsolescence.

RoHS banned specific substances in products sold in the European Union to help reduce electronic waste and encourage recycling (European Commission, 2003a, 2003b). In many instances, new environmental regulations would introduce new designs, production and testing regimes, thereby forcing firms to switch to the alternative (Howard, 2002). The growing global effort towards recycling has motivated some firms to re-use long-life components.

3.3. Quadrant III: life-cycle mismatch (long-life products with short-life parts)

Quadrant III displays life cycle mismatch where the product lasts longer than the components. One of the themes is that "*between part obsolescence and product obsolescence, part obsolescence needs more critical attention as the root of obsolescence at any product level, is the obsolescence of a part*" (Solomon et al. 2000: 2).

One of the main challenges facing supply chain managers is how to acquire obsolete components and how to manage obsolescence in the face of a changing competitive environment. This is more prominent in instances where parts or components with short life cycles are utilised in long-lived products such as capital-intensive military and electronic equipment (Bradley and Guerrero, 2008; Solomon et al., 2000; Underwood et al., 2014). The projected lifespan of large internet routers and military systems is around two decades, where the COTS electronics parts that support their functionality such as memory and microprocessors often have around two years' lifespan (Bradley and Guerrero, 2008; Livingston, 2000). Indeed, around 70% of the electronic parts are superseded even before the first system is installed (Sandborn, 2007a).

Original manufacturers can also upgrade their technologies and discontinue older generations of electronic parts, which then accelerate the pace of obsolescence. This mismatch creates conditions for technological obsolescence to occur. Many electronic products entail components with shorter lifespans which then forces firms or users seeking to prolong the usage of the product to seek new or alternative components. In many instances, where the original manufacturer has ceased operation, the product then becomes obsolete in the face of faults or component malfunction.

Over the years, the risk of obsolescence increasingly affects not only the aerospace and defence industry, but an array of technologies, industries and sectors with far-reaching consequences for firms and wider industry (Wallis, 2010). Sustainment-dominated systems such as avionics and military systems are often subjected to strict certification requirements and inspection regimes, which makes changes to the system expensive (Sandborn, 2007a).

Sustainment-dominated systems are produced to last for many years and sustained over the period as such sustainment-dominated products tend to have a higher rate of parts obsolescence (Feng et al., 2007; Singh and Sandborn, 2006). It has been established that "sustainment-dominated" systems often have long-term sustainment costs that may supersede their initial procurement costs (Sandborn, 2007a). It is also worth noting that high value equipment and machinery are at time designed to last with changeable parts and behave like consumables. Under such circumstance, the replacements of parts might not necessarily mean obsolescence.

At the centre of the obsolescence debates sit two pressing issues. First is that the lifespan of many electronics parts and components is getting shorter. At the same time, the life cycles of

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sustainment-dominated systems such as aircraft avionics are increasing, thereby making obsolescence a real issue facing firms (Livingston, 2000).

Furthermore, in light of the trend towards decreasing military spending and programmes by many countries, some innovative manufacturers have diversified into high-profit electronics for households such as TVs, kettles, computers and refrigerators, and the commercial sector. The strict requirements for military components in tandem with limited application in the non-military setting have contributed to the decision of many manufacturers to withdraw from the military market and target the consumer electronics market (Asher, 1999).

A prominent example relates to the development in United States Air Force F-22 aircraft, whereby within three years a number of the suppliers discontinued the production of the components, including Intel's I-960 chips required for the avionics systems (Bartels et al., 2012; Underwood et al., 2014). Many chip and component manufacturers producing military-specific microchips have often struggled to earn higher profits from the government contracts, thereby forcing many opting not to renew contracts (Underwood et al., 2014).

To further illustrate this quadrant, we turn to the case of Boeing 787 Aircraft, which entails components such as engines, landing gear, cargo doors, passenger doors, horizontal stabilisers, and centre and aft fuselage (Cavusgil et al., 2012; Tatge, 2006). The fuel-efficient aircraft has been projected to outlive many of the parts, which means many of the parts will become obsolete and would have to be replaced during the lifespan of the aircraft. In the face of the threat of obsolescence, many airlines have opted to regularly maintain and upgrade aircraft parts to help improve or maintain the security and safety track record. Although some planes might be over 20 years old, the engines and other major systems are recently manufactured or upgraded (Pawlowski, 2010).

In 2010, the average age of the fleet of the seven US airlines (i.e. Alaska, American, Continental, the merged Delta and Northwest, Southwest, United and US Airways) was around 14 years old with the aircraft out-living most of the components, which then require replacement of multiple parts and maintenance (Pawlowski, 2010; The Airline Monitor, 2010). With strict safety standards of inspection, maintenance and replacement of obsolete parts, some planes can stay safe for 25 to 30 years (Pawlowski, 2010). Indeed, many aircraft are designed to operate for 20–25 years (Howard, 2002). This argument is further reinforced by the fact that the US and most of the advanced economies have higher standards and maintenance regulations geared towards improving safety standards and facilitate the replacement of obsolete parts. In sharp contrast to advanced countries, in many emerging economies in Sub-Saharan Africa, the aviation industry is characterised by a growing number of ageing aircraft fleets with many aircraft exceeding 20 years old (Endres, 2008).

The dispersed body of academic literature and popular press have demonstrated that poor security and safety standards, poor inspection regimes, and replacement and upgrading of parts have led to many aircraft and airlines being blacklisted in the European Union, but continue to operate across the continent (Amankwah-Amoah and Debrah, 2016; Endres, 2006, 2008). This has been linked to the high accident rate in the aviation industry in Africa. It has been suggested that technology breakthroughs and the emergence of innovative and improved versions of products have led to a sharp decline of component life cycles from between 10 and 20 years to around 3–5 years (McDermott et al., 1999). Many product sectors such as aircraft, military systems, ships and power grids are subjected to the threat of obsolescence, but they have an extended lifespan extending over a decade (Feldman and Sandborn, 2007).

An obsolete component can mean that the systems can become unsustainable after a period of time. In the face of such challenges, many firms adopt strategies such as stockpiling discontinued components and incrementally discontinuing the use of the technology (Underwood et al., 2014). In some instances, the firm is forced to adopt the “life-time buy” or a “last-time buy” strategy, where it acquires a large quantity of parts to prolong the production using the current technology in the wake of impending closure of the original manufacturer (Bradley and Guerrero, 2008). This has been found to help mitigate part obsolescence (Solomon et al., 2000).

3.4. Quadrant IV: life-cycle match (long-life products with long-life parts)

Quadrant IV demonstrates a life cycle match where both the products and its components have longer lifespans. It has been established that long-life systems and long-life products such as avionics for aircraft are designed to require redesign throughout their lives, i.e. a kind of after-sales support service and maintenance of the product (Bartels et al., 2012; Sandborn, 2003).

Related to above, long-life products often entail parts which have a shorter or same lifespan relative to the life of the products. A notable risk of this quadrant is the end-of-support which occurs when the original supplier or manufacturer terminates the backup support which made continuous use risky and potentially catastrophic to the business (Sandborn, 2007a, 2007b). End-of-sale is where the original supplier decides to wind down the sale of the product, no longer offering the product for sale (Sandborn, 2007a, 2007b).

4. Impelling and impeding forces of change

When confronted by threat of obsolescence, firms often face the dilemma of persisting with the existing technology or component, or switching to a new technology and/or components. In this section, we borrow Lewin's (1951) concept of force-field analysis to explicate some of the underlying reasons for persistence.

Regarding forces against change, parts in products such as airplanes, ships, medical equipment, and computer networks for air traffic control and power grids are difficult to replace owing to the difficulties of adopting new technologies (Singh and Sandborn, 2006). These product sectors are seen to “lag” behind the normal technology wave owing to the high costs and long times linked to technology insertion and design refresh (Bartels et al., 2012; Singh and Sandborn, 2006). Indeed, many of the new technologies are considered “immature” and therefore represent a major risk to early adoption (Singh and Sandborn, 2006).

Another related point is that these product sectors utilise “safety critical” systems and components “*where lengthy and expensive qualification/certification cycles may be required even for minor design changes and where systems are fielded (and must be maintained) for long periods of time (often* 20 *years or more)*” (Singh and Sandborn 2006: 116; Solomon et al., 2000). Indeed, technologies in many key areas such as mass transit, medicine, air-traffic control and power-grid management often necessitate long design and testing cycles (Sandborn, 2008). The high costs and initial investments often mean that “*they can return the investment only if they are allowed to operate for a long time, often* 20 *years or more*” (Sandborn 2008: 42–58), thereby perpetuating the status quo (Solomon et al., 2000).

A related but distinct contributory factor is that many firms are often locked in to a particular technology over a long period of time which then forces them to persist with it even in the face of countervailing forces. By devoting considerably initial resources to acquire long lifespan products, firms make commit substantial resources in anticipation of higher returns in the future (Hennies and Stamminger, 2016). Such high investment can lock a firm out of latest technologies. The difficulty in reversing such decision can create conditions for persistence with inefficient and outmoded technology.

Another possible explanation revolves around the fact that the potential benefits or cost savings might remain unclear, thereby persuading firms to persist with the current technology (Bartels et al., 2012). The high costs of adopting an alternative technology at the early stage encourage strategic persistence with the old version. Often new technologies are associated with high price tags which decline as more users adopt them.

Besides the cost of switching to new technologies, the availability of spare parts from aftermarket sources encourages some firms to persist with old technology even as they are superseded by latest technology (Bradley and Guerrero, 2009; Pourakbar et al., 2012a, 2012b). By aftermarket, we are referring to "*the period after the original manufacturer has phased a part out of production*" (Bartels et al. 2012: 168).

More generally, aftermarket sources include third-party organisations that continue to manufacture the parts even after the original manufacturer has made the actual parts/technology groups obsolete (Feldman and Sandborn, 2007; Solomon et al., 2000). The authorised or approved aftermarket sources are often identified in product discontinuance notices issued by the original manufacturer, but this also does not guarantee that quality would be the same as the original parts (Sandborn and Singh, 2002). The aftermarket sources exist to fill a void in the market by providing products or services to cater for demand for discontinued components or parts. In some instances, electronic parts/components or equipment suppliers may forge closer relationships with aftermarket sources and sunset distributors to help ensure continued part availability for a limited time as the manufacturer exits the market (Sandborn and Singh, 2002).

Although use of the aftermarket for parts sourcing has become increasingly common, it has concurrently disrupted and hindered the adoption of latest technologies in many areas (Bartels et al., 2012). It is worth noting that there is little incentive for users to discontinue a product or technology use when the existing one continues to fulfil current needs to a satisfactory level (Guiltinan, 2009). It is quite possible that resource-poor firms will not be enticed by the emergence of latest technologies if the potential benefits are negligible.

Regarding forces for change, firms seeking to adopt a new technology can accrue first mover advantage stemming from being the first to adopt the new state-of-the art technology, which enables the firm to improve their processes and build a competitive base before adoption by rival firms (Afuah, 2009). This carries the risk that the technology might prove to be not as effective in the long run. Nevertheless, largely due to the high pioneering costs, some firms may opt to wait before adopting the new technology and are thereby able to learn from others' experiences.

A large and growing body of research indicates that late movers are able to learn from early adopters and leap directly to new and improved versions of the technology (Afuah, 2009; Wernerfelt, 1984). In the light of increasing technological breakthroughs, the cost of obtaining old equipment parts in many instances now supersedes new and improved versions which then forces firms to abandon the outmoded technology. Indeed, the cost of repairs and inability to obtain parts to fix problems associated with the old technology can prompt firms to accelerate the process of adopting the latest technology. As depicted in Fig. 3, a number of impelling and impeding forces interact to determine persistence in the face of threat of obsolescence.

5. Discussion and implications

The present study sought to explicate the dynamics of technology obsolescence and persistence with obsolete technologies. By integrating insights on the relationship between the life cycle of a product and life cycle of a product's components, we developed a multi-dimensional framework to account for the various facets of technology obsolescence leading to discontinuance. The four-domain framework encompassed two types of life cycle match (i.e. long-life products with long-life parts, and short-life products with short-life parts) and two types of life cycle mismatch (i.e. long-life products with short-life parts and short-life products with long-life parts).

Technology obsolescence can occur when there is life cycle mismatch between parts and products. The study indicates that life cycle mismatch has potential to lead to waste and misallocation of resources when components are not available in a timely manner. Quadrants I and IV are termed life cycle matches to reflect that the product becomes

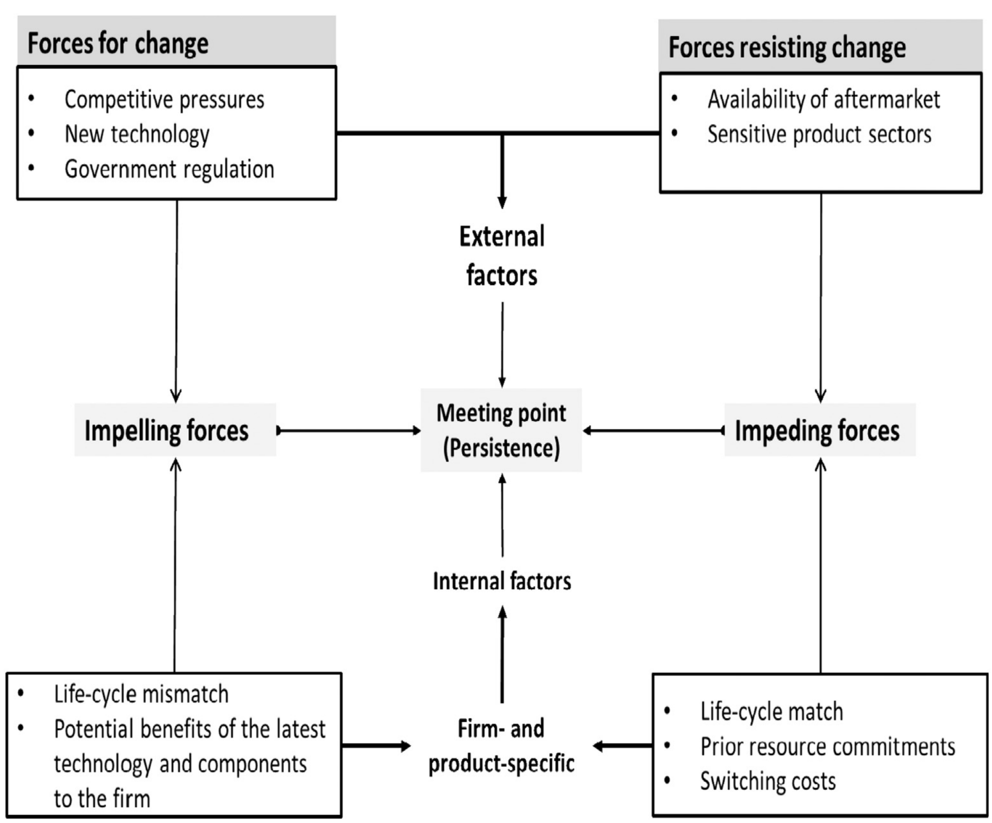

Fig. 3. Impelling and impeding forces of change.

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obsolete around the same time as the parts. The two life cycle matches are more likely to reduce or eliminate the misallocation of resources associated with the life cycle mismatches, which can lead to disposal of a product or component before their end of life. Thus, the study illuminates our understanding by taking into account that state of the products as well as the components in determining different types of obsolescence leading to technology discontinuance.

Another set of the findings identified a broad category of impelling and impeding forces of persistence with obsolete technologies such as availability of aftermarket sources, nature of systems, switching costs and availability of alternatives. Taken together, the study demonstrates that the obsolescence processes broadly influence the decision by firms to persist with or replace an old technology.

5.1. Contributions to theory

This article has some theoretical implications. First, although scholars have examined technology obsolescence (e.g. Bradley and Guerrero, 2009; Sandborn, 2007b; Solomon et al., 2000), there remains a lack of a comprehensive framework to articulate the dynamics of the subject. The study deviates from much of the existing literature by explicating the influences and effects of the product- and component-specific features in the processes leading to obsolescence. Thus, the paper goes far beyond the current focus of most studies by deepening our understanding of the processes of technology obsolescence.

In addition, in light of increasing technological breakthroughs and shortening product life cycles (Bradley and Guerrero, 2008; Fawcett and Waller, 2014), the present study also contributes to the literature by explicating persistence with obsolete technologies. In this direction, the study attempts to answer one of the pivotal and largely overlooked questions in contemporary strategy and technology literature, namely why some firms persist with obsolete technologies.

5.2. Managerial and public policy implications

Notwithstanding these observations, the study identified a number of practical implications. First of all, the analysis suggests that the problem of life cycle mismatch means that engineers and operations strategists in the automotive and avionics sectors need to develop a clear roadmap indicating when each component of life-long products and systems would become obsolete to enable them to plan replacements and develop a sustainable operations management strategy (Pecht and Humphrey, 2008). Indeed, next-generation parts often provide an opportunity to improve the performance and functionality of a system or product.

Besides amassing and utilising the latest information to update their technologies, the findings underscore the need for firms/users to be more attentive to the equipment and components as a means of identifying and responding to early-warning signals of obsolescence. For manufacturers and users, there is also a need for an effective mechanism for tracking and tracing products and devices as they move from one condition (functional) to another (not functional) (Obeng and Bao, 2016).

Furthermore, the findings indicate that skills in managing and shepherding a technology through stages of obsolescence from replacement of parts to complete cessation of technology can enhance the competitiveness of firms. It is also worth noting that lifetime or last-time buys can help eliminate the problems associated with replacing parts (Pecht and Humphrey, 2008).

From a public policy standpoint, the study indicates that a shift to more global and common standards for electronic components could help improve the availability of components as well as minimise the component obsolescence problem (Condra et al., 1997). It is also important to note that regulatory bodies and governments can also play a pivotal role by forcing firms to abandon outmoded technologies in a timely manner on safety grounds and for environmental protection (Bartels et al., 2012).

5.3. Research directions

In light of the conceptualisation, a number of promising avenues for future research deserve the greatest attention. A fruitful avenue for future research is the extent to which strategies to mitigate obsolescence are effective in the face of shortening product life cycles. This is a salient issue that has received scarce scholarly attention in operations management and general management literature.

Another starting point is for an empirical research to assess whether the dying of mature industries can be attributed to technology obsolescence. Such analysis would greatly illuminate our understanding of the degree to which technology impacts on industry conditions and structures. Complicating the picture painted above are the general observations that not all products or systems possess the simplified structural components as suggested. This represents an opportunity for future research to examine the applicability of the framework across industries and product sectors. It is hoped that this study helps to foster a better understanding of technology obsolescence.

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