

Business Model Innovation And Productivity



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Declaration

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Abstract

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Title: Business Model Innovation and Productivity

Rapid increase in computer power and performance at an exponential rate, coupled with significant reduction in costs of computer hardware and software, has been generally expected to help enhance productivity in many industries. However, recent global statistics show that productivity growth has slowed down in major industrialised nations, especially so in the United Kingdom since the 2007-2008 financial crisis. This phenomenon is now known as the “Productivity Paradox” and has attracted the interest of many researchers. Several hypotheses have been proposed to explain this productivity paradox, but they all have not quite unlocked the mystery nor completely revealed the real causes of the problem. Here we show that business model innovation can be an important source of productivity growth through both quantitative and qualitative studies.

The first study investigates the relationship between business model innovation and productivity growth. In this study, business model innovation is considered as an important organisational factor which may have an impact on productivity growth. In order to study the relationship between business model innovation and productivity empirically, this first study introduces a novel approach of measuring business model innovation by analysing changes in net asset turnover ratio. Through this newly introduced business model innovation variable, this study shows through empirical analysis that business model innovation contributed significantly to productivity growth across UK firms between 2003 and 2017.

After showcasing that there is a relationship between productivity and business model innovation and that business model innovation can be the source of productivity

growth in the first study, the second study looks further into how change in risks as a result of business model innovation affects productivity. The study also looks at servitization of manufacturing, as part of business model innovation, and its impact on productivity. As the servitization of business models changes the fundamental economics related to risk, strategic risk management is found to be one of the reasons why firms have servitized. To account for risk within different business models, this study introduces a novel approach to measure productivity by adjusting for risk, based on volatility and source of output variation. This study looks at the differences in risk and productivity between service and manufacturing sectors in UK manufacturing industry as a proxy of pre- and post-servitization of manufacturing. This empirical study compares risk adjusted productivity and unadjusted productivity between the service and manufacturing sectors in the UK between 2003 to 2018. The results show that the productivity gap between the manufacturing and service sectors reduces significantly after adjusting for risk. Although prior studies have found that the service sector contributes to a slowdown in productivity growth, this study provides empirical support that once adjusted for risk, the results show otherwise.

To understand the mechanics and consequences of business model innovation to productivity, the third study takes a closer look at a firm level case study of Rolls-Royce, to study the relationship between the servitization of business models and productivity growth. To understand what levers of business model influenced by servitization impact on productivity growth, both quantitative and qualitative methods were used. Through qualitative representation, the firm's business model choices based on business model levers were linked with profitability and productivity consequences. With quantitative analysis, the consequences of business model innovation to productivity can be quantified through a method of profit decomposition. The results of this study show that firms can increase or decrease their productivity through the use of different levers dependent on business model choice.

Our results from these three studies demonstrate that business model innovation can be one of the possible solutions to the productivity paradox puzzle. Overall, in the methodologies implemented herein, and their subsequent results, this dissertation contributes to the literatures of business model innovation, servitization and productivity. The results also have significant implications for both policy makers and managers on the importance of business model innovation, particularly servitization to achieve productivity growth.

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Chapter 1: Introduction

This chapter is an introduction chapter and has the following four aims. First, to introduce the productivity paradox and outline why the UK manufacturing industry was chosen as the subject of this study. Second, to provide a review of existing literature on the productivity paradox, productivity, and business model innovation. Third, to establish the research gap and research question. And lastly, to provide an overview of the structure of this dissertation.

This chapter starts with an overview of the research background and problem statement in Section 1.1. A literature review is provided in Section 1.2. The research gap and research questions are subsequently presented in Section 1.3 and Section 1.4 respectively. This chapter concludes with the key contributions of the dissertation, research methodology, and overall dissertation structure in Section 1.5, Section 1.6, and Section 1.7.

1.1 Background and Problem Statement

As Gordon Moore (1965) had predicted that computing performance would dramatically increase in power and decrease in relative cost at an exponential rate, rapid development in technology was expected to help increase productivity growth. Many governments and companies around the world have been putting more emphases on investments in technology and innovation as part of technical change, which are believed to be a driving force of productivity growth according to many renowned scholars such as Solow (1956, 1957), Kendrick (1956), Griliches (1985) and Brynjolfsson et al. (2008). As a result, the increase in power of computer performance has been one of the main focuses for governments and entrepreneurs around the world; hoping to increase productivity growth which would in turn increase the standard of living for people. Yet, the improvements in new technologies in recent years are still failing to prove the case. As such, the current available technologies have not been capitalised for their potential advantages. The problem of productivity slowdown, despite dramatic improvements in technology, was first mentioned in an article more than 30 years ago by Solow (1987) with his famous phrase, “we see the computer age everywhere except in the productivity statistics”. This problem has now become known as “Solow’s Productivity Paradox”.

Recently published macroeconomic data¹ have shown that global productivity growth has not really improved despite a rapid rise in new technologies and innovations across all industries and countries. As a result, the productivity paradox has become a global phenomenon (Haldane, 2017). From the current global statistics provided by

¹ For example, <https://www.conference-board.org/data/economydatabase/>, <http://www.euklems.net/>, and <https://tcdata360.worldbank.org/>

Conference Board², the annual growth in output per worker has been hovering around 2 percent for the past few years, compared to an average annual rate of 2.9 percent between 2000 and 2007. According to Giles (2019), all of this improvement came purely from increases in capital expenditure or improvement in the labour force. This evidence indicates that the recent development in new technologies has not contributed to the overall efficiency and productivity of the global economy, which is particularly shown in the UK.

Productivity Paradox in the UK Manufacturing Industry

To look at the productivity paradox in the UK, improvement in new technology in the UK was first observed. The UK appeared in the top 5 of the Global Innovation Index for each of the years since 2013. To support this, Figure 1.1-1 showed that since 2009, the share of the UK firms using basic information and communication technologies (ICT) which includes the use of a mobile broadband connection via a portable device, access to the internet, used of a fixed broadband connection and having a website had increased in adoption rates to over 90%.

² <https://www.conference-board.org/data/>

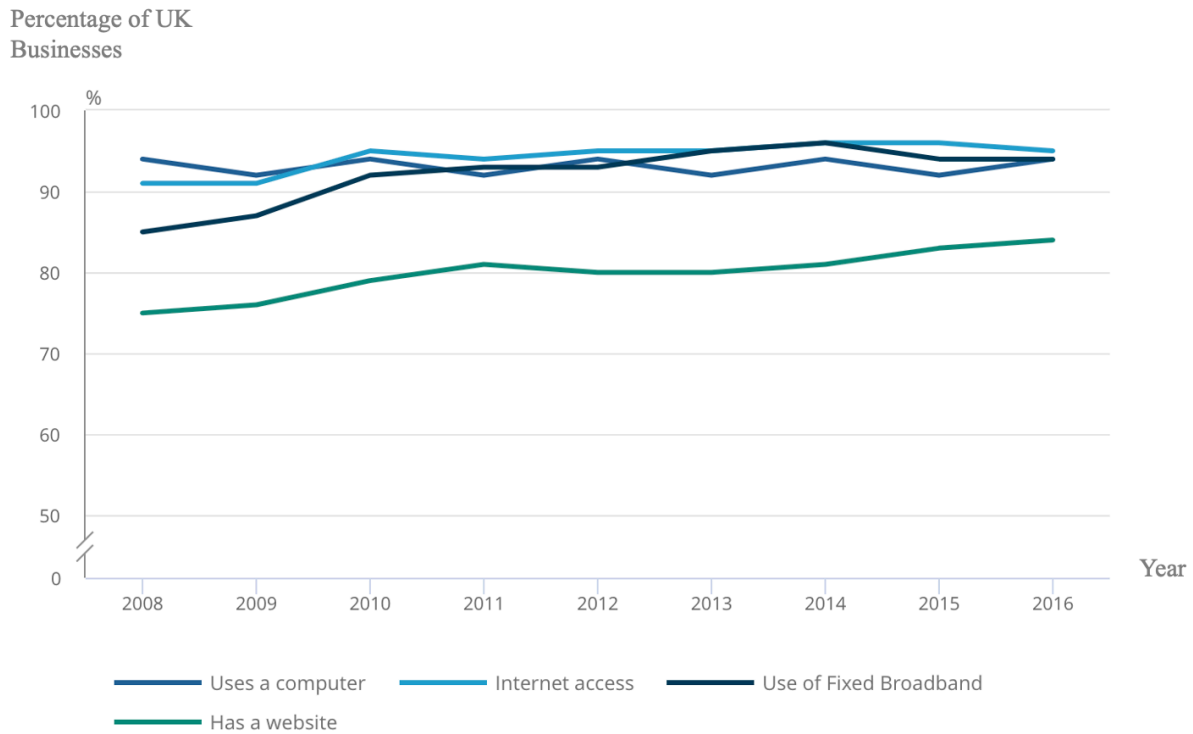


Figure 1.1-1: Trends in the adoption of basic ICT technologies among UK businesses

Source: Office of National Statistics UK, 2018

Figure 1.1-2 showed that the share of businesses using social media in the UK had also increased markedly from just over 4 in 10 firms in 2012 to more than 6 in 10 firms in 2016. Similarly, an increase in the share of firms adopting cloud computing technology was from around one-quarter of businesses in the UK in 2013 to over one-third in 2015.

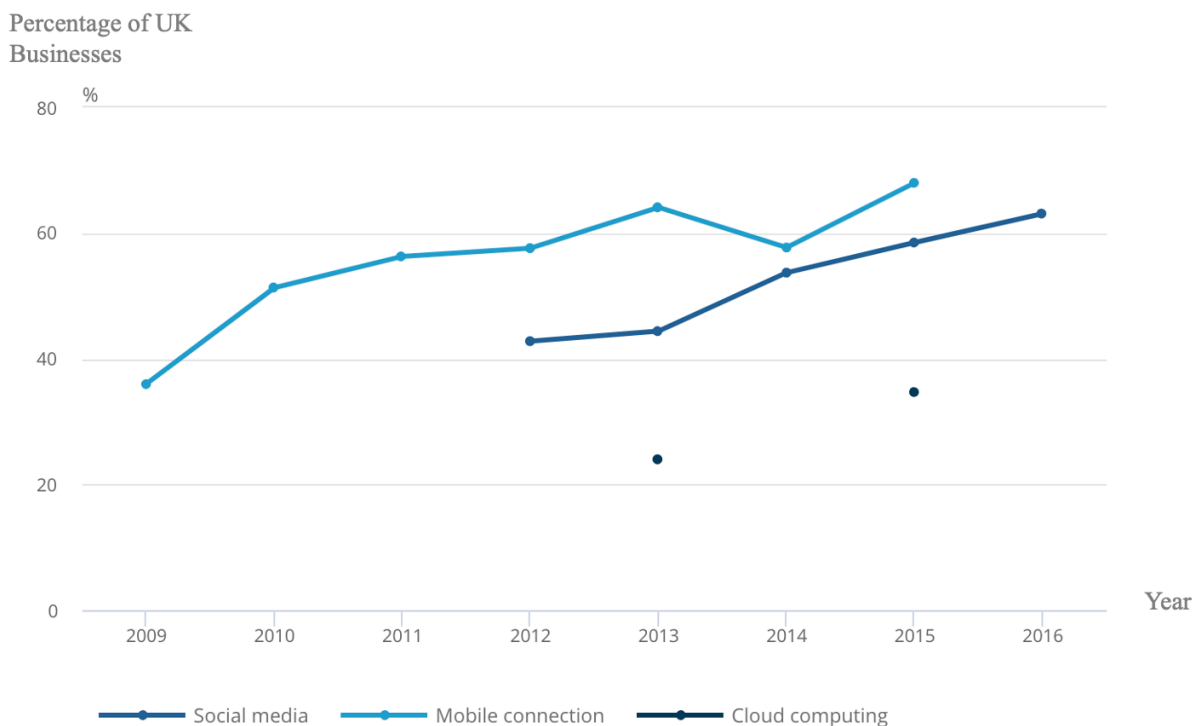


Figure 1.1-2: Trends in the adoption of other ICT technologies by UK businesses

Source: Office of National Statistics UK, 2018

Despite the improvements in technology shown earlier, the UK experienced a large fall in growth rate of real output per hour (shown in Figure 1.1-3) and has still had a flat-lined productivity growth which consistently underperformed below growth expectations since 2008 (Haldane, 2017). As shown in Figure 1.1-4, productivity growth has slowed down in almost all advanced economies since the financial crisis. But the UK slowdown has been more severe than elsewhere (Maier, 2017), so much so that it would take a UK worker five days to complete what an average G7 worker could do in just four days. The Office of National Statistic UK (2018) also highlighted that UK output per worker in 2016 was 17 percent lower than the G7 average, and below the national averages of USA (by 27 percent), France (by 12 percent), and Germany (by 9 percent).

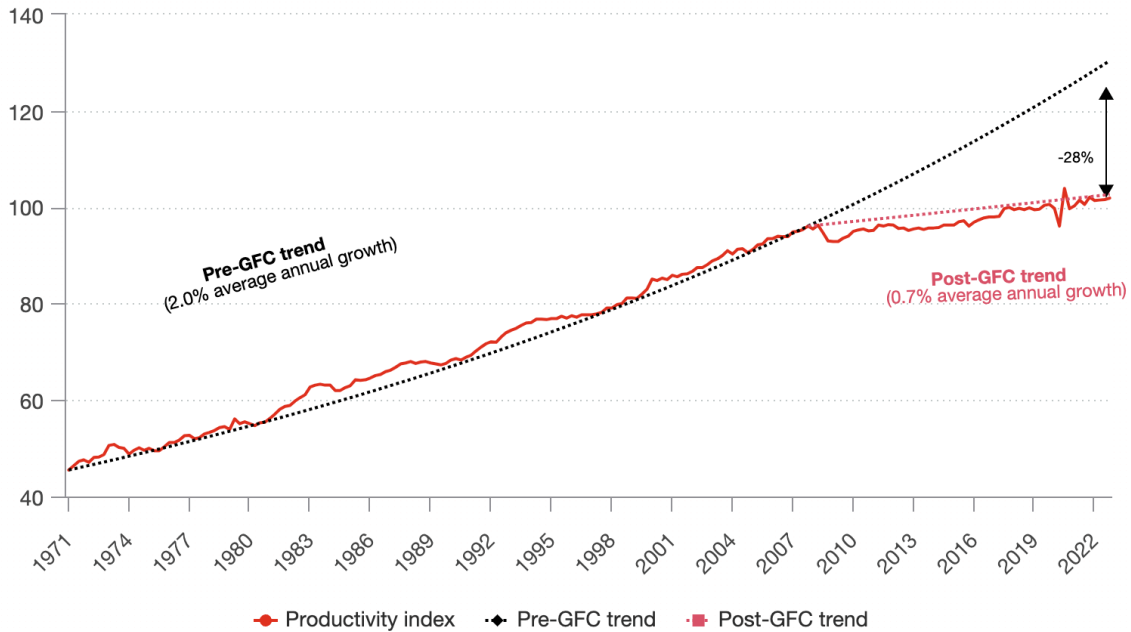


Figure 1.1-3: UK Real Output per Hour: Pre- and Post-Global Financial Crisis (GFC)

Source: PwC Calculation from Office of National Statistics UK Data, 2023

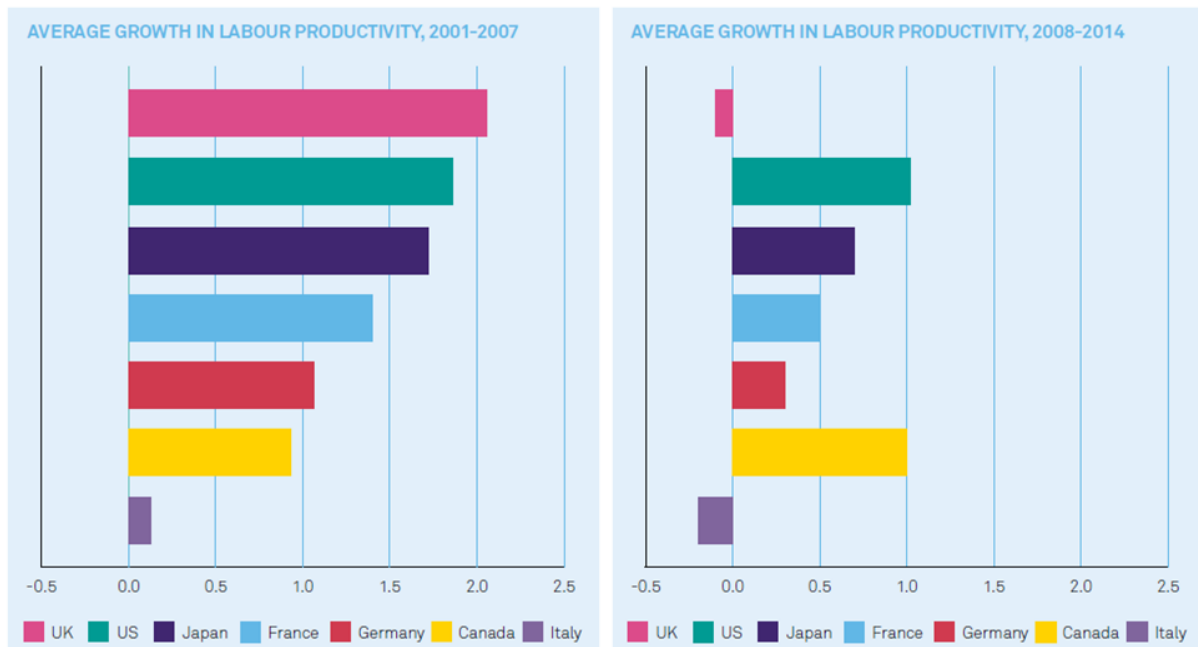


Figure 1.1-4 Comparison of Labour Productivity Growth

Source: The Made Smarter Review 2017

The Conference Board figures showed that the UK's annual growth in output for every hour worked fell from 2.2 percent between 2000 and 2007 to 0.5 percent between 2010 and 2017 and would likely fall to only 0.2 percent in 2019 (Giles, 2019). Data from Conference Board highlighted that the productivity crisis had struck the UK since the 2007-2008 financial crisis, with the slowdown worse than any other comparable countries (Giles, 2019). According to Haldane (2017) of the Bank of England, a tale of long waves of productivity stagnation was particularly strong by historical standard, and it could have profound implications for living standards amongst the general population (Krugman, 1994). As a result of this important implication, this dissertation chooses to focus on the problem of productivity paradox in the UK.

To understand the productivity paradox in the UK, this research aims specifically to explore manufacturing industry which is a major industry that has significant output for the UK. According to the True Impact of UK Manufacturing 2018 report (2018), the manufacturing industry directly employed 2.6 million workers across the UK, and collectively generated an estimated GBP 177 billion in GDP or nine percent of GDP and eight percent of employment during 2016. However, Figure 1.1-5 shows that a percentage of manufacturing sector's value added toward UK GDP has been decreasing from just above 16% in 1990 down to 9% over the past 30 years. Based on this information, the manufacturing industry is a suitable industry to study the productivity paradox.

Value-added as a percentage of GDP

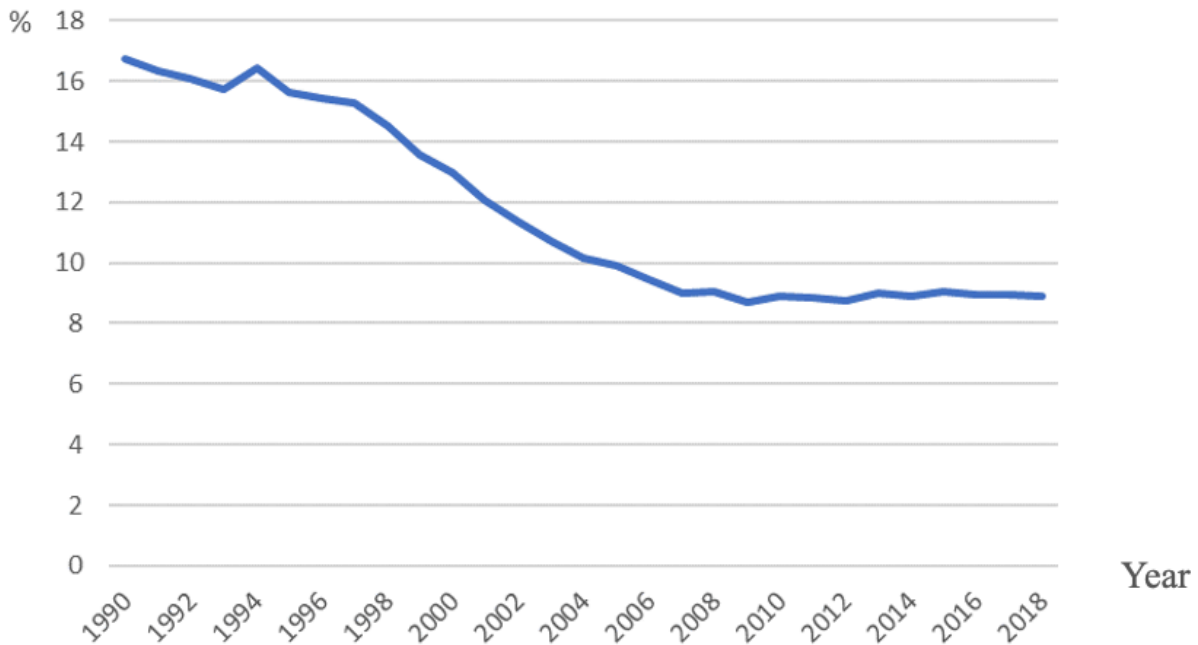


Figure 1.1-5 Manufacturing in the UK, value-added as a percentage of GDP

Source: The World Bank Data³

Apart from its contribution to the UK economy, the manufacturing industry also constitutes a dynamic change in business model. By breaking boundaries between manufacturing and service through technological development, especially data capturing and information processing, firms in the manufacturing industry are developing new business models (Neely, 2008). One important new business model in the manufacturing industry is providing service as a product, known as “servitization”, which is most prevalent in the US (Neely, 2008). With the US as one of the only few countries that has

³ <https://data.worldbank.org/indicator/NV.IND.MANF.ZS>

higher productivity growth compared to other developed countries, business model innovation and servitization could potentially be a reason why the US has higher productivity growth.

Additionally, there is limited empirical evidence on whether business model innovation, particularly servitization, is being adopted in practice and what impact the servitization of manufacturing has on productivity growth (Neely, 2008). Scholars have proposed multiple hypotheses to explain the productivity paradox, including the mismeasurement error, lags of technology diffusion, and skills mismatch. Yet many factors, such as a lack of business model innovation, which are believed to be the causes for the productivity slowdown, are not yet examined in depth. According to past literatures, business model innovation had been studied and linked with technology and firm's performance by helping compliment and integrate new technology into businesses to help create competitive advantage. The aim of this PhD dissertation is to look further into the relationship and ascertain whether business model innovation is a factor affecting the firm's productivity, particularly within the servitization of the UK manufacturing industry. The results of this dissertation can help provide a missing piece to the solution of the productivity paradox puzzle.

1.2 Literature Review

To lay an overall foundation for this dissertation, this section provides a brief review of relevant literatures in the area of productivity and business model innovation.

1.2.1 Productivity

Looking through previous literatures, productivity has been defined in several ways. According to Grifell-Tatje and Lovell (1999), the productivity effect was a part of production theory and the most common definition of productivity was the efficiency in which output was produced, or the ratio of output to input (Craig and Harris, 1973; Syverson, 2011), or the amount of output produced per unit of input (Brynjolfsson and Hitt, 1998). Simply put, productivity was the efficiency in the production process and an increase in efficiency must come from working smarter (Brynjolfsson and Hitt, 1998).

To put into perspective how important productivity is, an improvement in productivity is described as one of the most important aspects to help increase human living standards (Solow, 1956). Besides shaping living standards, Brynjolfsson and Hitt (1998) believed that productivity growth also determines the wealth of the nations which in turn strengthens the potential national security and future economic growth. In a business setting, organisations with higher productivity are more likely to survive than their less efficient industry competitors. As a result, productivity is quite literally a matter of survival for businesses (Syverson, 2011).

a) *Productivity and Technology*

To be able to increase productivity growth, one methodology is to focus on improvement in technology. The relationship between productivity and technology was first mentioned in the 1950s when Solow (1956) first published his paper stating that productivity growth came from new technologies, and new techniques of production and distribution. Recent scholars have shown particular interest in the study of technology and productivity from various angles. For instance, several studies such as Oliner and Sichel (2002) and Lehr and Lichtenberg (1999) looked at information technology (IT) capital and its relationship with

productivity. Jorgenson et al. (2002) also found that IT capital and IT-related total factor productivity (TFP) explained more than three-quarters of the post-1995 increase in productivity growth. According to Brynjolfsson and Hitt (1998), the greatest increase in productivity had historically been associated with a particular class of technologies called general purpose technologies.

However, this was argued by Comin and Mulani (2009) that general purpose technologies affected all firms in a relatively symmetric way; therefore they did not have significant effects on market shares and it was believed that research and development (R&D) investment was rather a solution to productivity growth. The relationship between R&D and productivity had been particularly highlighted by many researchers, such as Griliches (1985); Denison, (1985); Mairesse and Sassenou (1991); and Lokshin et al. (2008). For example, Doraszelski and Jaumandreu (2013) had found that R&D appeared to explain a substantial amount of productivity growth. Beside R&D, Jorgensen (2001) studied the accelerated IT price decline phenomena which provided incentives for the ongoing substitution of IT for other productive inputs and served as an indicator of rapid productivity growth in IT producing industries. Jorgensen (2005) further analysed all of the G7 nations and found that they had all experienced a rise in productivity growth in the IT-producing industries. The initial differences in levels of technology and relative rates of growth of output had also been studied by Abramovitz (1979); in which the study had shown that the country's degree of initial backwardness in the technology and productivity level could be regard as a rough measure for potential growth.

To further analyse the relationship of technology and productivity, several literatures also looked at the relationship at the cross-sectional level in both country and industry. For instance, Jorgenson and Nishimizu (1978) compared output between Japan and the US, and found that with rapid rise in level of Japanese technology which caught up with the US level of technology in 1979, the difference in levels of output between these two countries were purely from the differences in levels of labour and capital input. Matteucci et al. (2005) decomposed the sources of growth in the US and found that the

acceleration in the US productivity growth, when compared to other European countries, primarily came from a large increase in percentage point contribution of ICT capital and a marked acceleration in productivity growth. Kendrick (1956) looked at various industries within the US and found a significant acceleration of productivity advancement since the end of World War I.

b) Productivity Paradox

Based on previous studies, one would expect a rise in productivity growth after an investment and improvement in technology. However, researchers have not yet found evidence of visible progress in aggregate productivity growth despite a rapid decrease in the cost of ICT, increases in business spending on digital products and services investments, and a rise in IT performance (Van Ark et al., 2015). With a prolonged reduction in productivity growth rates over the last decade in major mature economies, as well as emerging markets, economic growth and development had been severely affected, especially in the post-2008 crisis period (Van Ark, 2016). Even worse, the most intensive users of digital technology had collectively accounted for the largest proportion of the productivity growth slowdown seen in the US, UK and Germany since 2007. Consequently, several studies highlighted the productivity paradox as the phenomenon in which economies seemed to be digitalising at an unprecedented pace while economic or productivity growth had yet to see a significant increase.

Attention was first drawn to the productivity paradox in 1987 by Stephen Roach of Morgan Stanley (Brynjolfsson and Hitt, 1998). The phenomenon arose from the fact that the residual of economic growth had slowed down considerably since 1973, precisely when IT investment had arisen to new heights (Jorgenson and Stiroh, 1999). Interest in this topic was brought up again by Solow (1987) with his famous phrase, “we see the computer age everywhere except in the productivity statistic”. Since then, productivity growth had almost disappeared as a source of economic growth in the G7 countries. Between 1989 and 1995

productivity growth was negative for five of the G7 countries, whilst positive growth was only experienced in Japan and the United States (Jorgenson and Yip, 2001).

There were some hopes when productivity growth suddenly picked up in 1995 and gave way to near universal belief in a productivity resurgence which had been led by improvements in IT in the late 1990s. However, according to Jorgenson et al. (2008), this resurgence was temporary due to positive supply shock from rapid price declines in the IT assets. Although Moor's Law predicts rapid rising trends in the capacity of microprocessors and storage devices, the rate of productivity growth around the world, especially the US economy, had yet to pick up (Jorgenson, 2001). As a result, the productivity paradox remains a mystery among academia and governments around the world.

c) *Recent Findings of Productivity Paradox*

With an interest in establishing the causes of the productivity paradox, many scholars have been trying to explain the phenomenon. The hypotheses from some of these studies are discussed below.

The first and the most mentioned hypothesis is the mismeasurement of productivity due to the digital economy (Solow, 1987; Griliches, 1998; Lehr and Lichtenberg, 1999). According to several literatures, such as Weil (1992) and Brynjolfsson et al. (2018), the mismeasurement of productivity growth could arise from investment in unmeasured capital goods, or firm and sector specific characteristics such as aspects of a firms climate which influences IT. However, Syverson (2017) challenged this hypothesis and showed several examples of why mismeasurement was unlikely to be sufficient to explain the slowdown in productivity growth. For example, Syverson (2017) suggested that for the mismeasurement hypothesis to explain productivity slowdown, the current GDP measure must be missing by hundreds of billions of dollars of incremental output.

The second hypothesis is lags and slowdown in technological diffusion. Brynjolfsson et al. (2017) claimed that this could be one of the biggest contributors to the

paradox due to evidence of the benefit of IT investments toward productivity. According to the hypothesis, both implementation and restructuring lags are a possible explanation for the juxtaposition of optimism about AI's potential and currently low productivity growth (Brynjolfsson et al., 2017). Similarly, David (2000), Brynjolfsson et al. (2002), and Brynjolfsson and Hitt, (2003) believed that computers may require substantial changes in complementary infrastructure and technical complements such as organisational characteristics, major organisational reconfiguration, and inter-company networking for the productivity gains to materialise. According to Brynjolfsson et al. (2018), the paradox is part of the Productivity J-Curve in which productivity was initially dipping while the investment rate in unmeasured capital was larger than the investment rate in other types of capital, and then rising as growing intangible stocks began to affect measured production.

The third hypothesis is skills mismatch. Some researchers believe that the productivity paradox is caused by a skill mismatch due to changes in product market structures driven by digitalisation (Van Ark et al., 2015). According to Goldin and Katz (2007), the race between technological change and an increase in demand for skilled and educated workers are common. From 1915 to 1980, education raced far ahead of technology and that served to reduce skill premiums and increase economic expansion. However, technology has been racing ahead of education in recent decades because educational growth has been sluggish, resulting in relative lower supply for skilled worker and slowdown in productivity growth.

The fourth hypothesis is that new technologies such as computer and information processing equipment actually accounted for only a small fraction of capital stock and a relatively small share of GDP, meaning aggregate effects would not be sufficient to raise productivity growth substantially (Oliner et al., 1994).

The fifth hypothesis is the fact that computers have not been as productive as they were thought to be. Bresnahan et al. (1992) explored the value of enhanced information in stock market and suggested that new technologies had no net overall effect on individuals or firms due to zero sum effect between individuals and firms.

The sixth hypothesis is the technical bottleneck from human input. According to Triplett (1999), most powerful personal computers wound up being used to do uncomplicated tasks such as typing letters. Consequently, it is not a limitation on the capacity from software or computer hardware, but rather human input or the person who types it.

Other alternative explanations for the productivity paradox are that a period of secular stagnation could still remain troubling (Summers, 2015), a diminishing return of the productivity growth from ICT revolution (Gordon, 2015), the legacy of the financial crisis causing the temporary dislocation of markets (Van Ark, 2014), the slowdown in the IT-producing and IT-using sectors (Fernald, 2014), an ongoing redistribution of resources and dissipation of profits (Brynjolfsson, 1993), or the dispersion of productivity between large and small firms especially in capital intensive industries due to greater capital intensity of larger firms (Leung et al., 2008).

However, despite the hypotheses mentioned, the productivity paradox is still left unanswered. Instead of solely emphasising on technological innovation, Tongur and Engwall (2014) suggested that firms need to master the complexity of both incremental and radical innovation, as well as business model innovation. As a result, this dissertation suggests that business model innovation can be one possible answer to help explaining the slowdown in productivity growth.

1.2.2 Business Model

To establish the connection between business model innovation and productivity growth, literatures on business model are analysed. Business models are understood to be the detailed specification of activities a firm undertakes to exploit an identified opportunity (Brink and Holmen, 2009) and to unlock potential values embedded in new technologies and converting them into market outcomes (Zott et al., 2011). Though there is no one

general accepted definition of business models, scholars have agreed that business models concern how a firm creates value, develops advantage, and captures value (Morris et al., 2005; Brea Solis et al., 2015). According to Velu (2018), business models could also be seen as complex systems with components that connected the customer value proposition, how value was created, the means of value capture, and the partners in the value network, which resulted in the four key components of business model or the four Vs (value proposition, value creation, value capture, and value network). Similarly, Amit and Zott (2012) defined a company's business model as a system of interconnected and interdependent activities that determined the way the company did business with its customers, partners, and vendors. To conceptualise as a component of competitive strategy, business models reside on how products are delivered to the chosen market segment as a part of existing strains of strategy theory (Santos et al., 2015). According to Teece (2010), the essence of a business model is to define the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit.

The business model has been the subject of a growing number of practitioner-oriented studies, with more than a thousand articles published in peer-reviewed academic journals since 1995 (Zott et al., 2011). Within this academic research area, three themes of study have emerged, according to a review by Lambert and Davidson (2013). This included the study of business models as the basis for enterprise classification, the study of business models and firm performance, and the study of business model innovation. To understand the relationship of business model innovation and productivity, this dissertation is looking further into existing studies of business model innovation.

a) *Business Model Innovation*

According to Schneider and Spieth (2013), business model innovation has no precise definition. For business model innovation to happen, a newly designed business model is

needed in order to align the customer value proposition with how value is created and captured (Velu and Stiles, 2013). This could involve changing the set of activities, changing the linkage between activities, changing the boundaries of the focal firm, or changing the location in which activities are performed (Santos et al., 2015). Morris et al. (2005) described business model innovation as a set of interrelated decision variables addressed to create sustainable competitive advantage in defined markets. Business model innovation was often defined as the process by which management had actively innovated the business model to disruptive market conditions (Saebi et al., 2017).

The need for business model innovation came from the failure of doing business in the conventional ways and the challenges faced by the firms from both internal and external factors such as technology. Because business models are a mediating factor between technology and firm performance, business model choice could influence the way in which technology is monetised into profit by allowing business model changes in order to create customer value from new technology (Baden-Fuller and Haefliger, 2013). While technology changes, firms can not solely invest in technological innovation as they need to ensure the advancement of business model innovation as well (Tongur and Engwall, 2014). Without the ability to find an appropriate business model to capture the value of a new potential technology, a discovered technology firm may lose its potential to capture value or profit to another firm who could find a more suitable business model (Chesbrough, 2010).

Therefore, business model innovation can be regarded as the key driver of success (Sosna et al., 2010), and can be particularly important during times of change and periods of resource scarcity, high uncertainty and volatility in environments that adversely affect revenue and profit (Amit and Zott, 2010). In a chaotic business environment, business model innovation can help firms operate with strong corporate decision processes and help to establish advantage over rivals (Chesbrough, 2010). While companies might have extensive investments and processes for exploring new ideas and potential technologies,

they often have little, if any, ability to innovate business models or to find appropriate business models in order to capture value (Chesbrough, 2010).

When looking through literatures regarding business model innovation, most research on business model innovation tries to explore and understand its importance through different methods, including a few recent studies mentioned by Schneider and Spieth (2013). To gain a deeper understanding of how business model innovation has impacted a firm's financial performance, several explored literatures provided evidence to show that there was a possibility of the relationship even though some of the evidence was not explicitly explained. For example, according to Porter and Millar (1985), superior financial performance would only be rewarded to companies which had not simply completed IT projects but had successfully integrated IT into their business processes. To support this, Stratopoulosa and Dehning (2000) agreed that how firms managed their IT assets was more important than how much they spent on IT. To profit from innovation, business pioneers needed to excel not only at product innovation but also at business model design, and to understand business design options as well as customer needs and technological trajectories (Teece, 2010). As a result, there is some evidence which links business model innovation and firm performance together.

b) Business Model Innovation and Performance

To better understand and explore the relationship between business model innovation and productivity, this dissertation looks at past literatures related to the relevant area of business model innovation and firm performance. For example, Pohle and Chapman (2006), through IBM Global Report, agreed and showed that some executives expected a larger performance gain from business model innovation than from a new product or service. According to Girotra and Netessine (2011), innovating business models through products or services offerings to existing customer's needs using existing technologies is more valuable and transformative than product-driven or technology-driven innovation.

Similarly, Aspara et al. (2010) and Visnjic et al. (2016) found that firms which emphasised business model innovation had exhibited a higher profitability than others. Velu (2015) argued that firm strategy, which influences firms structure via a degree of business model innovation, is a contingent factor affecting firm performance through survival. Business model innovation was also found to be related to costs reduction, and enhanced profits and firm performance (Chesbrough, 2007). Cainelli et al. (2006) examined and found a two-way relationship between innovation and performance. Siggelkow (2001) and Porter (1996) also connected the impact of business choices on performance based on the production frontier. There are also some empirical studies which report higher performance returns for firms that exhibit proactive innovation orientation in their strategies (Aspara et al., 2010).

However, only a very limited number of studies have discussed and linked business model innovation and productivity directly. One exception is a study by Brea-Solis et al. (2015) which developed a framework through business performance considering the link between productivity and influence of business model innovation at an individual firm level. However, the study had not yet examined the relationship between business model innovation and productivity at aggregate level. As a result, there has been no evidence of research that aimed to establish a systematic relationship between productivity and business model innovation using large empirical data until a relationship was shown by Wannakrairoj and Velu (2021) in their study of UK manufacturing industries.

c) Business Model Innovation and Technology

In order for business model innovation to be one of the hypotheses which explains the productivity paradox, evidence of a relationship between business model innovation and technology is needed. Even though there have been numerous literatures which linked productivity and technologies, studies on business model innovation and technologies are still limited and have often indirectly mentioned the business model framework. According

to observation, study of the business model innovation and technology can be categorised into two parts.

The first part discusses how technology is causing firms to change their business model. For example, Wirtz et al. (2010) and Lee et al. (2012) believed that an increase in the globalisation of the business environment, through technological and behavioural developments, was a key driver for firms to innovate their established business models. Similarly, Teece (2010) gave an example that the Internet was causing many ‘bricks and mortar’ companies to rethink their distribution strategies if not their whole business models.

Another part discusses how complementary business model innovation and technology are. For example, according to Christensen (2013), disrupters tend to focus on getting the business model right rather than product. Lambert and Davidson (2013) explained that business model innovation was necessary to capture the benefits of technology driven by changes in knowledge sharing, such as open innovation. Chesbrough (2010) agreed that the economic value of a technology remained latent until it is commercialised via a business model and that the same technology commercialised in two different ways would yield two different returns. Similarly, the Landmark MIT Study by Lipsey et al. (1989) also suggested that information technology was not generating a single inevitable course of action for companies, but it opened an array of possibilities to explore opportunities through different business models. The pattern of rising growth contributions over longer time periods suggested that computers were part of a larger system of technological and organisational changes that increased the firm level productivity over time (Brynjolfsson and Hitt, 2003). Brynjolfsson and Hitt (1998) believed that the greatest benefits of technological progress appeared to be realised when IT investment was coupled with other complementary investments such as new strategies, new business processes, new organisations, and decentralised work practices. Despite evidence of the relationship between business model innovation and technology, the complementary investments and the importance of organisational innovation were very much emphasised on changes at the

process improvement level, but this did not touch upon the notion of how technology coupled with business model innovation can help support productivity growth.

As a result, this dissertation is dedicated to developing and establishing the relationship between business model innovation and productivity. The ultimate aim of this research is to provide a solution to the productivity paradox based on the relationships and research gaps found in literatures between business model innovation, technology, and productivity.

1.3 Research Gaps

From the literature review in Section 1.2, knowledge gaps have been identified from the two research streams: productivity and business model. When looking at productivity, investigations on productivity growth are considered one of the important topics. By decomposing productivity growth into effects from each input factor, factors such as human capital, technical knowledge, innovation, IT capital, R&D, adjustment cost, and utilisation are then investigated. However, these factors have not yet explained all variations in productivity growth, as foreseen by productivity paradox, and therefore leaves a gap for scholars to explore.

Furthermore, with evidence of the relationship between productivity and technology, the productivity paradox, which was recognised by Solow (1987) and Roach (1987) since 1980's, has become a puzzle which many scholars have been trying to solve. Despite improvements in technology performance and reduction in cost, the overall measure of productivity growth at the aggregate level is still flattening. Several hypotheses have been formed to provide explanations of the paradox such as mismeasurement error, lags, and a slowdown in the diffusion of technology. However, the productivity paradox is still left an unsolved mystery and a big question for scholars to study. Research on other

hypotheses, which have not yet been mentioned, may also be worth investigating in order to find the root cause of the paradox.

One way to address these two gaps of the literatures in productivity is to propose a new factor which could explain a variation in productivity and therefore productivity paradox. By looking through business model literature, many researchers have provided evidence of how business models can be a source of competitive advantage and affect firm performance. Types of business model, and how business models help unlock new technology, have also been studied extensively. One missing dimension is how firms need to adapt or change their business model to rapidly changing and competitive environments enabled by new technologies. This dimension can be explained in part by business model innovation. However, in recent literatures, business models are often associated with a firm's profitability and not a firm's productivity. Therefore, this dissertation raises several research questions based on the relationship between business model innovation and productivity, which has not been studied extensively before.

1.4 Research Questions

This dissertation seeks to fill the gaps identified in the literatures above. To do this, it poses three research questions which will be explored:

- 1) Can business model innovation be the source of productivity growth?

- 2) How do changes in risks resulting from business model innovation affect productivity? Can the servitization of manufacturing, an example of business model innovation, impact productivity?

- 3) What are the levers that influence servitization-based business models that impact firm's productivity growth?

1.5 Key Contributions of the Dissertation

By answering these three research questions, this dissertation will make the following contributions.

1.5.1 Academic Contribution

The main academic contribution from this PhD dissertation is the establishment of the relationship between business model innovation and productivity using multiple studies. Furthermore, the methods and results from each of the studies within this PhD dissertation can contribute directly to the fields of business model innovation and productivity, and this could further enhance opportunities for more research in both fields.

In the first study, this PhD dissertation provides a better understanding of the relationship of business model innovation and productivity through a newly introduced business model innovation measure. To the best of present knowledge, this research is believed to be the first to attempt measuring and quantifying business model change and to show that business model innovation is a factor affecting productivity. The newly introduced business model innovation measure proposed in this study can also be used empirically in other areas beside productivity.

In the second study, this PhD dissertation provides an insight into the importance of risk management within servitization of the manufacturing industry. As research on the impact of risk management toward lower level of productivity in the service sector has not yet been explored, this research suggested that risk management can be an underlying reason why there is currently a wave of servitization in the manufacturing industry despite

lower productivity growth expectations. This second study provides a new productivity measure which takes risk into account to help better measure productivity for future research, and this can potentially be a solution to the productivity paradox problem.

In the third study, this PhD dissertation provides insight into the impact of business model innovation, particularly servitization, on the firm's productivity. As there are a limited number of studies that have examined the consequence of servitization in term of productivity growth and whether servitization is being adopted in practice, this research attempt to address this knowledge gap by analysing the relationship between the business model innovation, servitization, and productivity based on an in-depth analysis at a firm level which is an understudied area. The results in this study show how each business model levers impact the firm's productivity once servitized. On top of a contribution from the result, this third study also provides a novel approach of using both qualitative and quantitative analysis to help understand the relationship between business model innovation and productivity, especially in context of servitization.

1.5.2 Managerial Implications

In addition to academic contributions, the key results from the three studies in this PhD dissertation can help provide new insights for both policymakers and practitioners with a solution to increase firm productivity through business model innovation. With a better understanding of the relationship between business model innovation and productivity, businesses can take advantage of new technology by applying business model innovation to increase firm's productivity. With an understanding that business model innovation does not necessarily reduce productivity if properly taking risk into account, policymakers and practitioners can have more confidence in implementing business model innovation. Furthermore, based on the results found in this PhD dissertation, the widely observed productivity level should also be interpreted with caution, and that risk should be considered when making comparison of productivity between different industries or firms

with different business models. Moreover, this study demonstrates how change in business model levers through business model innovation impacts productivity based on a case study of Rolls-Royce. To improve productivity, practitioners can implement business model innovation through change in business model levers based on the case study provided in this study.

1.6 Research methodology

In order to answer the above-mentioned research questions, this dissertation adopts an integrated research methodology with mixed methods using a quantitative study with support from a qualitative aspect. This dissertation is divided into three connected studies in the field of business model innovation, productivity, and manufacturing under the central theme of the productivity paradox in the UK manufacturing industry, to help answer all three different research questions. The studies include Macro Exploratory Study, Industry Analysis, and Individual Firm Level Analysis.

Study 1: Macro Exploratory Study

The main objective of this study is to provide an answer to the first research question through an empirical study using quantitative methods. In Chapter 2, the study implements quantitative analysis to investigate the relationship between productivity and business model innovation at the aggregate level. This study proposes and introduces a novel approach to quantifying and capturing characteristics of business model change as a result.

Study 2: Industry Specific Analysis

The main objective of this second study is to provide an answer to the second research question and to help support results from the first study by looking at the servitization of manufacturing as part of the business model innovation. In Chapter 3, this study explores and compares whether there is a difference between a servitized business model and a product-based business model in term of risk profile and how it can affect productivity. As a result, this study develops two risk adjusted productivity models as a novel approach to help measure productivity by adjusting for risk within different business models.

Study 3: Individual Firm Level Analysis

The main objective of the third study is to address the final research question using an individual firm level analysis. Following the results of the first and second study, this study drills down further to understand how business model change can have an impact on the productivity of a firm. A case study of a specific firm which successfully innovated their business is selected to help provide a real-world perspective of the relationship between business model innovation and productivity growth. In Chapter 4, both quantitative and qualitative analysis methods are used to help demonstrate that business model innovation can contribute to a change in firm's productivity.

1.7 Organisation of Dissertation

This dissertation consists of five chapters, including this introductory chapter which introduced the productivity paradox in the UK as the central theme of this dissertation. The remaining chapters are as follows:

Chapter 2: Business Model Innovation and Productivity

To be able to answer the first research question, whether business model innovation can be a source of explanation to productivity growth, Chapter 2 introduces a novel approach of measuring business model innovation using the change in the net asset turnover ratio. The proposed variable is used in an empirical analysis to help quantify the impact of business model innovation toward productivity growth and provide evidence that business model innovation can be a source of explanation to productivity growth, and the productivity paradox, across firms in the UK. The insight obtained from this chapter not only helps fill a research gap, but also lays an important foundation to answer the other research questions in subsequent chapters.

Chapter 3: Risk Adjusted Productivity

With servitization, as a part of the business model innovation in the manufacturing industry found to be associated with risk-return trade-off, Chapter 3 proposes and demonstrates that risk level from different business models, which encapsulate how businesses operate, can have an impact on productivity. This chapter suggests that the choice of strategic risk management by businesses and risk-return trade-off needs to be considered when measuring and comparing productivity. Based on this, a novel approach to measure productivity by adjusting for risk based on volatility and source of variation of output is then introduced. Through two different risk adjusted productivity models, results from the study of the UK service and manufacturing industry provide evidence to address the second research question that management may implement business model innovation to help reduce risk. The results of this study also show how productivity measurement needs to be adjusted for risk accordingly. Besides answering the second research question, this chapter

also provides an alternative productivity measurement which could potentially be used to reassess the productivity paradox.

Chapter 4: Business Model Innovation and Productivity Growth: Servitization of Rolls-Royce

To understand the dynamics of business model change and its impact on productivity at the firm level, Chapter 4 re-examines the relationship between business model innovation and productivity growth. This is done by presenting a case study of Rolls-Royce as a manufacturing firm that has undergone servitization during the defined study period. Through using quantitative and qualitative methods, this chapter shows how Rolls-Royce management utilised different levers, each relating to profit and productivity, to enable their desired business model innovation. Through this case study, this chapter helps answer the third research question and firmly establishes the relationship between business model innovation and productivity found in the Chapter 2.

Chapter 5: Academic and Managerial Implications

This last chapter concludes the PhD dissertation by summarising key contents from all the previous chapters, as well as providing academic and managerial implications and some limitations.

Chapter 2: Productivity Growth and Business Model Innovation

The content of this chapter has been published in a peer-reviewed journal article: Wannakrairoj and Velu, 2021. Productivity Growth and Business Model Innovation. *Economics Letters*, 199, p.109679.

Available at: <https://www.sciencedirect.com/science/article/pii/S0165176520304390>

In order to identify a possible explanation for the productivity paradox, this chapter presents a macro exploratory study which investigates the relationship between productivity and business model innovation through an empirical analysis at the UK aggregate level. By using a quantitative method to study the relationship, this study introduces a variable which captures characteristics of business model innovation. The quantitative findings of this study help answer the first research question on whether business model innovation can be a source of productivity growth.

This chapter begins with an introduction to the analysis in Section 2.1, followed by a short review of literature in Section 2.2. The main topics captured within the literature review include “Total Factor Productivity”, “Total Factor Productivity and Other Factors”, and “Business Model Innovation and Productivity”. Next, Section 2.3 explains how to measure business model innovation and proposes a variable which can be used as a proxy variable for business model innovation. Section 2.4 then describes an empirical model used to explore the relationship of business model innovation and productivity. Data and the methodology implemented in this analysis are presented in Section 2.5 and 2.6 respectively. Results, discussion, and conclusions are subsequently presented in Section 2.7, 2.8, and 2.9 respectively.

2.1 Introduction

The exponential increase in computer power and performance, coupled with the significant reduction in costs of computer hardware and software, has generally been expected to help enhance productivities in many industries. However, recent global statistics show that productivity growth has slowed down in most industrialised nations since the 2007-2008 financial crisis (Van Ark, 2016). This phenomenon is known as the “Productivity Paradox” and has attracted the interest of many researchers. Several hypotheses such as mismeasurement error, slowdown in technological diffusion or skill mismatch have been proposed to explain this productivity paradox, but they all have not quite unlocked the mystery nor completely revealed the real causes of the problem. To help unlock this productivity paradox, this research proposes and considers business model innovation as a key factor.

Business model innovation, as a part of internal organisation factors, has been studied and linked with technology and firm’s performance by integrating new technology into the businesses to help create competitive advantage (Velu, 2015 and Zott and Amit, 2007). However, as many studies have looked at the interaction of firms’ organisational structures with productivity levels (Syverson, 2011), there is still a limited number of studies which emphasise the importance of business model innovation and productivity. For example, Brynjoldsson and Hitt (2003) suggested that the observed contribution of computerisation is often accompanied by relatively large and time-consuming investments in complementary inputs, such as organisational capital, which may be omitted in conventional calculations of productivity. However, the importance of business model innovation was not articulated and clearly explained. As a result, this chapter 2 extends Bloom et al. (2012) on their findings based on the US “productivity miracle” through US firms characteristics. According to Bloom et al. (2012), US multinationals operating in the UK do have higher productivity than non-US multinationals in the UK because the US

firms are better organised in such a way that allows them to better exploit and use new technologies more efficiently. This aligns with the assumption that business model innovation can have an effect on productivity growth. As a result, this research looks at the existence of a relationship between productivity and business model innovation using an empirical analysis through a newly introduced variable which captures business model innovation characteristics to help investigate the slowdown in productivity growth and to help answer the first research question.

Using secondary data, a regression analysis is implemented through the Cobb-Douglas production function to investigate the relationship between productivity and business model innovation factor. To enable the study of the relationship empirically, this research introduces a net asset turnover ratio (NATO) as a proxy variable for business model innovation. The reason to choose this ratio lies in its ability to capture and quantify a change in the firm's business model. Either a change in sales or in average net operating assets (a numerator and a denominator of NATO respectively), or both, would be expected to transpire when there is a change in the firm's business model. A change in business model can either cause sales to increase if a new business model is implemented successfully or decrease if otherwise. A business model change can also affect a firm's balance sheet due to a different nature of business model profile and operation in which the net operating assets number could change. This research also implements an instrumental variable to mitigate an endogeneity problem from the use of proxy variable.

By measuring the effect of business model change through a newly developed proxy variable on total factor productivity (TFP) using both Ordinary Least Squares (OLS) and 2-stage Least Squares (2SLS) to control for endogeneity problem via instrumental variables, the findings suggest a significant positive effect of business model innovation on TFP within the UK firms between 2003-2017. The result of the research provides evidence of the relationship between productivity and business model innovation through the proposed proxy variable.

This research explores and contributes to knowledge in the field of business model innovation and productivity in the following implications. First, to the best of present knowledge, this research is the first to attempt measuring and quantifying business model change and to show that business model innovation is a factor affecting productivity. Second, this research offers a solution on how firms need to adapt or change their business model in order to increase their productivity amid fast changing competitive environment enabled by new technologies. Through a better understanding of the relationship between business model innovation and productivity, businesses can take advantage of new technology in a more effective manner, which should allow them to increase productivity accordingly.

2.2 A Short Review of Literature

Building on section 1.2 in Chapter 1, this section further reviews literatures related to total factor productivity (TFP) and business model innovation to enable an effective investigation on the relationship between them.

2.2.1 Total Factor Productivity

This research focuses on the relationship between business model innovation and productivity using total factor productivity (TFP) as a productivity measurement. In theory, TFP is one of three main sources of the production function, together with labour and capital input. TFP provides a broader gauge of firm-level performance than some of the more conventional measures such as labour productivity or firm profitability (Imrohorglu and Tuzel, 2014). Several researchers (Kendrick, 1956; Comin, 2010) explain TFP to be an innovation and technological factor in the production process. In a short biography of

TFP, Hulten (2001) explained that many factors including technical innovations, organisational and institutional changes, shifts in societal attitudes, fluctuations in demand, changes in factor shares, omitted variables, and measurement error may cause a change in TFP or a shift in the production function.

TFP could be derived using different models based on the Cobb-Douglas (1928) production function which was comprised of output and inputs; within which the inputs were then decomposed into labour, capital, and a multiplier called “total factor productivity”. Through the production function, Solow (1957) was the first to conduct TFP analysis which had been subsequently studied and expanded widely.

Many scholars are trying to employ factors of interest to estimate their impacts against productivity. For example, Mankiw et al. (1992) used an augmented Solow growth model which defined output as a function of physical capital, human capital, and labour to study international differences in income per capita. Lehr and Lichtenberg (1999) decomposed assets into computer asset and non-computer asset and concluded that computer asset did contribute positively to productivity growth. The growth accounting approach to TFP estimation had been extensively employed to estimate the impact of ICT capital deepening on output and productivity growth across economies (Jorgenson and Stiroh, 1999; Oliner and Sichel, 2000; Oulton, 2002). Despite decomposing productivity growth into effects from each input factor such as human capital, technical knowledge, innovation, IT capital, R&D, adjustment cost, and utilisation, these candidates have not yet been able to explain all of the variation in productivity growth as foreseen by current productivity paradox and therefore leaves a gap for future research.

One way to address this gap is to propose a new factor which would be justified to explain a variation in productivity. By looking at literatures in business model stream, many researchers such as Velu (2015) and Zott and Amit (2007) have provided evidence of how business models can be a source of competitive advantage by affecting firm performance. However, there has been no indication of direct theoretical or empirical research on the relationship between TFP and business model innovation. Consequently,

this study aims to provide a meaningful contribution to knowledge in the field of business model innovation and productivity.

2.2.2 TFP and Other Factors

Besides technology, which was believed to be a backbone of TFP, many scholars have been trying to explore other factors which may affect the growth rate of TFP. According to Prescott (1998), there should be a theory which accounts for differences in TFP for reasons apart from the growth in the stock of technical knowledge. Even though innovation was needed to help sustain TFP growth in the long run, the evidence in the US post-2000 shows that apart from technological progress, TFP also reflects improvements in productive efficiency as well (Prescott, 1998). Denison (1962) argues that about one third of this productivity change actually reflected managerial and organisation improvement. Abramovitz (1962) further elaborated that TFP was a part of the advance of knowledge, scale effects, gain or loss from reductions or enlargements of market constrain, lags in application of knowledge, and other similar causes. By using an alternative approach to estimate trend of growth in TFP, Basu et al. (2001) presented that TFP can be explained by non-technological factors related to adjustment costs, scale economies, imperfect competition, and changes in utilisation. Mankiw et al. (1992) included human capital as an additional input to support the augmented Solow growth model. Similarly, Fox and Smeets (2011) and Dougherty and Jorgenson (1996) also focused on human and non-human capital as sources of growth. Furthermore, a study by Kendrick (1956) found that TFP was affected not only by technical change or innovation but reflected advanced know-how on production process. However, Prescott (1998) argued that adding intangible capital, such as human capital, did not make the neo-classical growth model a theory of international income differences, because intangible capital was not large enough to have important consequences for output per worker. It was further explained that what really accounted

for differences in TFP was the strength of resistance to the adoption of new technologies and to the efficient use of currently operating technologies.

With large differences in output between countries and firms, many of the scholars mentioned above were trying to explain the difference in the residual inside the TFP. However, what were the underlying causes of these large TFP differences still remained a mystery and were left unknown. According to Van Ark (2014), TFP growth mostly referred to the efficiency of labour and capital inputs, effects of changes in technology, and other unmeasured inputs such as human capital, but it provided little insight as to what took place inside the black box of technology.

2.2.3 Business Model Innovation and Productivity

As a result of this research gap, this study proposes business model innovation as one of the underlying causes of large differences in TFP. By looking at the academic research of business models, business model innovation is considered to be one of the three important themes of study (Lambert and Davidson, 2013). According to Amit and Zott (2012), business model innovation can occur in several ways, including by adding novel activities or new activity system (content), by linking activities in novel ways or new activity system (structure), and by changing one or more parties that perform any of the activities or new activity system (governance). According to Björkdahl and Holmén (2013), business model innovation is claimed to have a greater impact on profit margins than any other type of innovation and allows for more economically viable specialisation.

There are a few studies which have examined the relationship between business model innovation and productivity implicitly through profitability. For example, Bloom et al. (2012) suggested that the higher productivity of IT in the US has something to do with specific characteristics of US establishments or internal organisation, especially how US multinationals can partially export their business model outside the US and can change

their organisational structure more quickly. Siggelkow (2001) and Porter (1996) helped connect the impact of business choices on performance based on production frontier or on fitness landscape. Bernard et al. (2010) showed that a firm's productivity is positively correlated with the number of products it produces which indicates that productivity growth accompanies expansion of the variety of products a firm offers. Similarly, Visnjic et al. (2016) found the relationship between business model innovation and performance using dummy variable to measure different business models. Nevertheless, according to Lambert and Davidson (2013), there was no empirical research that aims to predict firm success, nor any empirical research study about business model innovation and productivity growth.

Therefore, the objective of this research is to investigate whether the variation in TFP can be explained empirically by business model innovation. This study suggests that business model innovation is one of many important factors in explaining TFP in the context of Cobb-Douglas production function.

2.3 Measuring Business Model Innovation

This study proposes business model innovation as a factor affecting TFP using net asset turnover ratio (NATO) as a proxy variable based on past literatures which link NATO with profitability (Fairfield and Yohn, 2001; Jansen et al., 2012) or with management's ability to generate sales for a given investment in assets or efficiency (Stratopoulos and Dehning, 2000). To estimate and quantify business model innovation, this study proposed that

NATO is used as a proxy variable which is operationalised as sales divided by average net operating asset⁴.

Through literatures such as Soliman (2008), asset turnover ratio measures asset utilisation and efficiency (which generally comes from the efficient use of property, plant, and equipment), efficient inventory processes, and other forms of working capital management. Soliman further stated that this measure ultimately evaluates sales growth while controlling for growth in the net operating assets used to generate those sales. As a measure for efficiency, Stratopoulos and Dehning (2000) found that total asset turnover is significantly different between successful IT users and non-successful IT users which is likely to be a result from the complimentary of new technology and business model innovation.

By adopting NATO as a proxy to quantify business model innovation, two assumptions for the variable are proposed. First, business model innovation is a radical change (Johnson et al., 2008; Duguet, 2006). According to Teece (2010), small improvements in the manufacturing process will usually not require business model innovation, and value can be captured by lowering price and expanding the market and market share. But the more radical the innovation and the more challenging the revenue architecture, the greater the changes are likely to be required. As a result, a larger change in NATO would be a good estimator for a radical change in business model. Second, business model innovation is done through a change from asset heavy to asset light business model or vice versa (Liou et al, 2008). According to Keen and Williams (2013), the most fundamental opportunity for IT, especially cloud computing and managed

⁴ Net operating asset equals short term debt + long term debt + shareholder fund + minorities + preferred share – cash. Alternatively, net operating asset variable is derived by calculating operating assets minus operating liabilities or as an addition of total debt and total equity which then subtracted by total cash.

networks, is the shift from fixed cost asset base to a variable cost financial structure that substitutes relationship for capital. This type of change can be captured by a change in NATO.

This research illustrates that NATO is a good proxy to measure differences in business models. This is demonstrated by comparing the NATOs of online retail and traditional bricks-and-mortar bookstores using data from Capital IQ (Figure 2.3-1). This research chose this example because there are three firms with different business models for the 10-year period of 2001 to 2011.⁵ The firms are Amazon.com (an online retail store), Borders Group, and Barnes & Noble Inc⁶ (both are primarily non-online retail stores). During the period of the case illustration, Amazon's business model was based on its e-commerce platform which operates 24/7 without physical stores. It also carries its own inventory within its network of warehouses or delivers directly from its suppliers. Such a business model enables Amazon to hold a relatively low inventory compared to traditional bricks-and-mortar stores. This research highlights two distinguishing features of NATO for Amazon, Borders Group, and Barnes & Noble Inc as shown in Figure 2.3-1. First, Amazon's NATO is significantly different compared to Borders Group and Barnes & Noble Inc which have large physical store footprints.⁷ Second, innovations of the business

⁵ Borders Group filed for Chapter 11 protection in 2011.

⁶ The annual reports show that Barnes & Noble Inc and Borders Group had average online sales of less than 10% and 5% of total sales respectively during the period of the case illustration.

⁷ Amazon has long credit terms from suppliers when compared to the cash receipt from buyers resulting in a large sum of cash and payables on its balance sheet with approximately one to one ratio. For this reason, Amazon's NATO is negative. In contrast, Borders Group and Barnes & Noble Inc have a very different business model than Amazon and have payables around 10 times the amount of cash they are holding.

models of these three firms during the period result in changes in NATO.⁸ However, such changes in NATO still maintain the difference in NATO of Amazon compared to Borders Group and Barnes & Noble Inc. The illustrations provide support to the proposition that changes in NATO is a good proxy to measure business model innovation.

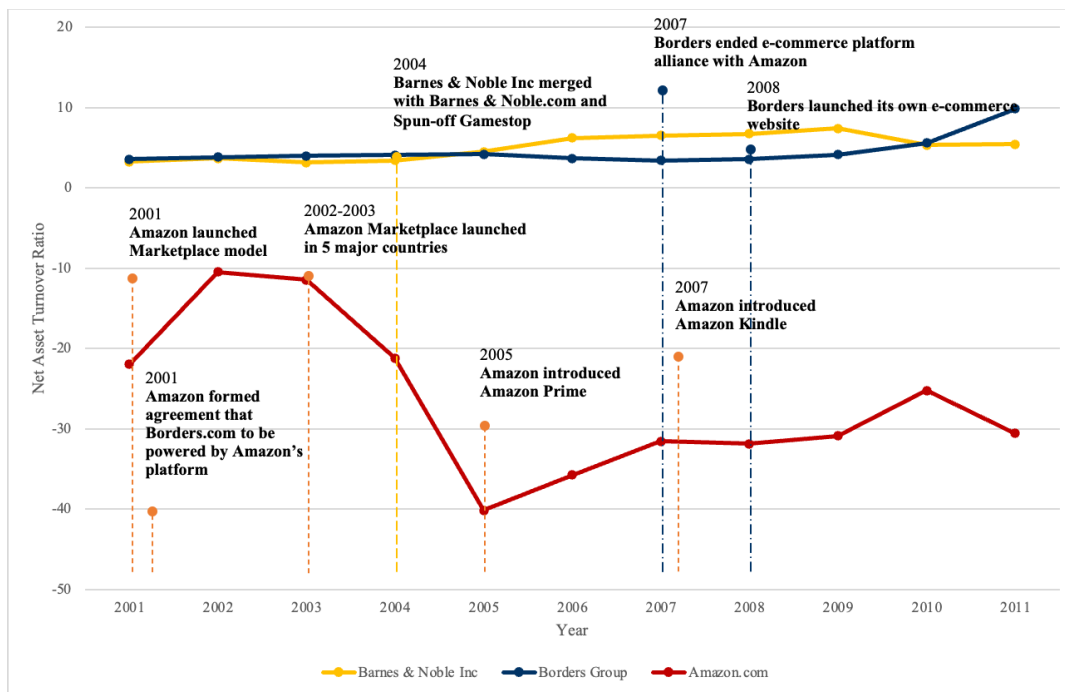


Figure 2.3-1: Net Asset Turnover Ratio: Book Retail

Source: Capital IQ, Annual Report, and Authors' Calculation

⁸ For example, the Borders Group's NATO increased from 4x to 6x after the introduction of its online store in 2008. Similarly, Barnes & Noble Inc simplified its corporate structure to be more focused on their core book business by merging its operations with Barnes & Noble.com and spinning-off GameStop Corp, its gaming merchandise retailer in 2004 resulting in a rise in NATO from an average of 3.5x to 6x. Amazon's NATO captures changes in its business such as when the firm launched Amazon Marketplace which enable third-party sellers on the Amazon platform and partnered with Borders to provide its online offering in 2001. Amazon also launched Marketplace in 5 major countries between 2002-2003, introduced Amazon Prime which is a membership-based loyalty program in 2005, and released Amazon Kindle, its first e-reader in 2007 resulting in changes to the NATO from an average of -10x to -20x during 2001-2004 to -30x to -40x during 2005-2011 respectively.

Furthermore, by looking closer at the company which has a change in business model such as Borders Group, Figure 2.3-2 shows that once Borders Group decided to launch its online store for the first time, their NATO shifted away from a flat trend (around 4x between 1997 to 2009). After their change in business model towards an online platform, their NATO increased to around 6x in 2010. The main reason for an increase in NATO for Borders Group is due to the changes toward online store resulting in lower inventory and fixed assets, hence lower net operating assets number. However, the ratio of Borders Group once they launched their online store is not the same as Amazon.com due to differences in many other factors, for instance the difference in credit terms with suppliers. The shift in Borders Group’s NATO once the company changed their business model more toward online provides further evidence of the proposed proxy variable of business model innovation. Both examples provide evidence to justify the value of this newly proposed proxy variable to measure business models.

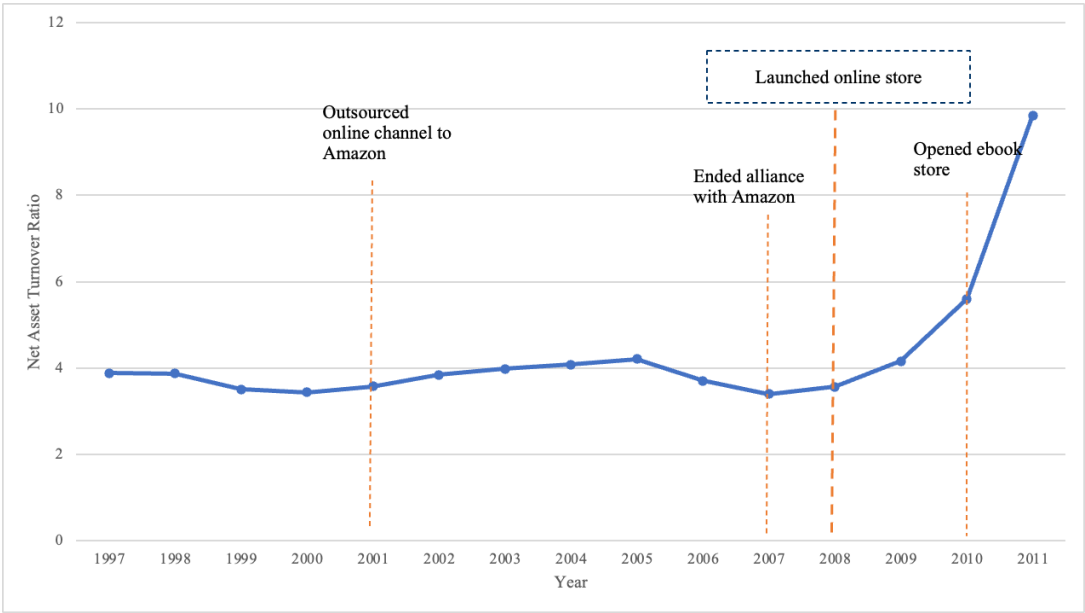


Figure 2.3-2: Net Asset Turnover Ratio: Borders Group

Source: Calculated from Capital IQ Financial Data

2.4 Empirical Model

To explore the relationship between productivity and business model innovation, this study presents an empirical model using the newly introduced NATO to estimate the TFP by extending the Cobb-Douglas (1928) production function form, Equation (Eq.) (1). This model has been used widely among academic literatures (Syverson, 2011) to find out relationship between productivity and variables of interest, such as internal organisation structure (Bloom et al., 2012), research and development (R&D) (Mairesse and Sasseniou, 1991) and information technology (IT) (Jorgenson et al, 2002). One advantage of using this model is that it can be estimated using a linear regression through logarithms of variables (Mairesse and Sassenou, 1991).

Based on the Cobb-Douglas production function, Eq. (1) can be linearised into natural log form to Eq. (2), assuming constant return to scale:

$$Y = AL^{\alpha}K^{\beta} \quad (1)$$

$$\ln Y = \ln A + \alpha \ln L + \beta \ln K \quad (2)$$

where A represents total factor productivity (TFP), Y represents output (revenue), L represents labour (number of employee), and K represents capital at firm-level (total asset).

The change in TFP ($\ln A$) is then modeled by a change in business model ($\ln BMI$) which is proxied by a change in NATO ratio and unobserved technological and efficiency factors (A').

$$\ln A = \mu \ln BMI + A' \quad (3)$$

Then Eq. (2) and Eq. (3) are combined into an extended Cobb-Douglas function which includes the proposed business model innovation variable.

$$\ln Y = \mu \ln BMI + \alpha \ln L + \beta \ln K + A' \quad (4)$$

Hence Eq. (5) for empirical estimation can be written as

$$\ln Y_{it} = \mu \ln BMI_{it} + \alpha \ln L_{it} + \beta \ln K_{it} + A'_{it} + u_{it} \quad (5)$$

Where u is an error term, subscript i denotes firm and t denotes year.

2.5 Data

Following the analytical model, this section explains where the data comes from and how each variable is calculated. In this study, the analysis is implemented using an empirical method with an unbalanced panel data from Bureau van Dijk (BvD) Fame. The data was extracted on January 2019 and consists of 16549 UK companies from 19 different industries from year 2000-2017. To calculate TFP at a firm level using Cobb-Douglas production function, this study uses number of employees as a labour input (Griliches and Jorgenson, 1967; Imrohoroglu and Tuzel, 2014; Lehr and Lichtenberg, 1999) and total assets as capital input (Griliches and Jorgenson, 1967; Imrohoroglu and Tuzel, 2014; Lehr and Lichtenberg, 1999; Lokshin et al., 2008). The total asset is calculated according to BvD Fame calculation as a combination of fixed and current assets where fixed assets is

calculated as a combination of freehold land, leasehold land, fixtures and fittings, plant and vehicles, other fixed assets, intangible assets, and investments. For output, gross value added (GVA) in the production function is a commonly used variable by many researchers but it can yield misleading results if there is imperfect competition or increasing returns to scale (Basu and Fernald, 1995; Hempell, 2005). As a result, this research presents results using firm's revenue as an output in the production function. This approach is similar to several scholars such as Soderbom and Teal (2004) and Griliches (1985) who used gross revenue as dependent variable for their production function.

The study also implements data cleaning procedures on several variables to prepare for logarithm transformation which requires non-negative and non-zero number. The data cleaning procedures are as follow. First, value of change in NATO is taken as an absolute number. As business model innovation can cause NATO to change in either positive or negative direction, taking an absolute is necessary to capture the business model innovation characteristic. Similarly, a percentage change in selling, general and administrative (SG&A) expense is also taken as an absolute number because business model change by firms can cause changes in investment in organisational capital in either positive or negative direction, and hence using an absolute number is necessary to capture those changes. Thirdly, firms without data on revenue, with negative revenue, with return on equity (ROE) and total asset equal zero, with ROE above 200% and less than -200%, without profit margin, and without employee number are all removed.

Table 2.5-1 shows average firm revenue and absolute change in NATO between year 2003-2017, summarised in five-year time periods and across the 19 industries in the sample. As shown in the last row of Table 2.5-1, the overall firm level aggregate data displays an increase in average absolute change in NATO and average revenues across the three five-year period. Although Table 2.5-1 provides an overall description of the data, the correlation and trend between these increases cannot be interpreted directly as they constitute averages across firms, industries and time periods. Moreover, they do not

account for other factors that could influence the relationship between productivity and business model innovation.

Table 2.5-1: Average Revenue and Absolute Change in NATO

	Obs.	2003-2007		2008-2012		2013-2017		2003-2017	
		Avg. Revenue (£ '000)	Avg. Change in NATO	Avg. Revenue (£ '000)	Avg. Change in NATO	Avg. Revenue (£ '000)	Avg. Change in NATO	Avg. Revenue (£ '000)	Avg. Change in NATO
Agriculture	141	38,883	0.25	67,942	0.30	80,127	0.22	65,460	0.26
Accommodation	476	42,210	0.51	48,974	0.44	52,011	0.30	46,787	0.38
Mining	163	3,681,477	0.55	4,033,393	7.45	3,299,850	0.48	3,348,108	2.63
Transportation	678	90,348	0.46	118,900	1.03	152,429	0.49	118,518	0.67
Construction	865	88,336	1.10	92,661	1.30	114,176	1.63	95,823	1.28
Wholesale and Retail	2583	130,652	0.39	180,737	0.46	180,435	0.62	161,028	0.42
Water Supply	85	55,629	1.02	70,616	0.38	74,567	0.29	63,224	0.40
Electricity	55	1,209,827	0.45	1,386,326	2.08	1,402,568	0.48	1,280,129	1.06
Manufacturing	3396	107,809	0.64	128,046	0.40	140,496	0.88	125,204	0.69
Information and Communication	1138	70,279	0.77	80,582	0.78	100,058	0.82	83,321	0.85
Financial and Insurance	1198	193,651	2.07	203,033	2.40	188,487	1.21	185,883	2.11
Real Estate	312	30,913	1.15	31,159	1.03	40,830	0.98	33,812	0.96
Professional	1350	150,128	1.15	168,551	1.12	174,452	2.21	152,711	1.66
Admin and Support	1548	70,204	1.15	75,202	1.04	97,181	0.84	80,979	0.91
Public Admin and Defence	60	63,733	0.92	51,949	1.02	76,977	0.68	55,572	0.97
Education	157	13,736	2.90	15,556	0.97	17,327	1.02	15,244	1.12
Health	475	23,028	0.95	35,530	0.88	48,274	0.73	38,416	0.91
Art	387	115,061	3.47	39,500	0.98	53,626	4.73	59,916	2.30
Other Services	777	31,657	1.24	28,036	1.16	32,529	0.82	27,728	0.99
Overall	15844	140,641	0.92	162,549	0.95	165,689	1.05	150,573	0.98

Source: Authors' Calculation

2.6 Method

To better understand the underlying relationships between business model innovation and productivity, this research uses panel linear regression econometric analysis (Least Squares method) to help analyse the introduced empirical model. The analysis is controlled for cross-section fixed effect, period fixed effect for unobserved time-invariant heterogeneity such as macroeconomic factor including inflation, and the firm's individual effect such as

human capital. According to Mairesse and Sassenou (1991), it is possible with panel data to safeguard against not only the omission of industry characteristics, but also firm characteristics. Given the data is unbalanced, this research implements listwise deletion method to exclude firms with missing data from the calculation. Period weight and corrected standard error (PCSE) coefficient covariance method, allowing for serial correlation, is applied as period heteroscedasticity in the data is expected. The study uses an extended Cobb-Douglas production function model, similar to Syverson (2011) and Fox and Smeets (2011). The diagnostic testing to check for Fixed/Random Effect through Hausman test, autocorrelation, multicollinearity, and normality of the model had been performed. The results for Hausman test indicated that the fixed effect is appropriate, while tests for correlation, multicollinearity, and normality of the model are satisfied accordingly.

2.6.1 Instrumental Variables

With potential endogeneity issues arising from limitations of the proxy variable to measure business model innovation, the instrumental variable (IV) estimation through two-stage least squares (2SLS) is recommended in order to address the issue. Euclidean return on equity (ROE) distance, the percentage change in selling, general and administrative expense (SG&A), and 1-year lagged NATO ratio are proposed as instrumental variables (IVs). This set of IVs is expected to have an indirect effect toward productivity through business model innovation (correlated with NATO variable), but not correlated with an error term (exogenous). To make sure that the chosen set of IVs are valid, this study ran a diagnostic test for weak IV by checking first stage R-squared and found no evidence of weak IV for all of the chosen IV variables. This study also shows results from both exact and over-identified model for IV as according to Woolridge (2001), it is always possible with over-identified parameters to improve upon two-stage least squares in the context of heteroscedasticity of unknown form. Similarly, Murray (2006) also stated that two-stage

least squares method requires at least as many instruments as there are troublesome explanatory and an increased number of over-identifying restrictions generally confers the benefit of a higher R-squared in the first stage of two-stage least squares and, therefore, yields standard errors closer to those of ordinary least squares.

2.6.1.1 Euclidean ROE Distance

The first instrumental variable proposed is Euclidean ROE Distance. Euclidean ROE Distance is used to compare a position of a focal organisation in the distribution of variation on a given organisation dimension where a larger distance implies less intense competition (Baum and Mezias, 1992). There are several literatures which discovered a relationship between innovation and competition, such as Goettler and Gordon (2011), Arrow et al. (1961), Comin (2010), and Porter (1980). This research adopts an assumption based on Aghion et al. (2005)'s relationship between competition and innovation which stated that competition has an effect on innovation which could affect a decision for business model innovation. To be able to capture this relationship, this research purposes Euclidean distance from ROE perspective by using Euclidean ROE Distance as the intensity of industry competitiveness which is expected to have an impact on a company decision and business model innovation. By using a distance between the firms' ROE and industry average ROE, the Euclidean ROE distance provides an estimation of where a firm compares to the industry average. Hence, it is likely to be a good instrumental variable for business model innovation as the Euclidean ROE distance or the position of a firm compared to the industry average implies an intensity of competition which correlates to the firms changing their business model.

The Euclidean ROE distance formula is presented as

$$E_{it} = \sqrt{\sum (L_{it} - L_{jt})^2}$$

where E represents Euclidean ROE Distance, L_i represents firm's ROE, L_j represents industry average ROE, and t represents year.

2.6.1.2 Lagged Explanatory Variable

The second instrumental variable proposed is the lagged explanatory variable. Similar to Soderbom and Teal (2004) and Mansury and Love (2008), this study proposes to use 1-year lagged value of the explanatory variables or lagged NATO as instruments to address the problems posed by the regressor potentially being correlated with the residual. According to Clemens et al. (2012), the lagging and differencing method can help avoid poor-quality instrumental variables and address potential biases from reverse and simultaneous causation. This is because lagged values are less likely to be influenced by current shocks and it can also capture a lag effect toward a change in productivity from firm's decision to innovate their business model.

2.6.1.3 A Change in Selling, General and Administrative (SG&A) Expense

The third instrumental variable proposed is a change in SG&A expense. SG&A expense is used to measure the stock of organisation capital with a logic that at least part of SG&A expense represents an investment in organisation capital through advertising, spending on distribution system, employee training, and payments to strategy consultants (Peters and Taylor, 2017). According to research on organisational change and innovation, the organisations' capabilities to renew and change are dependent on the underlying values

and beliefs of the organisational members as well as the organisational culture (Hock et al., 2016). As such, the organisational processes must be changed in order to overcome the barriers to business model innovation (Chesbrough, 2010). Therefore, a change in organisational capital for business model innovation could be reflected by a change in SG&A expense. This study proposes to use an absolute percentage change in SG&A expense as one of the instrumental variables for business model innovation and is calculated as a percentage increase of SG&A expense from previous year.

2.7 Results

From the analysis, the results from three models of the relationship between business model innovation and TFP through a proxy variable are presented in Table 2.7-1. From Table 2.7-1, the relationship of labour and capital as a component of the production function of all models are statistically significant, according to the theory. Models 1, 2, and 3 show a beta coefficient of 0.019, 0.003, and 0.004 for NATO in both pooled, period fixed effect, and cross-sectional fixed effect which all are significant at the 1% level respectively. As a result, the study shows that business model innovation has a significant positive effect on change in output through a change in productivity.

Table 2.7-1: OLS Results

Variable	Model		
	1	2	3
Ln (K)	0.607*** (0.001)	0.444*** (0.001)	0.397*** (0.002)
Ln (L)	0.359*** (0.001)	0.485*** (0.002)	0.496*** (0.002)
Ln (BMI Change)	0.019*** (0.001)	0.003*** (0.000)	0.004*** (0.000)
Fixed Effect - Cross Sectional	-	Yes	Yes
Fixed Effect - Period	-	-	Yes
Adjusted R ²	0.810	0.972	0.972
Cross-sections	15844	15844	15844
Unbalanced Observation	175391	175391	175391

Standard Errors are in parentheses

*** 1% significant

Source: Authors' Calculation

However, mismeasurement error and bias on the result are expected from a limitation on the proxy variable. Given that business model innovation had to be proxied, it is likely that the chosen proxy variable will have a tendency for a mismeasurement error, data collection error, and computational procedures errors which result in an endogeneity problem (Griliches and Mairesse, 1995). According to Van Beveren (2012), this problem can be partially resolved by introducing instrumental variable. Table 2.7-2 shows the results using two-stage least squares with the three instrumental variables of Euclidean ROE distance, a percentage change in SG&A and 1-year lagged NATO ratio respectively.

Table 2.7-2 reports the results from different combination of instrumental variables through two-stage least squares. For each model, the relationship of labour and capital as a component of production function of all models are statistically significant according to the theory. The results of business model innovation beta coefficient are positive and

statistically significant with beta coefficients ranging from 0.027 to 0.193 when instrumental variables are included individually in the model. The results are statistically significant when all possible instrumental variables combinations are applied (Table 2.7-2: the model 3-7). Business model innovation beta coefficients when two of the chosen instrumental variables are applied range from 0.035 to 0.100, while the beta coefficient of business model innovation when all three instrumental variables are applied is 0.055. These results show that a doubling in the NATO ratio of a firm due to changes in business model innovation results in approximately 2.7-19.3% increase in the firm's productivity (model 1-7). Furthermore, as expected, the coefficients of labour and capital have a statistically significant effect on productivity. As a result, the results from different combinations of instrumental variables through two-stage least squares confirms that business model innovation has a significant positive effect on change in output through a change in productivity.

Table 2.7-2: 2SLS Results

Variable	Model						
	1	2	3	4	5	6	7
Ln (K)	0.414*** (0.002)	0.402*** (0.002)	0.399*** (0.002)	0.406*** (0.002)	0.402*** (0.002)	0.400*** (0.002)	0.402*** (0.002)
Ln (L)	0.515*** (0.003)	0.501*** (0.002)	0.498*** (0.002)	0.506*** (0.002)	0.501*** (0.002)	0.499*** (0.002)	0.501*** (0.002)
Ln (BMI)	0.193*** (0.015)	0.056*** (0.008)	0.027*** (0.005)	0.100*** (0.007)	0.055*** (0.005)	0.035*** (0.004)	0.055*** (0.004)
Fixed Effect - Cross Sectional	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effect - Period	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2SLS IV - Ln (Euclidean ROE)	Yes	-	-	Yes	Yes	-	Yes
2SLS IV - Ln (Change Net Asset Turnover) (-1)	-	Yes	-	Yes	-	Yes	Yes
2SLS IV - Ln (Change in SG&A Expense)	-	-	Yes	-	Yes	Yes	Yes
Adjusted R ²	0.954	0.971	0.972	0.968	0.971	0.972	0.971
First Stage R ²	0.238	0.240	0.244	0.242	0.246	0.248	0.249
First Stage IV - Significant Level	***	***	***	***, ***	***, ***	***, ***	***, ***, ***
Cross-sections	15844	15844	15844	15844	15844	15844	15844
Unbalanced Observation	175391	175391	175391	175391	175391	175391	175391

Standard Errors are in parentheses
 *** 1% significant

Source: Authors' Calculation

For robustness, this research tested the model using OLS pooled method and two-stage least squares using revenue per employee as the dependent variable and the results are similar to that in Tables 2.7-1 and 2.7-2 respectively. While Cobb-Douglas is one of the most common parametric production functions, other approaches to measure productivity can also be used. In order to test the robustness of the results, this research also incorporates a more general approach to measure TFP using index numbers. This research adopts the index numbers approach found in Van Beisebroeck (2008) to calculate the change in TFP and re-estimated the regression based on model (7) in Table 2.7-2. This index number approach is similar to Solow (1957) whereby TFP growth is calculated by:

$$\ln A_{it} - \ln A_{it-1} = \ln (Y_{it} / Y_{it-1}) - ((S_{it} + S_{it-1}) / 2) \ln (L_{it} / L_{it-1}) - (1 - (S_{it} + S_{it-1}) / 2) \ln (K_{it} / K_{it-1})$$

Here, A_{it} represents TFP which differs across firms i and time periods t , Y represents output (revenue), L represents labour (number of employee), K represents capital at firm-level (total asset), and S represents the wage share or the fraction of wage in revenue.

From Table 2.7-3 and Table 2.7-4, the results from OLS pooled and two-stage least squares using revenue per employee specifications show a robust positive effect between business model innovation proxy variable and a change in productivity with beta coefficient of 0.019 and 0.063 respectively. These results are robust and consistent with the main findings showing that business model innovation is statistically significant at the 1% level with a coefficient of 0.010.

Table 2.7-3: OLS Pooled Results

Variable	Pooled OLS
Ln (K)	0.607*** (0.001)
Ln (L)	0.359*** (0.001)
Ln (BMI)	0.019*** (0.001)
Adjusted R ²	0.810
Pool Balanced Observation	701564

Standard Errors are in parentheses

*** 1% significant

Source: Authors' Calculation

Table 2.7-4: Two-Stage Least Squares – Revenue per Employee

Variable	Model							
	1	2	3	4	5	6	7	8
Total Asset per Employee Ln	0.446*** (0.001)	0.446*** (0.002)	0.446*** (0.001)	0.446*** (0.001)	0.446*** (0.002)	0.446*** (0.001)	0.446*** (0.001)	0.446*** (0.001)
Net Asset Turnover per Employee Ln	0.005*** (0.000)	0.213*** (0.015)	0.072*** (0.008)	0.025*** (0.005)	0.120*** (0.007)	0.061*** (0.005)	0.040*** (0.004)	0.063*** (0.004)
Fixed Effect - Cross Sectional	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effect - Period	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2SLS IV- Euclidean ROE Ln	-	Yes	-	-	Yes	Yes	-	Yes
2SLS IV - Net Asset Turnover Ln (-1)	-	-	Yes	-	Yes	-	Yes	Yes
2SLS IV - Change in SG&A Expense Ln	-	-	-	Yes	-	Yes	Yes	Yes
Adjusted R ²	0.931	0.877	0.926	0.931	0.915	0.928	0.930	0.927
First Stage R ²	-	0.236	0.238	0.242	0.240	0.244	0.246	0.248
First Stage IV - Significant Level	-	***	***	***	***, ***	***, ***	***, ***	***, ***, ***
Cross-sections	15844	15844	15844	15844	15844	15844	15844	15844
Unbalanced Observation	175391	175391	175391	175391	175391	175391	175391	175391

Standard Errors are in parentheses

*** 1% significant

** 5% Significant

* 10% Significant

Source: Authors' Calculation

2.8 Discussion

Based on the UK firm level data between year 2003-2017, the results under fixed effect OLS from Table 2.7-1 show that both labour variable and capital variable have statistically significant coefficients and show decreasing return to scale in all three models. Within these models under fixed effect OLS, the business model innovation variable through a proxy variable of a change in NATO shows statistically significant coefficients of 0.003 and 0.004 when both cross-section and period fixed effect are implemented and when implement cross-section fixed effect alone respectively. However, these two results are expected to be affected by an endogeneity problem and hence has a possibility of a bias in the results. Therefore, results in Table 2.7-2, using two-stage least squares, would be more appropriate for this study.

By instrumented business model innovation variable through a set of IVs with two-stage least squares to reduce endogeneity problem, the results in Table 2.7-2 show that business model innovation variable has statistically significant coefficients when all combinations of IVs are applied. The beta coefficients for business model innovation variable are ranging from 0.193 to 0.027 when a single IV is applied to around 0.055 when all three IVs are applied. Additionally, the coefficient of labour and capital are positive and statistically significant.

These results show that a percentage change in NATO would result in up to a 0.055 percent increase in productivity. This means that a large change in NATO number, which in this research is a proxy of business model change, would create a positive effect on productivity change. For example, a doubling of the NATO of a company (100 percent change in NATO) would result in approximately a 5 percent increase in the company's productivity. From the data and results, business model change and available instrumental

variables could in fact dramatically help improve businesses' productivity. Furthermore, the results from the model confirm a statistically significant effect for both labour and capital input with a decreasing return to scale for the sample data. These results help confirm the nature of the Cobb-Douglas production function that this research uses.

There are some limitations in this study which need to be recognised and documented. First, NATO can be a proxy of other factors besides business model innovation, such as efficiency, and therefore create more noise (unwanted signal) when used in the analysis. Second, apart from business model innovation, activities such as merger and acquisition (M&A) which result in an inflated balance sheet from goodwill and volatility in price of marketable securities in the companies' balance sheet may cause changes in NATO. Third, this study also raises a concern that using NATO as a proxy of business model innovation in an aggregated macro level may potentially post a problem. This is because changes in NATO across firms in macro level data may offset each other, hence do not show an intended business model innovation characteristic in the variable. Fourth, by using turnover instead of gross value added (GVA) in the production function, volatility in the turnover from one time sales item, extraordinary item, or a rapid change in financial instruments such as foreign exchange hedging or financial derivatives may cause noise and error in the production function. Fifth, due to the limitations of the collected data, the selection bias problem from failed company or missing data which are excluded in this study may affect the result. Such omissions could include companies which may possibly implement business model innovation but fail to survive in business. According to Van Biesebroeck (2008), there is the potential for selection bias when a panel dataset is used, as less efficient producers are more likely to exit from the sample. Sixth, this research is based on several assumptions and in reality, these assumptions (ie. assumption that business model innovation is a radical change) may not hold. Seventh, there are limitations on the approach in the research. Despite the fact that research with micro production data greatly expands the set of answerable questions and moves the level of analysis closer to where economic decisions are made than aggregate data do, it also raises measurement and

data quality issues more frequently (Syverson, 2011). According to Syverson (2011), potential problems include output, input, and TFP measures, and an econometric issue from correlation of inputs. Eighth, according to Mairesse and Sassenou (1991), the estimates based on productivity changes, may not give a precise interpretation that should be made of the estimates of the business model innovation elasticity. To support this, Murray (2006) also stated that the two-stage least squares estimator has larger standard errors than does ordinary least squares. Consequently, using instrumental variables to overcome the possible biases of ordinary least squares always comes at a cost through the loss of efficiency. Therefore, the study can only provide evidence of a significant effect of business model innovation toward productivity, but it is unlikely to provide an accurate elasticity number.

Based on the above limitations, further research on the relationship between business model innovation and productivity growth using different datasets, countries, and a more in-depth analysis of why business model innovation has such effects may well prove fruitful. Due to its simplicity and the availability of data, the NATO is believed to be a suitable variable to help understand business model innovation empirically at the firm level. However, development on a better business model innovation variable that could extract a better elasticity number could possibly be worth exploring to refine the results of the analysis. With a potential selection bias problem from missing data, a study on a different dataset (eg. different country) would be productive as it would allow the results to be compared and considered at a more macro level.

2.9 Conclusions

The purpose of this research is to provide a meaningful contribution to knowledge in the field of business model innovation and productivity. By applying the new important factor

of business model innovation empirically into TFP using the Cobb-Douglas production function, the results of this study help answer the first research question by showing that business model innovation, through both a proxy using NATO and three chosen instrumental variables, has a significant positive relationship toward TFP and a firm's output. This research helps provide an alternative view toward factors affecting productivity which in turn could help benefit society through the application of the results of this research.

This study has multiple important implications. For theory, this study promotes a new validated variable to quantify business model innovation and the study of the relationship between business model innovation and productivity. This research is believed to be the first to propose a novel approach to measure and quantify business model change and to show that business model innovation is a factor affecting productivity. This new knowledge provided by this study could further unlock more research in this field.

In practical terms, this study has important implications for managers and policymakers who should recognise how adapting or changing business models can help increase their productivity amid the fast-changing competitive environment enabled by new technologies. With a better understanding on the relationship between business model innovation and productivity, businesses can take advantage of new technology in a more effective manner, which should allow them to strive and increase their productivity accordingly. This research emphasises the importance of business model innovation in order for firms and policy makers to reap the full benefits of productivity growth.

Chapter 3: Business Model and Risk Adjusted Productivity

After establishing a relationship between business model innovation and productivity through empirical analysis in chapter 2, this chapter looks further into the manufacturing industry to understand more about one important element of business model innovation called risk. Based on evidence from the review of literatures, risk management is one of the possible motivations why manufacturing firms servitize their business model, an example of business model innovation. Despite lower productivity growth expectations, this chapter suggests that strategic risk management by businesses is a factor which may impact productivity growth and cause productivity slowdown. This research shows, through a case study of Caterpillar Inc. (CAT), that the risk-return trade-off based on the choice of strategic risk management and servitization of the business model can impact productivity levels. To control the impact of risk from different types of business models and their productivity levels, this research introduces a new approach to measure productivity by accounting for risk. To the best of present knowledge, this approach has not been conducted in the area of productivity before. By investigating both the service and manufacturing sectors within the UK manufacturing industry, this study helps answer the second research question on how changes in risks resulting from business model innovation affects productivity, and whether the servitization of manufacturing, an example of business model innovation, can impact productivity.

This chapter begins with an introduction in Section 3.1. The background of the relationship between servitization of manufacturing and risk management is presented in Section 3.2. This is followed by an investigation of risk-return trade-off and productivity through a case study of servitization of CAT in Section 3.3. Section 3.4 introduces an approach to risk adjusted productivity to be used in this study. To demonstrate how risk in

business model design affects productivity data, empirical models are described, and results are discussed in Section 3.5 and 3.6 respectively. Finally, the main conclusion of this chapter is presented in Section 3.7.

3.1 Introduction

Despite the evidence that a breakthrough in innovation and technology is a strong predictor of productivity growth (Kelly et al., 2021), the global stagnation of productivity growth is more clearly seen in the service sector where new technologies are more readily available. According to Riley et al. (2018), the service sector, especially in the UK, exhibits a lower level of labour productivity when compared to the manufacturing sector. Moreover, the service sector is the primary source of the large declines in total factor productivity (TFP) performance in the UK (Harris and Moffatt, 2017).

Several literatures have provided various explanations why the service sector is experiencing lower productivity. For example, Kozicki (1997) found that the shift in employment share from the manufacturing sector toward services contributed to higher labour productivity for manufacturing sector through reduction in number of employment share, hence increasing the difference in productivity growth between the manufacturing and service sector. Moreover, Gordon (1996) emphasised that the productivity slowdown came from services such as airlines which had reached a technological frontier in which the sources of earlier rapid productivity growth were exhausted. Gordon further agreed that the lower productivity in the service sector is due to measurement error of output growth which led to greater under-measurement of overall economic growth from a rising share of services in the economy. Rust and Huang (2012) developed a theory of optimal service productivity and suggested that there is a trade-off between productivity and customer satisfaction especially in service business, hence service sector often see lower productivity growth due to this trade-off. However, research on the impact of risk management toward lower level of productivity in the service sector is believed to be unexplored and this study proposes to investigate this relationship.

As a paradigm shift in business model towards servitization strategies and service offerings by manufacturing firms in developed economies (Neely, 2008), this study is

interested in risk management as the rationale behind a firm's decision to servitize their business model despite evidence of lower productivity. As many manufacturing firms are shifting toward service offerings as a new way of creating and capturing value (Kastalli et al., 2013), as well as the possibility to increase productivity (Wannakrairoj and Velu, 2021), another important motivation for manufacturing firms to servitize is to reduce risk (Raddats et al., 2016). It is well known that through changing to different forms of businesses, different types of risk can incur (Baines and Lightfoot, 2013). Consequently, this research is the first to suggest that risk-return trade-off based on the choice of strategic risk management is a reason why manufacturing firms have servitized their business models even though it may impact productivity growth, hence causing productivity slowdown in the manufacturing industry.

As a result, this research introduces a new approach to measure productivity by accounting for the impact of risk from different types of business models toward productivity growth, which is an understudied area. By using very distinguished features of standard deviation as a proxy for risk, the results of risk adjusted productivity between UK manufacturing and service industries between 2003 and 2018 appeared to show a significant reduction in the productivity gap when compared to pre-adjusted productivity. This result helps answer the second research question on how changes in risks as a result of business model innovation affects productivity, and whether the servitization of manufacturing, an example of business model innovation, can impact productivity.

In order to account for the risk in different business models, this research looks at the source of variation of output based on the input and adjust productivity measure accordingly. The results suggest that different business models of manufacturing and service have different sources affecting the variation of output, as well as the overall productivity level. Hence, this research shows that distinct business models can have different levels of risk originating in multiple factors in the production function and need to be adjusted accordingly when comparing productivity. This research proposes that risk

is appropriately considered when measuring and comparing productivity among different types of business model, both within and between different industries.

This research makes three contributions to knowledge in the field of business models and productivity. Firstly, this research suggests that risk management can be an underlying reason causing the rise in the servitization of manufacturing industry despite a lower productivity growth expectation. Secondly, when researching productivity, this research proposes that risk should be appropriately considered when making a comparison between industries or firms with different business models. Thirdly, this research introduces a co-contribution of methodologies, based on finance and agricultural literatures, to adjust for risk in productivity model. This new approach to use risk adjusted productivity should be applied when comparing productivity across different businesses models. It should also be used when analysing the productivity paradox problem.

3.2 Servitization of Manufacturing and Risk Management

First, this study looks at the relationship between servitization of manufacturing and productivity through the lenses of risk. As risk is a critical driver of value associated with creating and supplying consumer products and services which reside in a value chain (Girotra and Netessine, 2011), managing business risk lies at the heart of competitive strategy and is a key consideration in strategy formulation (Bettis ,1983; Amit and Wernerfelt, 1990). By managing risk better than competitors, risk management through business model can add value and play an important role to a superior ability in uncovering risk dependencies (Girotra and Netessine, 2014; Farrell and Gallagher, 2015). To add more value through risk reduction from new business model, companies can delay production commitments and reduce cycle times to eliminate risk arising from demand uncertainty, alter their risk profile by transferring risk to other parties by arranging contracts differently,

and improve the quality of information to be able to monitor risk elements (Girotra and Netessine, 2011). Given the importance of risk and business model innovation, four themes of study based on risk management and business models have emerged according to a review by Brillinger et al. (2020). The first theme explains ways to integrate risk management into the business model innovation process. The second theme provides beneficial and comprehensive high-level business risk frameworks. The third theme focuses on the ecosystem risk aspect of business models. And the fourth theme suggests considering risks in the business model design. Therefore, one important area of existing literature focuses on how businesses can reduce their business risk through business model innovation (Girotra and Netessine, 2011, 2014).

As servitization is one of the most important forms of business model innovation in the manufacturing industry (Kastalli and Van Looy, 2013; Frank et al., 2019), manufacturers, through a process of increasing their service provision, are engaging in increasing levels of strategic risk management as well as reducing business risk (Baines and Lightfoot, 2013). For example, moving from a cost-plus business model to a subscription business model can result in different risk profiles (Smith, 2013). By providing services, manufacturers can potentially reduce risk through higher revenue, greater stability in revenue, and an increase in profitability (Raddats et al., 2016). This is supported by Visnjic et al. (2016) that service business model innovation coupled with product innovation help benefit long-term performance of the firm. Evidence from industry and past literatures supports the argument that risk management, through securing revenue, is a significant reason why manufacturing firms have servitized their business models. For example, a study by Baines and Lightfoot (2013) found that manufacturers are adopting greater responsibility for their product's performance by adding a service provision to their offerings in order to be rewarded with higher revenue growth and longer profitable revenue streams by increasing their proportion of their customers' business. A study by Neely (2008), which was cited by Morris (2014), stated that a subscription model can help reduce risk by creating a more predictable service cost and a more regular and predictable

cashflow. This is exemplified by Apple Inc which according to Leswing (2022), are planning to shift their business model toward services through a hardware subscription service for iPhones in order to boost recurring revenue and more stable cashflow.

The benefit of stable cashflow from services can also help manufacturers reduce several traditional risks, especially during an economic downturn from counter-cyclical product sales (Raddats and Easingwood, 2010, Eggert et al., 2011, Benedettini et al., 2013). According to Benedettini et al. (2013), revenues from product support services, especially maintenance and support, are likely to increase during times of negative economic conditions as the customers may be willing to keep their assets in operation for longer. As a result, most manufacturers see their service strategy as being resilient to economic downturns (Baines et al, 2010). As business often face uncertainty (Gatignon and Anderson, 1988), manufacturing firms also benefit from more flexibility through service offerings by restricting their resource commitments as well as risks associated with fixed asset investments (Brouthers and Brouthers, 2003). Consequently, there is a recent paradigm shift by manufacturing firms in developed economies towards servitization strategies despite evidence of lower productivity in the service sector (Riley et al., 2018; Harris and Moffatt, 2017).

Based on the above review of literatures, this study suggested that risk-return trade-off based on the choice of strategic risk management through servitization of the business model could be a reason for productivity slowdown in manufacturing industry.

3.3 Risk-Return Trade-Off and Productivity: Servitization of Caterpillar Inc.

To support the claim, this research illustrates the relationship between risk-return trade-off, based on the choice of strategic risk management through the servitization of the business

model, and productivity slowdown by looking at Caterpillar Inc. (CAT) as an example. This research chose CAT as the world leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives which adopted and emphasised the servitization of business model. The company started to servitized their business model in 2005 when the company introduce a new strategy or “Vision 2020” by establishing a new business model. The company increased customer reliance on CAT’s services by providing digital enabled solutions and aftermarket care. Notably, as they serve many cyclical industries, CAT integrated their services businesses to help buffer the impact of the recession and be prepared in the event of a business downturn (Caterpillar Inc., 2008, 2009). According to the interview with the company’s CEO and Chairman, Jim Owens, in 2010 (Malik et al., 2011), this new long-term strategy introduced back in 2005 is designed to help the company prepare for extreme macro-economic fluctuations, especially economic troughs. According to Owen (Caterpillar Inc., 2009), trough planning for the event of business downturn was a big part of new strategy “Vision 2020” introduced in 2005. With the provision of new service businesses, such as CAT’s Equipment Management Services, CAT ensured greater stability to their revenue stream by offsetting any reduction in product sales with growth in revenues during an economic downturn (Baines and Lightfoot, 2013). By providing services including monitoring the condition, use and location of vehicles, preventive maintenance and unscheduled repairs, the effect of their newly servitized business model is shown through a slower decline in equipment rental (25%) when compared to the decline seen in equipment sales (90%) during the 2008 global economic downturn (Caterpillar Inc., 2008, 2009).

To recognise the significance shift in business model in 2005, this study uses content analysis through a basic textual analysis to illustrate the servitization of CAT’s business model. Without availability of the financial data and more availability of information from annual reports, news, and literatures, a content analysis is preferred over other methods. By looking at an average number of word count of the word “service” in CAT’s annual

reports (10-K) as a proxy of how CAT’s business model has changed over time from 2003 to 2018, the result in Table 3.2-1 shows a higher average use of the word “service” (average 315 words) in post-servitization period⁹ (years 2006-2018) when compared to the pre-servitization period (average 122 words) (years 1993-2005). This increase in the average numbers of the word “service” between the two periods demonstrates the increasing importance of services within their business.

Table 3.2-1 Average number of "service" word count per year in annual reports during year 1993-2005 and 2006-2018

Period	Average number of "service" word count in annual reports
1993-2005	122
2006-2018	315

Source: Caterpillar Inc.’s Annual Reports

To understand how servitization affects risk, this study further investigates how risk has changed when business model of CAT changed. As CAT deems extreme fluctuation of company’s performance as a risk, this research also looks at volatility as a risk for CAT’s business and proposes standard deviation of TFP as a risk variable. As a part of the production function, a volatility in productivity directly links to a variation of output and

⁹ Based on the Vision 2020 introduced in 2005, this research chooses the end of 2005 to be a starting point of servitization for CAT. As a result, period before 2006 is considered to be “Pre-Servitization” of CAT and period after 2005 is considered to be “Post-Servitization” of CAT.

hence volatility in both firm's performance and return to shareholders. Based on a concept of risk in finance literature, this research adopts standard deviation of Total Factor Productivity¹⁰ (TFP) as a proxy for risk. In finance literature, risk can be defined as variance in value of a portfolio (Markowitz, 1952; Tobin, 1958), covariance of market portfolio in capital asset pricing model (Sharpe, 1964), or variance of asset return in option pricings (Black Scholes, 1972; Merton, 1973). With several ways to look at risk in finance literature, standard deviation or volatility is most commonly used in finance literature as well as frequently used by practitioners in implementing financial strategies (Engel, 2004). In term of shareholders, they often demand lower risk or lower volatility in company's performance which is seen through a better managerial compensation contract (Goel and Thakor, 2003).

Therefore, CAT's TFP and standard deviation of TFP are calculated for the two sample periods to examine the effects on productivity and risk from different levels of service in CAT's business. Figure 3.2-1 shows that CAT has higher TFP with average of 8.56 in pre-servitization period (years 1993-2005) when compared to average TFP of 5.50 in post-servitization period (years 2006-2018). Figure 3.2-2 also shows that CAT has a higher level of standard deviation of TFP with average of 0.71 in pre-servitization period when compared to average standard deviation of TFP of 0.39 in post-servitization period. With differences in TFP, as well as risk level, the illustration from CAT's provides support for the proposition that shifting in business model from manufacturing to service or servitization of manufacturing business may change the fundamental economics in business model as well as risk level. This result is confirmed by a statement from Jim Owens that by changing business model towards services, the company can lower financial

¹⁰ TFP is calculated based on Cobb-Douglas production function and linear regression analysis. This study used total revenue as output, total asset as capital input, and number of employees as labour input. The data used in this analysis is obtained from Capital IQ and can be found in the Appendix A.

risk during a deep recession. According to Caterpillar Inc. (2009), these integrated services helped buffer the impact of the recession on CAT. These integrated services also climbed to 46 percent of the company’s 2009 sales.

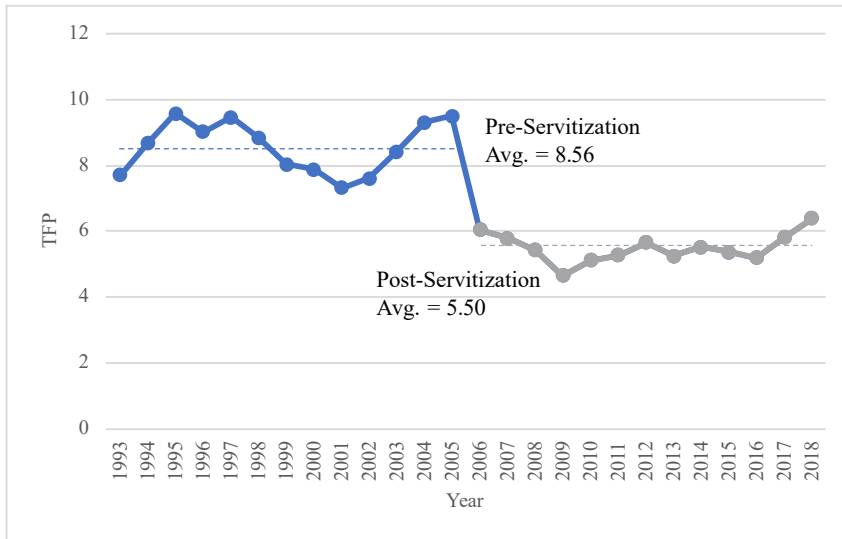


Figure 3.2-1 Total Factor Productivity of Caterpillar Inc.

Source: Capital IQ and Authors’ Calculation

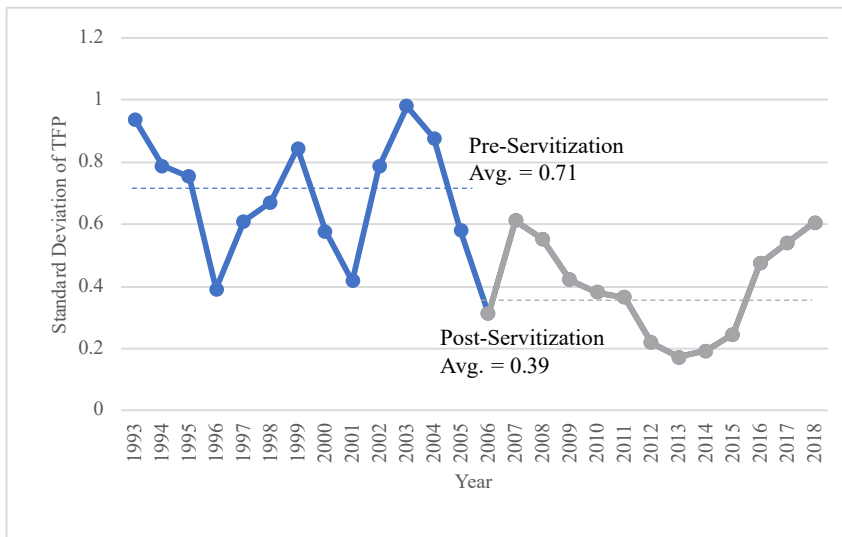


Figure 3.2-2 Standard Deviation of Total Factor Productivity of Caterpillar Inc.

Source: Capital IQ and Authors’ Calculation

By looking at standard deviation of TFP as risk, the illustration of servitization of CAT shows that productivity slowdown after CAT servitization is associated with a reduction in risk level. This evidence demonstrates the relationship between risk-return trade-off based on the choice of strategic risk management through servitization of the business model as one of the reasons behind the productivity slowdown in manufacturing industry. With this supporting evidence from the CAT's example as well as recent literatures, this research proposes that the impact of risk from different types of business models toward productivity growth should be controlled. As a result, this research introduces a new approach called risk adjusted productivity to measure productivity by accounting for risk.

3.4 Introducing Risk Adjusted Productivity

Despite business models having the ability to alter the risk-return equation for existing products and technologies (Girotra and Netessine, 2014), previous literatures only focused on productivity purely as a performance without considering risk. To account for risk, this research proposes a method to consider the trade-off between risk and level of productivity by introducing a new productivity measure called risk adjusted productivity. This risk adjusted productivity measure takes into account risk which underlies differences in business models. To the best of present knowledge, this measure has not been incorporated into productivity measures before.

This risk adjusted productivity concept is proposed based on a similar concept found in both finance and agricultural economics literature. Within finance literature (e.g. Sharpe (1966) and Modigliani and Modigliani (1997)), risk adjusted return is seen as a measure of the return on investment relative to the amount of risk of that investment. By adjusting for

risk based on volatility of productivity, risk adjusted TFP can be explained as productivity per a unit of risk.

The source of variation, based on the input concept from agricultural economics literature, is also used as evidence that risk levels from differences in how businesses operate can have an impact toward productivity measure. This research follows an approach used by Just and Pope's (1978, 1979) model to understand uncertainty of output from uncertainty of the production environment. Used in the agricultural economics literature, the approach combines deterministic production function and risk function. In order to understand the marginal risk effect of inputs on variance of output in agriculture, Just and Pope' approach measures the contribution of each factor input to variation of output.

Within this proposed risk adjusted productivity method, this research uses a key measurement of productivity similar to Chapter 2 called Total Factor Productivity or TFP. In terms of risk, this research defines risk as business risk which according to Van Horne and Wachowicz (2001) stated to be the risk inherent in the firm, independent of the way it is financed. According to Gabriel and Baker (1980), business risk is reflected in the variability of net operating income or net cash flows and is influenced by internal factors such as investment decision and management skills.

3.5 Data

This research illustrates servitization and its impact on risk and productivity by comparing results from manufacturing and service sub-manufacturing industry by using an example from manufacturing industry in the UK (Riley et al, 2018) as a representation for pre and post servitization of manufacturing firms. Currently, the manufacturing industry is operating within two main distinctive business models of manufacturing and service. The

manufacturing business model is based on being exposed to fixed assets and hence requires greater flexibility and requires relatively lower-control governance when facing high environmental uncertainty (Gatignon and Anderson, 1988). Service business model, on the other hand, relies on people intensity and can vary with respect to the asset specificity of their service and cannot be inventoried which suggests that service firms require relatively higher control governance in order to deal with changes in the environment (Brouthers and Brouthers, 2003). Given the importance of the manufacturing industry to the UK economy, as well as the existing characteristic of two prominent business models within one industry, the UK manufacturing industry is chosen as a prime example to be analysed. Researching the UK manufacturing industry will allow this research to compare how risk is embedded within different business models, and the subsequent impact on productivity.

This research obtained secondary firm-level sample data of UK manufacturing industry from Bureau van Dijk (BvD) Fame, which consists of 2768 firms in UK manufacturing industry¹¹. The data set contains unbalanced panel data from year 2003 to 2018. This data set was chosen as the firms in the dataset are classified into two sub-industries under manufacturing industry: namely, manufacturing and service. The UK Standard Industrial Classification (SIC) code is used to classify and identify firms under UK manufacturing industry. This research uses main activity classified by the Statistical Classification of Economic Activities in the European Community (NACE) or NACE code as a criterion to categorize firm into service and manufacturing as sub-manufacturing industry. To do this, manufacturing and service are classified using main activity label. After implementing data transformation and data cleaning, by removing negative and zero values of the variable before applying to the models, the dataset is left with a total of 2328 manufacturing firms and 440 service firms.

¹¹ The average data used in this study can be found in Appendix B and C.

3.6 Empirical Models and Results

3.6.1 Productivity-to-Variability Method

This study proposes that risk adjusted productivity is calculated by deriving the risk adjusted productivity model from the Sharpe ratio or reward-to-variability ratio (Sharpe, 1994). This method has been widely used among academics and practitioners in the field of finance to compare return per a unit of risk between different assets. Based on reward-to-variability ratio method, the risk adjusted productivity is calculated as per Eq. (1).

$$\forall = \frac{A}{\sigma_A} \quad (1)$$

$$A = \frac{Y}{L^\alpha K^\beta} \quad (2)$$

Where, A represents productivity using Total Factor Productivity (TFP) which is calculated as (2) through Cobb-Douglas production function; σ_A represents risk of productivity using three years moving average of standard deviation of TFP which is calculated from $\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$; \forall represents risk adjusted TFP; Y represents output (revenue); L represents labour (number of employee); K represents capital (total asset); α and β represent production function parameters of L and K respectively.

The ratio \forall computed from Eq. (1) can be used to compare firms' productivity performance while accounted for risk from productivity variability. By comparing productivity-to-variability ratio, the firm or industry which has higher ratio should be preferred and produce higher productivity per a unit of risk.

3.6.2 Productivity-to-Variability Result

Figure 3.6.2-1 and Figure 3.6.2-2 illustrate the geometric mean¹² of productivity and the geometric mean of standard deviation of productivity of manufacturing and service firms. Based on this observation, these two figures show a relationship between productivity and variability of productivity. From these two figures, the results show that manufacturing firms has a higher productivity as well as a higher standard deviation of productivity than service firms as mentioned by Harris and Moffat (2017). This result shows that higher productivity in manufacturing firms come with a higher cost through higher business risk. However, this higher cost is usually not taken into account when measuring productivity.

¹² The geometric mean is calculated as the Nth root of a product of N values. The geometric mean is used instead of arithmetic mean due to potential serial correlation and volatility of the dataset. The geometric mean has been widely used in calculating index number and is more effective and accurate than arithmetic mean. Furthermore, results and interpretation from either geometric mean or arithmetic mean in this study show indifference in conclusion.

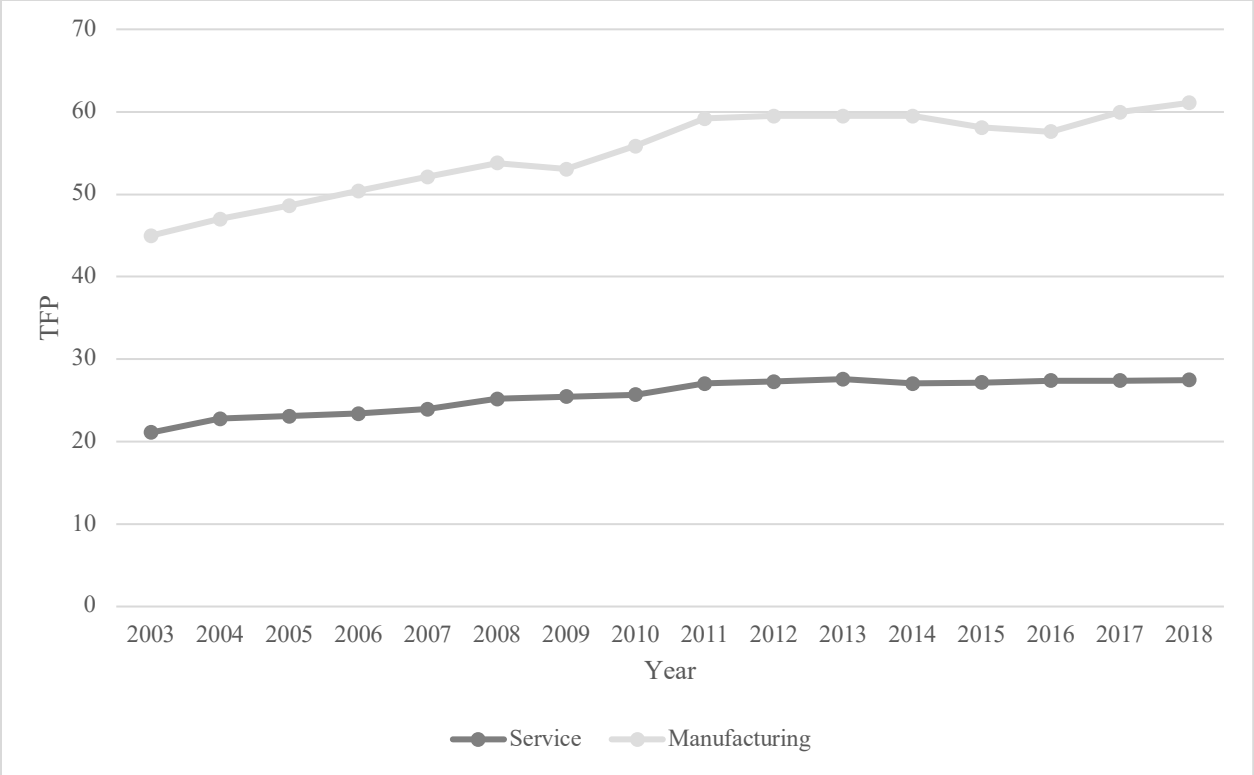


Figure 3.6.2-1 Total Factor Productivity of Manufacturing and Service Firms

Source: Authors' Calculation

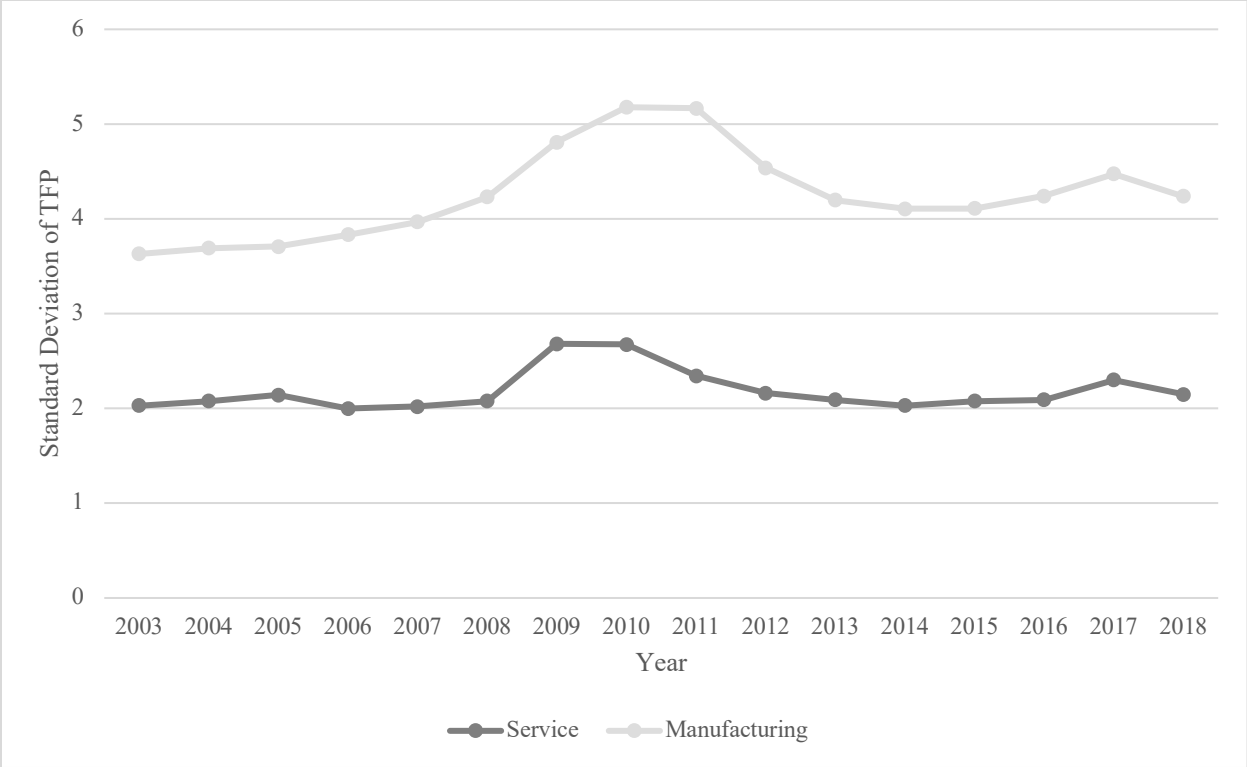


Figure 3.6.2-2 Standard Deviation of Total Factor Productivity of Manufacturing and Service Firms

Source: Authors’ Calculation

By applying risk adjusted productivity through the Productivity-to-Variability Method using standard deviation as a proxy for risk for both manufacturing and service firms, results from Figure 3.6.2-3 shows the comparison of risk adjusted productivity between service and manufacturing. If compared unadjusted with risk adjusted TFP (comparing Figure 3.6.2-1 and Figure 3.6.2-3), the productivity gap between manufacturing and service firms becomes significantly narrower after being adjusted for risk. This is confirmed by the differences in the mean values between manufacturing and service firms for both pre-risk adjustment and post-risk adjustment, as shown in Table 3.6.2-1. The differences in the mean values of TFP between manufacturing and service firms, after adjusting for risk, shows a smaller difference when compared to unadjusted TFP.

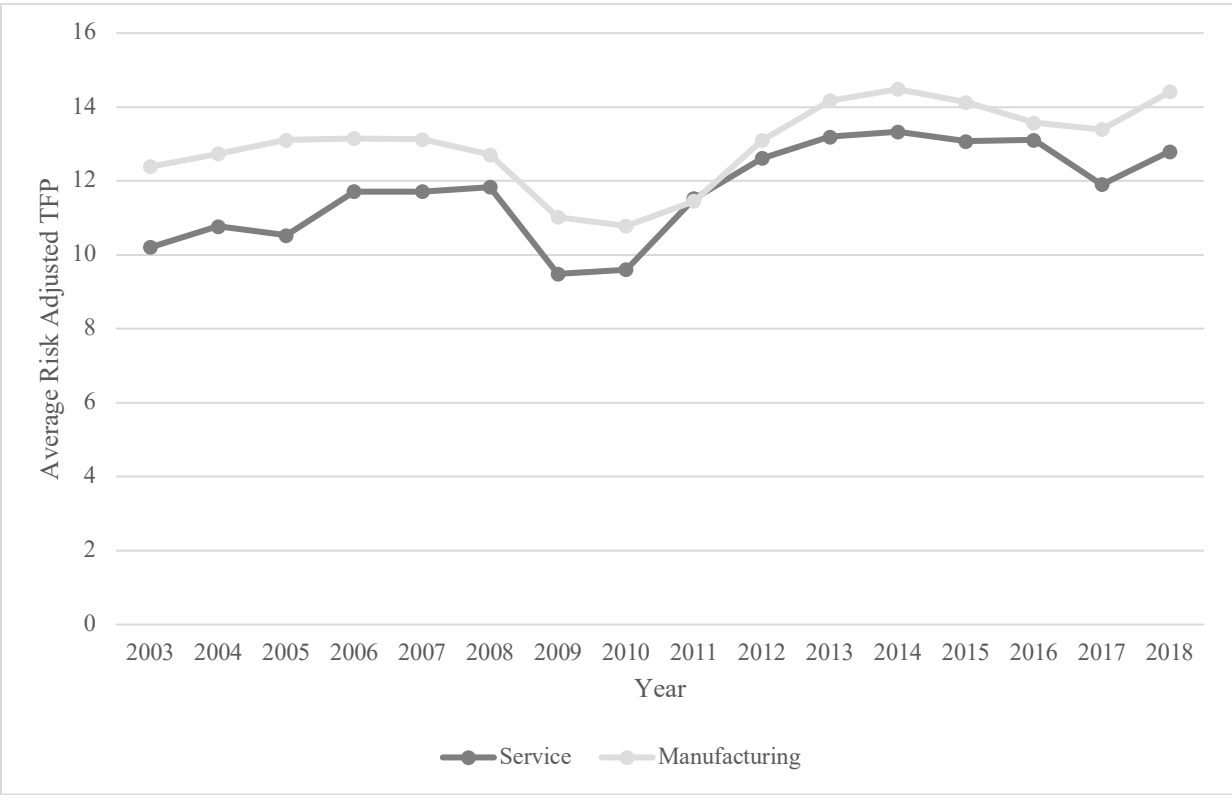


Figure 3.6.2-3 Mean of Risk Adjusted Total Factor Productivity of Manufacturing and Service Firms based on Productivity-to-Variability Method

Source: Authors’ Calculation

For robustness, the results of the differences between the mean of the product-to-variability ratio in the manufacturing and service firms for the 16 years between 2003 and 2018 are verified using an inferential statistical test through t-test. The results are statistically significant at 1% level of the differences between means of unadjusted TFP for the manufacturing and service firms for each year throughout 16 years period. However, once TFP is adjusted for risk, the number of years with statistically significant at 1% were reduced by 100% to zero year. From this robustness test, the results also show a trend of larger differences in the means of unadjusted TFP from 23.886 in 2003 to 33.604 in 2018, whereas the trend for the differences in the means of risk adjusted TFP are trending smaller

from 2.179 in 2003 to 1.619 in 2018. This result demonstrates that the differences in the mean values of TFP between manufacturing and service firms, after being adjusted for risk, shows a smaller difference when compared to unadjusted TFP.

Table 3.6.2-1 Differences in Mean of Pre and Post Risk Adjusted TFP of Manufacturing and Service firms

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Difference in Means Pre-Risk Adjusted	23.886	24.234	25.543	26.999	28.170	28.624	27.590	30.147	32.150	32.210	31.904	32.427	30.908	30.201	32.555	33.604
Difference in Means Post-Risk Adjusted	2.179	1.963	2.572	1.439	1.414	0.873	1.538	1.184	-0.074	0.481	0.972	1.150	1.055	0.465	1.492	1.619

Source: Authors' Calculation

3.6.3 Decomposing the Source of Variation in Productivity - Just and Pope Analysis

With the Productivity-to-Variability Method in Section 3.6.2 providing a broader way of measuring risk, this research incorporates further analysis to decompose the source of variation of productivity to understand more on whether different inputs, such as labour and capital, can result in different risk levels. The key question underpinning this research explores is how much of the variation in productivity is due to various factor inputs such as labour and capital. The answer to this question can help confirm the proposed hypothesis that risk level from differences in how businesses operate can have an impact on productivity. In this research, the concept developed by Just and Pope (1978, 1979), which is considered to be the starting point of understanding factors affecting risk of production within agricultural economics literature, is explored. Productivity is adjusted based on the uncertainty derived from the Just and Pope model which measures uncertainty of output from uncertainty of inputs. The model considers the heteroscedasticity error as production uncertainty. Eq. (3) shows the Just and Pope production function allowing flexibility with

two general functions; one which specifies the effects of input on the mean of output, and another which specifies the effects of input on the variance of output (Just and Pope, 1979).

$$Y = f^*(X)\varepsilon^{\delta^*} = f(X) + h^{1/2}(X)\varepsilon \quad (3)$$

$$Y_{it} = f(X_{it}; \alpha) + h^{1/2}(X_{it}; \beta)\varepsilon \quad (4)$$

From the Just and Pope production function, Y represents output, X represents a factor input which consists of labour and capital based on Cobb-Douglas (1928) production function, h represents risk function, and ε represents a stochastic disturbance. Eq. (5) shows the Just and Pope production function as an empirical model where α and β are unknown parameters, u is an error term, subscript i denotes firm and t denotes year.

Based on the Just and Pope production function, this research uses an empirical model which resides on the three-step Feasible Generalised Least Square (FGLS) approach. The FGLS is based on the Cobb-Douglas production function which consists of labour and capital as key factor inputs. The first stage of FGLS is to estimate a relationship based on production function between output and inputs, Eq. (5) is then rewritten as Eq. (6) and Eq. (7) for heteroscedastic regression of y on X where α and production uncertainty are estimated. This research use Generalised Least Squares (GLS) with White's consistent estimator framework due to existence of heteroscedasticity which was diagnosed using Breusch-Pagan test. The calculation is controlled for cross-section fixed effects. The result of this stage, $\hat{\alpha}$, shows a relationship α based on production function between output and inputs. The residual from this stage result in production uncertainty ε^* .

$$y_{it} = f(X_{it}; \alpha) + \varepsilon^*_{it} \quad (5)$$

$$y_{it} = \exp [(\ln X_{it})\alpha] + \varepsilon^*_{it} \quad (6)$$

$$\ln y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \varepsilon^*_{it} \quad (7)$$

In second stage of FGLS, residual is obtained from the first stage of the analysis based on Eq. (7) which can be estimated using Eq. (8). This residual can then be used to find a relationship between inputs and production uncertainty based on Eq. (9) which β is estimated using linear regression econometric analysis (Least Squares) with cross-section fixed effects. Using empirical model based on Eq. (10), the result, $\hat{\beta}$, shows how each input in production function affect production uncertainty. In this stage, the risk contribution to productivity variation from input is measured.

$$\varepsilon^* = y - f(X_{it}; \alpha) \quad (8)$$

$$\ln|\varepsilon^*_{it}| = \beta_0 + \frac{1}{2}(\ln X_{it})' \beta + u^*_{it} \quad (9)$$

$$\ln|\varepsilon^*_{it}| = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + u^*_{it} \quad (10)$$

Where $\ln h(X, \beta) = (\ln X)' \beta$ and $E(u^*) = 0$

The final stage of FGLS uses production uncertainty based on the coefficient from the second stage to weight and account for heteroscedasticity as per Eq. (11) which result in risk adjusted TFP. Using empirical model based on Eq. (12), the coefficient result in this stage, $\hat{\alpha}$, is a heteroscedasticity corrected and efficient estimates for productivity function similar to FGLS with White's consistent estimator framework (Saha et al., 1997).

$$y^*_{it} = f^*(X_{it}; \alpha) + \varepsilon^*_{it} \quad (11)$$

Where $y^*_{it} = y_t h^{-1/2}(X_t, \hat{\beta}) = y_t \exp[-\frac{1}{2}(\ln X_{it})' \hat{\beta}]$

and $f^*(X_{it}; \alpha) = \exp[(\ln X_{it})' \alpha - \frac{1}{2}(\ln X_{it})' \hat{\beta}]$.

$$\ln y_{it} = \alpha^*_0 + \alpha^*_1 \ln L_{it} + \alpha^*_2 \ln K_{it} + \varepsilon_{it} \quad (12)$$

3.6.4 Just and Pope Analysis Result

Based on the Just and Pope analysis, using the Cobb-Douglas production function, the regression results in Table 3.6.4-1 shows what types of factor inputs are driving risk in different type of business models. Based on adjusted R² value for manufacturing, service, and combined sample, the results indicate that 0.023 or 2.3%, 0.051 or 5.1%, and 0.027 or 2.7% of variation in productivity can be explained by variation in capital input and labour input in the model respectively. These results show that different types of business models display varying risk levels from a variation in inputs that affects productivity. The results, based on the second stage of FGLS, show that capital input in Figure 3.6.4-1 contributes positively to variation in productivity and is statistically significant with coefficients, as shown in Table 3.6.4-1, of 0.3351, 0.3169, and 0.3292 for manufacturing, service and combined respectively. These results mean that variation in capital input does increase variation in productivity, especially more in manufacturing. On the other hand, the results based on Figure 3.6.4-2 show that the risk from labour input contributes negatively to variation in productivity and is statistically significant with coefficient (Table 3.6.4-1) of -0.4797, -0.5883, and -0.5055 for manufacturing, service and combined respectively. These results mean that variation in labour input does in contrast decrease variation in productivity, especially in service. As shown in Figure 3.6.4-1 and Figure 3.6.4-2, the coefficient of capital and labour input were plotted to help get a better comparison between manufacturing, service, and combined sample data. With higher unadjusted productivity than service, risk contributions from capital toward output variation in manufacturing is greater than the combined case (Figure 3.6.4-1). On the other hand, manufacturing shows

less risk reductions from labour toward output variation than the combined case (Figure 3.6.4-2).

From the results, despite a lower unadjusted productivity level than manufacturing, service shows a lower risk contribution from capital input and more risk reduction from labour input toward output variation when compared to the combined case. The results also show a higher risk contribution from capital input for manufacturing when compared to services. In contrast, the results show a higher risk reduction from labour input for services compared to manufacturing.

The results also show that capital input is considered a primary contributor of risk and hence a source to variation in productivity, whilst labour helps contribute as a source of risk reduction. These results are consistent with past literatures which argue that manufacturers have higher fixed costs than service firms, due to being capital and financial intensive and less people intensive (Erramilli and Rao, 1993), and as a result is more vulnerable under uncertainty (Chod and Rudi, 2005). For example, Gatignon and Anderson, (1988) suggested that manufacturing firms have a need for greater flexibility under high environmental uncertainty or risks which associated with fixed asset investments. According to Kim and Hwang (1992), manufacturers need to limit exposure to risk associated with fixed asset investments by restricting their resource commitment. Brouthers and Brouthers (2003) also found that due to the investment intensive nature of manufacturing, risk and uncertainty has a high influence on manufacturers' decision on entry mode strategies than service firms. Therefore, the results from our study support that differences in proportion of labour and capital inputs from different business models of manufacturing and service have impact on variation of output and level of productivity. Hence, different levels of risk from different business models should be considered and adjusted accordingly when comparing productivity between firms or industries with different business model.

Table 3.6.4-1 Just and Pope second stage results

Just-Pope Second Stage	Manufacturing	Services	Combined
Capital	0.3351***	0.3169***	0.3292***
Labor	-0.4797***	-0.5883***	-0.5055***
Constant	-5.3260***	-4.3605***	-5.1015***
Adjusted R ²	0.023	0.051	0.027
Cross-sections	2328	440	2768
Unblanced observation	37248	7040	44288

Source: Authors' Calculation

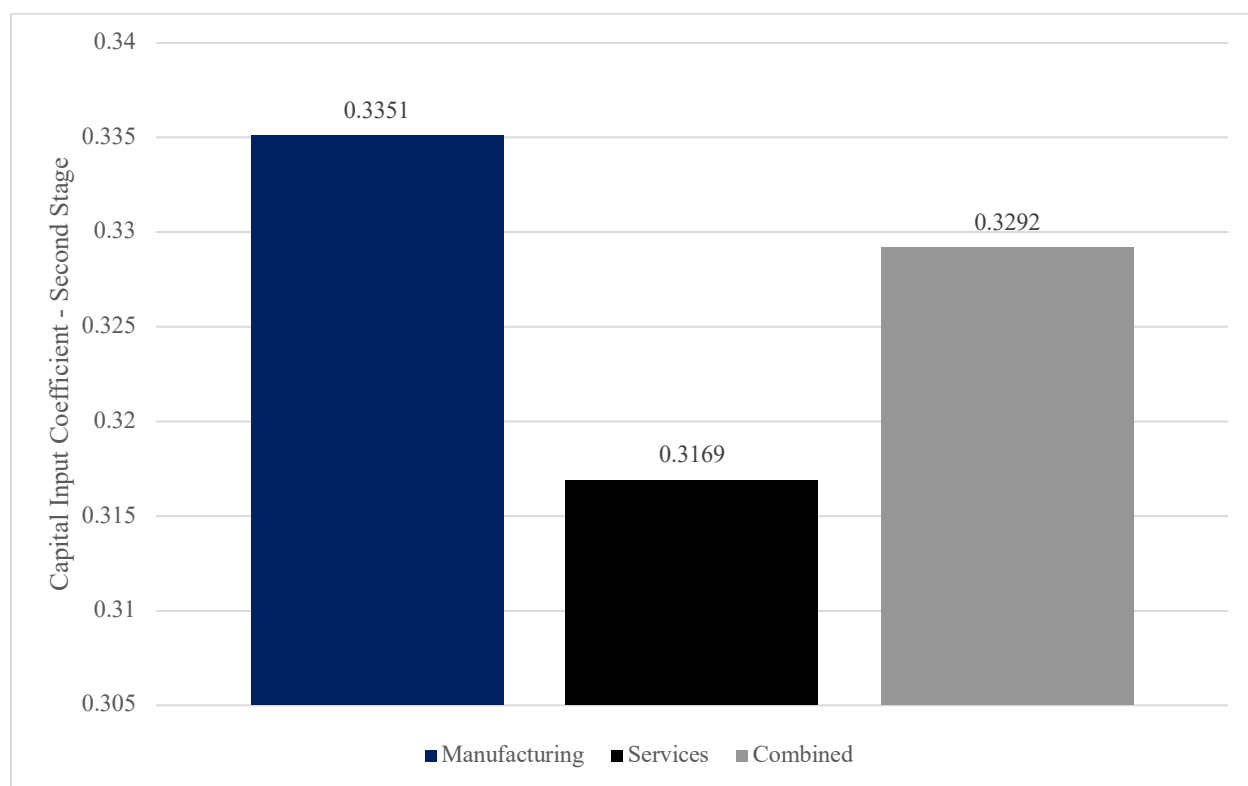


Figure 3.6.4-1 Comparison of capital input factor from second stage result using Just and Pope method

Source: Authors' Calculation

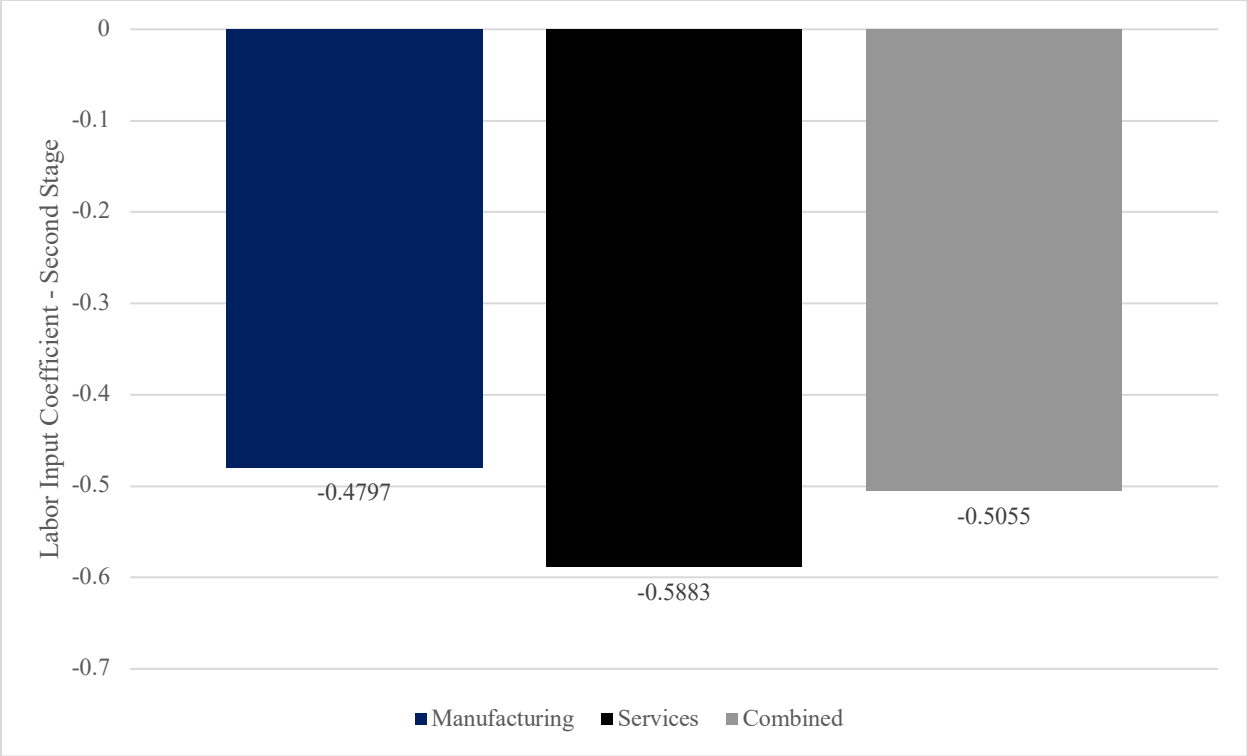


Figure 3.6.4-2 Comparison of labour input factor from second stage result using Just and Pope method

Source: Authors' Calculation

By adjusting productivity for risk from inputs using risk weighted coefficient based on the last stage of Just and Pope using FGLS with White's consistent estimator (Table 3.6.4-2), Figure 3.6.4-3 shows the results of comparing average risk adjusted TFP between the manufacturing and service sectors. When compared to average unadjusted TFP (Figure 3.6.2-1), the results using the Just and Pope method show that the gap between TFP of manufacturing and service is considerably smaller after being adjusted for risk. Despite initially showing lower productivity, service shows comparable productivity with manufacturing once adjusted for risk. These results suggest that the manufacturing sector can reduce their risk, or increase their productivity per unit of risk, by implementing business model innovation toward service.

Based on the results of both the Productivity-to-Variability method and the Just and Pope analysis, this research argues that the risk of the underlying business model needs to be taken into account when comparing productivity.

Table 3.6.4-2 Just and Pope FGLS results

FGLS - White	Manufacturing	Services	Combined
Capital	0.6194***	0.5845***	0.6147***
Labor	0.3189***	0.4125***	0.3374***
Constant	2.4353***	2.2410***	2.3807***
Adjusted R ²	0.954	0.965	0.961
Cross-sections	2328	440	2768
Unblanced observation	37248	7040	44288

Source: Authors' Calculation

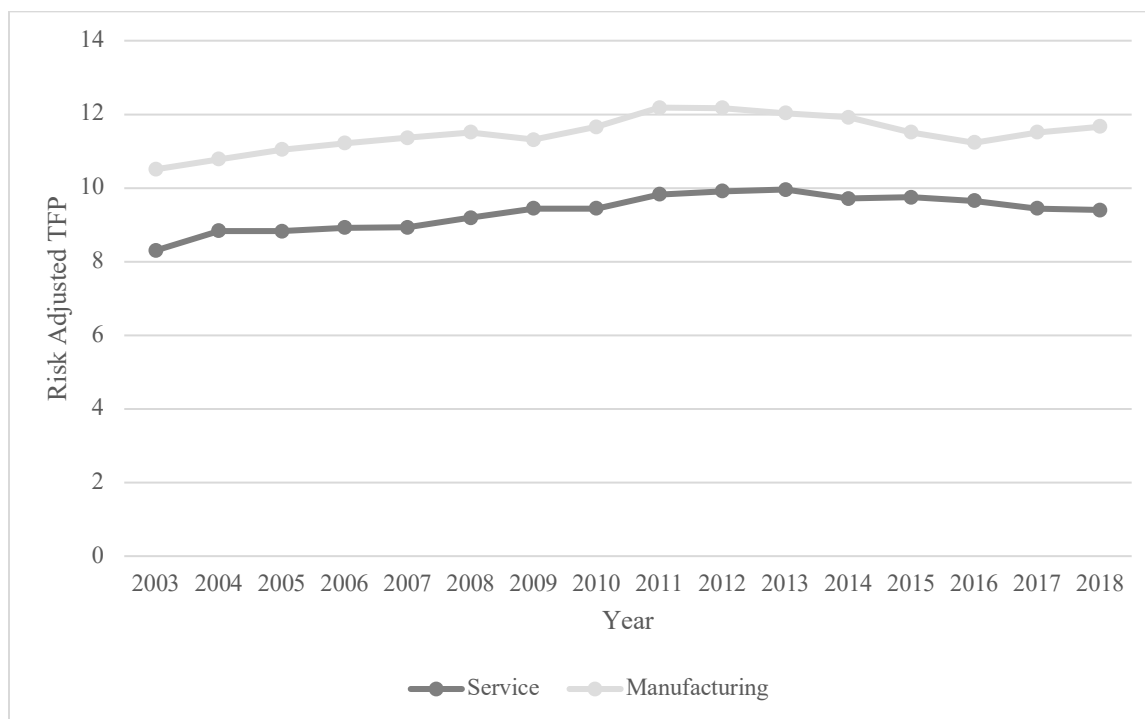


Figure 3.6.4-3 Risk Adjusted Total Factor Productivity based on Just and Pope method

Source: Authors' Calculation

There are some limitations in this study which needs to be recognised and documented. Firstly, standard deviation of total factor productivity (TFP) can represent other unwanted signal apart from risk. As a result, other risk variables and other types of risk may be worth exploring. Secondly, other factors apart from business model choice can also have an impact toward standard deviation of TFP. Hence, different level of standard deviation of TFP is not exclusively a result from different business model choice. Thirdly, there are many other types of risks which are not represented by the risk factor used in this research. In this research, risk is represented by a volatility of productivity. Fourth, this study noted that slowdown in productivity growth in service sector does not only come from risk management alone, but also the nature of service businesses which is very labour intensive and does not focus purely on growth. Fifth, there are limitations in both research method as well as the data used in this study. For the data, the selection bias problem from failed companies or missing data which are excluded in this study may affect the true result. This study also raised the potential concern that using an aggregated macro level panel data may cause the standard deviation of TFP across firms in macro level data to offset each other, hence reduce a true risk outcome. Furthermore, this study used total revenue instead of gross value added (GVA) as output in the production function due to a problem with negative GVA found in the data. As a result, volatility in the total revenue from one time sales item, extraordinary item, or a rapid change in financial instruments such as foreign exchange hedging or financial derivatives may cause noise and error in the production function and TFP estimation.

Based on the above limitations, this study suggests that future research should be undertaken to explore new risk and productivity variable to understand more about the nature of risk and servitization. To overcome limitation from data, future research could also further investigate the similar relationship of risk and business model innovation using different industry and different dataset. For methodology, this research adopts methods used in both finance and agriculture literatures to measure risk. However, there are other

potential methods which could have been applied to these studies. Therefore, further development on both methods and dataset in this area would be worth exploring. Lastly, future research should consider looking and understanding the importance of productivity growth in service industry.

3.7 Conclusion

The aim of this paper is to highlight how changes in risks resulting from business model innovation affect productivity, and to examine the impact of servitization as one of the most important business model innovations within the manufacturing industry on productivity. This research investigates the relationship between productivity and risk from two distinct business profiles of service and manufacturing within UK manufacturing industry. By introducing a new approach of measuring productivity through risk adjustment based on volatility, this study shows that, once risk has been accounted for, differences in productivity between the manufacturing and service sectors can be reduced significantly. Although prior literatures have found that services contribute to a slowdown in productivity, the results based on the risk adjusted productivity approach proposed in this study show otherwise. These results are consistent with industry evidence. This research contributes an alternative productivity measure that takes into account the risk profiles of different business models. This new measure is especially salient at the moment as digital technologies are contributing extensively to changes in business models (Wirtz et al., 2010), such as the servitization of manufacturing (Paschou et al., 2020).

In order to understand what drives the risk of different business models, this research also checked the source of variation of output and incorporated that to adjust productivity based on risk found from the source of variation from inputs. The results of risk adjusted productivity, using source of variation from inputs, are consistent with risk adjusted productivity based on volatility using standard deviation of TFP.

This research provided contributions to both academics and practitioners. Firstly, this research suggested that risk management can be an underlying reason why there is currently a wave of servitization in the manufacturing industry despite lower productivity growth expectations. As a result, this research found that the servitization of manufacturing and risk management from business model design can impact productivity levels. Secondly, this research emphasised that the widely observed productivity level should be interpreted with caution and risk should be considered when making a comparison between industries or firms with different business models. As such, there are important implications for policy makers as this research demonstrates that they need to understand underlying risk and business models before making any recommendation. For managers, this research demonstrates that they need to look beyond just productivity to consider the underlying risk and their business models. Thirdly, this research makes a methodology contribution through the introduction of a risk adjusted productivity which was developed through existing literature within the fields of business models, productivity, finance, and agricultural economics. This new approach to risk adjusted productivity should be used as a critical method when assessing the productivity paradox.

Chapter 4: Business Model Innovation and Productivity Growth: Servitization of Rolls-Royce

The two previous chapters outlined the relationship between business model innovation and productivity and highlighted how risks from different business models affect productivity. The emphasis on servitization in the manufacturing industry was used as an example in the previous chapter. This chapter further outlines how servitization as part of business model innovation impacts productivity growth. To do this, this chapter considers Rolls-Royce as a case study to help provide an understanding of the dynamics within the firm after business model change. Through both quantitative and qualitative analyses, results from this study help answer the final research question on what are the levers that influence servitization based business models which impact the firm's productivity growth.

This chapter starts with an introduction in Section 4.1, followed by a brief literature review of the relationship between servitization and productivity growth in Section 4.2. Section 4.3 then considers Rolls-Royce as a UK manufacturing firm which has servitized its business model. A methodology section, focusing on uses of both qualitative and quantitative approaches, can be found in Section 4.4. Section 4.5 looks at the data used in this study. Interpretation of the results is discussed in Section 4.6. Section 4.7 summarises the contributions of the study.

4.1 Introduction

Despite a rise in servitization strategies of business model by manufacturing firms in developed economies (Neely, 2008), several literatures such as Gebauer et al. (2005) suggested that a transition into services by manufacturing firms often result in lower-than expected higher return. In manufacturing industry, this phenomenon is known as service paradox. To understand this phenomenon, topic related to servitization of manufacturing are being studied and emphasised in many recent literatures as reviewed by Baines et al. (2009). A relationship between servitization and business model innovation as well as a relationship between servitization and productivity have also been highlighted by many scholars such as Frank et al., (2019); Luz Martin-Pena et al. (2018); Kastalli and Van Looy (2013); and Kharlamov and Parry (2021).

However, there are a limited number of studies that have examined whether servitization is being adopted in practice or what the impact of this servitization on manufacturing might be (Neely, 2008). As a result, a link between business model innovation, servitization of manufacturing, and the consequence of servitization in term of productivity growth are still left unexplored. To be able to understand the current industry dynamics and how the relationship between business model innovation, servitization, and productivity works, this research introduces a study so as to address this knowledge gap by proposing to understand the relationship between the business model innovation, servitization, and productivity based on an in-depth analysis at a firm level.

This research applies the analytical framework developed by Brea-Solis et al. (2015) which quantifies the links between firms' choices and their consequences to profit variation over time based on the economics of business performance and business model choices. This model is applied through an individual firm level approach so that the validation of the relationship can be tested. This research analyses a real-world example of servitization at Rolls-Royce, a manufacturing company in the civil airframe engines manufacturing

industry between period of year 1992 and 2019. With a distinct business model when compared to its competitors, by providing aircraft engines as a service rather than a product, Rolls-Royce is an ideal company to study consequences of servitization of manufacturers. This study of Rolls-Royce demonstrates how business model choice can have an impact on changes in profit and productivity. To provide a better understanding of servitization, this research uses both quantitative insight and qualitative representation into linking and analysing firm's business model choices, profitability, and productivity consequences.

As a result, this research makes three contributions to knowledge in the field of business model innovation, servitization, and productivity. First, this research uses Rolls-Royce as a case study to demonstrate how business model innovation through servitization can be an important factor to the firm's productivity growth. The results from this research demonstrate how business model innovation can be one of the possible solutions to the productivity paradox puzzle. Secondly, this research introduces both qualitative and quantitative approaches to help understand the relationship between business model innovation and productivity, especially in context of servitization. Thirdly, this research provides an example of a relationship between business model innovation through servitization and productivity at the firm level and shows how manufacturing firms such as Rolls-Royce can successfully enhance productivity through business model innovation. This real-world example can help provide practical implications for both industry and policymaker.

4.2 Servitization and Productivity Growth

To understand the relationship between business model innovation, servitization of manufactures and productivity growth, the following is a short review of relevant

literatures to provide the foundation for this study. According to Velu (2018), business models are complex systems with components that connect the customer value proposition, how value is created, the means of value capture, and the partners in the value network. Here, a business model is understood to be a detailed specification of activities which a firm undertakes to exploit an identified opportunity (Brink and Holmen, 2009) and to unlock potential values embedded in new technologies and converting it into market outcomes (Zott et al., 2011).

As technologies are developed, business model change is needed in order to align the customer value proposition with how value is created and captured (Velu and Stiles, 2013). To achieve this, business model change requires changing a set of activities, changing linkages between activities, changing boundaries of the focal firm, or changing location in which the activities are performed (Santos et al., 2015). This is known as business model innovation. According to Zott et al. (2011), there is an increasing consensus that business model innovation is key to firm performance. A significant number of scholars focus on business model innovation as a vehicle for corporate transformation and renewal (e.g., Demil and Lecocq, 2010; Pohle and Chapman, 2006; Hitt et al., 2001; Johnson et al., 2008; Sosna et al., 2010), as cited by Zott et al. (2011).

Servitization offers one route to business model innovation (Kastalli and Van Looy, 2013; Frank et al., 2019). The concept of servitization was first introduced by Vandermerwe and Rada in 1988 during a global surge in service offering, especially in manufacturing companies which innovated to create and keep customers and thereby sustain a competitive advantage. According to Vandermerwe and Rada (1988), services are performed rather than produced and servitization is undertaken when deregulation, technology, globalisation, and fierce competitive pressure force industries or companies to diversify their organisation into services. Such transformation in servitization strategy, by moving toward product-service system from product firms or product-centered firms, is considered to be a business model innovation (Frank et al., 2019). Manufacturing firms are able to develop new business models by breaking boundaries between manufacturing and

service through technological development, especially data capturing and information processing (Neely, 2008). Executives of manufacturing firms often play a significant role in driving their companies into services to gain competitive ground (Vandermerwe and Rada, 1988).

According to Wannakrairoj and Velu (2021), business model innovation is one of the most important factors affecting productivity growth. Velu and Chen (2021) found that with the compliment of new technology, business model innovation and productivity growth can be realised. With shifting towards service offering as a new way for company to create and capture value (Kastalli et al., 2013), Kharlamov and Parry (2021) found servitized firms to be more productive than pure product firms. Based on these academic literatures, this research therefore chooses to analyse the impact of servitization on productivity growth at a firm level which has never been done before. This exploration could potentially find a connection between the two and provide meaningful implications for both academia and industry in the field of business model innovation and productivity.

4.3 Servitization as Business Model Innovation: Rolls-Royce

With a unique business model, Rolls-Royce (RR) is an ideal example that can be used to study how business model choice, particularly servitization of manufacturers, impacts productivity. This study chose Rolls-Royce, one of the market leaders in the civil airframe engines manufacturing industry, as the subject of study as the company has successfully diversified into the service industry. From the beginning of “Power by the Hour” in 1962 to “CorporateCare” which was introduced in 2002, Rolls-Royce successfully implemented distinct business model innovations when compared to its peers. Rolls-Royce’s business strategy originally focused on a product-centric strategy just like its rivals Pratt and Whitney (RTX) and General Electric (GE). Under their product-centric strategy, the company

products increased from 4 civil airframe engines application in 1980 to 27 in 1996 (Smith, 2013). According to the company's annual reports, Rolls-Royce increased the delivery of their commercial engines by 300% between 1995 and 2000, and surpassed Pratt and Whitney in early 2000 to become the second largest aero engine manufacturer in the world (Lazonic and Prencipe, 2005). By 2003, Rolls-Royce had the largest engine orders after surpassing GE which was the market leader at that time (Michaels et al., 2005). Amid triumph over its rivals, Rolls-Royce took its first steps toward a customer-centric strategy in 1993 by creating and acquiring repair and overhaul facilities through joint venture with airlines and implementing a global maintenance repair and overhaul (MRO) service infrastructure within a period of just eight years (Smith, 2013). According to the company annual report in 2000, Rolls-Royce is the first aero engine company that anticipated the potential of engine leasing.

With an increasing engine reliability, many manufacturers have fallen victim to their own success (Kerr and Ivey, 2001). However, Rolls-Royce was the first to realise the impact of improvement in its engine durability and efficiency (Smith, 2013). Like “Power-by-the-Hour”, which has been offered to the US Navy since 1962 as a complete engine replacement service on a fixed-cost-per-flying-hour basis, Rolls-Royce's subscription business model “TotalCare” was fully launched in the mid-1990s to leverage the company's large installed engine base and superior durability of its engine. The TotalCare model charges the customer a fixed rate for each hour the engine is being utilised to power an aircraft (Rolls-Royce, 2017). According to Rolls-Royce (2022), the TotalCare option removes burden of engine maintenance from the customer and transfers the management of that associated risks to Rolls-Royce.

According to Rolls-Royce (2012), additional features which helped it realise this shift in business model included engine health monitoring on a 24-hour basis (Rolls-Royce, 2005), which tracks on-wing performance using onboard sensors, lease engine access to replace an operator's engine during off-wing maintenance which helps minimise downtime, and a global network of authorised maintenance centers to ensure that world-class support

is readily available to customers whenever required. These innovations within the “TotalCare” model effectively turned the physical engine into the equivalent of using a service and helped address the unpredictable timing and cost of engine overhauls and maintenance faced by airlines (Smith-Gillespie et al, 2019). From a risk management perspective, Rolls-Royce chose to change business model and take on availability and maintenance risk factors from their clients in order to create more value added and gain more market share. This ability to take on customer’s risk whilst reducing their own risk came from Rolls-Royce’s business model innovation and its superior technological advancements when compared to peers.

This research chose to take a closer look at productivity consequences after Rolls-Royce servitized its business model. In order to distinguish a period when Rolls-Royce started to change its business model, this research examines the company’s annual reports and utilises a word frequency analysis approach. First, this research analyses Rolls-Royce annual report and found that service offering was not emphasised much until 1999. Starting in their 1999 annual report, service offering was discussed as a way to ensure long term growth for the company. Sir Ralph Robins, the chairman of Rolls-Royce, emphasised the importance of creating embedded value through increasing service activities as more engines start entering service (Rolls-Royce, 1999). The plan to enter service business was also supported by Rolls-Royce’s innovative solutions and its ability to support growing demand from customers who are seeking a full spectrum of service and support (Rolls-Royce, 1999). Based on these annual reports, this study determines year 1999 to be the starting point of servitization of Rolls-Royce’s business model. As a result, the period before year 1999 is considered to be “Pre-Servitization” of Rolls-Royce and period from year 1999 onwards is considered to be “Post-Servitization” of Rolls-Royce.

Second, this research adopted a word frequency analysis approach in order to understand the significance of service in Rolls-Royce’s business model. To illustrate change in business model over time, this research analysed how many times the word “service” was mentioned per page in Rolls-Royce’s annual reports from year 1993 to 2019.

The results in Figure 4.3-1 show a steady increase in the use of the word “service” per page in annual reports, indicating a shift toward service business over time. This research further compares number of times “service” was referenced in Rolls-Royce’s annual reports between the two chosen periods, pre- and post-servitization (Figure 4.3-1). The pre-servitization period (1993-1998) shows an average “service” word count of 0.62 words per page, compared to an average of 1.57 words per page from post-servitization period (1999-2019). This dramatic increase in the number of times “service” was mentioned per page in the annual reports of Rolls-Royce demonstrates its importance toward Rolls-Royce’s business. Figure 4.3-2 also shows another comparison between Rolls-Royce’s EBITDA¹³ which is a measurement of profitability and “service” word count per page between year 1993 and 2019. The graph in Figure 4.3-2 shows a positive correlation between the company’s EBITDA and how Rolls-Royce became more service oriented over time. From the graph, shifting towards servitization commences around 1998 and became steadily in operation after 2002 when the company’s profitability showed an upward increase.

These results from the above analysis confirms that Rolls-Royce had a significant change in business model towards service after 1998, which resulted in improvement in financial performance.

¹³ Earnings before interest, taxes, depreciation, and amortization

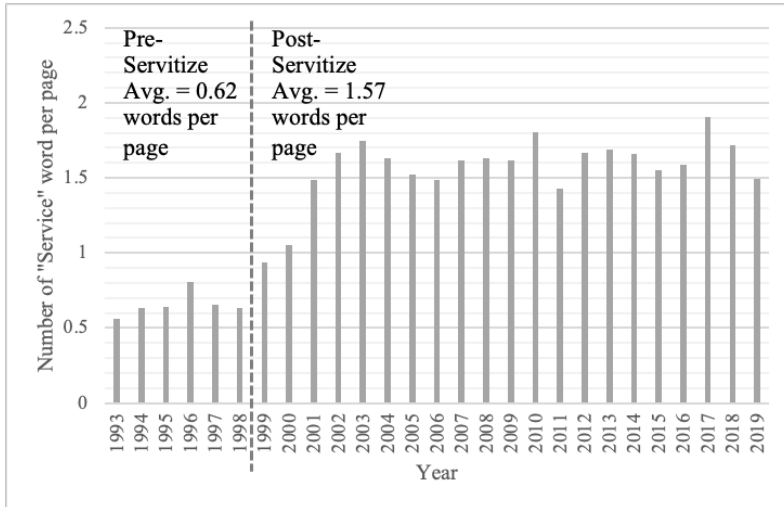


Figure 4.3-1 “Service” word count per page from Rolls-Royce’s annual reports

Source: Annual Report and Authors’ Calculation

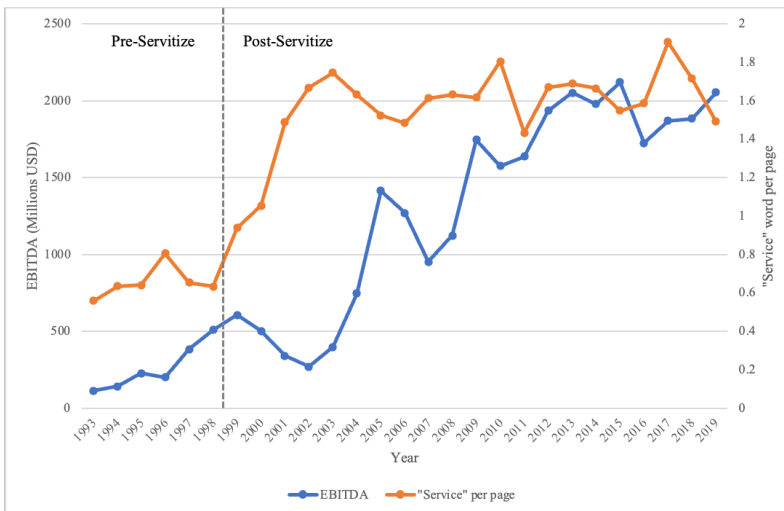


Figure 4.3-2 Rolls-Royce’s EBITDA and “Service” word count per page¹⁴

Source: Capital IQ, Annual Reports, and Authors’ Calculation

¹⁴ EBITDA from 2016 to 2019 is adjusted and calculated using average EBITDA margin from 2013 to 2015. The adjusted is needed due to extraordinary circumstances the company faced between 2016 to 2019 which cause a financial disruption for the company. These circumstances include corruption scandal and subsequent financial settlement between 2016 to 2017 and another major issue with Trent 1000 engine in 2018.

4.4 Methodology

After proposing and selecting Rolls-Royce as a case study firm, this research introduces the method of using both qualitative and quantitative analyses to help understand the relationship between servitization and productivity. The approach used in this research was developed by Brea-Solis et al. (2015), who studied sources of advantage from evolution of business models. This proposed method quantifies links between firm choices and consequences based on Casadesus-Masanell and Ricart (2010, 2011)'s business model decomposition framework. This framework described business models as being composed of two elements; namely, business model choices made by management, and the consequences of these choices. According to Brea-Solis et al. (2015), this causal link between choice and consequences helps explain the logic of the firms and how they create and capture value for their stakeholders. The result of both qualitative and quantitative research can help gain additional insight into the impact of business model lever on productivity, through contribution of price and quantity consequences toward change in profit.

4.4.1 Decomposition of Rolls-Royce's Business Model

In order to understand the business model of Rolls-Royce, an analytical framework developed by Brea-Solis et al. (2015) is implemented in this research. This research identifies categories of levers based on Porter's value chain (1985) which views an integrated set of choices as an explanation of firm's superb performance. According to Brea-Solis et al. (2015), the lever concept is useful in understanding the dual nature of business models which consist of a scale model and a role model. The lever concept also corresponds to a particular set of choices and consequences affecting the success or failure

of a business model. Firms make specific choices to configure each of these levers (Porters and Siggelkow, 2008) corresponding to quantity effect and price effect which then link to profit variation (Grifell-Tatje and Lovell, 2015).

First, this research builds qualitative representations of Rolls-Royce's business model choice using information from annual reports, extracted from the Mergent Archive from year 1990 to 2019. This research focused on specific sections of the annual reports in which company management explain any changes and consequences of the decisions made in each year. These sections include Company profile, Chairman's statement, Chief Executive's review, and Director's review.

To identify levers specific to Rolls-Royce, the relevant information to change in profits of Rolls-Royce based on price consequence and quantity consequence are extracted from the annual reports. This information is clustered into groups and periods, which are then categorised into levers based on the company's value chain adapted from generic value chain (Porter, 1985) and aerospace value chain (Porter and Takeuchi, 2013). This research chooses these two particular value chains because a pre-determined industry value chain is not appropriate to a specific company. According to Porter (1985), each company has a different value chain which embodies significant differences in their business despite being in the same industry. These differences in value chain are a key source of competitive advantage.

Each identified lever is then mapped on to price and quantity consequence based on information extracted from the annual reports. Through this analysis, this research identified a total of 7 categories of lever corresponding to price consequence and quantity consequence (Figure 4.4.1-1) similar to Brea-Solis et al. (2015). Based on the value chain, this research also divided lever choices into broader types of activities to help understand the broad function of each lever. Two types of activities are primary activities and support activities. According to Porters (1985), primary activities are the activities involved in the physical creation of the product and its sale and transfer to the buyer, as well as after-sale

assistance. Support activities are activities which enable primary activities by providing purchased inputs, technology, human resources, and various firmwide functions.

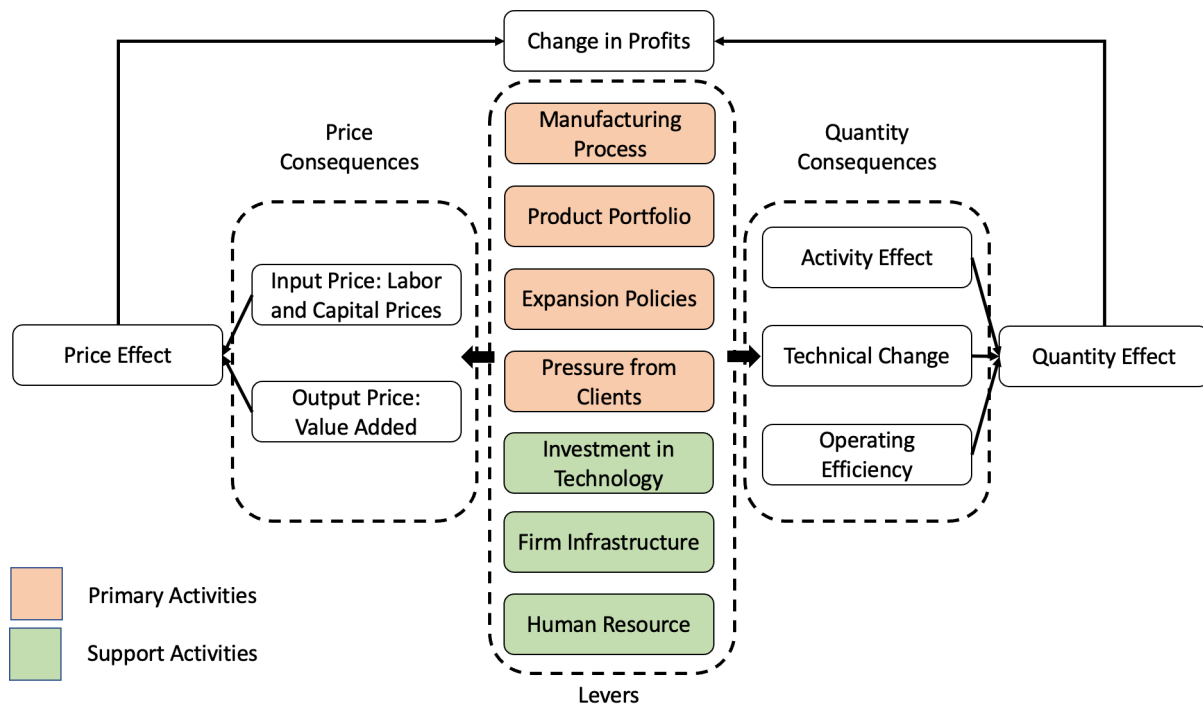


Figure 4.4.1-1 Rolls-Royce’s business model (developed based on Brea-Solis et al., 2015)

The 7 categories choice of lever are identified as follows:

Primary Activity

1. Manufacturing Process lever

The manufacturing process lever is one of the most important levers to help create a competitive advantage for a manufacturing company. This lever is associated with transforming inputs into a final product to be ready for delivery to customers. Rolls-

Royce, as a manufacturing firm, seeks to operate in the most efficient way in order to stay competitive in the market. Increasing efficiency is one of the highest priorities for the company. Operational efficiency, cost savings, supply chain, and risk reduction in manufacturing process are emphasised in both good and bad times. This manufacturing process lever can affect changes in profit of Rolls-Royce through both price and quantity consequence. With improvements in this lever, input price can be reduced, while able to achieve better operating efficiency and development in technical change.

2. Product Portfolio lever

The product portfolio lever is associated with providing customers with choice of products to choose from. Rolls-Royce, as an aero engine provider, offers a wider range of products in order to secure market share and create a strong market position. The quality and price of products and services are considered to satisfy customers' demand. A balanced product portfolio and business model are also needed to increase business resilience and capture growing opportunity in different sectors. This product portfolio lever can impact change in profit of Rolls-Royce through quantity consequence. With more product choice in the portfolio, more sales through activity effect can be captured by the company, while output price can be adjusted based on the product offerings.

3. Expansion Policies lever

The expansion policies lever is associated with increasing presence of the company and product and service to be available for customer to purchase. This research highlighted how Rolls-Royce choose to expand its businesses using different policies. Their strategy to broaden markets and to gain new market share are achieved through their extensive network base, the creation of new partnerships through joint ventures (JV), and the development of new production and service base around the world. This expansion policies lever affects change in profit of Rolls-Royce through quantity consequence. With better expansion policies, Rolls-Royce can increase activity effect

by selling more product in new markets as well as improving operating efficiency through a better network of facilities for after sale service.

4. Pressure from Clients lever

The pressure from clients lever is associated with pressure placed on Rolls-Royce to provide products and services to customers with appropriate terms and condition. Rolls-Royce faces significant external pressure from clients, economic uncertainty, and unexpected internal disruption. These environment conditions often result in volatility of demand and sales. To deal with these risk and uncertainty, Rolls-Royce needs to build a resilient and well positioned business model. This pressure from clients lever can affect changes in profit of Rolls-Royce through both price and quantity consequence. Negative pressure from clients lever can impact output price as well as lower demand from customers which impacts activity effect.

Support Activity

5. Investment in Technologies lever

As technology is embedded in almost every part of the value chain, the investment in technologies lever is a backbone of Rolls-Royce's competitive advantage. This lever is associated with how the company develops new technology in order to improve competitiveness as well as to develop new products to offer to customers. Rolls-Royce needs to develop cutting-edge technology to maintain their strategic position ahead of competitors and attract new demand from new and competitive products and services. A significant percentage of their company investment focuses on research and development (R&D). Technology and R&D are considered to be a core of business and a key to success for Rolls-Royce. This investment in technologies lever can affect change in the profit of Rolls-Royce through both price and quantity consequence. With better technology, Rolls-Royce can increase more value added in its product and service for customers. This, in turn, increasing Rolls-Royce's ability to demand higher selling

price from the customer. Better technology can also help Rolls-Royce improving its operating efficiency, reducing input cost, as well as technical change through spill-over of new technology to industry and vice versa.

6. Firm Infrastructure lever

The firm infrastructure lever is associated with the firm's management, organisational structure, governing affairs, and most of the back office or supporting operational activities. Rolls-Royce manages internal activities including strategic management and internal support structure to maintain and increase efficiency and productivity of the company. Organisational structure needs to be proportional to business and workload in order to maintain competitiveness. Reorganisation, activities rationalisation and cost reduction are needed to increase financial performance for Rolls-Royce. Hence, this firm infrastructure lever can affect changes in profit of Rolls-Royce both by price consequence through input cost and by quantity consequence through operating efficiency.

7. Human Resource lever

The human resource lever is associated with how firms manage human capital, which is one of the most vital inputs to any firm. Rolls-Royce relies on the human dimension to ensure a long-term competitive level. The company invests heavily in education and training for their employees and management to help improve firm's operational performance. Optimal headcount is also a big factor for company's productivity. This human resource lever can impact changes in profit of Rolls-Royce through both price and quantity consequence. Appropriate human capital through this human resource lever can help the company manage both input price from labour cost and operational efficiency effect.

To understand how each of the particular lever choices are corresponding to consequences of different business model choice, this research breakdown the analysis into two periods of pre and post-servitization based on analysis in section 4.3. The pre-servitization period is indicated to be a period between year 1992-1998 and post-servitization period to be between year 1999-2019. This research compares levers between these two periods through information mentioned by the company's management team which are extracted from the company annual reports. The findings of this research highlight that whilst there was no change in levers between two periods of two different business models, there is a significant shift in priority and focus of each lever resulted from the company servitizing its business model.

Business model choices between 1992-1998: Pre-Servitization of Rolls-Royce

During the pre-servitization period, Rolls-Royce operated on a reputation of excellence and focused on quality of its products. The company operated with two main business units which were the Aerospace Group and Industrial Power Group. The Aerospace Group built gas turbines for both civil and military aircraft, whilst the Industrial Power Group built power generation, transmission and distribution systems and major equipment for mining, marine propulsion, oil pumping, offshore and defence markets. In this period, Rolls-Royce wanted to improve global market presence and secure its market position through the development of new products and services. The company also had an aspiration to become the most efficient supplier in the industry. Rolls-Royce's business model choice during this pre-servitization period can be reflected through the following levers.

Primary Activity

1. Manufacturing Process lever

During the pre-servitization period, Rolls-Royce aimed to increase its worldwide operation's efficiency (Rolls-Royce, 1994) by focusing on cost-effectivity through lean manufacturing and streamlined manufacturing process (Rolls-Royce, 1995). The company based new products on known technologies to reduce cost and risk (Rolls-Royce, 1996). During this period, Rolls-Royce also re-engineered its repair process and overhaul business by reducing amount of time it took to overhaul engines (Rolls-Royce, 1997). Therefore, the manufacturing process lever impacted the company's profit variation through operational efficiency in quantity consequence, and input price consequence during this period.

2. Product Portfolio lever

During the pre-servitization period, Rolls-Royce had created one of the strongest product portfolios representing the world's broadest range of aero engine offered (Rolls-Royce, 1991). The company's strategy was to gain market share through product quality and a strong product portfolio (Rolls-Royce, 1992). Rolls-Royce provided products to customers with outstanding performance and real cost saving for the customers from higher efficiency and reliability (Rolls-Royce, 1992). As a result, more customers adopt and use Rolls-Royce's products.

Apart from products, service was also being offered to expand new customer group who has not previously been a Rolls-Royce's customer (Rolls-Royce, 1994). With more product and service offered, the company saw customers from other competitors switching to Rolls-Royce toward the end of pre-servitization period (Rolls-Royce, 1996). Reputation for reliability of Rolls-Royce's product led to more sales (Rolls-Royce, 1996). The company also rolled out new engines which developed a future embedded value in form of profitable aftermarket business (Rolls-Royce, 1997). Rolls-Royce became a top three aero-engine manufacturer in the world with the world largest leasing business at the end of this period (Rolls-Royce, 1997). In this period, Rolls-

Royce's profit variation through price consequence from ability to control output price were a result of the product portfolio lever.

3. Expansion Policies lever

During the pre-servitization period, Rolls-Royce improved its competitive position in the international market through the successful introduction of expansion policies (Rolls-Royce, 1994). One of the company's strategies was to increase penetration into world markets and to become a global company (Rolls-Royce, 1992). Their extensive network of joint ventures and new subsidiaries with oversea operation were seen as necessary tools to be competitive and to capture new opportunities (Rolls-Royce, 1993). Rolls-Royce also used the merger and acquisition (M&A) strategy to increase its comprehensive product family (Rolls-Royce, 1994). With an extensive network across the world, Rolls-Royce doubled its repair overhaul market share between year 1995-1997 (Rolls-Royce, 1997). In this period, the expansion policies lever had an impact on the company's profit variation mainly through quantity consequence from activity effect and operating efficiency.

4. Pressure from Clients lever

During the pre-servitization period, many of Rolls-Royce's businesses relied heavily on customers' orders which fluctuated based on the general health of the global economy. At the start of this pre-servitization period, the global economy was still in recession, resulting in a suppression of the demand for the company's products (Rolls-Royce, 1992). The global economic condition improved later in this period, nevertheless year 1997 to 1998 saw another global financial crisis in Asia (Rolls-Royce, 1998). With disruption from economic factors and the company's own internal factors, pressure from clients lever had an impact on the company's profit variation through quantity consequence, specifically activity effect.

Support Activity

5. Investment in Technologies lever

As 90% of Rolls-Royce's products were built around gas turbine technology during the pre-servitization period, the company considered itself to bring advanced technology to aerospace and industrial power systems market worldwide through its gas turbine technology (Rolls-Royce, 1994, 1997). Investment in cost effective technology, product infrastructure, product development, and R&D investment were emphasised throughout this pre-servitization period. Investment in technologies by the company was targeted to help enhance product competitiveness and bring product to the market (Rolls-Royce, 1995). Investment in technologies also improved the company's ability and internal capability to deliver products faster and at a lower cost (Rolls-Royce, 1997). Investment in technologies has become the main lever which help drives change in profit through both quantity and price consequences, particularly activity effect, technical change, and price effect through output price.

6. Firm Infrastructure lever

During the pre-servitization period, strategic management and firm infrastructure played an important role for Rolls-Royce, especially in challenging times. The consolidation of activities and restructuring of production facilities and manufacturing capacity were implemented to improve future competitiveness of the company (Rolls-Royce, 1991). Rationalisation of plants and workforce reduction were necessary to lower cost, to increase productivity, to create efficiency, to reduce lead time, and to maintain competitiveness (Rolls-Royce, 1992). Reorganisation and modification of management became priorities of the business (Rolls-Royce, 1993). For Rolls-Royce, the firm infrastructure lever effected change in profit through both price and quantity consequences. Price consequence was impacted by input price effect, while quantity consequence was impacted by operating efficiency.

7. Human Resource lever

During the pre-servitization period, Rolls-Royce credited workforce to have an impact on productivity improvement (Rolls-Royce, 1993). A high priority was given to workforce management and well-being to ensure that Rolls-Royce can remain competitive (Rolls-Royce, 1995). Rolls-Royce invested heavily in training and developing employee at all levels (Rolls-Royce, 1997). Overall, the human resource lever had an impact on the company's profit variation in terms of quantity and price consequences from operating efficiency and input price.

Business model choices between 1999-2019: Post-Servitization of Rolls-Royce

After the mid of 1990's, Rolls-Royce continued its operation to become a preferred supplier in the industry. Through this period, their investments to achieve better efficiency and to develop new products and service started to pay off. The company gained more market share and started to hold a leading position in operating markets. As more customers started seeking a full spectrum of service and support throughout the product life cycle, Rolls-Royce's focus then shifted towards achieving both short term profitability as well as providing long term value to the customers. As a result, Rolls-Royce started to develop solutions to serve customers using the aftermarket program. With pressure to improve its position in a growing market, Rolls-Royce decided to start offering product as a service through TotalCare commencing around year 1998-1999. Due to changes in the company's business model toward providing product as a service, Rolls-Royce had to alter some configuration in its business model levers. While other levers remained an important part of Rolls-Royce's business model, the following levers are argued to be key changes to Rolls-Royce's significant shift toward service during the post-servitization period.

Product Portfolio lever

Complimenting by the investment in technologies lever, product portfolio is another key lever which changed during the transition period from the pre-servitization to post-servitization. Despite developing a wide range of products, Rolls-Royce's product selection was changed to become much more aftermarket focused (Rolls-Royce, 1998). Over time, the company's product mix changed significantly from product oriented to service oriented. Service revenue increased from 35% of total sales in year 2000 to 55% of total sales in year 2004. Service revenue from programs such as TotalCare provided Rolls-Royce with more predictable and growing source of revenue based on increasing numbers of long-term contractual relationship with customers (Rolls-Royce, 2003). By year 2008, 90% of new engines sold by Rolls-Royce fell under their TotalCare subscription model. Overall, when compared to the pre-servitization period, the post-servitization period shows a shift in the product portfolio lever that impacted the company's profit variation mainly through quantity consequence from a change in activity effect, instead of the price consequence found in the pre-servitization period.

Pressure from Clients lever

With a new business model in the post-servitization period, there is a change in impact from pressure from clients lever toward the company's profit variation. In this period, there was a big shift in demand from customers toward a complete business solution rather than just a demand for product. As a result, Rolls-Royce captured this demand using its newly introduced service offerings. With more predictable and stable cash flow from their new service revenues, Rolls-Royce's resilience to short term challenges improved significantly. The shift in pressure from clients had shown through the company's ability to weather through uncertainty in demand in events such as 9/11 attack in 2001, Iraq war in 2002, and global financial crisis in 2008. As a result, similarly to the pre-servitization period, the pressure from clients lever still plays a big part in the company's profit variation from quantity consequence, specifically activity effect. However, in the post-servitization

period, the effect of the pressure from clients lever impacted the company's profit variation through price consequence from lower output price as a result of business model change.

Investment in Technologies lever

With help from investment in technologies in the pre-servitization period, Rolls-Royce was now able to offer better reliability and flexibility in its product to customers through the use of new technologies such as real-time data systems, advanced electrical systems and diagnostic technologies (Rolls-Royce, 2000). With new technologies available for predicting behaviour of components in service, Rolls-Royce can minimise interruption to operations and maximise the availability of assets to customers. By providing real time information and engine management, the use of artificial intelligence (AI) to monitor the health of system enabled Rolls-Royce to offer a growing range of value-added services (Rolls-Royce, 2000, 2001). As a result, Rolls-Royce was able to develop new service offerings for customers based on the outcome of past investment in technologies. With many new technologies resulting from the investments in the pre-servitization period, the emphasis on investment in technologies lever started to decline in the post-servitization period. The focus of R&D and investment in technologies during the post-servitization period by Rolls-Royce was aimed to just improve efficiency and to create new products (Rolls-Royce, 1999). Like the pre-servitization period, investment in technologies lever still mainly effect company's profit variation through quantity consequence, especially technical change. However, instead of activity effect and output price effect found in the pre-servitization period, price consequence from better input price and quantity consequence from improvement in operating efficiency are the main factors effecting profit variation resulting from the investment in technologies lever in the post-servitization period.

Other levers

When compared the post-servitization to the pre-servitization period, other levers including manufacturing process lever, expansion policies lever, firm infrastructure lever, and human resource lever remained to have the same effect on the company's profit variation from price and quantity consequences. However, the magnitude of the consequences and effects from each lever are different in the post-servitization period due to servitization.

Manufacturing Process lever

In term of the manufacturing process lever, the company continued to focus on improvements in efficiency and cost reduction after servitization. Significant improvements in delivery performance, manufacturing lead time and operating cost were achieved in this post-servitization period (Rolls-Royce, 2002). During this period, Rolls-Royce was transformed into a true lean enterprise from its simplified manufacturing process (Rolls-Royce, 2015). When compared to pre-servitization period, the manufacturing process lever continued to affect the company's profit variation through quantity consequence; from improvement in operational efficiency and technical change and price consequence from lower input price.

Expansion Policies lever

Similar to the pre-servitization period, the expansion policies lever continued to play a vital role to help Rolls-Royce expand its market share in the aftermarket segment. Merger and acquisition (M&A) still play a big part in the company's product and capability expansion. Moreover, Rolls-Royce expanded its repair and overhaul activities and comprehensive network mainly by working with strong partners through joint venture using risk and revenue sharing. Growing in comprehensive international network through M&A had helped Rolls-Royce with ability to access markets on global basis (Rolls-Royce, 2006). Similar to pre-servitization period, the effect on profit variation from expansion policies

lever is impacted through quantity consequence from improvement in operational efficiency and increase in activity effect.

Firm Infrastructure lever

For the firm infrastructure lever, Rolls-Royce's reorganisations were implemented to help improve customer focus and efficiency during this post-servitization period (Rolls-Royce, 1998). However, these major restructures of the firm infrastructure were seen throughout both pre-servitization and post-servitization periods due to nature of the industry which often comprise of both unexpected internal and external shocks. Because of these shocks, such as recession or operational disruption, which impacted demand and the firm's profitability, the firm infrastructure lever is often needed and plays a critical role for the survival of the company. Similar to the pre-servitization period, company's profit variation from the firm infrastructure lever is impacted through price and quantity consequences, especially from lower input price and increase in operating efficiency respectively.

Human Resource lever

Lastly, similar to the pre-servitization period, development of human capital, recruitment, and reduction in headcount were executed throughout the post-servitization period as part of human resource management. For example, according to Rolls-Royce (2003, 2004), the company completed a major rationalisation program including a net reduction of employee. Nevertheless, the company still invested in development opportunities and training programs for employee in this period. As a result of servitization, human resource lever still mainly affects profit variation in post-servitization period from better operating efficiency in quantity consequence and reduction in input price in price consequence.

With an improvement from servitization business model, the overall impact of the manufacturing process lever, the expansion policies lever, the firm infrastructure lever, and the human resource lever have similar corresponding consequences of different business

model choice toward change in profit from the pre-servitization period to the post-servitization period. Meanwhile, product portfolio lever, pressure from clients lever, and investment in technologies saw a significant shift in their corresponding consequences and effects toward the company's profit variation.

4.4.2 Quantifying The Effect of Rolls-Royce's Business Model Choice

After qualitatively mapping levers and consequences together in both pre-servitization and post-servitization periods, this research further quantifies the impact of Rolls-Royce's decision to servitize on productivity by decomposing change in profit into price effect and quantity effect which can then link to the levers from section 4.4.1.

To help assess the impact of Rolls-Royce's levers on firm's productivity, this study proposes a quantitative method using the theory of index numbers and the production theory based on Brea-Solis et al. (2015)'s framework. Through the combination of theory of index number and the production theory, this method helps link price and quantity consequences with price and quantity effects through profit decomposition. As productivity change effect is a part of quantity effect, the result of this proposed approach can help give an understanding of how each of Rolls-Royce's business model levers impacts change in profit and hence productivity in more detail.

Through profit decomposition, this proposed framework provides quantitative insight into Rolls-Royce's business model choices and productivity consequence. According to Brea-Solis et al. (2015), the theory of index numbers allows the impact on profit change from price consequence and quantity consequence to be estimated quantitatively. Moreover, the production theory helps provide insights on the relative contribution of different factors including productivity change effect toward quantity consequence.

By applied Grifell-Tatje and Lovell's (2015) profit decomposition framework (Figure 4.4.2-1), this research maps qualitative representations with analytical models that quantify Rolls-Royce's source of competitive advantage over time.

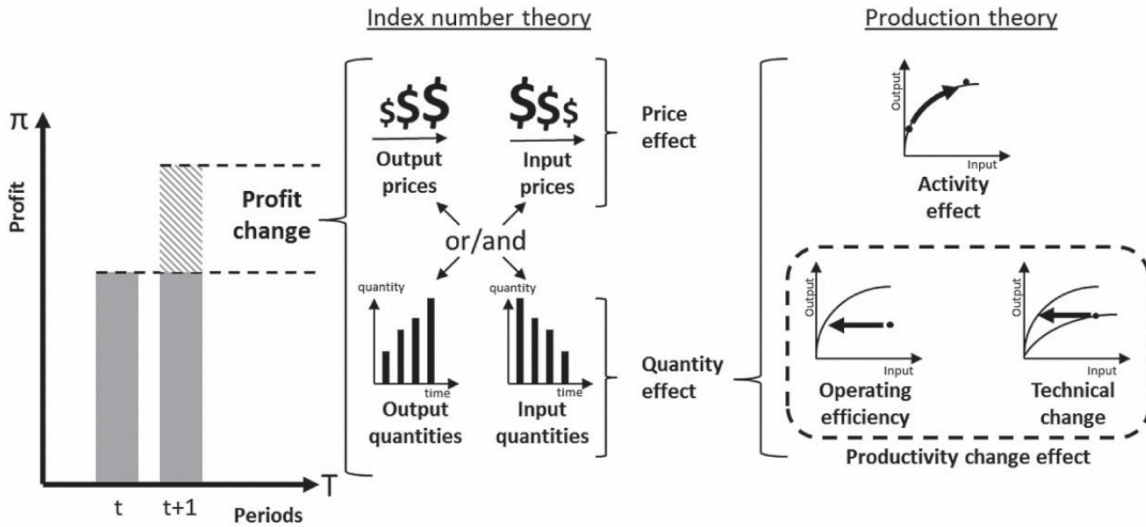


Figure 4.4.2-1 Profit Decomposition Diagram

Source: Brea-Solis et al. (2015)

The profit decomposition method comprises two stages. Based on Bennet's profit change decomposition (Grifell-Tatje and Lovell, 2015), profit change in this research is decomposed and defined as follows:

$$\pi^{t+1} - \pi^t = [\bar{p}^T(y^{t+1} - y^t) - \bar{w}_c^T(x_c^{t+1} - x_c^t) - \bar{w}_l^T(x_l^{t+1} - x_l^t)] + [\bar{y}^T(p^{t+1} - p^t) - \bar{x}_c^T(w_c^{t+1} - w_c^t) - \bar{x}_l^T(w_l^{t+1} - w_l^t)] \quad (1)$$

Where the profit (π) is equal to revenue minus operating cost or $\pi = p^T y - w^T x$. Revenue (R) is $R = p^T y = \sum p_m y_m$ where output vectors are $y = (y_1, \dots, y_M) \in R_+^M$ and output price vectors are $p = (p_1, \dots, p_M) \in R_{++}^M$. Operating cost (C) is $C = w^T x = \sum w_m x_m$

where input vectors are $x = (x_1, \dots, x_M) \in R_+^N$ and input price vectors are $w = (w_1, \dots, w_M) \in R_{++}^N$. Vector \bar{p} , \bar{y} , \bar{w} and \bar{x} are averages of current and next period vectors.

The first stage is using index number theory to deconstruct profit change into price effect and quantity effect. Price effect can further breakdown into impact of input price and output price. First term in Equation (1) is the quantity effect or how change in quantity between year t and t+1 effect changes in profit. The quantity effect consists of activity effect and productivity effect base on production theory. The quantity effect can be written as Equation (2).

$$\text{Quantity Effect} = \left[\bar{p}^T (y^{t+1} - y^t) - \bar{w}_c^T (x_c^{t+1} - x_c^t) - \bar{w}_l^T (x_l^{t+1} - x_l^t) \right] \quad (2)$$

The second term in Equation (1) is the price effect or how change in price between year t and t+1 affect changes in profit. Price effect can be broken down into input price and output price. The price effect can be written as Equation (3).

$$\text{Price Effect} = \left[\bar{y}^T (p^{t+1} - p^t) - \bar{x}_c^T (w_c^{t+1} - w_c^t) - \bar{x}_l^T (w_l^{t+1} - w_l^t) \right] \quad (3)$$

In the second stage, quantity effect is decomposed into activity effect, operating efficiency effect, and technical change effect. Based on Equation (2) and Figure 4.4.2-1, quantity effect can be decomposed and written as term (4) where (5) is activity effect, (6) is operating efficiency effect, and (7) is technical change effect. According to Brea-Solis et al. (2015), activity effect measures how much variation in profit is due to changes in sales volume and change in the volume of inputs employed. Operating efficiency effect measures the change in the difference between the chosen number of inputs used to produce the observed level of output and the efficient number of inputs needed to produce that level of output. Technical change effect measures changes in efficient quantity input needed to product output from industry-wide improvement in technology.

$$[\overline{p}^T(y^{t+1} - y^t) - \overline{w}_c^T(x_c^{t+1} - x_c^t) - \overline{w}_l^T(x_l^{t+1} - x_l^t)] \quad (4)$$

$$= [\overline{p}^T(y^{t+1} - y^t) - \overline{w}_c^T(x_c^C - x_c^B) - \overline{w}_l^T(x_l^C - x_l^B)] \quad (5)$$

$$+ \overline{w}_c^T(x_c^t - x_c^A) - \overline{w}_l^T(x_l^{t+1} - x_l^C) + \overline{w}_c^T(x_c^t - x_c^A) - \overline{w}_l^T(x_l^{t+1} - x_l^C) \quad (6)$$

$$+ \overline{w}_c^T(x_c^A - x_c^B) - \overline{w}_l^T(x_l^A - x_l^B) \quad (7)$$

To be able to calculate activity effect, operating efficiency effect, and technical change effect, unobserved input vectors x^A , x^B , and x^C are required to be calculated. According to Brea-Solis et al. (2015), the input vector x^A is equal to $\theta^A x^t$, the input vector x^B is equal to $\theta^B x^t$, and the input vector x^C is equal to $\theta^C x^{t+1}$. This research uses data envelopment analysis (DEA) to calculate θ^A , θ^B , and θ^C based on the value of the input distance function $D^t(y^t, x^t) = 1/\theta^A$, $D^{t+1}(y^t, x^t) = 1/\theta^B$, and $D^{t+1}(y^{t+1}, x^{t+1}) = 1/\theta^C$.

The second stage of analysis uses data envelopment analysis (DEA) method (Charnes et al., 1978; Fare et al., 1994) to help calculate distance function in order to decompose quantity effect into activity effect, operating efficiency effect, and technical change effect based on production theory (Grifell-Tatje and Lovell, 2015). The DEA approach uses a nonparametric frontier as a benchmark for efficiency measure. According to Coelli and Rao (2005), DEA is a linear programming methodology which use input and output quantities from a group of comparable companies to construct a piece-wise linear frontier (Figure 4.4.2-2). Introduced by Farrell (1957), this approach calculates distance function and its relationship to the technical-efficiency measure which can then be used to decompose productivity into a change in efficiency and a change in technology (Fare et al., 1994).

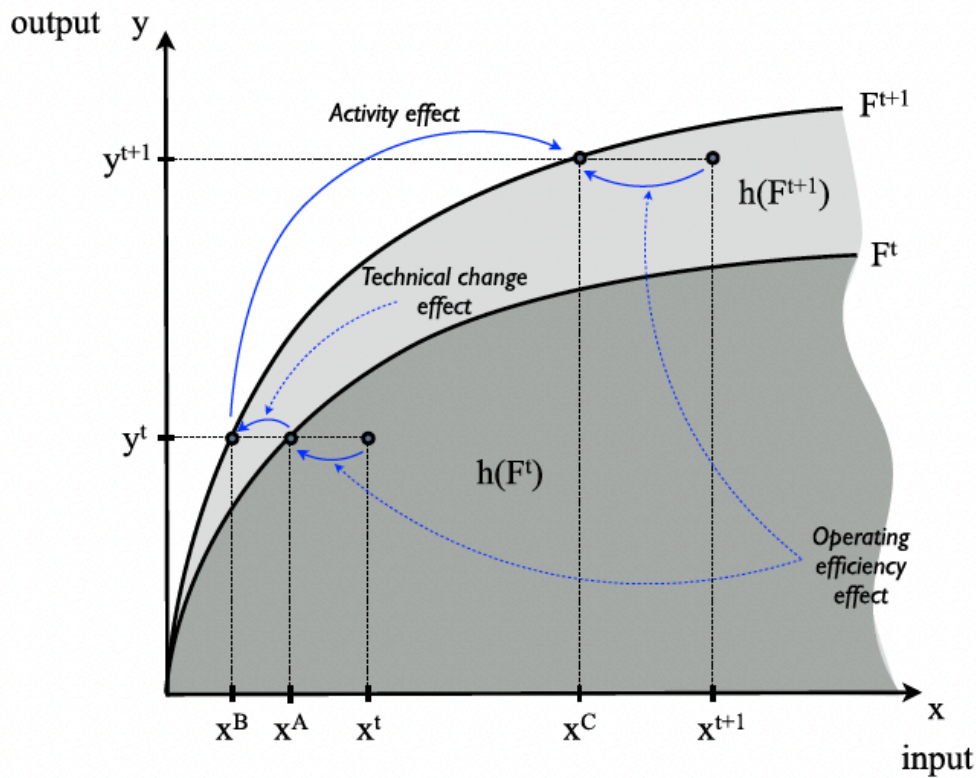


Figure 4.4.2-2 Decomposition of Quantity using Frontier Analysis

Source: Brea-Solis et al. (2015)

For DEA analysis, this research derived DEA results using STATA programming. Like Fare et al. (1994), this research applies output orientation constant-return-to-scale (CRS) technology assumption to the DEA analysis. Output orientation CRS is selected as an assumption in this research based on limitations from investment and input constraints faced by manufacturers. With these limitations and constraints, manufacturers often have to maximise output from a given set of inputs. With output oriented, DEA method seeks the maximum proportional increase in output production, with input levels held constant. By using constant-return-to-scale, output or input oriented should also provide the same technical efficiency score (Coelli and Rao, 2005). Apart from helping decompose quantity effect into activity effect, operating efficiency effect, and technical change effect based on production theory, the DEA result from this research is used to help compare how Rolls-

Royce is ranked among different comparable firms based on its efficiency and its relationship to the efficient frontier.

4.5 Data

Following the analytical model being introduced and explained in Section 4.4.2, this section provides explanations of where the data comes from and how each variable is calculated. To execute the proposed two-stage profit decomposition method, this research obtained Rolls-Royce's financial data¹⁵ between year 1990 to 2019 from S&P Capital IQ database and company's annual reports which extracted from Mergent Archives.

Similar to Brea-Solis et al. (2015), the followings variables are used to calculate two-stage profit decomposition method. Profit is defined as revenue minus cost of goods sold (COGS), selling, general and administrative expenses (SG&A) and interest expense. Output (y) is defined by sales. Price (p) is defined by sales minus COGS per unit of output. Quantity of labour input (x_l) is defined by number of employee. Cost of labour (w_l) is defined by SG&A per employee. Quantity of capital input (x_c) is defined by net property, plant and equipment. And cost of capital (w_c) is defined by depreciation and amortisation plus net interest paid to the quantity of capital input.

To estimate DEA analysis using best practice frontier in the second stage of the analysis, peer samples of Rolls-Royce are defined based on key competitors mentioned by Rolls-Royce in their annual reports and research report by Fortune Business Insight (2020). The list of company includes Bombardier Inc (Canadian manufacturer of aircraft, rail

¹⁵ The average data of Rolls-Royce can be found in Appendix D.

transportation equipment and systems, and motorised consumer products), MTU Aero Engines AG (German leading aircraft engine manufacturer), MAN SE (German manufacturing and engineering company with primary output of commercial vehicles and diesel engines), GE (American multinational conglomerate and a parent company of Engine Alliance which is an American aircraft engine manufacturer), Raytheon Technologies Corporation (American multinational aerospace and defence conglomerate, former United Technologies Corporation and Raytheon Company; parent company of Pratt and Whitney (American aerospace manufacturer) and Engine Alliance), Honeywell International Inc. (American multinational conglomerate which operates in four areas of business: aerospace, building technologies, performance materials and technologies, and safety and productivity solutions) and Safran SA (one of the world largest aircraft equipment manufacturer). These companies are direct competitors of Rolls-Royce with similar product and service offerings as well as conglomerate structure which are suitable to be used in constructing a nonparametric frontier as a benchmark for efficiency measure. The financial data¹⁶ (between year 1990 to 2019) of the seven main Rolls-Royce competitors used in this analysis was obtained from S&P Capital IQ database. This research implemented data cleaning by replacing any missing data with data acquired from the companies' annual reports which were extracted from Mergent Archives. For a comparison purpose, this research also implements foreign currency conversion of all the data to US dollar value based on year-end exchange rate provided by the Bank of England. The movement of exchange rate and purchasing power using CPI have been incorporated into the analysis but are not materially affect the result.

¹⁶ The average data of Rolls-Royce's seven main competitors can be found in Appendix E.

4.6 Result and Discussion

Based on the presented method to assess the impact of Rolls-Royce's business model choice on productivity, the results of the company's profit decomposition are shown in Table 4.6-1. From the column, profit is broken down based on two stages of the analysis. In the first stage, change in profit is decomposed into price effect and quantity effect. In the second stage of analysis, quantity effect is then decomposed into activity effect and productivity effect. Productivity effect is further broken down into technical change effect and operational efficiency effect. The last column of the table also shows a ranking between Rolls-Royce and peers sample using frontier analysis. Table 4.6-2 shows a result from the decomposition of price effect which broken down into input price effect and output price effect. From both table 4.6-1 and 4.6-2, the results show average numbers of each decomposition. Average numbers are divided into two periods: pre-servitization period (year 1992-1998) and post-servitization period (year 1998-2019).

Table 4.6-1 Decomposition of Change in Profit of Rolls-Royce from 1993 to 2019 (in million USD)

Period	Change in profits		Change in profits		Quantity effect		Activity effect		Quantity effect		Productivity effect		Productivity effect		Rank compare to peers	
	Price effect	Quantity effect	Price effect	Quantity effect	Activity effect	Productivity effect	Technical change	Operational efficiency	Technical change	Operational efficiency	t	t+1	t	t+1		
1992-1993	390.06	382.53	7.53	-17.00	24.53	-33.41	57.94	-33.41	4/6	6/6			4/6	6/6		
1993-1994	-26.39	-17.37	-9.02	-34.43	25.41	28.98	-3.57	28.98	6/6	6/6			6/6	6/6		
1994-1995	39.12	-63.68	102.80	96.96	5.84	-16.27	22.11	-16.27	6/6	6/6			6/6	6/6		
1995-1996	-304.92	-461.73	156.81	125.63	31.18	17.10	14.08	17.10	6/6	8/8			6/6	7/8		
1996-1997	186.25	142.33	43.92	42.16	1.76	-13.59	15.35	-13.59	8/8	7/8			8/8	7/8		
1997-1998	130.28	66.25	64.03	20.71	43.32	18.47	24.86	18.47	7/8	6/8			7/8	6/8		
Aug.1992-1998	69.07	8.06	61.01	39.00	22.01	-5.21	27.22	-5.21								
1998-1999	-210.31	-78.10	-132.21	-67.34	-64.87	-42.46	-22.41	-42.46	6/8	6/8			6/8	6/8		
1999-2000	-142.67	-341.72	199.05	161.48	37.56	-92.87	130.43	-92.87	6/8	6/8			6/8	6/8		
2000-2001	-70.11	-184.64	114.53	38.89	75.64	86.60	-10.96	86.60	6/8	6/8			6/8	6/8		
2001-2002	26.73	20.53	6.20	-47.91	54.11	39.53	14.57	39.53	6/8	6/8			6/8	6/8		
2002-2003	153.31	-60.33	213.64	11.27	202.38	305.07	-102.69	305.07	6/8	5/8			6/8	5/8		
2003-2004	420.24	185.09	235.15	111.18	123.98	-46.28	170.26	-46.28	5/8	3/8			5/8	3/8		
2004-2005	673.45	664.60	8.85	36.51	-27.66	-24.37	-3.29	-24.37	3/8	4/8			3/8	4/8		
2005-2006	-186.76	-676.21	489.45	332.50	156.94	47.09	109.85	47.09	4/8	2/8			4/8	2/8		
2006-2007	-327.76	-388.55	60.80	69.79	-8.99	-155.35	146.36	-155.35	2/8	4/8			2/8	4/8		
2007-2008	4104.35	4787.98	-683.63	-588.75	-94.88	-67.60	-27.27	-67.60	4/8	6/8			4/8	6/8		
2008-2009	-6248.85	-7033.67	784.82	589.27	195.55	256.69	-61.15	256.69	6/8	3/8			6/8	3/8		
2009-2010	2769.21	2737.32	31.88	-16.29	48.18	-23.38	71.56	-23.38	3/8	3/8			3/8	3/8		
2010-2011	88.27	224.58	-136.31	-136.31	0.00	292.04	-292.04	292.04	1/8	1/8			1/8	1/8		
2011-2012	424.62	68.00	356.62	296.47	60.15	0.00	60.15	0.00	1/8	1/8			1/8	1/8		
2012-2013	117.39	-140.83	258.22	258.22	0.00	0.00	0.00	0.00	1/8	1/8			1/8	1/8		
2013-2014	-85.30	446.82	-532.11	-317.48	-214.63	-419.53	204.90	-419.53	1/8	4/8			1/8	4/8		
2014-2015	159.53	245.99	-86.46	-180.43	93.97	-235.71	329.68	-235.71	4/8	5/8			4/8	5/8		
2015-2016	-1634.68	-1230.63	-404.05	-214.33	-189.72	-323.25	133.53	-323.25	5/8	7/8			5/8	7/8		
2016-2017	141.25	95.70	45.55	-120.51	166.06	683.07	-517.01	683.07	7/8	4/8			7/8	4/8		
2017-2018	-2055.96	-1924.51	-131.45	244.48	-375.93	-522.54	146.61	-522.54	4/8	5/8			4/8	5/8		
2018-2019	304.63	406.55	-101.92	-329.54	227.62	520.05	-292.43	520.05	5/8	6/8			5/8	6/8		
Aug.1998-2019	-75.21	-103.62	28.41	6.25	22.16	13.18	8.98	13.18								
Aug.1992-2019	-43.15	-78.80	35.66	13.53	22.13	9.09	13.04	9.09								

Source: Authors' Calculation

Table 4.6-2 Decomposition of Price Effect of Rolls-Royce from 1993 to 2019 (in million USD)

	Output price	Output price effect	Input price K	Input price L	Input price effect	Price effect
1992-1993	411.34	411.34	9.24	19.56	28.81	382.53
1993-1994	93.59	93.59	34.11	76.85	110.96	-17.37
1994-1995	-29.97	-29.97	-32.50	66.21	33.71	-63.68
1995-1996	-240.77	-240.77	142.12	78.83	220.95	-461.73
1996-1997	119.56	119.56	-41.55	18.77	-22.77	142.33
1997-1998	57.24	57.24	-87.57	78.56	-9.01	66.25
Total 1992 - 1998	411.00	411.00	23.86	338.79	362.66	48.34
1998-1999	44.61	44.61	72.20	50.51	122.71	-78.10
1999-2000	-232.34	-232.34	-60.37	169.75	109.38	-341.72
2000-2001	-76.04	-76.04	57.61	50.99	108.60	-184.64
2001-2002	47.42	47.42	-116.98	143.87	26.89	20.53
2002-2003	136.26	136.26	-33.05	229.65	196.59	-60.33
2003-2004	401.18	401.18	101.26	114.83	216.10	185.09
2004-2005	591.69	591.69	18.78	-91.68	-72.91	664.60
2005-2006	-406.54	-406.54	181.90	87.77	269.67	-676.21
2006-2007	-426.16	-426.16	1.77	-39.38	-37.61	-388.55
2007-2008	84.02	84.02	-4486.54	-217.41	-4703.96	4787.98
2008-2009	60.84	60.84	6893.12	201.38	7094.51	-7033.67
2009-2010	-72.46	-72.46	-2958.94	149.15	-2809.79	2737.32
2010-2011	373.13	373.13	20.65	127.90	148.55	224.58
2011-2012	80.01	80.01	24.58	-12.57	12.01	68.00
2012-2013	-188.36	-188.36	-47.78	0.25	-47.53	-140.83
2013-2014	396.28	396.28	194.79	-245.32	-50.53	446.82
2014-2015	116.53	116.53	3.72	-133.18	-129.46	245.99
2015-2016	-636.81	-636.81	-43.17	636.99	593.82	-1230.63
2016-2017	-798.02	-798.02	-227.57	-666.14	-893.71	95.70
2017-2018	-1761.81	-1761.81	-184.87	347.57	162.70	-1924.51
2018-2019	-406.82	-406.82	-356.77	-456.60	-813.37	406.55
Total 1998-2019	-2673.37	-2673.37	-945.67	448.32	-497.35	-2176.03
Total 1992-2019	-2262.38	-2262.38	-921.80	787.11	-134.69	-2127.69

Decomposition of Profit

From Table 4.6-1, the results show that average change in profit for Rolls-Royce during the pre-servitization period of USD 69.07 million (mm) is mainly resulting from quantity effect rather than price effect. During the pre-servitization period, average quantity effect is USD 61.01mm, while average price effect is USD 8.06mm.

However, average change in profit for Rolls-Royce decreased dramatically to USD -75.21mm in the post-servitization period mainly from both decrease in price effect and quantity effect. During the post-servitization period, the average price effect decreased more drastically to USD -103.62mm, while quantity effect also decreased to USD 28.41mm.

To understand why there is a radical reduction in both price and quantity effect post servitization of Rolls-Royce, this study further investigates by decomposing each of the effects.

Decomposition of Price Effect

With a decrease in price effect during the post-servitization period, this research looks deeper into a significant change in price effect between the two identified periods. Table 4.6-2 shows that the average price effect turned negative post servitization period mainly due to large magnitude of fluctuations in yearly price effect. To break it down, the negative price effect post servitization period is a result of larger negative declines in average output price effect, while offsetting with help from reduction in average input price effect.

This decline in output price and reduction in input price are consistent with the impact of change in Rolls-Royce's business model choice. To understand the effect of servitization, this research further compares output price and input price effect for both pre- and post-servitization periods.

Output Price

Causing a negative change in profit for Rolls-Royce in the post-servitization period, a major negative output price effect in the post-servitization period comes from both business model change and operational disruption.

For business model change, Rolls-Royce moved from a product-centric strategy to the subscription business model which caused a change in the output price through shifts in product portfolio lever and investment in technologies lever.

However, the important reason for a decline in output price came from operational disruption by the company, which was being impacted through pressure from clients lever, especially between 2017-2018. This was when Rolls-Royce faced a significant disruption from major issues found in Trent 1000 engine between year 2017-2018. According to a statement in 2018 full year presentation by the company's CEO Warren East, Rolls-Royce faced an unacceptable level of customer disruption and expected to incur cash cost to mitigate in service issues on Trent 900 and Trent 1000 of up to GBP 1.5 bn and material until 2020.

Input Price

On the other hand, a reduction in input price effect occurred throughout the post-servitization period. This is due to the nature of a new business model caused by a shift in manufacturing process lever, investment in technologies lever, firm infrastructure lever, and human resource lever. According to Lee et al. (2016), obtaining cost efficiency is found to be an important factor to achieving competitive advantage in the servitization strategy. The company's policies to increase efficiency, better cost control and lower investment of the capital are also big factors in reducing input cost. According to a statement in 2016 full year presentation by the director of investor relations John Dawson, Rolls-Royce added

pace and simplicity to engineering efficiency by reducing complexity, improving work prioritisation, and simplifying structure. During economic slowdowns, Rolls-Royce also managed and reduced cost by reducing staffs. This method of cutting cost by reducing staff number has been implemented by Rolls-Royce throughout the period. For example, according to the CEO (Rolls-Royce, 2018), the company reduced 2300 jobs in 2018 to be cost neutral.

One important note is that, despite a lower average negative effect towards the change in profits than an average of output price effect, the yearly input price effect shows much larger fluctuation after Rolls-Royce servitized. By looking closely, the fluctuations in input price effect are mainly the result of capital input price effect which is believed to be a by-product of servitization which potentially increases the use of financial instruments such as derivative hedging. According to Rolls-Royce (2009, 2010), the company had a fair value loss in derivative instruments of GBP 2.3bn in 2008 and a fair value gain in derivative instruments of GBP 1.7bn the next year. Hence, this research notes that change in profit post servitization period can also be affected by volatility of price effect due to the use of financial hedging instruments to support servitization of business model.

Decomposition of Quantity Effect

Apart from price effect, this research looks further into quantity effect which declined from USD 61.01mm in the pre-servitization period to USD 28.41mm in the post-servitization period. By decomposing quantity effect into activity effect and productivity effect, the decline in quantity effect in the post-servitization period can be found mainly from activity effect rather than productivity effect. This decline in activity is however contradictory to the effect from servitization. To understand the reason why there is a decline in quantity effect after Rolls-Royce servitized, this research further investigates activity effect and productivity effect for both pre- and post-servitization periods.

Activity Effect

The result shows a significant decline in activity effect from USD 39mm in the pre-servitization period to USD 6.25mm in the post-servitization period. This decline is mainly due to a negative impact from pressure from client lever, while offsetting with a positive impact from servitization of business model by Rolls-Royce which caused a shift in product portfolio lever and expansion policies lever.

By servitizing its business model, product portfolio lever and expansion policies lever are expected to impact change in profit of Rolls-Royce through increase in activity effect. As a result, Rolls-Royce are expected to receive higher revenue from newly introduced leasing service (Baines and Lightfoot, 2013; Raddats et al., 2016). Furthermore, servitization of Rolls-Royce's business model also require a need to expand operation globally to meet service demand, hence an expansion in activity effect is expected from increase in expansion policies lever.

However, during the post-servitization period, the company faced a large decline in activity effect which is contradictory to what is expected from the impact of servitization. This decline in activity effect is mainly due to the impact of pressure from clients lever resulting from poor reputation of the company from several incidents. A key incident is a corruption scandal involving large-scale bribery across three continents between year 1989 to 2013. According to Evans and Pegg (2019) in the Guardian, the bribery case settlement started in 2016 and closed in 2019 with a total fine of GBP 671mm. Another major problem costing a significant financial burden as well as reputation for Rolls-Royce, is a durability issue with the Trent 1000 engine in 2018. This issue took two years for the company to resolve with the total cost of more than GBP 2bn (Bloomberg, 2021).

Productivity Effect

Another important factor of quantity effect is productivity effect. This productivity effect is the main interest of this study. The result from Table 4.6-1 shows that average productivity effect had been both positive for both pre-servitization and post-servitization periods. Rolls-Royce had almost identical average productivity effect for both periods, with an average productivity effect in the pre-servitization period of USD 22.01mm and USD 22.16mm in the post-servitization period. This consistent positive productivity effect can be seen in the company's annual report throughout the study period including in Rolls-Royce 1993, 1998, 1999, 2005, 2007, 2009, 2011, 2013, 2019 annual report.

However, if decomposing productivity further affects technical change effect and operational efficiency effect, this research shows that productivity effect in the pre-servitization period can be attributed to technical change effect, resulting from a shift in production technology frontiers or an improvement industry as a whole. During the pre-servitization period, Rolls-Royce's productivity effect consists of USD 27mm in technical change and USD -5.21mm in operational efficiency. During post-servitization period, productivity effect is mainly contributed from operational efficiency which is a firm specific effect. Rolls-Royce showed improvement in average operational efficiency to USD 13.18mm, offsetting with a slight reduction in average technical change of USD 8.98mm. Despite having almost identical productivity effect in both periods, productivity effect in the pre-servitization period mainly consists of technical change effect, while productivity effect in the post-servitization period mainly contributed from operational efficiency.

Technical Change Effect

Despite acting as a main contribution toward productivity effect during pre-servitization period, technical change effect became less important for Rolls-Royce's productivity

during the post-servitization period. When compared to pre-servitization period, average technical change effect during post-servitization period declined from USD 27.22mm to USD 9.98mm. This decline in technical change effect for Rolls-Royce results from change in investment in technologies lever and manufacturing process lever due to servitization of business model. In the post-servitization period, Rolls-Royce started to invest in R&D to help with improvement in efficiency and placed less emphasis on investment in new cutting-edge technology. According to Rolls-Royce's annual report (2003), the company started to focus less on investment in cutting edge technology and more on reusing common technology. In year 2000, the company stated in its annual report that the focus for the company's R&D is to acquire only necessary knowledge to build future success and aim to implement "create once, use many times" method in technology. The "create once, use many time" policy had been emphasised as a strategy to maximise the benefit of investment which Rolls-Royce implements in its R&D by identifying and investing in only key technologies and processes, which can be utilised in many applications apart from its initial area of business (Rolls-Royce, 2002). For example, Rolls-Royce focuses on gas turbine technological base as a common technology which underpinned the company's four main sectors of power-systems, including civil aerospace, defense aerospace, marine and energy (Rolls-Royce, 2004). Apart from changing in the two levers due to business model change, a decline in technical change effect is also a reflection of a lower marginal improvement in technological advancement for the industry as a whole.

Operational Efficiency Effect

Another important factor effecting productivity effect is operational efficiency effect. By comparing operational efficiency between the two periods, Rolls-Royce showed much improvement in average operational efficiency in the later period. The improvement in operational efficiency in the post-servitization period is due to business model change resulting in changes in the investment in technologies lever and continued improvement in

other levers including manufacturing process lever, expansion policies lever, firm infrastructure lever, and human resource lever. For example, improvement in technologies such as real-time data system, advance electrical systems and diagnostic technologies, as well as upgraded technology in facilities across the world allowed Rolls-Royce to become more efficient (Rolls-Royce 2000, 2005, 2010). Impact of firm infrastructure lever and human resource lever from Rolls-Royce's objective to enhance and improve firm's productivity also helped increase operational efficiency effect in the post-servitization period. This can be seen from Rolls-Royce's improvement in productivity from workforce (Rolls-Royce, 1993) and supply chain restructuring and lead time reduction (Rolls-Royce, 2004).

Frontier Analysis

In addition to the results of the profit decomposition, this research delivers comparable insights on efficiency measure by ranking Rolls-Royce in term of efficiency among a set of chosen competitors using frontier analysis. The result (Table 4.6-1) shows how Rolls-Royce compares in term of efficiency to its competitors as well as to the efficient frontier. From Table 4.6-1, the last column shows Rolls-Royce's efficiency ranking based on frontier analysis between year 1992 and 2019. Based on the result, Rolls-Royce was ranked behind its peers in term of efficiency in most years before 1999. After servitizing its business model, Rolls-Royce showed much improvement in terms of ranking, especially from year 2003 to 2013 when the company was placed on the efficient frontier for several years. However, Rolls-Royce saw a decline in ranking after year 2013. A sharp drop in ranking after 2014 was while MTU aerospace, one of Rolls-Royce's competitors, started to emphasise its commercial maintenance service business, as well as the rise in idiosyncratic risk by Rolls-Royce from issues such as corruption scandal and problems with Trent 1000 engine. Despite all these problems, Rolls-Royce still shows much improvement in its ranking when compared to pre-servitization period.

Robustness Check

For robustness check, Roll-Royce's productivity from year 1992 to 2019 is plotted using output per labour on y-axis and output per capital on x-axis of Figure 4.6-1. The graph clearly shows improvements in productivity after Rolls-Royce servitized. From the graph, Rolls-Royce's labour productivity (output per labour) during the pre-servitization period is between 0.1-0.2, while capital productivity (output per capital) fluctuated around 4. From year 1998 onwards, Rolls-Royce's productivity started to increase, especially in labour productivity which increased above 0.2 after year 2000. Rolls-Royce's productivity is peaked around 2009-2010 and leveled off until year 2013. This is consistent with the earlier results derived from the profit decomposition method. After year 2013, the productivity started to fluctuate and eventually declined due to rise in investment in capital from high growth expectation coupled with several demand shocks from issues such as corruption scandal and problems with Trent 1000 engine. Subsequently, the main decline in productivity is shown in capital productivity rather than labour productivity.

Another hypothesis explaining the slowdown in Rolls-Royce's productivity after year 2013 is the increased in adoption of the servitization business model by competitors in the industry, resulting in a decline in the marginal benefit of service business model. As a result, Rolls-Royce may need to consider developing and introducing a new business model in order to retain its productivity growth.

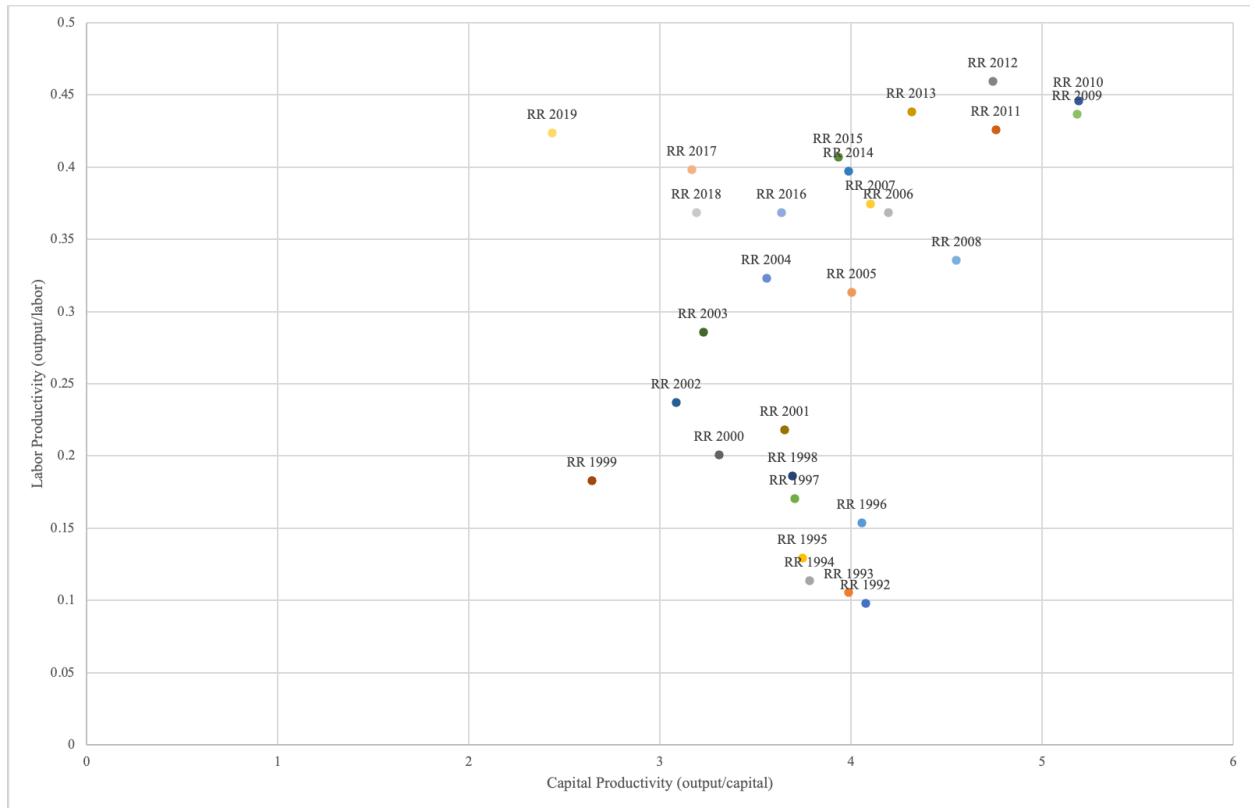


Figure 4.6-1 Rolls-Royce Productivity (1992-2019)

Source: Authors' Calculation

Limitation

This research has some limitations on the data used in the analysis. Due to the cyclical nature of the industry chosen, most aero engine manufacturers in the world need to build a robust business to mitigate financial impacts from economic and industry cycles. Hence, most companies in the industry have multiple businesses in their portfolio. For example, Rolls-Royce has a civil aerospace group, a defence aerospace group, a marine group, and an energy group under its portfolio. Rolls-Royce's main competitors such as GE and Pratt & Whitney also operate as conglomerates with businesses in sectors such as healthcare, aviation, defence, power, renewable energy, digital industry, additive manufacturing and venture capital and finance. With multiple businesses, the result from the DEA analysis

using data from aerospace industry can only be considered an estimate. To help overcome this limitation, this research uses both quantitative and qualitative methods to help support the analysis.

Furthermore, for profit decomposition method, this research uses proxy variables similar to Brea-Solis et al. (2015) for certain variables such as input price, output price, and quantity of output due to limitation of the data. To alleviate this problem, this research uses DEA or a nonparametric frontier as a benchmark to help obtain missing variables needed in the analysis. Therefore, the results from this study may be different if using exact variables in the analysis.

Based on these limitations, future research on case studies of other industries or firms which have a single business unit could be a better option in studying the relationship between business model innovation and productivity. Additionally, given that there are multiple types of business model innovations, further analytical work should be conducted on other business models to identify whether the identified relationship between business model innovation and productivity holds true. Beside focusing mainly on change in productivity after servitization of Rolls-Royce's business model, this study also called attention to the high volatility in price effect toward change in profit. Based on information from annual reports, the high volatility in price effect, especially capital input price effect is a result from financial instruments used by Rolls-Royce to support financing business in service business model. As a result, future research on financial assets risk from servitization should explore and further study other factors such as risk and cost from servitization.

4.7 Conclusion

In summary, this research shows how the relationship between servitization of business model and productivity works based on the results from both qualitative and quantitative analysis of Rolls-Royce. It is important to note that this research shows a positive relationship between servitization of business model and productivity. By using a qualitative approach, this improvement in operating efficiency effect and productivity effect can be linked to the alterations of the business mode lever due to servitization. By using quantitative method, the post-servitization period showed an improvement in Rolls-Royce's productivity when compared to the pre-servitization period. This is largely due to operational efficiency effect.

This research hopes to provide three main contributions to knowledge in the field of business model innovation, servitization, and productivity as well as practical implication and new perspective for policy makers and managements. Firstly, this research emphasises the positive impact on productivity growth from a transition into services by manufacturing firms, using Rolls-Royce as an example. The results of this study sends an important message to both policy makers and managers on the importance of business model innovation on productivity growth. Despite a trade-off between customer satisfaction and productivity in the service firm (Rust and Huang, 2012) and service paradox in manufacturing companies found in past literatures, this research still provided evidence of servitization as a source of higher productivity growth. Secondly, this research used both qualitative and quantitative approaches to help understand the relationship between business model innovation in the context of servitization and productivity, an approach which is underutilised. Thirdly, this research provides an example of the relationship between business model innovation through servitization, and productivity based on firm level analysis. This research shows how manufacturing firms such as Rolls-Royce can successfully enhance productivity through business model innovation.

Furthermore, this research pointed out the volatility of price effect from financial instruments due to servitization of business model. This important finding on risk, arises from the nature of service business and activities from servitization, can lead to further exploration of the relationship between business model innovation and risk.

Chapter 5: Academic and Managerial Implication

The objective of this chapter is to provide a summary of this PhD dissertation. In addition to the key findings from each of the three studies, academic contributions and managerial implications from this PhD dissertation will also be highlighted in this chapter.

This chapter provides a summary of this PhD dissertation in Section 5.1 and discusses research and managerial implications and contributions in Section 5.2.

5.1. PhD Dissertation Summary

This PhD dissertation focuses on developing an understanding of the relationship between business model innovation and productivity. The motivation of this dissertation lies within the productivity paradox which is a term used to describe the problem of the slowdown in productivity despite vast improvements in technology. This PhD dissertation employs three different research approaches with a central focus of explaining this productivity paradox problem through the lens of business model innovation. As the relationship between business model innovation and productivity had not been established in previous academic literature, the goal of this PhD dissertation is: 1) to quantify business model innovation so the relationship between productivity and business model innovation can be analysed quantitatively, 2) to understand the relationship between the servitization of manufacturing and productivity through the perspective of risk management, and 3) to understand the relationship between business model innovation, especially servitization, and productivity from the point of view of a firm (Rolls-Royce). Through establishing the relationship between business model innovation and productivity, this dissertation helps contribute directly to the academic fields of business model innovation and productivity, as well as provides important implications for managements and policy makers.

The first study in this PhD dissertation is outlined in Chapter 2. In this chapter, a novel approach of measuring business model innovation is introduced. This study proposes a use of net asset turnover ratio (NATO) as a proxy variable for business model innovation. With the ability to quantify business model innovation, this study provides one of the possible solutions to investigate the relationship between business model innovation and productivity growth. The empirical findings, using this newly introduced business model innovation variable, show that business model innovation significantly contributed to productivity growth across UK firms between year 2003 and 2017. The results from this study helps answer the first research question: “Can business model innovation be the source of productivity growth?”

The second study in this PhD dissertation is outlined in Chapter 3. To support the empirical establishment of the relationship between business model innovation and productivity in the first study, this second study looks further at the servitization of manufacturing, an example of business model innovation, and analyses its impacts on productivity. Based on an insight that risk management is one of the main motivations behind why manufacturing firms servitize their business model despite lower productivity growth expectations, this chapter suggested that risk-return trade-off from business model choice should be considered when comparing productivity. As a result, this second study introduces the “risk adjusted productivity” method to measure productivity by taking into account the differences in risk level originating from different business models. When compared to the pre-risk adjusted data, the findings of the risk adjusted productivity result show a reduction in the productivity gap between service and manufacturing sectors in the UK manufacturing industry. The results from this study help answer the second research question: “How do changes in risks as a result of business model innovation affect productivity? Can the servitization of manufacturing, an example of business model innovation, impact productivity?”

The third study is outlined in Chapter 4. This third study looks deeper into a specific firm, Rolls-Royce, to help understand the mechanics and consequences of business model innovation on productivity at the firm level. By using both qualitative and quantitative methods and linking firm’s business model choices, profitability, and productivity consequences together, this case study of Rolls-Royce demonstrates how business model choice impacts firm’s productivity. The results from this study help answer the third research question: “What are the levers that influence servitization based business models that impact firm’s productivity growth?”.

5.2. Research Contributions

Based on the three studies, key contributions and advancement in knowledge from this PhD dissertation are summarised as follows.

5.2.1 Academic Contribution

The main academic contribution from this PhD dissertation is the establishment of the relationship between business model innovation and productivity using multiple studies. Furthermore, the methods and results from each of the studies within this PhD dissertation can contribute directly to the fields of business model innovation and productivity, and this could further enhance opportunities for more research in both fields.

In the first study, this PhD dissertation provides a better understanding of the relationship of business model innovation and productivity through a newly introduced business model innovation measure. To the best of present knowledge, this research is believed to be the first to attempt measuring and quantifying business model change and to show that business model innovation is a factor affecting productivity. The result from this first study shows a positive relationship between business model innovation and productivity growth. Hence, the result provides an important knowledge that improvement in technology alone, which are believed to be a driving force of productivity growth according to many renowned scholars such as Solow (1956, 1957) and Brynjolfsson et al. (2008) may not be enough to help increase productivity growth but need to be coupled with business model innovation. The newly introduced business model innovation measure proposed in this study can also be used empirically in other areas beside productivity.

In the second study, this PhD dissertation provides an insight into the importance of risk management within servitization of the manufacturing industry. With slowdown in productivity from services are being emphasized (Gordon 1996) and research on the impact of risk management toward lower level of productivity in the service sector has not yet been explored, this research suggested that risk management can be an underlying reason

why there is currently a wave of servitization in the manufacturing industry despite lower productivity growth expectations. Apart from providing insight into why manufacturers servitize their business models, this second study also provides a new productivity measure which takes risk into account. By adjusting for risk, this new productivity measure is a better productivity measure for future research, and this can potentially be a solution to the productivity paradox problem.

In the third study, this PhD dissertation provides insight into the impact of business model innovation, particularly servitization, on the firm's productivity. As there are a limited number of studies that have examined the consequence of servitization in term of productivity growth and whether servitization is being adopted in practice (Neely, 2008), this research attempt to address this knowledge gap by analysing the relationship between the business model innovation, servitization, and productivity based on an in-depth analysis at a firm level which is an understudied area. The results in this study show how each business model levers impact the firm's productivity once servitized which builds on the results shown by Wannakrairoj and Velu (2021) and Velu and Chen (2021). By using both quantitative and qualitative approaches, the results from this study provide more detail on how Roll-Royce as a case study company improves its productivity through servitization. On top of a contribution from the result, this third study also provides a novel approach of using both qualitative and quantitative analysis to help understand the relationship between business model innovation and productivity, especially in context of servitization.

5.2.2 Managerial Implications

In addition to academic contributions, the key results from the three studies in this PhD dissertation can help provide new insights for both policymakers and practitioners with a solution to increase firm productivity through business model innovation. With a better understanding of the relationship between business model innovation and productivity, businesses can take advantage of new technology by applying business model innovation

to increase firm's productivity. With an understanding that business model innovation does not necessarily reduce productivity if properly taking risk into account, policymakers and practitioners can have more confidence in implementing business model innovation. Furthermore, based on the results found in this PhD dissertation, the widely observed productivity level should also be interpreted with caution, and that risk should be considered when making comparison of productivity between different industries or firms with different business models. Moreover, this study demonstrates how change in business model levers through business model innovation impacts productivity based on a case study of Rolls-Royce. To improve productivity, practitioners can implement business model innovation through change in business model levers based on the case study provided in this study.

5.3. Limitations and Future Research

5.3.1 Limitations

Some common limitations can be found from this PhD dissertation study as follows:

(1) Limitations with proxy variables may be identified, both for business model innovation and risk. By using a proxy variable, a true variable of interested factor is not precisely measured, but is rather proxied by another variable. This could result in unwanted signal or noise in the analysis.

(2) Choice of variables used for the production function is proposed as a standard function and is not a true measure which may cause noise and error in the production function. Other variables proposed by past literature may be used as an alternative. For example, gross value added may be used as an output variable instead of turnover used in this PhD dissertation.

(3) Based on the production function used in Chapter 2 and 3, other factors apart from business model choice can also have an impact towards standard deviation of TFP.

Hence, different level of standard deviation of TFP is not exclusively a result from different business model choice.

(4) Limitations from the collected data such as selection bias problem, nature of the panel data, or a chosen case study may affect the results. For example, there is also some concern that using panel data of a proxy variable of NATO for business model innovation and standard deviation for risk in an aggregated macro level study may potentially post a problem as changes in the interested variables across the firms in macro level data may offset each other. Another concern maybe the cyclical nature of the chosen aerospace industry which results in multiple business segments in companies' portfolios. Hence, the result from the analysis using data from aerospace industry is not accurately represented and need to be carefully interpreted.

(5) Due to unobtainable data for profit decomposition method, Chapter 4 uses nonparametric frontier as a benchmark to help obtain certain variables such as input price, output price, and quantity of output. Therefore, the results based on this limitation may not be accurately measured.

(6) Studies in this PhD dissertation are based on several assumptions and in reality, these assumptions (ie. business model innovation is a radical change and risk is represented by a volatility of productivity) may not always hold.

(7) There are limitations on the approach in the research study. This PhD dissertation study recognised that measurement of data and data quality may have potential limitations and can be improved in future studies.

5.3.2 Future Research

Based on the above limitations, the following future research studies are proposed.

(1) Further development of a better business model innovation variable and risk adjusted measurement could possibly be worth exploring. Besides net asset turnover ratio and other proposed dummy variable used in past literatures, a thorough survey on other

potential business model innovation variables should be implemented. In addition, there should be further exploration of other potential development and method which could have been applied for risk adjusted productivity.

(2) Future research on case studies of other industries or firms which have a single business unit could also be explored as an option. Similarly, a replication of the study using a new dataset of different country and industry for an empirical study on business model innovation as well as risk adjusted productivity can help support the proposed variables.

(3) Given that there are multiple types of business model innovations, further analytical work should be conducted on other business models to verify that the identified relationship between business model innovation and productivity holds true.

(4) With a newly proposed business model innovation variable, an empirical case study on the relationship between business model innovation and other factors such as firm's stock performance are now possible and may well prove fruitful.

(5) Further study on a change in risk level from business model innovation is needed. Productivity measure using risk adjusted productivity should also be applied more widely to help compare productivity levels between different firms, industries, and countries.

(6) This PhD dissertation also calls for an attention to look deeper into risk factor for business model innovation, especially from the evidence found from high volatility in price effect towards the change in profit as a result of financial instrument used to support service business in Chapter 4. Based on this evidence, a study on the impact of financial assets risk from servitization could well be another interesting topic for future research.

(7) Lastly, this PhD dissertation noted that slowdown in productivity growth in service sector does not only come from a result of risk management alone, but also the nature of service business which require labour intensive activities to focus on quality of the service and not purely focusing on productivity growth. Hence, future research in this area is worth considering.

In conclusion, this PhD dissertation denotes an attempt to address knowledge gaps which have been identified from productivity and business model research stream. The overview of the three different studies are linked under a central theme of productivity paradox and business model innovation. As evidenced in this dissertation, business model innovation can represent a new stream of knowledge in studying the productivity paradox. It is hoped that this PhD dissertation could become the initial platform for many inspiring future works within this area.

6. References

Abramovitz, M. (1962). Economic growth in the United States. *The American Economic Review*, 52(4), pp.762-782.

Abramovitz, M. (1979). Rapid growth potential and its realisation: the experience of capitalist economies in the post-war period. *Economic Growth and Resources*. Palgrave Macmillan, London, (pp. 1-51).

Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005). Competition and innovation: An inverted-U relationship. *The Quarterly Journal of Economics*, 120(2), pp.701-728.

Amit, R. and Wernerfelt, B. (1990). Why do firms reduce business risk? *Academy of Management Journal*, 33(3), pp.520-533.

Amit, R. and Zott, C. (2010). Business model innovation: Creating value in times of change. *IESE Business School*, (No. D/870).

Amit, R., and Zott, C. (2012). Creating value through business model innovation. *MIT Sloan Management Review*, 53(3), 41-49.

Arrow, K. J., Chenery, H. B., Minhas, B. S., and Solow, R. M. (1961). Capital-labour substitution and economic efficiency. *The Review of Economics and Statistics*, 43(3), 225-250.

Aspara, J., Hietanen, J., and Tikkanen, H. (2010). Business model innovation vs replication: financial performance implications of strategic emphases. *Journal of Strategic Marketing*, 18(1), 39-56.

Baden-Fuller, C., and Haefliger, S. (2013). Business models and technological innovation. *Long Range Planning*, 46(6), 419-426.

Baines, T.S., Lightfoot, H.W., Benedettini, O. and Kay, J.M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*.

Baines, T.S., Lightfoot, H.W., Benedettini, O., Whitney, D. and Kay, J.M. (2010). The adoption of servitization strategies by UK-based manufacturers. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 224(5), pp.815-829.

Baines, T.S. and Lightfoot, H. (2013). *Made to serve: How manufacturers can compete through servitization and product service systems*. John Wiley and Sons.

Basu, S., and Fernald, J. G. (1995). Are apparent productive spillovers a figment of specification error? *Journal of Monetary Economics*, 36(1), 165-188.

Basu, S., Fernald, J. G., and Shapiro, M. D. (2001). Productivity growth in the 1990s: technology, utilization, or adjustment? *Carnegie-Rochester Conference Series on Public Policy* (Vol. 55, No. 1, pp. 117-165). North-Holland.

Baum, J. A., and Mezias, S. J. (1992). Localized competition and organizational failure in the Manhattan hotel industry, 1898-1990. *Administrative Science Quarterly*, 580-604.

Benedettini, O., Neely, A. and Swink, M. (2013). Service types and their differential risk effects for manufacturing firms: an empirical analysis. *Frameworks and Analysis*, 15.

Berman, E., Bound, J. and Griliches, Z. (1994). Changes in the demand for skilled labour within US manufacturing: evidence from the annual survey of manufactures. *The Quarterly Journal of Economics*, 109(2), pp.367-397.

Bernard, A. B., Redding, S. J., and Schott, P. K. (2010). Multiple-product firms and product switching. *American Economic Review*, 100(1), 70-97.

Bettis, R.A. (1983). Modern financial theory, corporate strategy and public policy: Three conundrums. *Academy of Management Review*, 8(3), pp.406-415.

Björkdahl, J. and Holmén, M. (2013). Business model innovation—the challenges ahead. *International Journal of Product Development*, 18(3/4), pp.213-225.

Black, F. and Scholes, M. (1972). The valuation of option contracts and a test of market efficiency. *The Journal of Finance*, 27(2), pp.399-417.

Bloom, N., Sadun, R., and Van Reenen, J. (2012). Americans do IT better: US multinationals and the productivity miracle. *American Economic Review*, 102(1), 167-201.

Bloomberg (2021). *Rolls-Royce Close to Resolving Costliest Jet-Engine Issue*. Available at: <https://www.bloomberg.com/news/articles/2021-07-02/rolls-royce-close-to-resolving-costliest-jet-engine-issue> (Accessed: June 2022).

Brea-Solís, H., Casadesus-Masanell, R., and Grifell-Tatjé, E. (2015). Business model evaluation: Quantifying Walmart's sources of advantage. *Strategic Entrepreneurship Journal*, 9(1), 12-33.

Bresnahan, T.F., Milgrom, P. and Paul, J. (1992). The real output of the stock exchange. In *Output measurement in the service sectors* (pp. 195-216). University of Chicago Press.

Brink, J., and Holmén, M. (2009). Capabilities and radical changes of the business models of new bioscience firms. *Creativity and Innovation Management*, 18(2), 109-120.

Brynjolfsson, E. (1993). The productivity paradox of information technology. *Communications of the ACM*, 36(12), 66-77.

Brynjolfsson, E., and Hitt, L. M. (1998). Beyond the productivity paradox: Computers are the catalyst for bigger changes. *Communications of the ACM*, 41(8), 49.

Brynjolfsson, E., and Hitt, L. M. (2003). Computing productivity: Firm-level evidence. *Review of Economics and Statistics*, 85(4), 793-808.

Brynjolfsson, E., Hitt, L. M., and Yang, S. (2002). Intangible assets: Computers and organizational capital. *Brookings Papers on Economic Activity*, 2002(1), 137-181.

Brynjolfsson, E., McAfee, A., Sorell, M., and Zhu, F. (2008). Scale without mass: business process replication and industry dynamics. *Harvard Business School Technology and Operations Mgt. Unit Research Paper*, (07-016).

Brynjolfsson, E., Rock, D., and Syverson, C. (2017). Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics (No. w24001). *National Bureau of Economic Research*.

Brynjolfsson, E., Rock, D., and Syverson, C. (2018). The productivity J-curve: How intangibles complement general purpose technologies (No. w25148). *National Bureau of Economic Research*.

Brink, J. and Holmén, M. (2009). Capabilities and radical changes of the business models of new bioscience firms. *Creativity and Innovation Management*, 18(2), pp.109-120.

Brillinger, A.S., Els, C., Schäfer, B. and Bender, B. (2020). Business model risk and uncertainty factors: Toward building and maintaining profitable and sustainable business models. *Business Horizons*, 63(1), pp.121-130.

Brouthers, K.D. and Brouthers, L.E. (2003). Why service and manufacturing entry mode choices differ: The influence of transaction cost factors, risk and trust. *Journal of Management Studies*, 40(5), pp.1179-1204.

Cainelli, G., Evangelista, R., and Savona, M. (2005). Innovation and economic performance in services: a firm-level analysis. *Cambridge Journal of Economics*, 30(3), 435-458.

Caterpillar Inc. (2008). Annual report. Illinois, U.S.A. *Caterpillar Inc.*

Caterpillar Inc. (2009). Annual report. Illinois, U.S.A. *Caterpillar Inc.*

Casadesus-Masanell, R. and Ricart, J.E. (2010). From strategy to business models and onto tactics. *Long Range Planning*, 43(2-3), pp.195-215.

Casadesus-Masanell R, Ricart JE. (2011). How to design a winning business model. *Harvard Business Review* 89(1/2), pp. 100-107.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European Journal of Operational Research*, 2(6), pp.429-444.

Chesbrough, H. (2007). Business model innovation: it's not just about technology anymore. *Strategy and Leadership*, 35(6), 12-17.

Chesbrough, H. (2010). Business model innovation: opportunities and barriers. *Long Range Planning*, 43(2-3), 354-363.

Christensen, C.M. (2013). The innovator's dilemma: when new technologies cause great firms to fail. *Harvard Business Review Press*.

Clemens, M.A., Radelet, S., Bhavnani, R.R. and Bazzi, S. (2012). Counting chickens when they hatch: Timing and the effects of aid on growth. *The Economic Journal*, 122(561), pp.590-617.

Cobb, C. W. and Douglas, P. C. (1928). A theory of production. *The American Economic Review*, 18(1), pp.139-165.

Coelli, T.J. and Rao, D.P. (2005). Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980–2000. *Agricultural Economics*, 32, pp.115-134.

Comin, D. (2010). Total factor productivity. *Economic Growth*. Palgrave Macmillan, London, pp. 260-263.

Comin, D., and Mulani, S. (2009). A theory of growth and volatility at the aggregate and firm level. *Journal of Monetary Economics*, 56(8), 1023-1042.

Craig, C. E., and Harris, R. C. (1973). Total productivity measurement at the firm level. *Sloan Management Review (pre-1986)*, 14(3), 13.

David, P. A. (2000). Understanding digital technology's evolution and the path of measured productivity growth: present and future in the mirror of the past. *Understanding The Digital Economy: Data, Tools, and Research*. MIT, Cambridge, MA.

Demil, B. and Lecocq, X. (2010). Business model evolution: In search of dynamic consistency. *Long Range Planning*, 43(2-3), pp.227-246.

Denison, E.F. (1962). Education, economic growth, and gaps in information. *Journal of Political Economy*, 70(5, Part 2), pp.124-128.

Denison, E. (1985). *Trends in American economic growth*. Brookings Institution Press.

Doraszelski, U., and Jaumandreu, J. (2013). R&D and productivity: Estimating endogenous productivity. *Review of Economic Studies*, 80(4), 1338-1383.

Duguet, E. (2006). Innovation height, spillovers and TFP growth at the firm level: Evidence from French manufacturing. *Economics of Innovation and New technology*, 15(4-5), pp.415-442.

Dougherty, C. and Jorgenson, D.W. (1996). International comparisons of the sources of economic growth. *The American Economic Review*, 86(2), pp.25-29.

Eggert, A., Hogreve, J., Ulaga, W. and Muenkhoff, E. (2011). Industrial services, product innovations, and firm profitability: A multiple-group latent growth curve analysis. *Industrial Marketing Management*, 40(5), pp.661-670.

Engle, R. (2004). Risk and volatility: Econometric models and financial practice. *American Economic Review*, 94(3), pp.405-420.

Erramilli, M.K. and Rao, C.P. (1993). Service firms' international entry-mode choice: A modified transaction-cost analysis approach. *Journal of Marketing*, 57(3), pp.19-38.

Evans, R. and Pegg, D. (2019). Campaigners condemn closure of Rolls-Royce bribery inquiry. *The Guardian*.

Available at: <https://www.theguardian.com/business/2019/feb/22/campaigners-condemn-closure-of-rolls-royce-bribery-inquiry> (Accessed: June 2022).

Fairfield, P.M. and Yohn, T.L. (2001). Using asset turnover and profit margin to forecast changes in profitability. *Review of Accounting Studies*, 6, pp.371-385.

Fare, R., Grosskopf, S., Lindgren, B. and Roos, P. (1994). Productivity developments in Swedish hospitals: a Malmquist output index approach. In *Data Envelopment Analysis: Theory, Methodology, and Applications*. Springer, Dordrecht, pp. 253-272.

Farrell, M.J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General)*, 120(3), pp.253-281.

Farrell, M. and Gallagher, R. (2015). The valuation implications of enterprise risk management maturity. *Journal of Risk and Insurance*, 82(3), pp.625-657.

Fernald, J. G. (2015). Productivity and Potential Output before, during, and after the Great Recession. *NBER Macroeconomics Annual*, 29(1), 1-51.

Fortune Business Insights (2020). *Aircraft Engine Market*. Available at: <https://www.fortunebusinessinsights.com/industry-reports/aircraft-engine-market-101766> (Accessed: June 2022).

Fox, J. T., and Smeets, V. (2011). Does input quality drive measured differences in firm productivity?. *International Economic Review*, 52(4), pp.961-989.

Frank, A.G., Mendes, G.H., Ayala, N.F. and Ghezzi, A. (2019). Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change*, 141, pp.341-351.

Gabriel, S.C. and Baker, C.B. (1980). Concepts of business and financial risk. *American Journal of Agricultural Economics*, 62(3), pp.560-564.

Gatignon, H. and Anderson, E. (1988). The multinational corporation's degree of control over foreign subsidiaries: An empirical test of a transaction cost explanation. *Journal of Law, Economics, and Organization*, 4(2), pp.305-305.

Gebauer, H., Fleisch, E. and Friedli, T. (2005). Overcoming the service paradox in manufacturing companies. *European Management Journal*, 23(1), pp.14-26.

Giles, C. (2019). UK productivity warning rings alarm bells. *Financial Times*. Available at: <https://www.ft.com/content/19acce50-5e90-11e9-b285-3acd5d43599e> (Accessed April 15, 2019)

Girotra, K. and Netessine, S. (2011). How to build risk into your business model. *Harvard Business Review*, 89(5), pp.100-105.

Girotra, K. and Netessine, S. (2014). *The risk-driven business model: Four questions that will define your company*. Harvard Business Press.

Goettler, R. L., and Gordon, B. R. (2011). Does AMD spur Intel to innovate more?. *Journal of Political Economy*, 119(6), 1141-1200.

Goel, A.M. and Thakor, A.V. (2003). Why do firms smooth earnings? *The Journal of Business*, 76(1), pp.151-192.

Goldin, C., and Katz, L. F. (2007). *The race between education and technology: The evolution of US educational wage differentials, 1890 to 2005* (No. w12984). National Bureau of Economic Research.

Gordon, R.J. (1996). Problems in the measurement and performance of service-sector productivity in the United States. *NBER Working Paper*, No. 5519, 1996.

Gordon, R. J. (2015). Secular stagnation: A supply-side view. *American Economic Review*, 105(5), 54-59.

Grifell-Tatjé, E. and Lovell, C.K. (1999). Profits and productivity. *Management Science*, 45(9), pp.1177-1193.

Grifell-Tatjé, E. and Lovell, C.K. (2015). *Productivity Accounting*. Cambridge University Press.

Griliches, Z. (1985). Productivity, R&D, and basic research at the firm level in the 1970s. (No. w1547). *National Bureau of Economic Research*.

Griliches, Z. (1998). Productivity, R&D, and the data constraint. In *R&D and productivity: The Econometric Evidence* (pp. 347-374). University of Chicago Press.

Griliches, Z., and Jorgenson, D. W. (1967). The explanation of productivity change. *Review of Economic Studies*, 34(3), 249-283.

Griliches, Z., and Mairesse, J. (1995). *Production functions: the search for identification* (No. w5067). National Bureau of Economic Research.

Haldane, A. (2017). Productivity puzzles. *speech at the London School of Economics*, 20.

Harris, R. and Moffat, J. (2017). The UK productivity puzzle, 2008–2012: Evidence using plant-level estimates of total factor productivity. *Oxford Economic Papers*, 69(3), pp.529-549.

Hempell, T. (2005). What's spurious, what's real? Measuring the productivity impacts of ICT at the firm-level. *Empirical Economics*, 30(2), 427-464.

Hitt, M.A., Ireland, R.D., Camp, S.M. and Sexton, D.L. (2001). Strategic entrepreneurship: Entrepreneurial strategies for wealth creation. *Strategic Management Journal*, 22(6-7), pp.479-491.

Hock, M., Clauss, T. and Schulz, E. (2016). The impact of organizational culture on a firm's capability to innovate the business model. *R&D Management*, 46(3), pp.433-450.

Hulten, C. R. (2001). Total factor productivity: a short biography. In *New Developments in Productivity Analysis* (pp. 1-54). University of Chicago Press.

İmrohoroğlu, A., and Tüzel, Ş. (2014). Firm-level productivity, risk, and return. *Management Science*, 60(8), 2073-2090.

Jansen, I.P., Ramnath, S. and Yohn, T.L. (2012). A diagnostic for earnings management using changes in asset turnover and profit margin. *Contemporary Accounting Research*, 29(1), pp.221-251.

Johnson, M.W., Christensen, C.M. and Kagermann, H. (2008). Reinventing your business model. *Harvard Business Review*, 86(12), pp.50-59.

Jorgenson, D. W. (2001). Information technology and the US economy. *American Economic Review*, 91(1), 1-32.

Jorgenson, D. W. (2005). Capital Accumulation, Productivity and Growth. *Rivista di Politica Economica*, 95(1), 25-56.

Jorgenson, D. W., and Nishimizu, M. (1978). US and Japanese economic growth, 1952-1974: an international comparison. *The Economic Journal*, 88(352), 707-726.

Jorgenson, D. W., and Stiroh, K. J. (1999). Information technology and growth. *American Economic Review*, 89(2), 109-115.

Jorgenson, D., and Yip, E. (2001). Whatever happened to productivity growth?. In *New developments in productivity analysis* (pp. 509-540). University of Chicago Press.

Jorgenson, D. W., Ho, M. S., and Stiroh, K. J. (2002). Projecting productivity growth: Lessons from the US growth resurgence. *Economic Review-Federal Reserve Bank of Atlanta*, 87(3), 1.

Jorgenson, D. W., Ho, M. S., and Stiroh, K. J. (2008). A retrospective look at the US productivity growth resurgence. *Journal of Economic Perspectives*, 22(1), 3-24.

Just, R.E. and Pope, R.D. (1978). Stochastic specification of production functions and economic implications. *Journal of Econometrics*, 7(1), pp.67-86.

Just, R.E. and Pope, R.D. (1979). Production function estimation and related risk considerations. *American Journal of Agricultural Economics*, 61(2), pp.276-284.

Kastalli, I.V. and Van Looy, B. (2013). Servitization: Disentangling the impact of service business model innovation on manufacturing firm performance. *Journal of Operations Management*, 31(4), pp.169-180.

Kastalli, I.V., Van Looy, B. and Neely, A. (2013). Steering manufacturing firms towards service business model innovation. *California Management Review*, 56(1), pp.100-123.

Keen, P., and Williams, R. (2013). Value architectures for digital business: beyond the business model. *Mis Quarterly*, 37(2), 643-647.

Kelly, B., Papanikolaou, D., Seru, A. and Taddy, M. (2021). Measuring technological innovation over the long run. *American Economic Review: Insights*, 3(3), pp.303-20.

Kendrick, J. (1956). Productivity trends: capital and labor. In *Productivity Trends: Capital and Labor* (pp. 3-23). National Bureau of Economic Research (NBER).

Kerr, C.I.V. and Ivey, P.C. (2001). A strategic review of the large civil aeroengine market and the paradigm shift to a service. *The Aeronautical Journal*, 105(1047), pp.287-293.

Kharlamov, A.A. and Parry, G. (2021). The impact of servitization and digitization on productivity and profitability of the firm: a systematic approach. *Production Planning and Control*, 32(3), pp.185-197.

Kim, W.C. and Hwang, P. (1992). Global strategy and multinationals' entry mode choice. *Journal of International Business Studies*, pp.29-53.

Kozicki, S. (1997). The productivity growth slowdown: Diverging trends in the manufacturing and service sectors. *Economic Review-Federal Reserve Bank of Kansas City*, 82, pp.31-46.

Krugman, P. (1994). *The age of diminishing expectations: US Economic Policy in the 1990s*. Massachusetts: MIT Press Cambridge.

Lambert, S. C., and Davidson, R. A. (2013). Applications of the business model in studies of enterprise success, innovation and classification: An analysis of empirical research from 1996 to 2010. *European Management Journal*, 31(6), 668-681.

Lazonick, W. and Prencipe, A. (2005). Dynamic capabilities and sustained innovation: strategic control and financial commitment at Rolls-Royce plc. *Industrial and Corporate Change*, 14(3), pp.501-542.

Lee, S. M., Olson, D. L., and Trimi, S. (2012). Co-innovation: convergenomics, collaboration, and co-creation for organizational values. *Management Decision*, 50(5), 817-831.

Lee, S., Yoo, S. and Kim, D. (2016). When is servitization a profitable competitive strategy? *International Journal of Production Economics*, 173, pp.43-53.

Lehr, B., and Lichtenberg, F. (1999). Information technology and its impact on productivity: Firm-level evidence from government and private data sources, 1977-1993. *The Canadian Journal of Economics/Revue Canadienne d'Economique*, 32(2), 335-362.

Leswing, K. (2022). Apple is reportedly preparing an iPhone subscription service that could launch this year. *CNBC*. Available at: <https://www.cnbc.com/2022/03/24/apple-planning-iphone-subscription-that-could-launch-this-year-report.html> (Accessed on May 30, 2022).

Leung, D., Meh, C. and Terajima, Y. (2008). *Firm size and productivity* (No. 2008-45). Bank of Canada.

Liou, F. M., Tang, Y. C., and Huang, C. P. (2008). Asset-light business model: A theoretical framework for sustained competitive advantage. *Journal of Business and Policy Research*, 4(1), 104-115.

Lipsey, R., Sifonis, J. G., and Meyerson, M. (1989). *The landmark MIT study: management in the 1990's*. Arthur Young.

Lokshin, B., Belderbos, R., and Carree, M. (2008). The productivity effects of internal and external R&D: Evidence from a dynamic panel data model. *Oxford Bulletin of Economics and Statistics*, 70(3), 399-413.

Luz Martín-Peña, M., Díaz-Garrido, E. and Sánchez-López, J.M. (2018). The digitalization and servitization of manufacturing: A review on digital business models. *Strategic Change*, 27(2), pp.91-99.

Maier, J. (2017). *Made smarter review 2017*. Department for Business EIS. The Stationery Office. London.

Mairesse, J., and Sassenou, M. (1991). *R&D productivity: A survey of econometric studies at the firm level* (No. w3666). National Bureau of Economic Research.

Malik, Y., Niemeyer, A. and Ruwadi, B. (2011). Building the supply chain of the future. *TMI-Treasury Management International*, 83, p.21.

Mankiw, N. G., Romer, D., and Weil, D. N. (1992). A contribution to the empirics of economic growth. *The Quarterly Journal of Economics*, 107(2), 407-437.

Mansury, M. A., and Love, J. H. (2008). Innovation, productivity and growth in US business services: A firm-level analysis. *Technovation*, 28(1-2), 52-62.

Markowitz, H. (1952). Portfolio selection. *Journal of Finance*, 7, 77-91.

Matteucci, N., O'Mahony, M., Robinson, C., and Zwick, T. (2005). Productivity, workplace performance and ICT: industry and firm-level evidence for Europe and the US. *Scottish Journal of Political Economy*, 52(3), 359-386.

Merton, R.C. (1973). An intertemporal capital asset pricing model. *Econometrica: Journal of the Econometric Society*, pp.867-887.

Michaels, D., Kranhold, K. and Lunsford, J. (2005). Rolls-Royce takes fight to GE: battle heats up to supply engines for new Boeing, Airbus models. *Wall Street Journal*.

Modigliani, F. and Modigliani, L. (1997). Risk-adjusted performance. *Journal of Portfolio Management*, 23(2), pp.45-54.

Moore, G. E. (1965). Cramming more components onto integrated circuits. *Electronics*, 38 (8).

Morris, M. (2014). *Total Care® Accounting*. Rolls-Royce plc., London, UK.

Morris, M., Schindehutte, M. and Allen, J. (2005). The entrepreneur's business model: toward a unified perspective. *Journal of Business Research*, 58(6), pp.726-735.

Murray, M. P. (2006). Avoiding invalid instruments and coping with weak instruments. *Journal of Economic Perspectives*, 20(4), 111-132.

Neely, A. (2008). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, 1(2), pp.103-118.

Office for National Statistics UK. (2018). *International comparisons of UK productivity (ICP), final estimates*. Available at:
<https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/bulletins/internationalcomparisonsofproductivityfinalestimates>
(Accessed on April 15, 2019)

Oliner, S.D. and Sichel, D.E. (2000). The resurgence of growth in the late 1990s: is information technology the story? *Journal of Economic Perspectives*, 14(4), pp.3-22.

Oliner, S. D., and Sichel, D. E. (2002). Information technology and productivity: where are we now and where are we going? *Technology, Growth, and the Labor Market*, pp.41-94.

Oliner, S. D., Sichel, D. E., Triplett, J. E., and Gordon, R. J. (1994). Computers and output growth revisited: how big is the puzzle? *Brookings Papers on Economic Activity*, 1994(2), 273-334.

Oulton, N. (2002). ICT and productivity growth in the United Kingdom. *Oxford Review of Economic Policy*, 18(3), pp.363-379.

Paschou, T., Rapaccini, M., Adrodegari, F. and Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management*, 89, pp.278-292.

Peters, R.H. and Taylor, L.A. (2017). Intangible capital and the investment-q relation. *Journal of Financial Economics*, 123(2), pp.251-272.

Pohle, G., and Chapman, M. (2006). IBM's global CEO report 2006: business model innovation matters. *Strategy and Leadership*, 34(5), 34-40.

Porter, M. E. (1980). Industry structure and competitive strategy: Keys to profitability. *Financial Analysts Journal*, 36(4), 30-41.

Porter, M.E. (1985). *Competitive advantage: Creating and sustaining superior performance*. The Free Press.

Porter, M. E. (1996). What is strategy. *Harvard Business Review*, November – December 1996.

Porter, M. E., and Millar, V. E. (1985). How information gives you competitive advantage. *Harvard Business Review*, July-August 1985, pp.149-152.

Porter, M. and Siggelkow, N. (2008). Contextuality within activity systems and sustainability of competitive advantage. *Academy of Management Perspectives*, 22(2), pp.34-56.

Porter, M.E. and Takeuchi, H. (2013). *Aerospace cluster in the Toulouse region*. Harvard Business School.

Prescott, E.C. (1998). Lawrence R. Klein lecture 1997: Needed: A theory of total factor productivity. *International Economic Review*, pp.525-551.

PwC UK. (2023). *Productivity Tracker*. Available at:

<https://www.pwc.co.uk/industries/manufacturing/insights/productivity-tracker.html>

(Accessed on July, 2023)

Raddats, C. and Easingwood, C. (2010). Services growth options for B2B product-centric businesses. *Industrial Marketing Management*, 39(8), pp.1334-1345.

Raddats, C., Baines, T., Burton, J., Story, V.M. and Zolkiewski, J. (2016). Motivations for servitization: the impact of product complexity. *International Journal of Operations and Production Management*. 36(5), pp. 572-591.

Riley, R., Rincon-Aznar, A. and Samek, L. (2018). Below the aggregate: a sectoral account of the UK productivity puzzle (No. ESCoE DP-2018-06). *Economic Statistics Centre of Excellence (ESCoE)*.

Roach, S. S. (1987). *America's technology dilemma: A profile of the information economy*. Morgan Stanley.

Rolls-Royce. (1991). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1992). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1993). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1994). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1995). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1996). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1997). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1998). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (1999). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2000). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2001). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2002). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2003). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2005). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2006). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2007). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2009). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2010). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2011). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2012). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2013). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2015). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2016). *2016 Full year results presentation*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2017) *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2017). *Power by the hour*. Available at: <https://www.rolls-royce.com/media/our-stories/discover/2017/totalcare.aspx> (Accessed: June 2022)

Rolls-Royce. (2018). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2019). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rolls-Royce. (2022). *Annual reports*. London, UK. Rolls-Royce Holdings PLC.

Rust, R.T. and Huang, M.H. (2012). Optimizing service productivity. *Journal of Marketing*, 76(2), pp.47-66.

Saebi, T., Lien, L., and Foss, N. J. (2017). What drives business model adaptation? The impact of opportunities, threats and strategic orientation. *Long Range Planning*, 50(5), 567-581.

Saha, A., Havenner, A. and Talpaz, H. (1997). Stochastic production function estimation: small sample properties of ML versus FGLS. *Applied Economics*. 29(4), pp.459-469.

Santos, J., Spector, B., and Van der Heyden, L. (2015). Toward a theory of business model change. *Business Model Innovation. The Organizational Dimension*, 43-63.

Schneider, S., and Spieth, P. (2013). Business model innovation: Towards an integrated future research agenda. *International Journal of Innovation Management*, 17(01), 1340001.

Sharpe, W.F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. *The Journal of Finance*, 19(3), pp.425-442.

Sharpe, W.F. (1966). Mutual fund performance. *The Journal of Business*, 39(1), pp.119-138.

Sharpe, W.F. (1994). The Sharpe ratio. *Streetwise—the Best of the Journal of Portfolio Management*, pp.169-185.

Siggelkow, N. (2001). Change in the presence of fit: The rise, the fall, and the renaissance of Liz Claiborne. *Academy of Management Journal*, 44(4), 838-857.

Smith, D.J. (2013). Power-by-the-hour: the role of technology in reshaping business strategy at Rolls-Royce. *Technology Analysis and Strategic Management*, 25(8), pp.987-1007.

Smith-Gillespie, A., Muñoz, A., Morwood, D. and Aries, T. (2019). Rolls-Royce: a circular economy business model case. *R2Pi Project*, The European Commission.

Söderbom, M., and Teal, F. (2004). Size and efficiency in African manufacturing firms: evidence from firm-level panel data. *Journal of Development Economics*, 73(1), 369-394.

Soliman, M. T. (2008). The use of DuPont analysis by market participants. *The Accounting Review*, 83(3), 823-853.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 70(1), 65-94.

Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 312-320.

Solow, R. M. (1987). We'd better watch out. *New York Times Book Review*, 36.

Sosna, M., Trevinyo-Rodríguez, R.N. and Velamuri, S.R., (2010). Business model innovation through trial-and-error learning: The Naturhouse case. *Long Range Planning*, 43(2-3), pp.383-407.

Stratopoulos, T., and Dehning, B. (2000). Does successful investment in information technology solve the productivity paradox? *Information and Management*, 38(2), 103-117.

Summers, L. H. (2015). Demand side secular stagnation. *American Economic Review*, 105(5), 60-65.

Syverson, C. (2011). What determines productivity? *Journal of Economic Literature*, 49(2), 326-65.

Syverson, C. (2017). Challenges to mismeasurement explanations for the US productivity slowdown. *Journal of Economic Perspectives*, 31(2), pp.165-186.

Teece, D. J. (2010). Business models, business strategy and innovation. *Long range planning*, 43(2-3), 172-194.

Tobin, J. (1958). Liquidity preference as behaviour towards risk. *The Review of Economic Studies*, 25(2), pp.65-86.

Tongur, S., and Engwall, M. (2014). The business model dilemma of technology shifts. *Technovation*, 34(9), 525-535.

Triplett, J. E. (1999). The Solow productivity paradox: what do computers do to productivity? *The Canadian Journal of Economics/Revue Canadienne d'Economique*, 32(2), 309-334.

True Impact of UK Manufacturing 2018 report (2018). Oxford Economics. Available at: <https://www.oxfordeconomics.com/resource/bd178a1a-dbb9-4651-9b0c-4aac020e109f/> (Accessed: May 2019).

Van Ark, B. (2014). *Total factor productivity: Lessons from the past and directions for the future* (No. 271). NBB Working Paper.

Van Ark, B. (2016). The productivity paradox of the new digital economy. *International Productivity Monitor*, (31), p.3.

Van Ark, B., Ozyildirim, A., Bhide, P., Crofoot, E., Erumban, A., and Levanon, G. (2015). *Prioritizing productivity to drive growth, competitiveness, and profitability*. The Conference Board.

Van Beveren, I. (2012). Total factor productivity estimation: A practical review. *Journal of economic surveys*, 26(1), 98-128.

Van Biesebroeck, J. (2008). The sensitivity of productivity estimates: Revisiting three important debates. *Journal of Business and Economic Statistics*, 26(3), 311-328.

Van Horne, J. C. and Wachowicz, J.M. (2001). *Fundamentals of Financial Management*. Pearson Educación, 2001.

Vandermerwe, S. and Rada, J. (1988). Servitization of business: adding value by adding services. *European Management Journal*, 6(4), pp.314-324.

Velu, C. (2015). Business model innovation and third-party alliance on the survival of new firms. *Technovation*, 35, 1-11.

Velu, C. (2018). Coopetition and business models. *In The Routledge Companion to Coopetition Strategies* (pp. 336-346). London, UK: Routledge.

Velu, C. and Chen, Y. (2021). Repaying the National Debt: Post-Pandemic Prosperity Through Business Model Innovation and Productivity Growth. *Cambridge BMI Group Working Papers: 01/2021*.

Velu, C., and Stiles, P. (2013). Managing decision-making and cannibalization for parallel business models. *Long Range Planning*, 46(6), 443-458.

Visnjic, I., Wiengarten, F., and Neely, A. (2016). Only the brave: Product innovation, service business model innovation, and their impact on performance. *Journal of product innovation management*, 33(1), 36-52.

Wannakrairoj, W. and Velu, C. (2021). Productivity growth and business model innovation. *Economics Letters*, 199, p.109679.

Weill, P. (1992). The relationship between investment in information technology and firm performance: A study of the valve manufacturing sector. *Information Systems Research*, 3(4), 307-333.

Wirtz, B.W., Schilke, O. and Ullrich, S. (2010). Strategic development of business models: implications of the Web 2.0 for creating value on the internet. *Long Range Planning*, 43(2-3), pp.272-290.

Wooldridge, J. M. (2001). Applications of generalized method of moments estimation. *Journal of Economic Perspectives*, 15(4), 87-100.

Zott, C. and Amit, R., 2007. Business model design and the performance of entrepreneurial firms. *Organization Science*, 18(2), pp.181-199.

Zott, C., Amit, R., and Massa, L. (2011). The business model: recent developments and future research. *Journal of Management*, 37(4), 1019-1042.

Appendix A: Caterpillar Inc. Financials from 1993 to 2018

Year	Total Revenue (USD '000)	Total Assets (USD '000)	Employees (USD '000)
1993	11,615	14,807	51
1994	14,328	16,250	54
1995	16,072	16,830	54
1996	16,522	18,728	57
1997	18,925	20,756	60
1998	20,977	25,128	66
1999	19,702	26,635	67
2000	20,175	28,464	68
2001	20,450	30,657	72
2002	20,152	32,851	69
2003	22,763	36,465	69
2004	30,251	43,091	77
2005	36,339	47,069	85
2006	41,517	50,879	95
2007	44,958	56,132	101
2008	51,324	67,782	113
2009	32,396	60,038	94
2010	42,588	64,020	104
2011	60,138	81,446	125
2012	65,875	89,356	125
2013	55,656	84,896	119
2014	55,184	84,681	114
2015	47,011	78,497	106
2016	38,537	74,704	95
2017	45,462	76,962	98
2018	54,722	78,509	104
Avg.	34,755	50,217	86

Source: S&P Capital IQ Database

Appendix B: Average Manufacturing Data

Year	Number of Firm	Avg. Turnover (£ '000)	Avg Total Assets (£ '000)	Avg. Number of Employee
2003	2,328	73,257.24	75,947.45	462
2004	2,328	77,360.81	76,409.13	456
2005	2,328	81,705.19	80,317.22	459
2006	2,328	89,126.35	86,212.42	452
2007	2,328	95,268.72	94,327.88	463
2008	2,328	108,803.26	116,392.08	478
2009	2,328	107,041.10	119,196.86	458
2010	2,328	113,726.68	122,305.92	440
2011	2,328	123,397.75	127,888.96	449
2012	2,328	122,013.59	132,514.54	455
2013	2,328	124,231.54	135,744.31	462
2014	2,328	126,552.33	134,872.21	467
2015	2,328	123,480.97	148,167.37	475
2016	2,328	124,144.82	158,050.14	450
2017	2,328	140,089.91	217,793.63	455
2018	2,328	150,033.87	227,538.94	471

Source: Bureau van Dijk (BvD) Fame and Authors' Calculation

Appendix C: Average Service Data

Year	Number of Firm	Avg. Turnover (£ '000)	Avg. Total Assets (£ '000)	Avg. Number of Employee
2003	440	204,870.42	218,186.74	1,061
2004	440	211,552.69	213,969.79	1,066
2005	440	211,568.48	243,919.63	1,088
2006	440	248,727.98	252,429.68	1,133
2007	440	263,681.62	267,178.87	1,249
2008	440	300,020.98	331,872.14	1,166
2009	440	309,519.58	346,090.22	1,129
2010	440	311,994.03	354,725.32	1,125
2011	440	329,861.90	365,394.44	1,168
2012	440	342,858.60	375,766.42	1,179
2013	440	361,797.28	402,071.07	1,063
2014	440	363,786.81	402,975.34	1,201
2015	440	358,640.89	422,724.74	1,232
2016	440	372,729.80	459,022.83	1,265
2017	440	391,113.25	490,184.30	1,238
2018	440	400,442.03	485,364.12	1,250

Source: Bureau van Dijk (BvD) Fame and Authors' Calculation

Appendix D: Average Financials of Rolls-Royce

Rolls-Royce Holdings plc	Year 1990-2019
Avg. Total Revenue (USD '000)	12,758.61
Avg. Cost Of Goods Sold (USD '000)	10,407.50
Avg. Selling General & Admin Exp. (USD '000)	1,060.29
Avg. Depreciation & Amort. (USD '000)	608.33
Avg. Net Interest Exp. (USD '000)	(98.12)
Avg. Net income (USD '000)	419.11
Avg. Net Property, Plant & Equipment (USD '000)	3,360.05
Avg. Number of Employee	45,293

Source: Authors' Calculation from S&P Capital IQ Database and the Company's annual reports which extracted from Mergent Archives

Appendix E: Average Financials of Rolls-Royce's Competitors

	Year	Avg. Revenue (USD '000)	Avg. Total Asset (USD '000)	Avg. Number of Employee
Bombardier Inc.	1996-2019	14,185.32	19,053.59	56,061
MTU Aero Engines AG	1996-2019	3,419.44	4,052.08	7,810
MAN SE	1989-2019	15,451.86	16,668.55	56,230
GE	1991-2019	114,520.28	504,217.68	291,889
Raytheon Technologies Corporation	1990-2019	40,903.60	52,105.00	194,207
Honeywell International Inc.	1991-2019	27,904.00	31,653.37	112,626
Safran SA	1989-2019	10,371.13	16,564.44	38,851

Source: Authors' Calculation from S&P Capital IQ Database and the Company's annual reports which extracted from Mergent Archives