Cost Efficiency in the UK Life Insurance Industry in the post-Global Financial Crisis Period

by
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An Applied Dissertation Submitted to the
University of Hertfordshire in Partial Fulfilment of the Requirement
of the Degree of Doctor of Business Administration

University of Hertfordshire
September 2019

Approval Page

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This applied dissertation represents my original work, except where I have acknowledged the ideas, words, or material of other authors.

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Acknowledgements

I would like to acknowledge my employer Canada Life, and specifically the Chief Financial Officer, Kathryn Bateman and the Chief Actuary, Chris Lewis, for their support and understanding during this research project. I would also like to thank my supervisors Dr Aarti Rughoo and Dr Yaping Yin for always being at hand to help me when needed, and for always having this final deliverable in mind during the whole process. I also want to acknowledge Andrew Field at S&P Global for the help he provided with gaining access to the SynThesys Insurance regulatory database. A special mention also goes to the DBA directors, past and present, and fellow DBA students, for creating an environment that allowed me to learn from a variety of speakers and peers during the process. I would like to thank my parents, siblings and friends for cheering me on, and keeping me accountable! Finally, I would like to thank and dedicate this Degree to my wife Ngoni and my son Mudiwa, for inspiring and motivating me to complete this research project.

Abstract

The aim of this research project is to adopt a two-stage approach for empirically measuring and determining the level of cost efficiency in the UK Life Insurance industry during and after the Global Financial Crisis (GFC). Stage one employs a Data Envelopment Analysis (DEA) technique with Variable Returns to Scale (VRS) to estimate the cost efficiency scores for the whole UK Life Insurance Industry for the period 2007 to 2015. In the second stage, a panel Tobit regression technique is used to examine the effects on cost efficiency of a set of determinants that are largely drawn from the recent literature on Financial and Risk Management (FRM). The findings suggest that the average cost efficiency in this period was lower than the level previously reported in the literature, but, by 2015, a clear improvement is noted. The findings also suggest that some potentially effective measures to improve operational efficiency include the reduction of the use of reinsurance, increasing firm size and relocation of office space away from Central London.

Keywords: Cost Efficiency, Life Insurance, Data Envelopment Analysis, Global Financial Crisis, Financial and Risk Management

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Chapter 1: Introduction

1 Introduction

This research project, entitled *Cost Efficiency in the UK Life Insurance Industry in the post-Global Financial Crisis Period* uses empirical data for the UK Life insurance industry in the period 2007 – 2015 to analyse cost efficiency for the UK insurance industry and its determinants. This section provides a brief overview of the industry, the aims and objectives of this project and how it will contribute to practice and the literature. This section also includes a reflective section by the researcher, which highlights their professional context, philosophical paradigm and motivation for conducting the research. Section 2 summarises the critical conceptual and empirical literature review that was conducted as part of this project, while Section 3 provides details of the methodology that was employed in the study. Section 4 discusses the results of the project, and the report concludes with conclusions in Section 5.

1.1 Overview of the UK Insurance Industry

1.1.1 High-level context of the Industry

The UK Insurance Market is the 4th largest in the world by Premiums Written, after the United States of America (U.S.), China and Japan[1]. It is therefore the largest in Europe, and also has one of the highest penetration rates in the region (see Figures 1-1 and 1-2 below). This suggests that the performance of this industry is important both in the UK, and within the Global context.

The UK Insurance market is dominated by the Life insurance sector, which has made up around 75% - 85% of the whole industry by Gross Written Premiums (GWP) over the decade up to 2015 (see Figure 1-3). This sector is therefore the focus of this research project.

[1] Source: https://www.swissre.com/dam/jcr:a160725c-d746-4140-961b-ea0d206e9574/sigma3_2018_en.pdf

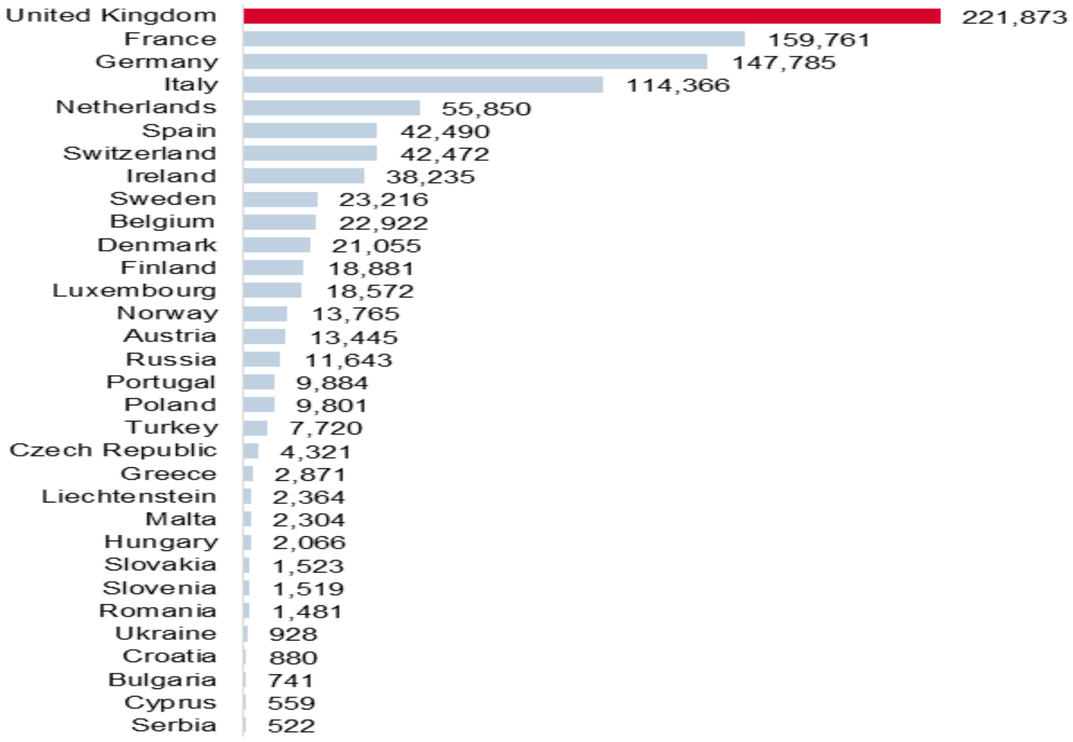
As at YE15[2], the UK Life insurance industry was made up of 95 legal entities (down from 147 in 2007), some of which are part of wider Financial Services groups (e.g. Abbey Life was owned by Deutsche Bank), while some were owned by a single parent (e.g. Aviva Life and Pensions and Friends Life Limited were both owned by Aviva plc). As well as providing traditional Life insurance services (e.g. term assurance claims, annuity payments), the industry is a significant player in the Asset Management arena, with around £1.6 trillion of assets under management. The average profit margin across the industry was 12.5% in 2015 (made up of £224.6 trillion of revenue – which mainly comes from premiums written, and £196.2 trillion of expenditure – which is driven by claims payments).

Firms in the industry are typically owned by public or private shareholders, but could also be wholly owned policyholders (i.e. mutual organisations). Aviva plc is an example of a shareholder-owned firm, while Liverpool Victoria and Royal London are examples of mutual firms[3].

There have been a number of recent developments in this industry, which suggest that a fresh look at efficiency measurement and drivers is necessary. Some of these developments are discussed in sections 1.1.2 to 1.1.9 below.

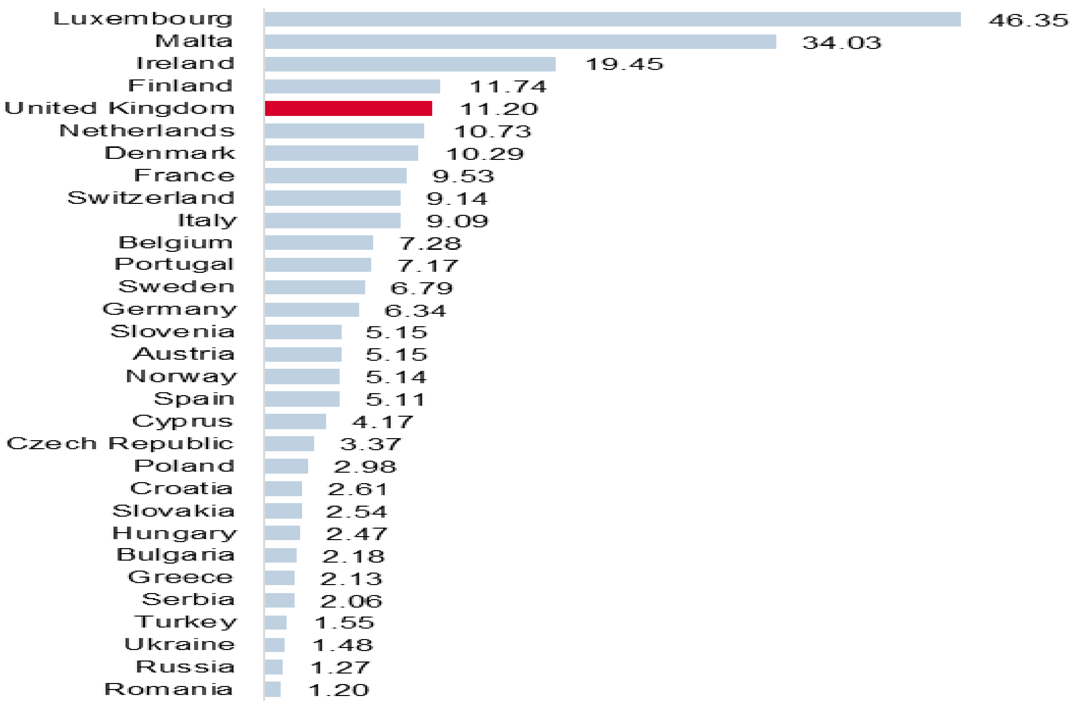
[2] Sourced from SynThesys Life 10.1 Database, and excludes firms without all of expenses, claims and asset data
[3] Source: www.aviva.com, www.lv.com and www.royallondon.com

Figure 1-1: European insurance market size, by Gross Written Premium (£M), FY'15



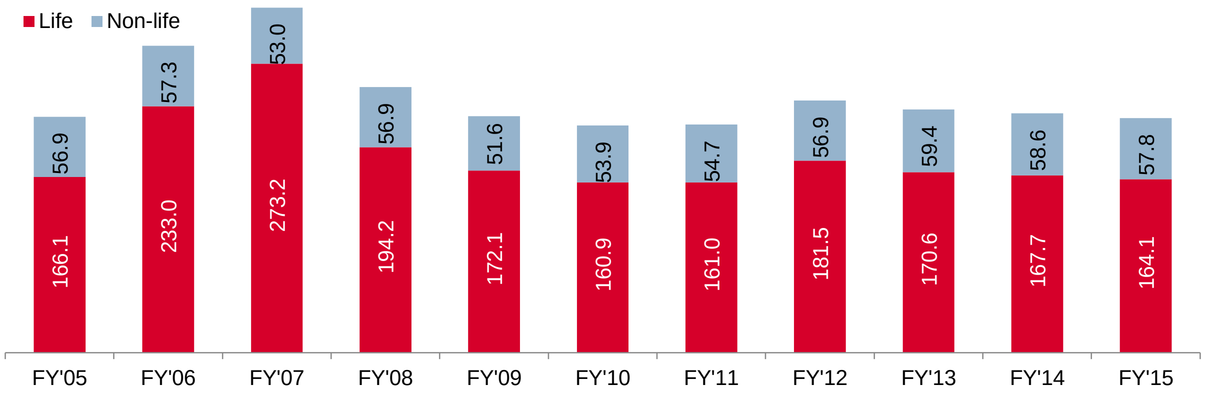
Source: *2015 Insurance Market Report*, S&P Global Market Intelligence

Figure 1-2: Insurance penetration, expressed as Gross Written Premium/GDP (%), FY'15



Source: *2015 Insurance Market Report*, S&P Global Market Intelligence

Figure 1-3: History of the Life/non-Life split of the UK Insurance Sector by GWP



Sources: *Bank of England; S&P Global Market Intelligence*

1.1.2 The Global Financial Crisis

The significant role of the UK Life Insurance industry within the European and Global context has seen it go through significant events and changes in recent years. As part of the Financial Services industry, it was within the epicentre of the Global Financial Crisis, which saw the closure or bailout of some multinational banking and insurance institutions (e.g. Lehman Brothers[4] & American International Group[5]). To its credit, the UK insurance industry did not experience any explicit closures or bailouts, perhaps attributable to a risk-based capital regulatory regime that had been introduced by the Financial Services Authority (FSA) in 2004, called 'Individual Capital and Adequacy Standards (ICAS)'[6]. However, the crisis might have left some individual companies with weaker balance sheets, which arguably squeezed financially non-critical (but commercially critical) budgets like Research & Development. This in turn, might have left companies restricted in their ability to invest in the most technically efficient methods to run their businesses (e.g. a move from traditional

[4] Source: https://www.investopedia.com/articles/economics/09/lehman-brothers-collapse.asp
[5] Source: https://www.forbes.com/pictures/eddk45fhljj/aig-bailout-in-brief-5/#6ae298ec6857
[6] Source: https://www.kent.ac.uk/smsas/casri/news/news-archive/pdf/NickDumbreck.pdf

in-house computer servers to cloud[7] computing). It also arguably made more companies vulnerable to takeover bids, as weaker companies sought the protection of stronger balance sheets for continued survival, while the stronger companies might have looked for value creation by realising synergies with other companies. In addition, the regulatory response of the UK government to the crisis was to abolish the FSA and replace it with two regulators[8]: the Prudential Regulatory Authority (PRA), which focusses on the financial soundness of all financial institutions; and the Financial Conduct Authority (FCA), which aims to regulate the products that insurance and other financial institutions sell to customers. Although PRA & FCA appear to be mutually exclusive, they are arguably going to overlap from time to time. In addition, increased focus in one area potentially leads to increased regulation in that area. This could therefore all amount to a potential increase in compliance costs for insurance companies, thus reducing efficiency from a cost perspective.

1.1.3 The Sovereign Debt Crisis

Whilst the full extent of the Global Financial Crisis was still unfolding, the European Sovereign Debt crisis also began to unfold from 2010 to 2012, creating challenges for – amongst other economic players - the Insurance Industry in Europe (Gonzalez et al. (2017)). Although there does not appear to be any relevant literature in relation to the impact of this crisis-within-a-crisis on the UK Insurance Industry, it is unlikely to have been spared, because EU regulations on Insurance Solvency (discussed in more detail in Section 1.1.4) apply favourable regulatory capital treatment if an insurance company in one country wants to invest in the sovereign debt of another EU country. Some UK insurance companies might therefore have had exposure to Sovereign bonds of affected countries like Spain and

[7] Basic information on cloud computing can be found here: https://azure.microsoft.com/en-gb/overview/what-is-cloud-computing/
[8] Source: https://www.barnett-waddingham.co.uk/comment-insight/blog/2013/04/03/goodbye-fsa-hello-pra-and-fca/

Greece. This could therefore have led to companies either retaining earnings to support the capital position after allowing for any defaults, or raising more capital externally. Any externally raised capital would have increased costs for the affected insurer, and therefore potentially impacted on cost efficiency. In addition, if the cashflows of these bonds were being used to match policyholder benefit payments, affected companies might have needed to rebalance their asset portfolios to restore the match. This could have also affected efficiency, by increasing the cost of doing business (through portfolio rebalancing costs) without reducing the output (i.e. benefit payments).

1.1.4 Solvency II and IFRS 17

Running alongside any UK-specific regulatory changes, were preparations for a holistic approach to the regulation of financial soundness of insurance companies across Europe called 'Solvency II', which came into effect on 1 January 2016. Solvency II replaced ICAS in the UK, and the industry view is that this has resulted in more onerous capital requirements and maintenance costs than under the ICAS regime[9]. If a company needed to raise this additional required capital, it would have incurred a cost of this new capital. In addition, the new regulatory regime appears to have created additional headcount for some companies (e.g. it makes specific reference to a Risk function, leading to a need for Risk professionals that might not have been previously required by insurance companies). This appears to have further reduced efficiency from a cost perspective.

Work has also begun on implementing a major change to the financial reporting landscape of the insurance industry from a global perspective. This initiative – known as IFRS17 - is being led by the International Accounting Standards Board, and is expected to become

[9] Source: 'Solvency II and Current Economic Environment – Impact on Consumers' by the Institute & Faculty of Actuaries.

effective for annual reporting periods beginning on or after 1 January 2021[10]. Although it is currently unclear if this major change will result in a long-term ongoing increase to a company's cost base, industry practitioners expect it to increase the running costs in the industry[11], which would put a further strain on ongoing efficiency from a cost perspective. In addition, a project of this magnitude is likely to result in significant costs in the implementation phase.

1.1.5 Pension Freedoms and Equity Release Mortgages

The post-2008 period has seen another fundamental regulatory change, which allowed maturing pension savings to be available as cash, as opposed to automatically purchase an income for life (also known as an annuity)[12]. This has risked reducing efficiencies that come from economies of scale for Life Insurance companies, since companies would now need to cover any fixed expenses they could not pass on to the reduced number of policyholders. It also potentially increased insurance companies Research and Development costs, as they sought to find alternative future income streams that were lost due to this regulatory change.

One innovation that some insurance companies have turned to in response to falling income streams is the Equity Release Mortgage. This product recognises that many UK pensioners have valuable capital locked in their residential properties, so allows policyholders to release this value during their retired life, in exchange for part or all of the residential property on death[13]. However, this is a regulatory capital-intensive product (due to the

[10] Source: https://www.ifrs.org/issued-standards/list-of-standards/ifrs-17-insurance-contracts/
[11] Source: http://www.theactuary.com/news/2018/05/ifrs-17-to-be-more-costly-than-solvency-ii/
[12] Source: https://www.pensionsadvisoryservice.org.uk/about-pensions/pension-reform/freedom-and-choice
[13] Details of Equity Release Mortgages: https://www.moneyadviceservice.org.uk/en/articles/equity-release

associated complex risks that are not publicly assessable), which might inadvertently decrease the efficiency of insurers that offer it.

1.1.6 Insure-tech companies

Entrance into the industry of insure-tech companies like Vitality[14] has also put pressure on business volumes of traditional insurance companies, thus threatening their Economies of Scale. These new companies have little or no legacy systems, and are arguably able to offer the same benefit as a traditional insurer with less inputs (e.g. capital), because – for example – much better knowledge of the policyholder through smart watch data means less prudent reserves for the policy need to be set up.

1.1.7 Prevailing Market Conditions

The impact of the regulatory changes discussed above has been compounded by the low interest rate environment in the aftermath of the Global Financial Crisis (see Figure 1-4). The Solvency II Balance Sheet is made up of the following key items at a high level:

Distributable Surplus = Market Value Assets – Present Value of Policyholder Liabilities - Risk Margin - SCR

Where:

- SCR, or Solvency Capital Requirement is the regulatory capital under the Solvency II rules; and
- Risk Margin is a regulatory requirement for an insurance company to hold an amount to pass on to a third party in the event of insolvency. This amount would allow the third party to pay for the cost of capital raised to cover inherited

[14] https://www.vitalitygroup.com/

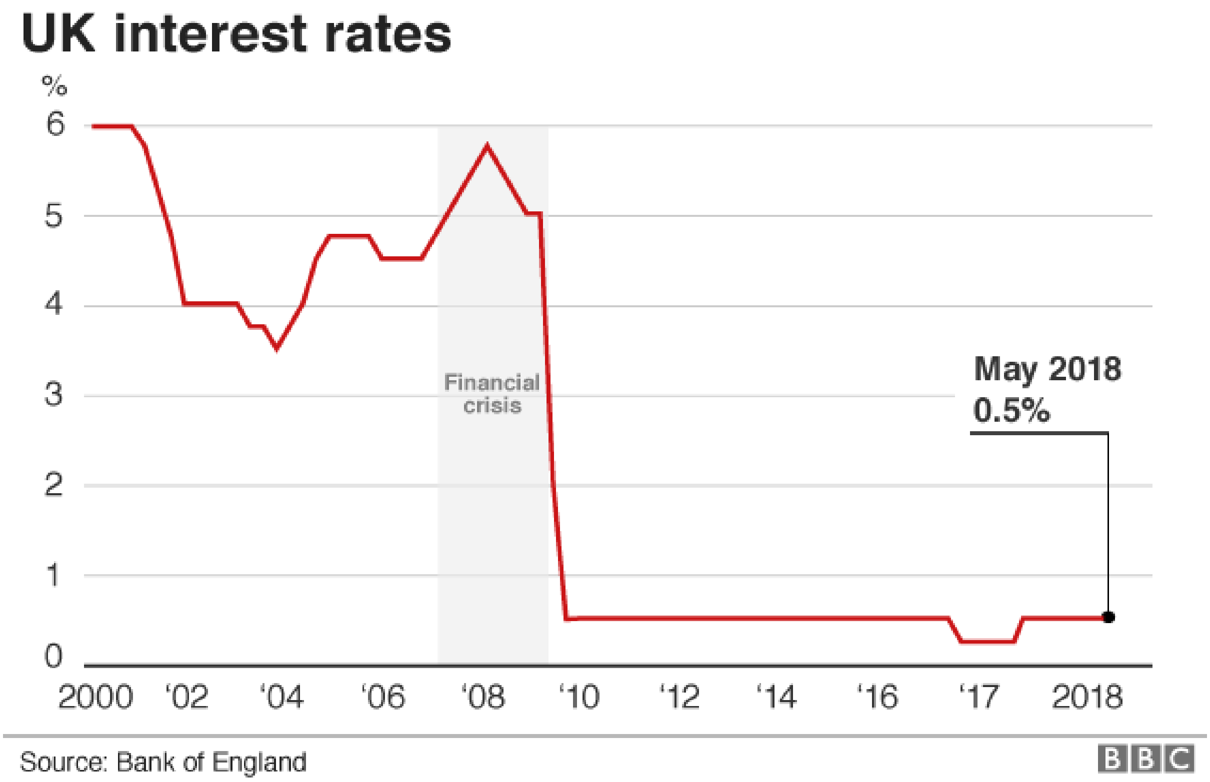
regulatory capital requirements in all future years until the last policyholder goes off the books. The cost of capital in each future year is then discounted to the present day using the current and relevant forecast interest rates, with this present day value being high when interest rates are low (and vice versa).

The prevailing low interest rate environment has therefore led to high Risk Margins. This is especially so in the Life Insurance sector, where products like annuities and death in service spouse's pensions mean it could be a few decades before the last policyholder goes off the books, meaning many more years for an annual cost of capital to apply. The very long-term nature of the Risk Margin commitment in this case also makes it difficult to manage interest rate volatility, since it tends to be difficult find assets in the open market that can mirror such a long-term commitment. Companies therefore usually resort to holding an additional capital buffer above the regulatory SCR to absorb this interest rate volatility, thus increasing the input required for a given level of output.

Existing business on 1 January 2016 (when Solvency II became effective) was effectively shielded from the additional capital requirements via transitional arrangement (the Regulator acknowledged that the business was written in a different regulatory regime). However, new business from the implementation date needs to fully meet these additional capital requirements. This suggests that companies have either had to adjust prices upwards or reduce the profit margin in the price (or both) to account for these additional capital requirements. The former is made more challenging by the pension freedoms discussed in section 1.1.5, since it makes the purchase of an annuity even more unattractive compared to the alternatives.

Interest rate levels are also important for insurers, because they can influence a firm's cost of capital, so could therefore influence efficiency or inefficiency. For example, a loan to a firm can be based on the bank base rate plus a margin[15].

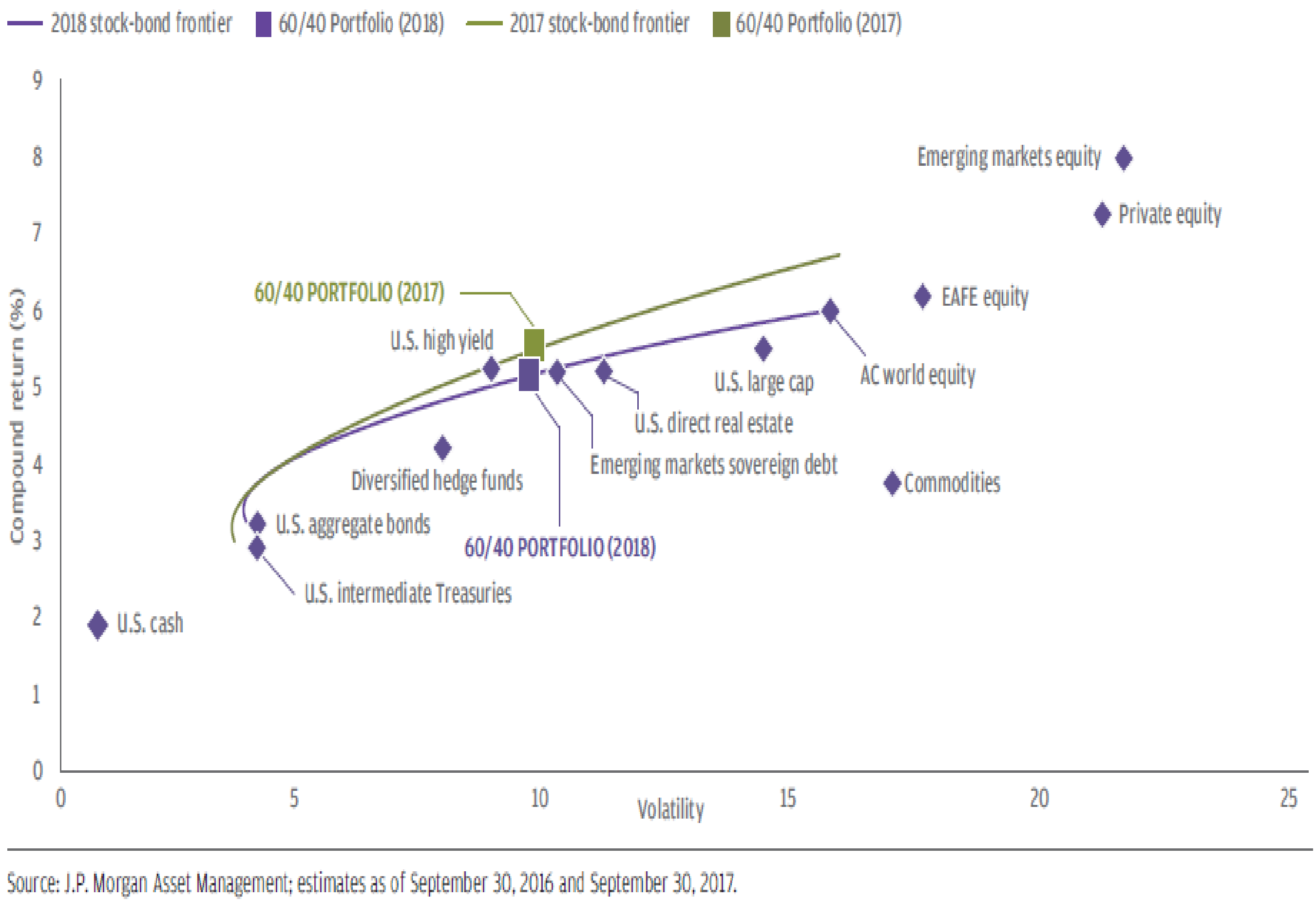
Figure 1-4: UK Interest Rate History



Another prevailing feature of current market conditions – which affects the *Market Value of Assets* part of the *Distributable Surplus* calculation – is the high risk/return efficiency in a subdued investment market (see an example in Figure 1-5 below, which shows a lot of asset classes clustered around the efficient frontier, and shows a downward shift of this frontier year-to-year). Investment managers have arguably increased this efficiency post-2008 to ensure they optimise the returns they can get for a given level of risk. This has therefore left insurance companies with limited scope to increase efficiencies on the investment side, and pointed further to the need to reassess efficiencies elsewhere on the balance sheet.

[15] An example of this can be found here: http://www.ddjcap.com/documents/ddjopportunistichighyieldfund-comm-20151112.pdf

Figure 1-5: Asset Risk-Return Efficient Frontier



1.1.8 Current industry activity and potential inefficiency levels

All these activities post-2008 have led to significant activity in the UK insurance industry, with 'efficiency' and/or 'cost-savings' being cited as reasons behind key business decisions. Some examples can be found in a survey of industry practitioners by Finances Services consulting firm PwC entitled *European Life Insurance Back Book Management 2017*[16]. Firstly, the survey found that "minimising expenses remains high on the agenda for many firms, and is a significant driver of consolidation activity and management of cost-cutting and efficiency programs". The survey also concluded that the UK insurance market was expected to remain at the forefront of consolidation activity in Europe. Secondly, it also specifically highlighted the changing regulatory environment as one of the drivers for the

[16] Source: https://www.pwc.co.uk/audit-assurance/assets/pdf/european-life-book-survey-2017.pdf

increased cost burden. Finally, companies were also found to be looking at the disposal of non-core businesses and changes to their investment strategies to improve efficiencies. These recent industry developments and the increasing importance of capital management in the industry suggest a need to understand the current capacity to improve cost efficiency. This will help industry practitioners make informed strategic decisions and potentially help to reduce the impact of the new financial and regulatory landscape eating into value and profits. Understanding the commercial effects of the regulatory changes can also provide a useful input into policy-making decisions.

There is wide variety of potential categories of efficiency or inefficiency drivers in the industry, which practitioners could consider as part of attempts to improve efficiency at their firms. One such category is Financial Risk Management, and this is introduced in section 1.1.9 below.

1.1.9 Financial Risk Management in the UK Insurance Industry

Financial Risk Management[17] appears to be a key part of the UK Insurance industry, with around 15% reinsurance cover, 59% Free Asset cover and 23% of liquid assets across the industry, as well as 30% of firms making use of Derivative instruments as at YE15[18]. Bartlett et al. (2008) looked at overall Risk Management in this industry in more detail, by reviewing results of relevant surveys, and concluded that there is evidence to indicate that insurers' risk management practices have been improving significantly over time, but there was still room for the industry to do much better than it is doing to manage its risks. One of the obstacles to effective risk management in the UK insurance industry that was cited by Bartlett et al. (2008) was the cost of implementing it. It is therefore worth exploring if

[17] Defined (by *Peter F. Christoffersen (22 November 2011). Elements of Financial Risk Management. Academic Press)* as the practice of economic value in a firm by using financial instruments to manage exposure to risk.
[18] According to summary data compiled from the SynThesys Life 10.1 Database.

common Financial Risk Management tools are making firms less cost-efficient, or whether the opposite is true, with the use of these tools actually leading to improved efficiency (and thus providing evidence of support for Risk Management from a commercial perspective).

The various aspects of the UK Life Insurance industry discussed in this section influenced the formulation of this study's purpose and research questions. These are discussed in section 1.2 below.

1.2 Purpose and Research Questions

The purpose of this study is to conduct an empirical investigation on the level of cost efficiency in the UK Life Insurance industry during and after the Global Financial Crisis, as well as test the statistical significance of a sample of potential drivers of efficiency that are largely drawn from the area of Financial and Risk Management. This purpose has helped to shape the two key research questions in this study. The first question asks about the level of cost efficiency in the industry at the end of each year, from 2007 to 2015, and what the average level was over the whole period. The second question looks to explore the statistical significance of reinsurance cover, financial derivative use, free assets on the Balance Sheet, the level of liquid assets, the size of a company and a Central London office location on insurance firms' cost efficiency inefficiency. The next section is a reflective summary of the motivations behind these research objectives and research questions.

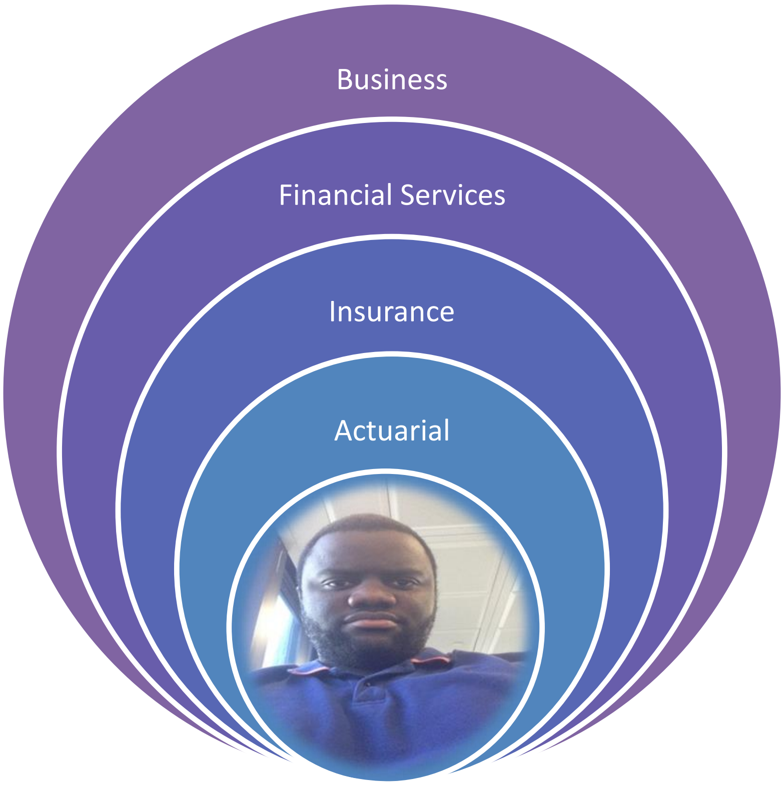
1.3 Researcher's Motivations

The extract below is from my Curriculum Vitae, and summarises who I am within my professional context:

I am an actuary with 15 years' actuarial experience (including 8 years post-qualification). I have worked in both consulting and industry environments, which has led to extensive Employee Benefits Consultancy and Life Industry exposure, as well as some Non-Life Industry exposure. I currently *manage an actuarial team of seven (including five qualified actuaries), and am one of five Heads in Canada Life's Corporate Actuarial department. My team's responsibilities include; Capital Management and Optimisation, Capital Methodology Review, Stress and Scenario Testing, Financial Planning and Regulatory Engagement Support.*

Based on the paragraph above, I consider my context to have a few professional context layers, as shown in Figure 1-6 below.

Figure 1-6: The Researcher's Professional Context



I view my current role at Canada Life as straddling all the layers above, because I see Capital projects in Insurance as contributing to an insurer's strategic Business objectives within the Financial Services industry in general, and the Insurance industry in particular. However, due to the nature of products transacted by insurers (which are mainly focussed on statistically uncertain future events), these Capital projects rely significantly on the Actuarial skillset.

As an actuary by training, I am partial to following Popper's Principle of Empirical Falsification, which states that a hypothesis can be tested by empirical experiment (Popper, 1959). My research questions therefore emerged by reading widely on empirical studies in efficiency research in the insurance industry, and then looking in more detail at the UK and European literature, to explore what had been explored, and where the gaps were. Having spotted what appeared to be a gap that was relevant to my Professional Context, I then sought to find out what data was available to perform my own empirical study for the UK market from the perspective of my Professional Context. I then formulated my research questions on the back of this.

Even though I am partial to empirical studies, there was still a need to guard against viewing efficiency as a purely scientific topic, with little debate about how it is measured or what drives it. There was also a need to appreciate the limitations of my findings. For example, the findings might only be generalizable within the UK industry, and for a specific amount of time within that industry. That said; I also needed to acknowledge that the approach to this study was going to be influenced by this actuarial training.

As well as a professional interest in the subject of insurance efficiency, this study was also motivated by a desire to add a practitioner perspective to this research area, which appears to be dominated by academic researchers. While this report has been written in a scholarly manner, there are a lot of examples throughout that reflect this practitioner perspective.
In addition to my individual interest, the findings of this study might also be of interest to professional and industry bodies within my professional context. For example, the Institute and Faculty of Actuaries (IFoA) and the Association of British Insurers (ABI) have recently

highlighted research done at the University of Kent on Equity Release Mortgages as something that might be useful for practitioners[19]. A study on a topical issue such as efficiency might therefore potentially attract similar industry-wide interest. There might also be interest in the findings from my senior managers at Canada Life, since their firm will be included in the analysis, suggesting that the findings will be directly relevant. These motivations and biases, as well as my chosen philosophical underpinning, influenced the literature I have reviewed in this study. This is discussed in Chapter 2.

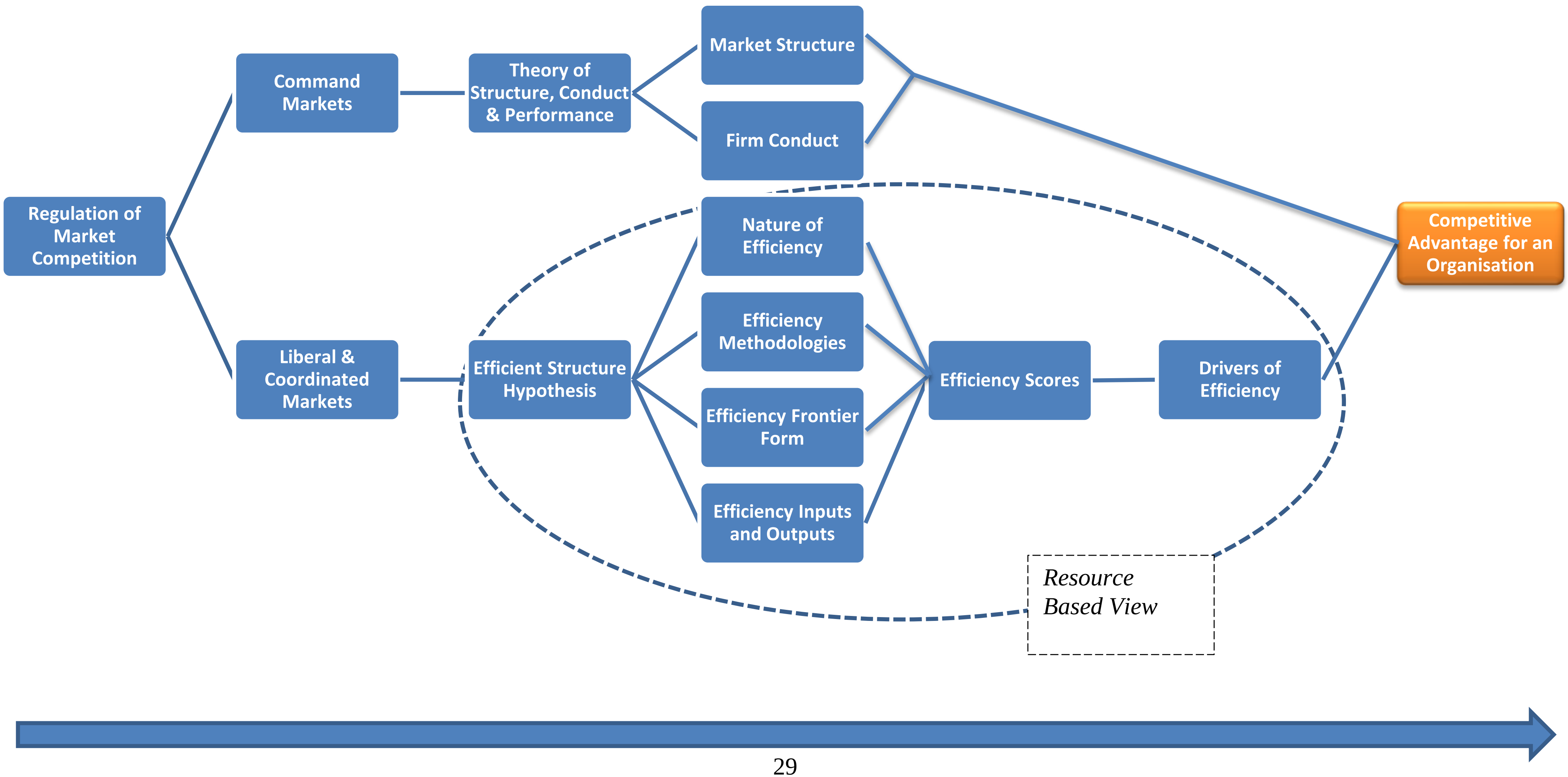
[19] Source: https://www.actuaries.org.uk/documents/review-no-negative-equity-guarantee

Chapter 2:
Literature Review

2 Literature Review

Review of literature in this project provides a conceptual framework to look at efficiency within the overarching context of market regulation, and its influence on competitive advantage. This framework provides regulatory conditions which need to be met before efficiency management can be used to drive company performance. There also appears to be a significant amount of empirical literature on efficiency in the insurance industry. These studies mainly differ by the country in which the study is conducted (e.g. Ward (2002) in the UK, and Xie (2010) in the USA), the types of Efficiency investigated (e.g. cost or profit), the efficiency methodologies applied (e.g. Data Envelopment Analysis or Stochastic Frontier Approach), Insurance Inputs and Outputs (i.e. differing approaches of measuring intangible financial services such as risk pooling) and the efficiency determinants investigated (e.g. corporate governance or product distribution systems). The conceptual framework as devised by the author on the basis of the existing strands within the literature can be seen on Figure 2-1 below. The literature review is then discussed in more detail in the rest of this section.

Figure 2-1: The Conceptual Framework for the Research Project



2.1 Regulation

The source of a company's ability to outperform another company can arguably be found in the prevailing regulation around market competition. In their simplest form, market competition regulations can be seen to either encourage (liberal and coordinated markets[20]) or discourage (command markets[21]) competition. The nature of the regulation would then determine the performance paradigm that applies. The diagram above suggests that efficiency research can only be conducted in markets that encourage competition. The following paragraphs explore if the UK Insurance industry is suitable for efficiency research from a regulatory perspective.

The UK Insurance Industry is part of the European Insurance Industry, through the UK's membership of the European Union (EU). Through the Treaty of Rome of 1957, Insurance and other industries were set on a path of a single, unified market across the EU. Campbell et al. (2003) discuss the relevant legislative developments since the Treaty of Rome, which culminated in The EU's Third Generation Directives for Life and Non-Life Insurance in 1994. This created a single passport enabling free access to establish insurance offices in any EU country. The UK Insurance Industry has therefore become more open due to these European Directives. Although the UK is in the process of leaving the European Union, these directives are expected to be transposed into UK law at the date of exit, and would therefore still apply in the short to medium term. In addition, foreign insurance companies have been able to enter the market for many years (e.g. Canada Life started its UK

[20] The term is taken from Peter A. Hall and David Soskice (2001): 'Varieties of Capitalism. The Institutional Foundations of Comparative Advantage' *Oxford University Press*.

[21] A 'command economy' is defined by Hilbert and Wright (2017) as one in which there is a high of level control of economic activity by the elected and appointed officials of a nation state.

operations in 1903[22]). Local UK regulation is also geared towards encouraging competition, with both the PRA and FCA having the promotion of effective competition as a key objective[23].

Although the classification of a liberal/coordinated or command market is subjective, the UK Insurance Industry is considered to be a liberal market for the purpose of this research, on the basis of the regulatory analysis discussed above. This view is arguably supported by the research done by Hall and Soskice (2001), where they specifically compared liberal and coordinated economies, and concluded that the UK as a whole was a liberal economy that had competitive advantage in the high-tech and services sectors (of which UK Life Insurance industry is a part). They also add that the aims of economic policies in a liberal market like the UK include minimising regulation, which is aligned to the relevant EU competition rules discussed in this section. The next section therefore assumes that the UK insurance industry exists in a Liberal Market, and explores how efficiency fits in as a measure of performance.

2.2 SCP and Efficient Structure Hypothesis

If the UK insurance industry is a liberal market, then the analysis by Barney and Clark (2007) that compares companies that are subject to the Theory of Structure, Conduct and Performance (SCP), versus those that fall under a Resource-Based View (of which the Efficiency Structure Hypothesis is a part), would suggest that the UK Insurance Industry falls under the Resource Based View. The background of both SCP and the Efficient Structure Hypothesis, including how the latter appears to have been built on the former, is discussed in sections 2.2.1 and 2.2.2 below.

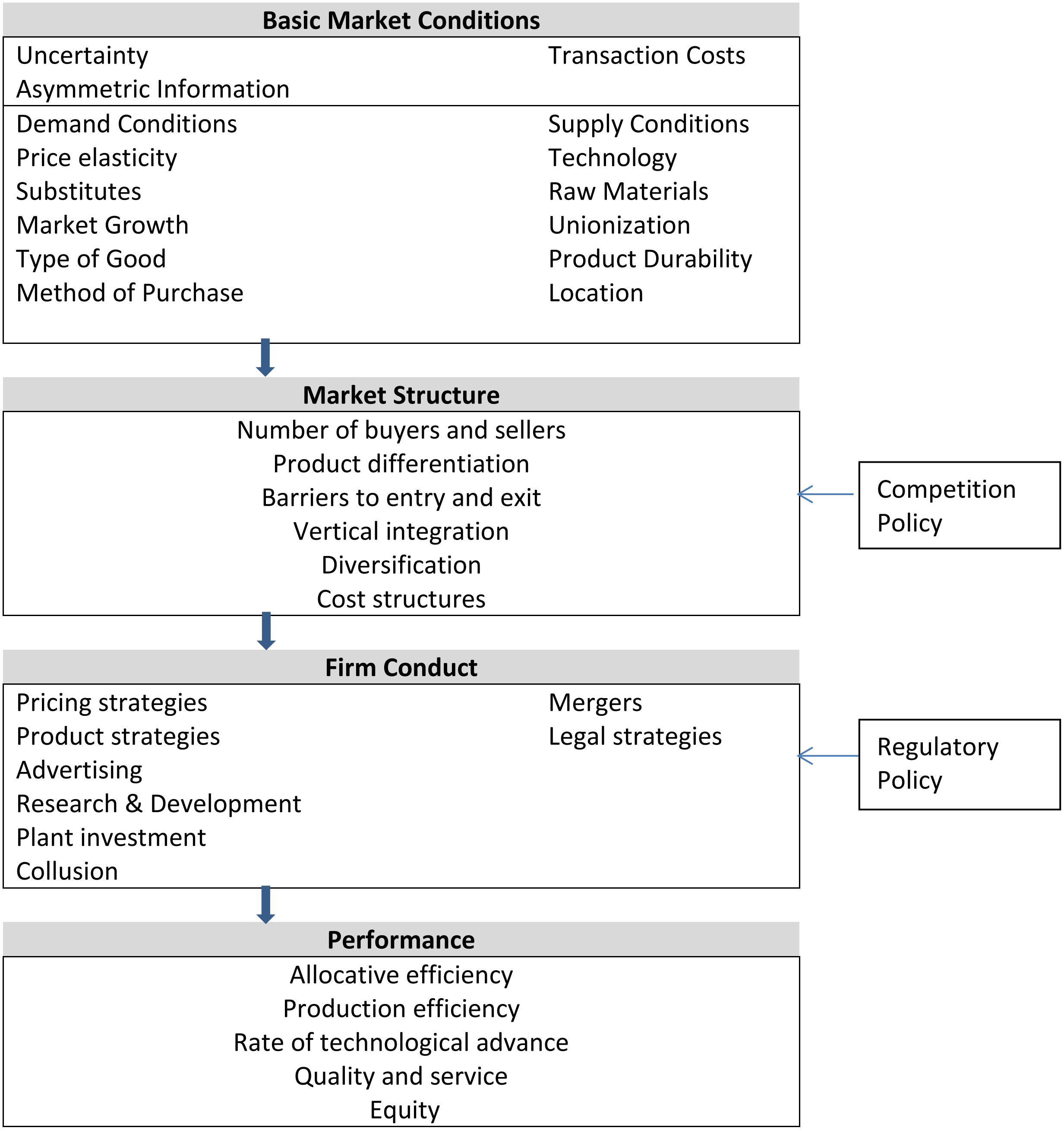
[22] Source: www.canadalife.co.uk/about-us
[23]FCA: https://www.fca.org.uk/publication/corporate/fca-approach-advancing-objectives-2015.pdf
PRA: https://www.bankofengland.co.uk/-/media/boe/files/annual-report/2016/competition-2016.pdf

2.2.1 SCP

The SCP theory was developed by Bain (1956), as part of an effort to understand why some companies outperform others. At a high level, SCP states that a company's performance is based on market power and drivers, including barriers to entry and regulation. In this paradigm, Efficiency is seen as one measure of performance, but not a driver of it. The SCP Paradigm was summarised concisely by Jedlicka & Jumah (2006) (see Figure 2-2 below). Porter (1979, 1981) also appears to draw heavily on SCP in his explanation of the impact that a firm's 'market power' has on its ability to raise prices above a competitive level. If entries into industries where firms are exercising market power are restricted by various barriers, then these performance differences can persist.

Pope and Ma (2008) noted that the *Harvard Paradigm* provides a conceptual framework from which the market structure–performance relationship can be assessed and has proven to be readily adaptable as a conceptual model of insurance market operations (Swiss Re, 1996). In his presentation of the Paradigm, Porter (1980) identified five forces (characteristics of market structure) that influence a market's conduct, which in turn determines the market's performance. Four of the forces can be considered external to the industry: the threat of entry, the threat of substitution, the bargaining power of consumers, and the bargaining power of suppliers. The fifth force, the level of market competition, is conceived of as an internal force and is generically described as the intensity of rivalry among current market competitors. Additionally, Porter (1991) later noted that these dynamics are subject to the influence of regulatory oversight, which may serve as a catalyst (or inhibitor) of innovation in the marketplace.

Figure 2-2: The SCP Paradigm



Source: Jedlicka & Jumah (2006)

Pope and Ma (2008) also add that, within the insurance market context, the roles of buyer and supplier of the product are uniquely intertwined. Conceptually speaking, the premiums paid by insurance policyholders are pooled to create a fund from which qualified claims are paid. Therefore, within the insurance context, the insurance policyholders may be conceived of as being both the buyers for the products as well as the suppliers of the necessary capital to create a functioning insurance market. The insurance market is traditionally composed of a number of relatively small consumer entities having only weak negotiating power. The same is true in their role as suppliers of capital for the insurance mechanism. A decision on the part of even the largest commercially insured entity to withdraw from the insurance market would have little impact on the total capital available to the market place. Thus, within the context of the Paradigm suppliers and buyers have little actual influence on the industry's operations. The structural forces that remain to be considered are the level of market competition, the threat of entry, and the threat of substitution.

Although the *Harvard Paradigm* may provide a conceptual framework, Cowling and Waterson (1976) supported the SCP hypothesis by theoretically identifying a positive relationship between the profit–margin ratio (a measure of market performance) and market concentration. This relationship is written formulaically below:

$$\frac{\pi}{R} = \frac{H}{\eta}(1 + \mu) \qquad (1)$$

Where:

π is the Market Profit

R is Market Revenue

H is the Herfindahl Index of market concentration

η is the price elasticity of demand

μ is the weighted sum of conjectural variations.

Thus, Cowling and Waterson (1976) established a theorized positive relationship between market concentration (H) and profitability (π /R) in Equation (1). Additionally, they identified a theorized negative relationship between market profitability and the price elasticity of demand (η).

2.2.2 Efficient Structure Hypothesis

As discussed above, a key condition that underpins the SCP paradigm is that entries into industries where firms are exercising market power are restricted by various barriers. So although this arguably applies in – say – an oligopoly that heavily restricts new entrants, the Paradigm is open to challenge in industries that have little or no barriers. For example, the UK Life Insurance industry is currently subject to the EU's Third Generation Insurance Directive of 1994, whose objective was to remove such barriers by creating a single market for insurance products across Europe via deregulation in the relevant member states (Cummins et al, 1996). In addition, foreign insurance companies have been able to enter the market for many years (e.g. Canada Life started its UK operations in 1903[24]). Similar arguments across other countries and industries led to the development of the second explanation to rival the '*Market Power*' view discussed in section 2.2.1. Peltzman (1977) also highlights that the '*Market Power'* view does not take relationships between market share, concentration, and efficiency into consideration.

The alternative view therefore focusses less on market power, and more on the differential ability of some firms to more effectively and efficiently respond to customer needs (Demsetz 1973). Demsetz (1973, 1974) and Peltzman (1977) provided a foundation for this alternative view to the SCP Paradigm by proposing the Efficient Structure hypothesis. This hypothesis suggests that the structure of the market in which a firm operates is also determined by efficiency. In this alternative paradigm, higher profits are earned by relatively

[24] Source: https://www.canadalife.co.uk/about-us

more efficient firms, and since concentration is a by-product of efficiency, these profit gains are viewed as economic rents rather than monopoly rents. This explanation was supported by Rumelt (1984), who suggested that if it is costly for less efficient and effective firms to copy more efficient and effective firms, then the superior performance of these latter firms can persist. Foss and Knudsen (2003) noted how this explanation draws heavily on neoclassical price theory.

Wernerfelt (1984) arguably produced the first publication that provided a conceptual framework relating to this alternative view to a firm's performance, which was titled a "Resource-Based-View". Independent of the Efficient Structure hypothesis, Wernerfelt (1984) attempted to develop a theory of competitive advantage based on the resources a firm develops or acquires to implement product market strategy as a complement or dual of Porter (1980)'s theory of competitive advantage based on a firm's product market position. It was called a 'view' because Wernerfelt (1984) was simply viewing the same competitive problem described by Porter (1980) from the perspective of the resources a firm controls.
Barney (1986) supported Wernerfelt (1984)'s view that it is possible to develop a theory of persistent superior firm performance based on the attributes of the resources a firm controls. However, Barney (1986) moved beyond Wernerfelt (1984) by arguing that such theory can have very different implications than theories of competitive advantage based on the product market positions of firms. Barney (1986) therefore began a shift from the Resource-Based-View to what researchers like Barney and Clark (2007) now call *Resource-Based-Theory*. The Efficient Structure Hypothesis therefore sits within this Resource-Based framework.

It's worth noting that the SCP Paradigm recognises the efficiency of firms (as can be seen in Figure 2-2 above). However, under that Paradigm, efficiency appears to be seen as a measure of performance, as opposed to a driver behind that performance. The Resource-Based approach, on the other hand, sees a key role for efficiency as a driver of a firm's overall performance.

From the perspective of insurance efficiency research, the Efficient Structure Hypothesis laid the groundwork for empirical studies to be conducted across the globe which mainly looked to:

a) quantify the levels of efficiency or efficiency change prevailing in the chosen industries; and
b) explore the drivers behind efficiency in the chosen industries, once quantification had taken place.

The following section explores these empirical studies, and their relevance to the study documented in this thesis.

2.3 Empirical Literature Review

An extensive systematic empirical literature review, consisting of publications from peer-reviewed journals for the period 1990-2019, was conducted for the purpose of this study. The start-point of the period was chosen to coincide with the period just before the Third Insurance Directive in 1994, which arguably fully liberalised the insurance industry in the European Union, and is therefore arguably the most relevant period for efficiency studies in this region (including in the UK). The end-point (the beginning of July 2019) was chosen to ensure that the review attempted to cover the most recent published literature at the time of the first draft of this report. Finally, the review was restricted to published and peer-reviewed work to support the validity of the findings of this study, in the event that they are implemented in practice or are used as the foundation of future empirical literature.

Sections 2.3.1 and 2.3.2 summarise and analyse the results of this detailed review under two broad categories:

- Stage 1: Efficiency Measurement
- Stage 2: (in) Efficiency Drivers.

Section 2.3.3 then reports on a more detailed review of some of the European literature, which is arguably of most relevance given the context of the UK Life Insurance Industry.

2.3.1 Stage 1: Efficiency Measurement

Table 2-1 below provides details of the literature review performed on the Efficiency Measurement aspect of the study. The most common approach (as well as the approach used more in recent published papers such as Eling and Jia (2018) and Karbhari et al. (2018)) used in Stage 1 appears to be the non-parametric Data Envelopment Analysis (DEA) approach. Eling and Luhnen (2010) suggest that the appeal of this approach is the fact that it does not make an assumption about the distribution of the error term in the production or cost function in the same way that a parametric approach like the Stochastic Frontier Analysis (SFA) would require. That said, there are debates in the literature about which approach is the most appropriate, with some authors finding that the choice of approach did not significantly alter the finding (e.g. Fecher et al. (1993)) while the opposite is true in other studies (e.g. Cummins and Zi (1998)). In order to align the methodology with the most common one used in recent literature, but also acknowledge the debate between parametric and non-parametric approaches, this study will use the DEA approach to estimate efficiency scores, and then validate and conduct robustness checks on the output using the SFA, which appears to be the most common parametric approach, and also appears to have been used in all UK-focussed studies reviewed as part of this study.

There appears to be reasonable consensus about what constitutes insurance inputs to an insurance firm's production process in the literature; namely: Labour, Business-related services (e.g. office accommodation) and Financial Capital (in the form of Equity Capital and Debt Capital). Labour and Financial Capital appear to be commonly picked as core parts of inputs, with Business related services and the granular elements of Financial Capital being used where available. For UK data, Hardwick and Li (1997) argue that Labour costs make up 80% of operating expenses, while Ward (2002) notes that looking at the granular elements of Financial Capital is problematic because of the existence of mutual organisations that cannot raise equity capital. This study will therefore use Labour and a combined measure of Financial Capital as a minimum. Details of the exact choices are discussed in section 3.

Unlike inputs, there appears to be more debate in the literature about what constitutes insurance outputs. Although a variety of approaches of looking at outputs are used, the majority of studies appear to use the 'valued-added' approach, which looks at an insurance firm as primarily providing value-added services to policyholders, consisting mainly of Risk-Pooling and Financial Intermediation services. Since these are intangible outputs, proxies are required to represent them in empirical studies. There are again a variety of proxies used in the literature, but a measure of claims/losses incurred or premiums appears to be commonly used as a proxy for Risk-Pooling, while Invested Assets or Additions to Reserves are used as a proxy for Financial Intermediation. While there does not appear to be criticism against using either of the Financial Intermediation proxies, the use of premiums as an output is seen as problematic by some authors because it contains an element of price, so is not just representing the risk being pooled (Eling and Luhnen (2010)). The U.S.A literature, which currently dominates research in the area of insurance efficiency, appears to commonly use claims and invested assets as insurance outputs. In the UK, 3 of the 5 studies reviewed use claims as a risk-pooling proxy, with no clear dominant proxy used for Financial Intermediation. This study acknowledges the limitations of using premiums as an output, and will therefore use claims and invested assets as outputs.

These inputs and outputs are then used to measure different types of efficiencies (e.g. cost, profit, revenue). The most recent study to measure any type of efficiency in UK Life Insurance Industry appears to be by Hardwick et al. (2011). This study will therefore look to update the literature by measuring efficiency with more up to date data, and its focus will be on input-oriented cost efficiency, which is defined by Cummins and Xi (2012) as minimising input quantities for a given level of input prices and output quantities. This appears to be the most explored measure of efficiency, and is arguably what practitioners refer to when they discuss improvements to efficiency (i.e. reduction of costs for a given level of output). This will be discussed further in section 3.

Table 2-1: Literature Review for Efficiency Measurement

(Inputs and Outputs are based on the Value-Added Approach, unless stated otherwise)

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
Angola	Barros et al. (2014)	Life, non-life	Cost	DEA	Labour, Operating Expenses, number of employees, Capital	Claims, Profits, Premiums, Ceded reinsurance
Australia	Worthington and Hurley (2002)	Non-life	Pure Technical, Scale, Allocative, Cost	DEA	Labour, information technology, materials (physical capital), debt capital	Premiums, invested assets
Austria	Ennsfellner et al. (2004)	Life, non-life	Technical	SFA	Expenses, Equity Capital, Technical Provisions	Invested assets, claims, change in reserves
	Mahlberg and Url (2003)	Life, non-life	Technical	DEA	Expenses, cost of capital	Claims, changes in reserves, investment returns, bonuses, returned premiums
BRICS countries	Huang and Eling (2013)	Non-life	Technical, Pure Technical, Scale	DEA	Number of employees, Debt Capital, Equity Capital	Premiums, Invested Assets
Canada	Mcintosh (2016)	Life, Non-life	Scale	Bespoke approach	N/A	N/A
	Wu et al. (2007)	Life	Investment, Systematic, Production	DEA	*Value Added Approach/Financial Intermediation Approach:* Labour, Equity Capital, Claims, Actuarial Reserves, Total investments, segregated funds	*Value Added Approach/Financial Intermediation Approach:* Premiums, net income, investment gains
	Yang (2006)	Life	Investment, Systematic, Production	DEA	*Value Added Approach/Financial Intermediation Approach:* Labour, Equity Capital, Claims, Actuarial Reserves, Total investments, segregated funds	*Value Added Approach/Financial Intermediation Approach:* Premiums, net income, investment gains

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
China	Leverty et al. (2009)	Life, non-life	Technical, Pure Technical, Scale	DEA	Business expenses, Equity Capital, Debt Capital	Life: Premiums, Invested Assets Non-Life: Claims, Invested Assets
	Long Kweh et al. (2014)	Non-life	Cost	DEA	Operating expenses, Debt Capital, Equity Capital	Claims plus additions to reserves, Investment income
	Yao et al. (2007)	Life, non-life	Technical	DEA	Labour, Capital, Claims	Premiums, Investment income
Europe	Bahloul and Bouri (2016)	Non-life	Cost	SFA	Labour, Business Services, Debt Capital, Equity Capital	Claims, Gross Reserves, Ceded Reserves, Invested Assets
	Bahloul et al. (2013)	Non-life	Cost	FFA	Labour, Business Services, Debt Capital, Equity Capital	Claims, Gross Reserves, Ceded Reserves, Invested Assets
	Berger (2003)	Life, non-life	Cost, Scale, Revenue	N/A – Analysis of findings from previous empirical efficiency studies		
	Cummins et al. (2017)	Life	N/A – Efficiency is considered in a broader context, as part of the Transmission Mechanism Hypothesis			
	Diacon et al. (2002)	Life	Pure, Technical, Scale	DEA	Expenses, Debt Capital, Total Capital, Technical Reserves	Premiums, Investment Income
	Eling and Jia (2018)	Life, Non-life	Technical	DEA	Labour, Capital and Surplus	Total Liabilities, Claims, Invested Assets
	Fenn et al. (2008)	Life, non-life	Cost	SFA	Total Capital, Debt Capital, Labour, Technical Provisions	Claims
	Klotzki et al. (2018)	Life	Scale	Economies of Scale calculated using Houston and Simon (1970) methodology		
	Vencappa et al. (2013)	Life, Non-life	Technical, Scale	SFA	Labour and material inputs, financial capital	Premiums, Claims, Change in Reserves
Finland	Toivanen (1997)	Non-life	Cost	SFA	*Physical Approach*: Labour	*Physical Approach*: Number of units produced
France	Fecher et al. (1993)	Life, non-life	Technical	DEA, SFA	Labour, Other expenses	Premiums

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
GCC Countries	Al-Amri (2015)	Takaful	Cost, Technical, Pure Technical, Allocative	DEA	Labour, Debt Capital, Equity Capital	Premiums, Invested Assets
	Al-Amri et al. (2012)	Life, Non-life	Technical	DEA	Direct costs, Indirect costs	Premiums, Investment income
	Alshammari (2018)	Takaful, Life, Non-life	Cost	SFA	Labour, Debt Capital, Equity Capital	Claims, Additions to Reserves, Invested Assets
	Karbhari et al. (2018)	Takaful	Technical, Scale	DEA	Admin Expenses, Labour, Capital	Premiums
Germany	Diboky and Ubl (2007)	Life	Technical, Cost, Allocative	DEA	Labour, Other expenses, Debt Capital, Equity Capital	Premiums, Net income
	Luhnen (2009)	Non-Life	Cost, Technical	DEA	Labour, Debt Capital, Equity Capital	Claims, Invested Assets
	Mahlberg and Url (2010)	Life, Non-life	Scale	DEA	Administration and Distribution Costs, Debt Capital, Equity Capital	Claims, Additions to Reserves, Investment Income
Germany, U.K.	Rees and Kessner (1999)	Life	Technical	DEA	Distribution Cost, Administrative Cost	Premium income, Change in premium income (UK), Aggregate Sum Assured and Change in Aggregate Sum assured (Germany)
Ghana	Alhassan et al. (2013)	Life, Non-life	Technical, Pure Technical	DEA	Labour and Business Services, Equity Capital	Premiums, total income (net of tax)
	Ansah-Adu et al. (2011)	Life, Non-Life	Cost	DEA	Total Capital, Total Operating Cost, Invested Assets	Profits, Premiums, Investment Income
Global	Biener and Eling (2011)	Life, Non-Life (Micro-Insurance)	Technical, Allocative, Cost	DEA	Labour and Business Services, Debt Capital, Equity Capital	Claims plus additions to reserves, Invested Assets
	Biener et al. (2017)	Life, Non-life	Cost, Scale, Allocative, Technical, Pure Technical ,Revenue	DEA	Number of employees, Business services, Equity Capital	Premiums, Claims, Invested Assets

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
Global	Gaganis et al. (2013)	Life, Non-Life	Profit, Cost	SFA	Equity Capital, Technical Reserves, Management and Commission costs ,Claims	Premiums, Invested Assets
	Kader et al. (2010)	Takaful	Cost, Technical, Pure Technical, Scale, Allocative	DEA	Labour, Capital, Total Operating expenses	Premiums
	Kader et al. (2014)	Takaful	Cost, Technical, Pure Technical, Scale, Allocative	DEA	Labour, Capital	Premiums
Greece	Barros et al. (2010)	Life, Non-life	Technical	DEA	Labour, Non-Labour Cost, Equity Capital	Invested Assets, Claims, Ceded Reserves, Retained Reserves
	Nektarios & Barros (2010)	Life, Non-Life	Scale, Pure Technical	DEA	Labour, Non-Labour Cost, Equity Capital	Invested Assets, Claims, Ceded Reserves, Retained Reserves
	Noulas et al. (2001)	Non-life	Technical	DEA	Salaries, Production expenses	Premiums, Investment income
India	Dutta and Sengupta (2011)	Life	Technical, Pure Technical	DEA	Claims, Operating Expenses, Agent Commission	Premiums
	Tone and Sahoo (2005)	Life	Technical, Allocative, Cost, Scale	DEA	Labour, Business Services, Debt Capital, Equity Capital	Claims, ratio of liquid assets to liabilities
Italy	Cummins et al. (1996)	Life, non-life	Technical	DEA	Labour, fixed capital expense, equity capital	Claims/losses incurred, change in reserves, invested assets
	Turchetti and Daraio (2004)	Non-life (Motor)	Technical, Allocative, Cost, Scale	DEA	New Business expenses, Overhead expenses, fixed capital, equity capital, debt capital	Claims, Invested assets
Japan	Fukuyama (1997)	Life	Technical, Pure Technical, Allocative, Scale	DEA	*Financial Intermediation Approach*: Labour, Capital	*Financial Intermediation Approach*: Technical Reserves, Loans
	Fukuyama and Weber (2001)	Non-life	Technical	DEA	*Financial Intermediation Approach*: Labour, Capital	*Financial Intermediation Approach*: Technical Reserves, Loans

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
Japan	Hirao (2004)	Non-life	Cost	SFA	Labour, agencies, materials	Claims, Change in Reserves
	Jeng and Lai (2005)	Non-life	Technical, Cost	DEA	*Value-Added Approach*: Labour, business services, Capital *Financial Intermediation Approach*: Surplus from previous year, change in surplus, expenses, policyholder debt capital	*Value-Added Approach*: Number of policies, Total invested assets *Financial Intermediation Approach*: Return on Assets, Three Principal Components of Financial Conditions.
Malaysia	Baharin and Isa (2013)	Life, Takaful	Cost	FFA	Labour, materials, Capital	Premiums, Investment Income
	Chen et al. (2014)	Non-life	Technical	DEA	Labour and Business Services, Debt Capital, Equity Capital	Claims plus additions to reserves, Invested Assets
Mozambique	Barros and Wanke (2014)	Life, Non-life	Cost, Scale	DEA	Operating costs, number of employees, Wages, Capital	Claims, Premiums, Profits, Ceded Reserves
OECD countries	Rai (1996)	Life, non-life	Cost	DFA, SFA	Labour, Capital, Claims	Premiums
Portugal	Barros et al. (2005)	Life, Non-Life	Scale, Technical, Pure Technical	DEA	Premiums, Investment Income, Capital and Wages	Claims, Profits
	Brito et al. (2013)	Non-life	Cost	SFA	*Physical Approach:* Acquisition costs, labour and business services, Claims, Capital	*Physical Approach:* Number of policies
Saudi Arabia	Akhtar (2018)	Takaful, Life, Non-life	Technical, Super-Efficiency	DEA	Equity, Net Claims incurred, General and Administrative expenses	Investment Income, Premiums, Investment and Management Fee Income
	Benyoussef and Hemrit (2019)	Takaful, Life, Non-life	Technical, Scale	DEA	Capital, Premiums	Claims, Investment Income
South Africa	Alhassan and Biekpe (2016)	Non-life	Cost, Profit	SFA	Labour and Business Services, Debt Capital, Equity Capital	Claims, Investment Income
South Korea	Park and Park (2015)	Non-life	Technical, Scale	DEA	Labour, Capital, Business Services	Refunded Premiums, Invested Assets

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
Spain	Cummins and Rubio-Misas (2006)	Life, non-Life	Allocative, Cost, Pure Technical, Scale	DEA	Labour, Business Services, Debt Capital, Equity capital	Losses incurred, reinsurance reserves, non-reinsurance reserves, invested assets
	Cummins et al. (2004)	Life, non-Life	Allocative, Cost, Revenue, Technical	DEA	Labour, business services, debt capital, equity capital	Losses incurred
	Fuentes et al. (2001)	Life, non-life	Technical	SFA	Labour	Annual Premiums
	Segovia-Gonzalez et al. (2009)	Life, non-life	Cost	DEA	Number of claims, Cost of Claims, Number of claims when policy taker is guilty	Premiums (Gross of reinsurance), Premiums (Net of reinsurance)
Switzerland	Biener et al. (2016)	Life, non-life	Cost, Technical, Allocative, Scale, Revenue	DEA	Labour, business services, debt capital, equity capital	Claims, Invested Assets
	Jametti and von Ungern-Sternberg (2005)	Life, non-life	Cost	Bespoke approach that measures efficiency as the Claims: Premium Ratio	N/A – Bespoke approach	
Taiwan	Hao and Chou (2005)	Life	Cost	DFA, SFA	Labour, Physical Capital, Claims	Premiums, Invested Assets
	Hu and Yu (2015)	Life	Cost (Operating)	SFA	Operating Costs, Non-operating Costs	Securities Assets, Other Assets
	Huang et al. (2019)	Life	Technical, Scale	SFA	Number of internal staff, number of field staff, total fixed assets	Premiums, Investment Income
	Hwang and Kao (2008)	Non-Life	N/A – Methodology issues	DEA	*Bespoke approach:* New Business Expenses, Overhead Expenses	*Bespoke approach:* Premiums, Underwriting Income, Investment Income

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
Taiwan	Wang et al. (2007)	Life, Non-life	Cost, Technical, Allocative	DEA	Labour, Business Services, Equity Capital	Claims, Invested Assets
Thailand	Yaisawarng et al. (2014)	Non-life	Cost	SFA	Labour, Business Services, Capital	Number of policies, Invested Assets
The Netherlands	Bikker and Gorter (2011)	Non-life	Cost	SFA	Labour, Debt Capital, Equity Capital	Premiums, Claims, Invested Assets
	Bikker and van Leuvensteijn (2008)	Life	Cost	SFA	*Physical Approach:* Acquisition costs, all other costs	*Physical Approach:* Premiums, Outstanding number of policies, Total of insured annuities, total of insured capital
Turkey	Kasman and Turgutlu (2009)	Life, Non-life	Cost, Scale	SFA	Labour, Business Services, Capital	Claims plus additions to reserves, Invested Assets
U.A.E	Rao et al. (2010)	Life, non-life	Allocative	DEA	Operating expenses, equity and change in reserves	Investment income, liquid asset to total liabilities ratio
U.K.	Hardwick and Li (1997)	Life	Economic, Scale, Total	SFA	Labour, Capital	Premiums
	Hardwick et al. (2011)	Life	Profit	SFA	Labour, Business Services, Equity Capital, Debt Capital	Claims, Additions to reserves
	Klumpes (2004)	Life	Cost, Profit	SFA	Labour, Materials, Debt Capital, Equity Capital	Claims, Invested Assets
	Letza et al. (2001)	Life	Cost	SFA	Inputs and Outputs do not appear to be explicitly described in the journal paper.	
	Ward (2002)	Life	Cost, Revenue, Profit	SFA	Labour, Capital	Claims, Additions to Reserves
U.S.	Berger et al. (1997)	Non-Life (Property-liability)	Cost, Profit	DFA	Financial Equity Capital, Business Services, Labour, Debt Capital	Claims and invested assets
	Berger et al. (2000)	Life, Non-Life (Property-liability)	Revenue, Profit, Cost	SFA, TFA	Financial Equity Capital, Business Services, Labour, Reserves	Claims/losses incurred and invested assets

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
U.S.	Brockett et al. (2004a)	Non-Life (Property-liability)	n/a	DEA	*Financial Intermediation Approach:* Previous year's surplus, change in capital and surplus, underwriting and investment expenses, policyholder-supplied debt capital	*Financial Intermediation Approach:* Return on Investment, Liquidity assets to liability ratio, solvency score
	Brockett et al. (2004b)	Life (Health)	Technical	DEA	*Physical Approach:* Premiums, expenses	*Physical Approach:* Number of outpatient visits, Number of Hospital days, number of member months
	Brockett et al. (2005)	Non-Life (Property-liability)	n/a	DEA	*Financial Intermediation Approach:* Previous year's surplus, change in capital and surplus, underwriting and investment expenses, policyholder-supplied debt capital	*Financial Intermediation Approach:* Return on Investment, Liquidity assets to liability ratio, solvency score
	Choi and Weiss (2005)	Non-Life (Property-liability)	Cost, Revenue	SFA	Labour, materials, equity capital	Invested assets, Losses incurred
	Cummins and Nini (2002)	Non-Life (Property-liability)	Allocative, Cost, Revenue, Technical	DEA	Labour, Materials and Business Services, Equity Capital	Invested assets, Losses incurred
	Cummins and Xie (2008)	Non-Life (Property-liability)	Cost, Technical, Pure Technical, Scale, Revenue	DEA	Labour, materials, equity capital	Losses incurred, total invested assets
	Cummins and Xie (2013)	Non-Life	Cost, Pure Technical, Scale, Allocative	DEA	Labour, Business Services, Equity Capital	Claims, Invested Assets
	Cummins and Zi (1998)	Life	Allocative, Cost, Technical	DEA, DFA, FDH, SFA	Labour, Financial Capital, materials	Benefit payments (claims), additions to reserves

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
U.S.	Cummins et al. (1999a)	Life	Cost, Technical, Pure Technical, Scale, Revenue	DEA	Labour, Business Services, Financial Capital	Incurred benefits, additions to reserves
	Cummins et al. (1999b)	Non-Life (Property-liability)	Cost, Technical	DEA	Labour, materials, debt capital, equity capital	Losses incurred, total invested assets
	Cummins et al. (2009)	Non-life	Cost	SFA	Labour, materials, debt capital, equity capital, Total cost	Invested Assets, Investment Income, Turnover, Dollars Surplus Duration
	Cummins et al. (2010)	Life, Non-life	Cost, Revenue, Profit	DEA	Labour, materials, debt capital, equity capital	Claims, Invested Assets
	Erhemjamts (2007)	Life	Technical	DEA	Labour, Business Services, Debt Capital, Equity Capital	Claims, Additions to Reserves
	Grace and Timme (1992)	Life	Scale and Scope	SFA (Cost Function)	Labour, Other Expenses, Capital	Premiums, Claims, Invested Assets
	Grace et al. (2015)	Life, non-life	Cost, Revenue	DEA	Labour, materials, debt capital, equity capital	Claims, Invested Assets
	Greene and Segal (2004)	Life	Cost	SFA	Labour, materials, capital	Claims, Invested Assets
	He et al. (2011)	Non-life	Cost, Revenue	DEA	Labour, materials, equity capital	Claims, Invested Assets
	Huang et al. (2011)	Non-life	Cost, Technical	DEA	Labour, materials, equity capital	Claims, Invested Assets
	Jeng et al. (2007)	Life	Cost, Technical, Allocative	DEA	*Value-Added Approach*: Labour, business services, Capital *Financial Intermediation Approach*: Surplus from previous year, change in surplus, expenses, policyholder debt capital	*Value-Added Approach*: Number of policies, Total invested assets *Financial Intermediation Approach*: Return on Assets, Three Principal Components of Financial Conditions.

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
U.S.	Leverty and Grace (2010)	Non-life	Pure Technical, Scale, Allocative, Cost, Revenue	DEA, RAM	*Value-Added Approach*: Labour, materials, debt capital, equity capital *Financial Intermediation Approach*: policyholder surplus, underwriting and investment expenses, policyholder debt capital	*Value-Added Approach*: Claims, Invested Assets *Financial Intermediation Approach*: Return on Assets, Liquid Assets to Liabilities, Solvency Score
	Park et al. (2009)	Non-life	Cost, Revenue	SFA	Labour, materials, equity capital	Claims, Invested assets
	Pottier (2011)	Life	Cost, Revenue, Profit	DEA	Labour, materials, debt capital, equity capital	Claims, Invested assets
	Shi and Zhang (2011)	Non-life	Cost (X-efficiency)	SFA	Labour, materials, capital	Claims, Invested assets
	Shim (2011a)	Non-life	Cost, Revenue, Pure Technical, Scale, Allocative	DEA	Labour, materials, financial equity capital	Claims, Invested assets
	Shim (2011b)	Non-life	Bespoke approach that measured efficiency as Return of Assets, Return on Equity and Earnings Volatility	N/A – Bespoke approach		
	Weiss (1991)	Non-Life	Technical, Allocative, Scale	SFA	Labour, Materials, Capital	Claims, Reserves
	Weiss and Choi (2008)	Non-life	Cost, Revenue	SFA	Labour, materials, equity capital *(Inputs are unclear from the journal, but it says the approach used is consistent with Choi and Weiss* (2005)*)*	Invested assets, Losses incurred *(Inputs are unclear from the journal, but it says the approach used is consistent with Choi and Weiss* (2005)*)*

Country	Journal Paper	Line of Business	Efficiency Type	Empirical Method	Inputs	Outputs
U.S.	Xie (2010)	Non-life	Scale, Allocative, Technical, Cost, Revenue	DEA	Labour, materials, equity capital	Claims, Invested assets
	Yuan (2011)	Life, Non-life	Bespoke approach that measured operational (cost) efficiency as the Expense Ratio, and Surplus Utilization efficiency as the Return on Policyholder Surplus.	N/A – Bespoke approach		

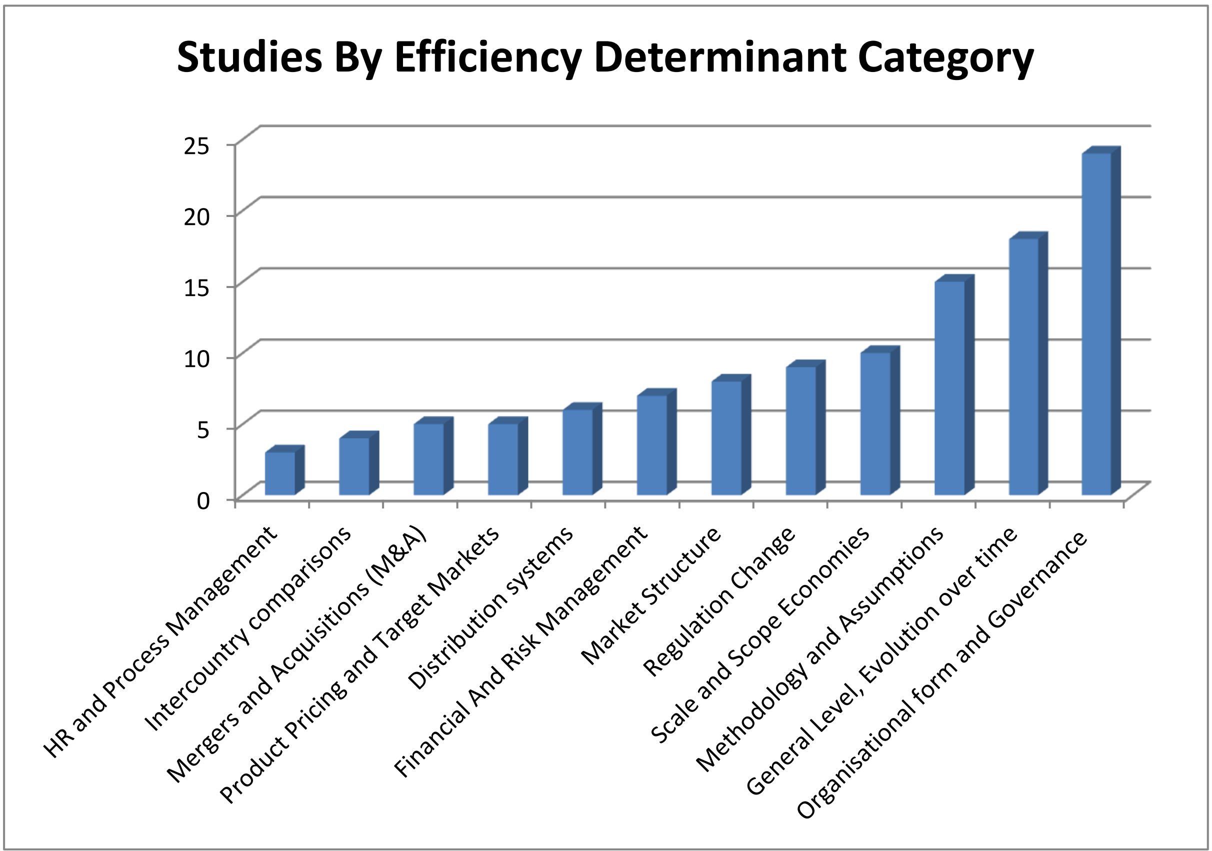
2.3.2 Stage 2: Efficiency Drivers

Table 2-2 below provides details of the literature review performed on potential efficiency or inefficiency drivers in this study. Although some studies appear to only measure efficiency and how it evolves over time (e.g. Al-Amri et al. (2012)), most studies go on to explore the statistical significance of drivers of efficiency or inefficiency, which is called 'Stage 2' in this study. Eling and Luhnen (2010) suggested that the literature on Stage 2 falls into 11 broad determinant categories. This study uses these determinant categories, and proposes two new additional categories that appear to have emerged in recent literature, which the author has called 'Human Resource and Process Management', and 'Product Pricing and Target Markets'. Table 2-2 assigns a category to each study, while Figure 2-3 below provides a summary of the literature by determinant category.

UK studies to date appear to have focussed on either Organisational Form and Corporate Governance, or Distribution Systems. In addition, Financial and Risk Management appears to be one of the categories in the Global literature with potential for further exploration, with only seven previous studies identified so far. This study will therefore look to add to the UK and Global literature by exploring Financial and Risk Management efficiency or inefficiency drivers. The nature of the results from Stage 1 also means that the evolution of efficiency during and after the Global Financial Crisis can also be analysed.

The findings within a category appear to be contextual, and can differ by data set or sample period. For example, a US study by Berger et al. (1997) found that firms using independent agents are not as cost-efficient as those using direct writers. On the other hand, a subsequent US study by Brockett et al. (2005) for a different and more up to date data sample found that the opposite was true. This suggests that findings are generalizable for the firms in the data sample at a particular point in time.

Figure 2-3: Empirical Literature by Potential Efficiency Determinant



Stage 2 is commonly implemented via a regression approach, and the literature appears to use a variety of approaches (as shown in Table 2-2). These approaches vary in complexity, from the relatively simple Ordinary Least Squares (OLS) approach, to more complex approaches, such as Simar and Wilson (2007)'s truncated bootstrap regression approach. Simar and Wilson (2007) were trying to get round the perceived weaknesses of another commonly used approach in the literature - the Tobit approach, which are summarised by Luhnen (2009) as the use of conventional approaches to inference, which are invalid due to the (downward) bias in the estimated efficiency scores and the complicated and unknown serial correlations among the scores. This study acknowledges this literature debate on regression techniques, and will base the results on the Tobit approach (after checking for the presence of serial correlations), with the Simar and Wilson's truncated bootstrap approach and OLS approaches being used as validation tools. A detailed justification of the regression approach and other details of Stage 1 and Stage 2 methodologies are discussed in Chapter 3, with the remainder of this chapter taking a more detailed critical look at the European literature.

Table 2-2: Literature Review for potential (in) efficiency drivers

Country	Journal Paper	Regression Method	Application Category	Selected findings
Angola	Barros et al. (2014)	Truncated Bootstrap	General level of efficiency and evolution over time	Older insurance companies with Portuguese origin tend to be more efficient.
Australia	Worthington and Hurley (2002)	Tobit	General level of efficiency and evolution over time	High levels of allocative inefficiency, leading to low levels of overall efficiency
Austria	Ennsfellner et al. (2004)	N/A – Comparisons of efficiency scores over time	Regulation Change	Deregulation increased production efficiency
	Mahlberg and Url (2003)	Tobit	Regulation Change	Regulation change led to increased productivity, but considerable inefficiency still remains.
BRICS countries	Huang and Eling (2013)	Truncated Bootstrap	Intercountry comparisons	Environment affects the efficiency of non-life insurers operating in different countries, which makes it difficult to do cross-country efficiency comparisons. Size, profitability, solvency, and ownership form contribute positively to efficiency in the BRIC countries.
Canada	Mcintosh (2016)	Exploratory variables included in the Cost Function	Scale and Scope Economies	Significant short-run scale economies are found with respect to both the output of new policies and the stock of policies issued.
	Wu et al. (2007)	N/A – no second stage analysis	Methodology issues, comparing different techniques or assumptions	The study used a bespoke approach that combines production performance and investment performance. The industry was highly efficient on the whole.
	Yang (2006)	N/A – no second stage analysis	Methodology issues, comparing different techniques or assumptions	The study (also) used a bespoke approach that combines production performance and investment performance. The industry was (also observed to be) highly efficient on the whole.

Country	Journal Paper	Regression Method	Application Category	Selected findings
China	Leverty et al. (2009)	Stochastic Frontier Analysis	Regulation Change	There was a structural improvement in efficiency after WTO accession, but geographic and product market restrictions placed on foreign firms reduce these positive effects.
	Long Kweh et al. (2014)	Ordinary Least Squares	Human Resources and Process Management	Insurers have almost monotonically decreasing efficiency for the period from 2006 to 2010. Regression results show that human capital, structural capital and relational capital are significantly and positively related to operating efficiency.
	Yao et al. (2007)	Ordinary Least Squares	General level of efficiency and evolution over time	The Non-life segment of the industry had a slightly higher average efficiency score than the life segment.
Europe	Bahloul and Bouri (2016)	Ordinary Least Squares	Market Structure	Firms become more efficient and more profitable with a higher concentration ratio and this is in accordance with the structure-conduct-performance (SCP) theory.
	Bahloul et al. (2013)	Exploratory variables included in the Cost Function	Organisational form, Corporate Governance Issues	After the integration of the CEO power score, not only efficiency scores in each country have changed, but also the order of non-life insurance systems. Also, the CEO power influences the growth of productivity and an optimal power of the CEO can allow the insurance firm to be more productive and more efficient.
	Berger (2003)	N/A – Analysis of findings from previous empirical efficiency studies	Regulation Change	The creation of a single market for the European financial services industry is not likely to bring about strong efficiency gains and that cross- border efficiency barriers may prevent the single market from becoming a reality.
	Cummins et al. (2017)	Ordinary Least Squares	Market Structure	Efficiency is the mechanism through which competition contributes to insurer solvency.
	Diacon et al. (2002)	Tobit	Intercountry comparisons	Evidence of differences of efficiency levels by country, and decreasing levels of technical efficiency over the sampling period.
	Eling and Jia (2018)	Logistic	Financial And Risk Management	Firms that are more technically efficient are less likely to fail.

Country	Journal Paper	Regression Method	Application Category	Selected findings
Europe	Fenn et al. (2008)	Exploratory variables included in the Cost Function	Market Structure	Most European insurers operating under Increasing Returns to Scale. Size and domestic market share lead to higher levels of cost inefficiency.
	Klotzki et al. (2018)	Ordinary Least Squares	Scale and Scope Economies	Economies of scale exist for all considered markets (Germany, Italy, Spain and the UK) and for most of the considered years. However, the extent of economies of scale varies considerably across countries.
	Vencappa et al. (2013)	N/A – the research calculated results using different output proxies.	Methodology issues, comparing different techniques or assumptions	The choice of output proxies appears to be critical, particularly when exploring long-term productivity trends.
Finland	Toivanen (1997)	Ordinary Least Squares, Generalised Least Squares	Scale and Scope Economies	There are economies of scope in the production process, and economies of scale at the branch level of a firm, but there are diseconomies of scale at the overall firm level.
France	Fecher et al. (1993)	Ordinary Least Squares	Methodology issues, comparing different techniques or assumptions	High correlation between parametric and non-parametric efficiency results. A wide dispersion of efficiency scores by company.
GCC Countries	Al-Amri (2015)	N/A – efficiency score comparisons	Intercountry comparisons	The Takaful insurance industry in GCC is highly technical and pure technical efficient. However, it is moderately cost efficient, and there is a large opportunity for improvement. UAE and Qatar score the highest technical efficiency, while Saudi Arabia and UAE are the most cost efficient among the GCC countries.
	Al-Amri et al. (2012)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	The insurance industry in the GCC is moderately efficient and there is large room for improvement.

Country	Journal Paper	Regression Method	Application Category	Selected findings
GCC Countries	Alshammari (2018)	Exploratory variables included in the Cost Function	Market Structure	The relationship between competition and efficiency is negative where conventional insurance is concerned and positive only for Takaful. Support for the Quiet Life (QL) hypothesis, where managers in a less competitive market may utilise the market power of their firms and reduce their efforts.
	Karbhari et al. (2018)	Truncated Bootstrap	Organisational form, Corporate Governance Issues	Non-executive directors, audit committees, and product diversification do not improve technical efficiency. Audit committees and regulatory jurisdiction tends to reduce scale efficiency. CEO/chair duality, board size, organizational age, regulatory jurisdiction and firm size have a positive relationship with technical efficiency. Non-executive directors, Shari'ah board, product diversification and institutional ownership improve scale efficiency.
Germany	Diboky and Ubl (2007)	Truncated Bootstrap	Organisational form, Corporate Governance Issues	Shareholder-owned companies are more efficient than mutual companies.
	Luhnen (2009)	Truncated Bootstrap	Distribution systems	Insurers with a direct distribution channel are more efficient than insurers using either of the two other distribution methods
	Mahlberg and Url (2010)	Truncated Bootstrap	Regulation Change	There is a significant long-term decline for cost efficiency scores.
Germany, U.K.	Rees and Kessner (1999)	N/A – efficiency score comparisons	Regulation Change	Looser regulation and increased competition increase efficiency.

Country	Journal Paper	Regression Method	Application Category	Selected findings
Ghana	Alhassan et al. (2013)	Ordinary Least Squares	Market Structure	Support for the Efficient Structure hypothesis for both life and non-life insurance markets. While conflicting results was found for SCP hypothesis in the non-life insurance market, it was rejected in the life insurance market. The life insurance sector has higher levels of efficiency compared to the non-life sector.
	Ansah-Adu et al. (2011)	Truncated Bootstrap	Financial And Risk Management	Market share, firm size and the ratio of equity to total invested assets are important determinants of an insurance firm's efficiency.
Global	Biener and Eling (2011)	Truncated Bootstrap	Organisational form, Corporate Governance Issues	An increase in size is not necessarily optimal for overall efficiency because technical efficiency is negatively correlated with size. Large and for-profit micro insurers are best able to improve performance when focusing on the use of state-of-the-art technology whereas concentrating on cost-minimizing input combinations is appropriate to address cost inefficiencies for small and non-profit micro insurers. The provision of group policies is more efficient than providing individual policies only.
	Biener et al. (2017)	Generalised Least Squares	Scale and Scope Economies	Large reinsurers are characterized by high cost efficiency, while small reinsurers exhibit superior efficiency only when specialized. Large reinsurers also exhibit revenue scope economies when operating both life and nonlife reinsurance.
	Gaganis et al. (2013)	Ordinary Least Squares	Financial And Risk Management	There is a positive and statistically significant relationship between profit efficiency change and market adjusted stock returns. However, there is no robust evidence that cost efficiency change is associated with stock returns.

Country	Journal Paper	Regression Method	Application Category	Selected findings
Global	Kader et al. (2010)	Logit	Organisational form, Corporate Governance Issues	Non- executive directors and separating the Chief Executive Officer and Chairman functions do not improve cost efficiency. However, board size, firm size and product specialisation have positive effects on the cost efficiency of Takaful insurers. The regulatory environment is found not to be statistically significant in terms of improving cost efficiency.
	Kader et al. (2014)	Logit	Organisational form, Corporate Governance Issues	Average levels of cost efficiency in takaful insurance markets mirror the efficiency in developed non-life insurance markets. The relative influence of board composition, such as the proportion of non-executive directors on the board, on the cost efficiency of takaful insurers depends on its interaction with other firm-specific characteristics such as board size. Hence, the effect of corporate governance systems on the cost efficiency of takaful insurers can be complicated by various firm-specific factors.
Greece	Barros et al. (2010)	Truncated Bootstrap	General level of efficiency and evolution over time	The first stage results indicate a decline in efficiency over the sample period, while the second stage results confirm that the competition for market shares is a major driver of efficiency in the Greek insurance industry.
	Nektarios & Barros (2010)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	Productivity growth varies by sector, with the Life sector being the most productive.
	Noulas et al. (2001)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	Wide dispersion of efficiencies scores between different companies, but the industry is highly efficient on the whole.

Country	Journal Paper	Regression Method	Application Category	Selected findings
India	Dutta and Sengupta (2011)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	Reforms in insurance sector which have led to high competition in the market have increased the technical efficiency of the life insurance industry as a whole, but reduced firms' scale efficiency.
	Tone and Sahoo (2005)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	An increase in allocative inefficiency after a certain point in the sample period, while cost efficiency started to increase after a later point in the sample period.
Italy	Cummins et al. (1996)	Tobit	General level of efficiency and evolution over time	Stable efficiency over time (70% – 78% for the industry), with sharp decline in productivity (25% cumulative) due to regression in technology.
	Turchetti and Daraio (2004)	N/A – General level of efficiency over time after regulation change	Regulation Change	Total Factor Productivity and Cost Efficiency increase over time, especially after the EU market regulation changes of 1994.
Japan	Fukuyama (1997)	Kruskal-Wallis test	Organisational form, corporate governance issues	No evidence of efficiency differences between shareholder-owned and mutual companies.
	Fukuyama and Weber (2001)	N/A – General level of efficiency over time.	General level of efficiency and evolution over time	Productivity and technical efficiency progress over time in Japan.
	Hirao (2004)	Magnus–Woodland type error components model	Scale and Scope Economies	Statistically significant economies of scale and scope.
	Jeng and Lai (2005)	ANOVA, Wilcoxon	Organisational form, Corporate Governance Issues Methodology issues, comparing different techniques or assumptions	Keiretsu firms are more cost efficient than non-specialised independent firms, but deteriorating efficiency for all company types. Value added and financial intermediation approaches to measuring outputs produced different results.

Country	Journal Paper	Regression Method	Application Category	Selected findings
Malaysia	Baharin and Isa (2013)	N/A – Direct comparison of efficiency scores by organisational form.	Organisational form, Corporate Governance Issues	Takaful has lower cost efficiency than conventional insurance
	Chen et al. (2014)	Tobit, Ordinary Least Squares	Human Resources and Process Management	Intellectual Capital has significantly positive impacts on changes in productivity.
Mozambique	Barros and Wanke (2014)	Truncated Bootstrap	General level of efficiency and evolution over time	Mozambique insurance companies' output-increasing potentials are severely constrained, particularly in terms of the ceded reinsurance increasing potentials.
OECD countries	Rai (1996)	N/A – Intercountry comparisons	Intercountry comparisons	Firms in Finland and France had highest efficiency, while those in the UK had the lowest from the sample chosen. Small firms were more cost-efficient than larger firms, while specialised firms were more cost-efficient than multiproduct firms.
Portugal	Barros et al. (2005)	Tobit	General level of efficiency and evolution over time	Improvement of technical efficiency over the sampling period
	Brito et al. (2013)	2SLS	Mergers and Acquisitions (M&A)	For the period following the mergers, there is no evidence of an increase in market power through coordinated behaviour, or changes in cost efficiency levels.
Saudi Arabia	Akhtar (2018)	Truncated Bootstrap	Product Pricing and Target Markets	Small firms are more efficient than large firms. Market share and profitability are important determinants of efficiency. Economies of scale and scope potential for Takaful and large conventional firms.
	Benyoussef and Hemrit (2019)	N/A – Direct comparison of efficiency scores by organisational form.	Organisational form, Corporate Governance Issues	Takaful insurers are relatively more efficient than cooperative insurance companies.

Country	Journal Paper	Regression Method	Application Category	Selected findings
South Africa	Alhassan and Biekpe (2016)	Ordinary Least Squares	Market Structure	Non-life insurers have high levels of efficiency in cost and low efficiency in profit. There is a positive effect of competition on cost and profit efficiency to validate the "quiet-life" hypothesis which posits that competition improves efficiency.
South Korea	Park and Park (2015)	Ordinary Least Squares	Human Resources and Process Management	There is a strong positive association between Enterprise Resource Planning (ERP) implementation and the insurers' efficiency and profitability. However, firms may experience a decrease in efficiency and profitability during the first and second year after ERP implementation.
Spain	Cummins and Rubio-Misas (2006)	N/A – General level of efficiency over time after regulation change	Regulation Change	Consolidation leads to growth in the Total Factor Productivity index, and increases the number of companies operating with decreasing returns to scale.
	Cummins et al. (2004)	Frontier Distance	Organisational form, Corporate Governance Issues	In both cost and revenue efficiency, Shareholder-owned companies are more efficient than mutual companies in some segments of the market, while mutual companies are more efficient in other segments. Large mutual companies are also no more or less efficient than Shareholder-owned companies.
	Fuentes et al. (2001)	N/A – Methodology issues	Methodology issues, comparing different techniques or assumptions	Total Factor Productivity, which is usually estimated using a non-parametric approach, can also be estimated using a parametric frontier approach.
	Segovia-Gonzalez et al. (2009)	ANOVA	Product Pricing and Target Markets	Revenue efficiency is increased by young policyholders who drive expensive cars, as well as young female policyholders.
Switzerland	Biener et al. (2016)	Truncated Bootstrap	Product Pricing and Target Markets	Diversification strategies directed to the European market are more beneficial for efficiency than those targeting markets outside of Europe.
	Jametti and von Ungern-Sternberg (2005)	Consistent Adjusted Least Squares	Methodology issues, comparing different techniques or assumptions	Public insurance providers are about 20% more cost efficient than their private counterparts.

Country	Journal Paper	Regression Method	Application Category	Selected findings
Taiwan	Hao and Chou (2005)	Generalised Least Squares	General level of efficiency and evolution over time	Market share improves profit efficiency, and there's no evidence that product diversification improves efficiency.
Taiwan	Hu and Yu (2015)	2SLS	Financial and Risk Management	There is a positive relation between inefficiency and product risk. At the same time, efficient insurers are seen as taking higher asset risk than inefficient insurers. Well-capitalized insurers operate more efficiently than poorly capitalized insurers.
	Huang et al. (2019)	N/A – Direct comparison between two stages of the production process	Methodology issues, comparing different techniques or assumptions	Twenty-six of Taiwan's life insurers have a higher average technical efficiency score in the investment stage than in the marketing stage. Scale economies and technical advancements prevail in the two production stages over the sample period.
	Hwang and Kao (2008)	N/A – Methodology issues	Methodology issues, comparing different techniques or assumptions	A bespoke relational model is more reliable in measuring efficiencies than independent models.
	Wang et al. (2007)	Unclear what approach was used.	Organisational form, Corporate Governance Issues	Insider ownership, cash-flow rights, and the presence of outside directors have positive impacts, whereas concentrated ownership, deviation between voting rights and cash-flow rights, board size, and the presence of CEO duality have negative impacts on insurers' efficiency.
Thailand	Yaisawarng et al. (2014)	Exploratory variables included in the Cost Function	Product Pricing and Target Markets	The most efficient firms tend to strategically select types of insurance services and underwrite average and small size sum insured per policy to diversify their risks. In addition, they tend to be savvy investors. The opposite holds for the least efficient firms which concentrate in providing labour-intensive, small sum automobile insurance policies or underwrite large coverage policies for fewer policyholders.

Country	Journal Paper	Regression Method	Application Category	Selected findings
The Netherlands	Bikker and Gorter (2011)	Exploratory variables included in the Cost Function	Organisational form, Corporate Governance Issues	More specialized insurers have lower costs. Thick frontier efficiency estimates point to large cost X-inefficiencies that have moderately decreased over time.
	Bikker and van Leuvensteijn (2008)	Exploratory variables included in the Cost Function	General level of efficiency and evolution over time	Cost efficiency of 72% on average.
Turkey	Kasman and Turgutlu (2009)	Logistic	Scale and Scope Economies	Economies of scale appear present and significant for any firm size.
U.A.E	Rao et al. (2010)	N/A – General level of efficiency over time	General level of efficiency and evolution over time	There was a considerable degree of managerial inefficiency among the insurers, with the least efficiency in 2000, and higher efficiency in 2004.
U.K.	Hardwick and Li (1997)	Exploratory variables included in the Cost Function	General level of efficiency and evolution over time	Cost efficiency of 70% on average. Most firms exhibit Increasing Returns to Scale.
	Hardwick et al. (2011)	Tobit, Generalised Least Squares	Organisational form, corporate governance issues	Board characteristics tend to have little effect on firm efficiency in the UK life insurance market. However, the proportion of non-executive directors on the board exhibits a significant effect on the profit efficiency, once the interaction effects among governance mechanisms are taken into account. The effect can be either positive or negative depending on whether there is separation of the CEO and board chairman positions and whether there is an audit committee.
	Klumpes (2004)	Bespoke approach	Distribution Systems	Firms using direct sales agents are more cost and profit efficient than those using independent sales agents.
	Letza et al. (2001)	Ordinary Least Squares	Organisational form, corporate governance issues	Weak evidence to support the contention that mutual insurers are most cost efficient than proprietary insurers.

Country	Journal Paper	Regression Method	Application Category	Selected findings
U.K.	Ward (2002)	Exploratory variables included in the Cost Function	Distribution Systems	Cost efficiencies higher for firms focussing on one type of distribution system than those that use more than one.
	Berger et al. (1997)	Bespoke approach	Distribution Systems	Firms using independent agents are not as cost-efficient as those using direct writers, but are just as profit-efficient.
	Berger et al. (2000)	Bespoke approach	Scale and Scope Economies	Strong support for the strategic focus hypothesis, with the conglomeration hypothesis holding for some types of firms.
	Brockett et al. (2004a)	Logistic	Methodology issues, comparing different techniques or assumptions	Using solvency scores as outputs has a limited impact on efficiency scores
U.S.	Brockett et al. (2004b)	Bespoke approach	Organisational form, corporate governance issues Methodology issues, comparing different techniques or assumptions	Application of a new game-theoretic DEA Model on two types of health organisations: Independent Practice Organisations (IPOs) and Group/Staff Health Maintenance Organisations (HMOs). IPOs found to be more technically efficient than HMOs.
	Brockett et al. (2005)	Range-Adjusted Measure	Organisational form, corporate governance issues Distribution systems	Shareholder-owned companies are less efficient from an inputs perspective, while mutual companies are less efficient from an outputs perspective. Direct systems are less efficient than independent agents.
	Choi and Weiss (2005)	Generalised Method of Moments, H2SLS	Market Structure	Cost-efficient firms charge lower prices and earn higher profits. In addition, profits and prices are higher in revenue-efficient firms.
	Cummins and Nini (2002)	Ordinary Least Squares	Financial and Risk Management	Scope to significantly reduce inputs (e.g. labour costs by 62%) without affecting outputs. Capital found to be used sub-optimally.

Country	Journal Paper	Regression Method	Application Category	Selected findings
	Cummins and Xie (2008)	Ordinary Least Squares	Mergers and Acquisitions (M&A)	Insurers targeted for acquisition achieve greater cost and allocative efficiency gains than firms that have not been involved in an M&A exercise. Acquiring firms achieved more revenue efficiency than non-acquiring firms.
	Cummins and Xie (2013)	Ordinary Least Squares	Scale and Scope Economies	The majority of firms below median size in the industry were operating with increasing returns to scale, and the majority of firms above median size were operating with decreasing returns to scale. However, a significant number of firms in each size decile have achieved constant returns to scale.
	Cummins and Zi (1998)	N/A – Methodology issues	Methodology issues, comparing different techniques or assumptions	Efficiency scores are largely consistent between the different types of econometric approaches, but less consistent between econometric and mathematical programming methods.
U.S.	Cummins et al. (1999a)	Probit	Mergers and Acquisitions (M&A)	Insurers targeted for acquisition achieve greater efficiency gains than firms that have not been involved in an M&A exercise.
	Cummins et al. (1999b)	ANOVA, Wilcoxon	Organisational form, corporate governance issues	Shareholder-owned companies are more cost-efficient than mutual companies.
	Cummins et al. (2009)	Ordinary Least Squares	Financial and Risk Management	Both Risk Management and Financial Intermediation significantly increase the efficiency of the property-liability insurance industry.
	Cummins et al. (2010)	Unclear what approach was used.	Scale and Scope Economies	Property-liability insurers realize cost scope economies, but they are more than offset by revenue scope diseconomies. Life-health insurers realize both cost and revenue scope diseconomies.
	Erhemjamts (2007)	Logistic	Organisational form, corporate governance issues	Shareholder-owned companies are more efficient than mutual companies.
	Grace and Timme (1992)	N/A – comparison of firms' scale economies	Scale and Scope Economies	Most firms have significant economies of scale, and the largest companies operate with approximate Constant Returns to Scale.
	Grace et al. (2015)	Weighted Least Squares	Financial and Risk Management	The use of economic capital models and dedicated risk managers improve operating performance.

Country	Journal Paper	Regression Method	Application Category	Selected findings
	Greene and Segal (2004)	Ordinary Least Squares	Organisational form, corporate governance issues	Market share improves profit efficiency, and there's no evidence that product diversification improves efficiency.
	He et al. (2011)	Logistic	Organisational form, corporate governance issues	Firms with a CEO turnover, especially those with a non-routine turnover, experience more favourable efficiency changes than firms without a CEO turnover.
	Huang et al. (2011)	Truncated Bootstrap	Organisational form, corporate governance issues	There is a significant relationship between efficiency and corporate governance.
U.S.	Jeng et al. (2007)	Logistic	Methodology issues, comparing different techniques or assumptions Organisational form, corporate governance issues	No efficiency improvements after demutualisation under both the value-added and Financial intermediation approaches to choosing outputs, with the exception of mutually-controlled insurers, which showed improved efficiency under the Financial Intermediation approach.
	Leverty and Grace (2010)	Logistic	Methodology issues, comparing different techniques or assumptions	Efficient value-added approach firms are less likely to go insolvent, while firms characterized as efficient by the flow approach are generally more likely to fail. The theoretical concern regarding the value-added approach's use of losses as a measure of output is not validated empirically.
	Park et al. (2009)	Ordinary Least Squares	Distribution Systems	Independent agent insurers are found to be cost inefficient compared to insurers with other distribution systems, but the independent agent insurers have better revenue efficiency compared to their long counterpart, the exclusive agent insurers.

Country	Journal Paper	Regression Method	Application Category	Selected findings
U.S.	Pottier (2011)	Ordinary Least Squares	Regulation Change	Insurer cost efficiency is inversely related to the number of states licensed and directly related to total assets, after controlling for geographic concentration, insolvency risk and other firm-specific characteristics.
	Shi and Zhang (2011)	N/A –Methodology issues	Methodology issues, comparing different techniques or assumptions	Time-variant and time-invariant methods result in significantly different efficiency estimates.
	Shim (2011a)	Ordinary Least Squares	Mergers and Acquisitions (M&A)	M & A activity has the potential to create inefficiencies.
	Shim (2011b)	Ordinary Least Squares	Mergers and Acquisitions (M&A)	Acquirers' financial performance decreases and earnings volatility increases during the gestation period after the M & As. Specialised insurers outperform the product-diversified insurers.
	Weiss (1991)	Ordinary Least Squares	General level of efficiency and evolution over time	Inefficiency of between 12% and 33% of premiums
	Weiss and Choi (2008)	2SLS	Market Structure	Potential to charge higher unit prices through market power in a competitive and loosely regulated business environment. Lower cost and revenue efficiencies in more regulated states than those which are less regulated and more competitive.
	Xie (2010)	Probit	Organisational form, corporate governance issues	IPO firms experience no post-issue under-performance in efficiency, operations, or stock returns; register improvement in allocative and cost efficiency; and reduce financial leverage and reinsurance usage.
	Yuan (2011)	Bespoke Approach	Product Pricing and Target Markets	Firms jointly producing banking and insurance services perform better in their traditional lines of business.

2.3.3 Detailed review of the literature across Europe

This section splits the literature between the pre and post 2000 periods, with supporting or opposing literature from the past or future included in each subsection were relevant. The focus of the detailed literature review is the post-1994 period, as explained further below.

2.3.3.1 1990 - 2000

Efficiency in the European insurance industry has been widely researched in the recent past, and appears to have been mainly driven by the EU's Third Generation Insurance Directive of 1994 (Cummins et al, 1996). Cummins et al. (1996) conducted one of the early studies around insurance efficiency in Europe by looking at efficiency and productivity in the Italian insurance industry in the period 1985 to 1993. The study noted the contested nature of insurance inputs and outputs, because they are not tangible, so proxies have to be used. In their study, they used acquisition costs, labour costs, fixed capital (e.g. office costs) and equity capital as inputs. The outputs used were Losses Incurred and Invested Assets. They found no relationship between business mix and technical efficiency, but found that mutual companies are more efficient than stock companies. This second finding is surprising, because the *expense preference hypothesis* would suggest the opposite, since shareholders have more control on the actions of managers than mutual members (Mester, 1989). They also found that companies that sell both Life and Non-life products are less efficient that specialist companies. This finding challenges the Economies of Scope principle, which refers to lowering the average cost for a firm in producing two or more products (Panzar and Willig, 1981).

Hardwick and Li (1997) conducted a similar study to that of Cummins et al. (1996) in the UK, with a similar time period (1989 – 1993), but focussed on cost efficiency of Life Insurance companies. Their study findings contradicted those of Cummins et al. (1996), by concluding that organisational form (i.e. mutual versus stock) did not have an impact on efficiency. This was later supported by Letza et al. (2001), who also concluded that there was weak evidence to suggest that mutual companies are more efficient than proprietary ones in the UK Life Insurance market. Hardwick and Li (1997) also found that – on average – larger companies were more efficient than smaller ones. The geographical location of a company in the UK was also seen to have no bearing on its cost efficiency. A direct comparison of this study with Cummins et al. (1996) is made difficult because Hardwick and Li (1997) used SFA to calculate efficiency scores as opposed to DEA, although various studies have suggested use of either approach should not affect the outcome of the analysis. The inputs and outputs are also slightly different, with the UK study using Net Premiums as an output. The findings could be challenged because investment assets or income - a key contributor to insurance earnings – is not included as an output. A later Europe-wide study by Fenn et al (2008) also used a parametric efficiency score approach and excluded assets from the outputs, but they concluded that large companies and those with large market shares were in fact inefficient. This suggested that the efficiency of large companies varied across Europe, with companies in some countries being more efficient than similar companies in other countries. Fenn et al (2008) also used data after the EU's Third Generation Insurance Directive came into force (1995 – 2001), introducing the possibility of a link between the reduced efficiency of large companies with the introduction of the Directive.

Rees and Kessner (1999) explored the impacts of regulation on insurance efficiency in Europe, by looking at the UK and Germany markets using data from 1992 – 1994, as well as comparing the respective regulatory regimes analytically. The two markets were considered to be at the extreme ends of the regulation spectrum, with the UK considered to be lightly regulated, while Germany was considered to be heavily regulated. The study concluded that tighter regulation allowed for the survival of higher cost firms. It also suggested that there was more intra-industry efficiency in the UK than in Germany. One potential limitation of this study is that the efficiency scores were not calculated on a consistent basis, given that Premium Income was used as the UK output, whereas the Germany output is the Aggregate Sums Assured.

2.3.3.2 2001-2019

Diacon et al (2002) attempted to build on earlier attempts by Rai (1996) to undertake an international comparison of the efficiency of companies transacting long-term insurance business. Their study focussed on Europe, and included a large data set of 450 companies over the period 1996 – 1999. Their study supported findings by Cummins et al. (1996) that mutual companies are more efficient than proprietary companies. Although they also agreed with Hardwick and Li (1997) that large companies are efficient, they found that very small specialist companies are also among the most efficient, and therefore disagreed with their general conclusion that larger companies are more efficient than smaller ones. In addition, financial security was also found to be a determinant of efficiency. The study produced a detailed country-by-country comparison of efficiency, with the UK, Spain, Sweden and Denmark found to be highly technically efficient. They also found that overall technical efficiency appeared to reduce over the research period. They also speculated that this could have been due to structural changes in the industry as a reaction to the Third Insurance Directive, but it was not explored, and is potentially the subject of future research.

Berger (2003) added to the knowledge on Europe-wide insurance efficiency by looking at the potential efficiency effects of a European Single Market for financial services (including insurance). This study analysed the findings of relevant research papers without conducting an empirical study itself, and concluded that the creation of a single market for the European financial services industry is not likely to bring about strong efficiency gains and that cross-border efficiency barriers may prevent the single market from becoming a reality. This could be supported or challenged by empirical studies around the Third Generation Directive and post implementation of the Solvency II Directive of 2009 (which complemented the Third Generation Insurance Directive, by harmonising solvency regulation across Europe with effect from 1 January 2016[25]), which could test the first part of this finding around strong efficiency gains. An empirical study around the Third Generation Directive was conducted by Marlberg and Url (2010), where they investigated the impact of the Single Market on productivity in the German insurance industry in the period 1991 - 2006. They supported the findings by Berger (2003), by finding a long-term decline for cost efficiency scores over the research period. However, they also found that productivity increased during that period, thus suggesting that efficiency does not necessarily lead to increased productivity.

Klumpes (2004) sought to benchmark performance in Financial Services, with a specific focus on the UK Life Insurance industry from 1994 - 1999. In that study, profit and cost efficiency were chosen as performance measures to conduct this benchmarking. This suggests that efficiency is an accepted key performance measure in the insurance industry. The study found that companies that employed their own sales force where more cost and

[25] Solvency II Directive source: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0138

profit efficient than those that used Independent Financial Advisors (IFAs), even after controlling for organisational form, firm size and product mix. This is an important finding, since many insurance companies use the IFA distribution route. However, the data period misses the impact of potential organisational restructures that could have occurred in preparation for Solvency II.

Barros et al. (2005) added to the European literature by looking at efficiency and productivity in Portugal's insurance sector from 1995 – 2001. Their main finding was that some companies experienced productivity growth in the research period, while others experienced a decrease in productivity. These findings could be contested, because investment income and premiums are considered to be inputs – this is inconsistent with many previous studies summarised in Table 2-1. Their literature review also appears to suggest that premiums are an output, and it is not clear why premiums have ended up as an input.

Cummins and Rubio-Misas (2006) explored the role of efficiency in deregulation and consolidation, using the Spanish Insurance industry as an example. The data period (1989 – 1998) spanned the introduction of the EU's Third Generation Insurance Directive, so captures the deregulation and industry restructuring that came with it. They concluded that small, inefficient and financially underperforming firms were eliminated from the market during this time period due to insolvency or liquidation. They also found that consolidation of the industry created larger companies that are efficient, but experience decreasing returns to scale after a certain point. This suggests that companies looking to merge with or acquire other companies should consider the efficiency effects of the transaction as part of the decision-making process.

Bikker and Van Leuvensteijn (2008) looked at the relationship with efficiency and competition by focusing on the Dutch Life Insurance Industry in the period 1995 – 2003. They concluded that there was evidence of substantial economies of scale and inefficiencies in the market due to limited competition. Bikker and Gorter (2011) conducted a similar study in a similar time period (1995 – 2005), but turned their focus to the Non-Life part of the Dutch insurance industry and adding an organisational form perspective. Their findings supported the conclusion of substantial economies of scale in the Dutch Insurance industry, and that mutual and proprietary companies both have comparative advantages. They also supported the findings of Cummins et al. (1996) – which used pre-Third Generation Directive data - that specialist companies experience better efficiency than their counterparts with a diversified product pool. A significant question before applying these findings to practice would be whether the findings still hold, in light of significant regulatory developments after 2005 (i.e. Solvency II).

Luhnen (2009) provided an example of how efficiency can be investigated at an industry sub-section level, by investigating the determinants of efficiency and productivity in the Property-Liability section of the Non-Life Insurance industry in Germany from 1995 – 2006. Luhnen (2009) agreed with Hardwick and Li (1997) that larger companies are more efficient than smaller ones (based on UK data). They also support the findings of Klumpes (2004) that using a direct sales force distribution system is more efficient that Independent Financial Advisors (also based on UK data). This suggests that the German and UK Insurance markets

– two key insurance markets in Europe – have common determinants of efficiency. The study also waded into the debate about the impact of organisational form on efficiency, and supported the findings by Cummins et al (1996) that mutual companies are more efficient than proprietary ones (and thus contradicted the relevant findings by Hardwick and Li, 1997). This suggests at least one key difference between efficiency determinants in the Germany and UK insurance markets. Their findings also added to earlier contributions that specialist firms are more efficient than diversified ones – there generally appears to be agreement in the literature on the impact of this determinant. Luhnen (2009) also found that higher levels of leverage are associated with better efficiency levels, and that companies that are growing tend to be less efficient than those that are not.

Hardwick et al. (2011) attempted to explore new potential efficiency determinants that had not been previously considered in the literature, by looking at the impact of corporate governance mechanisms on Profit efficiency in the UK Life Insurance industry from 1994 - 2004. They found that - viewed in isolation - board characteristics tended to have little effect on firm efficiency in the UK life insurance market. However, they did find that the proportion of non-executive directors on the board exhibited a significant effect on the profit efficiency, once the interaction effects among governance mechanisms were taken into account. The effect could be either positive or negative depending on whether there was separation of the CEO and board chairman positions and whether there was an audit committee. This introduces a potential link between an organisation's key personnel, and its efficiency. Bahloul et al. (2013) explored this link further, by looking at the influence of CEO power on a company's efficiency and productivity. They used Europe-wide Non-Life Insurance industry data from 2002 – 2008, and found that optimal power for the CEO can allow an insurance company to be more efficient and more productive. However, given the findings by Hardwick et al. (2011) that efficiency in the UK's life insurance industry is not affected by Board characteristics (which include a prominent role for the CEO, sometimes as Board Chairman), these findings could be challenged at Member-State level. In addition, the data in both studies by Hardwick et al (2011) and Bahloul et al. (2013) precede the period after the global financial crisis (2008 – Present), which arguably had a huge impact on the roles of the Board and the CEO. The findings of both papers might therefore be challenged in light of this.

Biener et al. (2016) appear to have continued on the trajectory of finding new determinants of efficiency that had not been previously explored in European literature, by considering the impact of product diversification strategies on efficiency and productivity on the Swiss Insurance industry. They concluded that diversification strategies directed to the European market are more beneficial compared to those targeting markets outside of Europe. Their study appears to be unique compared to previous studies in a couple of important ways:

1. It starts to refresh the European literature in this area with post-Global Financial Crisis data (the data sample period was 1997 – 2013)
2. It considers efficiency drivers that firms could potentially implement without making significant changes to how they operate their businesses. This is distinct from say, changing the organisational form of a firm from mutual to proprietary.

Although this study is based on one European industry, it builds a foundation upon which studies in other markets can build, in terms of the post Global Financial Crisis period and the exploration of efficiency levers that can be implemented relatively easily. Eling and Jia (2018) appear to build on this foundation, by appearing to be the first European study to consider Financial and Risk Management determinants of firms across 16 different European countries, using data from 2006 to 2013. Their study concluded that firms that are more technically efficient reduce the risk of business failure. Eling and Jia (2018) therefore appeared to establish a link between Risk Management and Efficiency, and there is potential for this link to be explored further, either by focussing on specific markets within their study, or looking at specific Risk Management levers that have a relationship with efficiency. Cummins et al. (2017) focussed on the potential wider importance of efficiency in the European insurance industry by testing the *transmission mechanism hypothesis*, which was developed by Schaeck and Cihák (2013). This hypothesis proposes that competition - measured by the Boone (2008) indicator - enhances financial stability, with efficiency being the transmission mechanism through which competition increases financial stability. Their findings supported this hypothesis, so could be important for EU regulators, who – by encouraging competition – could help meet one of their key objectives of financial stability in the industry. However, one could argue that the EU has already done all it can to encourage competition – via the Third Generation Directive – and the findings of this study just serve to support the decision to implement that Directive.

This section concludes by considering the study by Klotzki et al. (2018), who acknowledged the need to reconsider efficiency in the European insurance industry on the back of the low interest rate environment discussed in section 1.1.7 of this study, as well as an apparent increase in acquisition costs, price transparency, cost transparency and competition with banks. Their study focused on Economies of Scale, and they found that – of the four European markets they considered - Germany showed the lowest extent of economies of scale, whereas the UK and particularly Spain and Italy exhibited a considerably stronger extent of economies of scale. This therefore supports efforts by the UK insurance industry to improve operational efficiency via consolidation, as discussed in section 1.1.8. That said, consolidation tends to create larger organisations, and it is not clear from the study by Klotzki et al. (2018) if firms that attempt to utilise this opportunity of economies of scale via consolidation actually succeed, i.e. whether larger organisations are more efficient than smaller firms, in any of the markets explored. With the literature review chapter complete, the next chapter explores the methodology used in this study in more detail.

Chapter 3: Methodology

3 Methodology

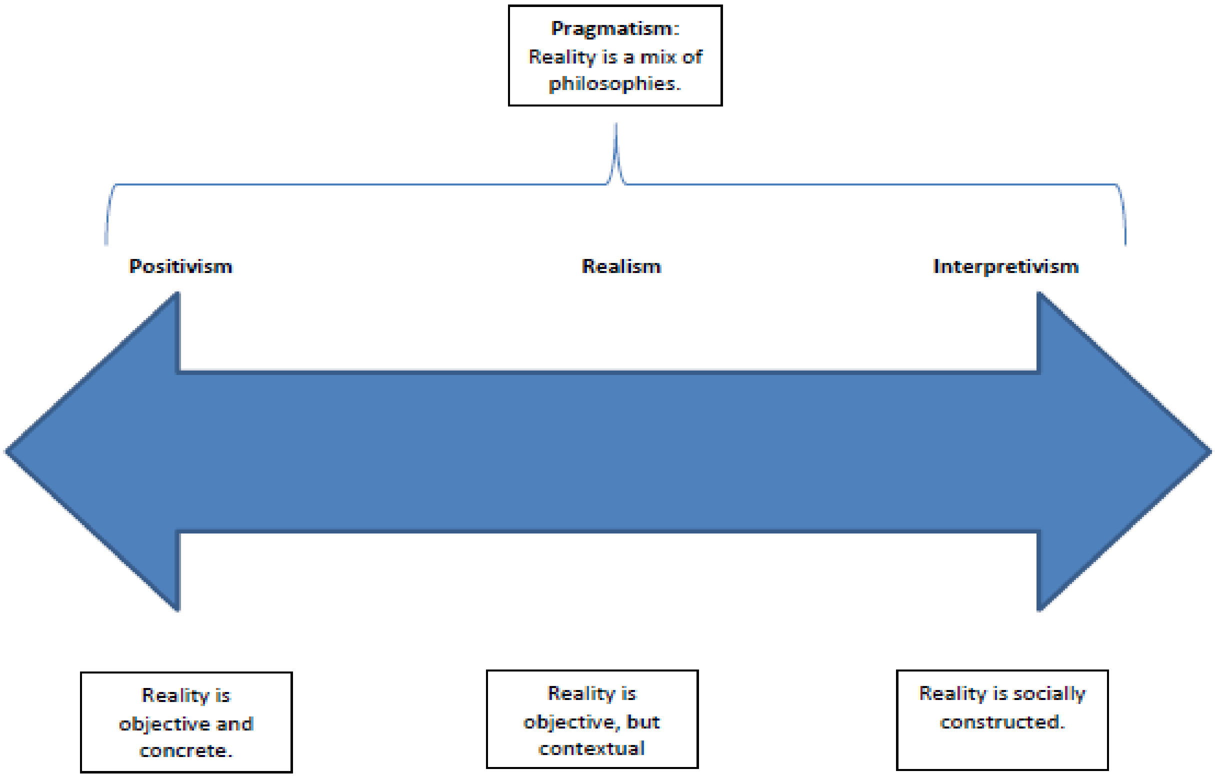
This chapter explains in detail the methodological approach that has been set to meet the aims and research questions of this study, as described in section 1.2. It starts with a detailed discussion on the design of the research, followed by a description and justification of the chosen data. It will then explain the hypotheses that will be tested, as well as outlining how the data and results will be analysed. It will then conclude by discussing ethics considerations in empirical studies that use secondary data.

3.1 Research Philosophy

Underpinning the choice of research methods is the philosophical paradigm under which the research will be conducted. Figure 3-1 below provides a high-level summary of the philosophical spectrum under which Business research can be carried out, according to Saunders et al. (2009). The choice of paradigm is subjective, and will be done through a process of elimination. The elimination steps are discussed in the next few paragraphs.

A key aim of the research – which other aims and objectives depend on – is to investigate the levels of efficiency in the UK insurance industry. This is therefore deductive research, since the level of efficiency already exists and is not going to be constructed. In addition, the research questions are also deductive, as they are looking to test the economic and statistical significance of certain business decisions on the level of efficiency. This conclusion appears to rule out interpretivism as a possible paradigm for this research.

Figure 3-1: Philosophical Paradigms



Source: Derived from information in Saunders et al. (2009)

Since this a deductive study, it could be considered under the Positivist paradigm. However, it might be difficult to argue for pure positivism, because that would imply that the findings of the study would be the same under all scenarios and circumstances, which is unlikely for efficiency research. Later sections in this chapter will outline numerous methodological considerations that need to be made before determining the level of efficiency that exists, and it is possible that different methodological considerations could lead to a different outcome – even when using the same set of data. The choice of data set or data period could also have a bearing on the findings. A pure positivist approach is therefore ruled out on this basis. These exclusions leave Realism and Pragmatism as the potential approaches. A more detailed look at these two approaches is summarised in Table 3-1 below.

Table 3-1: Realism versus Pragmatism

	Realism	Pragmatism
Ontology: *the researcher's view of the nature of reality or being*	Objective. Exists independently of human thoughts and beliefs or knowledge of their existence (realist), but is interpreted through social conditioning (critical realist).	External, multiple, view chosen to best enable answering of research question.
Epistemology: *the researcher's view regarding what constitutes acceptable knowledge*	Observable phenomena provide credible data, facts. Insufficient data means inaccuracies in sensations (direct realism). Alternatively, phenomena create sensations which are open to misinterpretation (critical realism). Focus on explaining within a context or contexts.	Either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. Focus on practical applied research, integrating different perspectives to help interpret the data.
Axiology: *the researcher's view of the role of values in research*	Research is value laden; the researcher is biased by world views, cultural experiences and upbringing. These will impact on the research.	Values play a large role in interpreting results, the researcher adopting both objective and subjective points of view.
Data collection techniques most often used	Methods chosen must fit the subject matter, quantitative or qualitative.	Mixed or multiple method designs, quantitative and qualitative.

Source: Saunders et al. (2009)

Table 3-1 suggests that pragmatism could be used, since it gives the researcher the freedom to choose research methods that are most suitable to answer the research question. That said, realism (and critical realism in particular) – which appears to give a narrower scope of the possible research methods, would ensure that this research is kept to a similar narrow scope as all the studies discussed in Tables 2-1 and 2-2, which employ a deductive approach to research in this area. This would also support the stated focus of this paper, which aims to contribute more to practice than theory, and therefore intends to intentionally avoid theoretical debates wherever possible. Finally, in the context of insurance efficiency research, critical realism appears to allow the researcher to make every effort identify and implement valid analytical methods to address different efficiency measurement issues, but also recognise that there is always scope for future improvement in both the conceptual framework and analytical methods.

Based on the discussion above, the choice is to underpin this study on Critical Realism. This consideration acknowledges potential biases of the researcher, which might have contributed to arriving at this conclusion:

1. With a mathematical background, the researcher is partial to following Popper's Principle of Empirical Falsification, which states that a hypothesis can be tested by empirical experiment (Popper, 1959).
2. The researcher's current professional role involves managing a key input into Canada Life's cost base (i.e. Capital). There is therefore an inclination to seek outcomes related to capital via deductive research (e.g. will investing in a certain type of asset improve the company's capital position?).

Table 3-1 suggests that the research method can be qualitative or quantitative, but must fit the subject matter. In this instance, the subject matter is to conduct an empirical study, which is quantitative by nature. This is consistent with all previous studies listed in Tables 2-1 and 2-2. Details of the quantitative approaches used are discussed in the remainder of this chapter.

3.2 Types of Efficiency

The Efficient Structure Hypothesis discussed in section 2.2.2 introduced the concept of efficiency as a driver of competitive advantage. This concept has since evolved into different types of efficiency, some of which are related. Due to these different types, empirical studies tend to focus on one or two types of efficiency, and explore them in detail. The next step in developing the methodology therefore involves choosing the appropriate type of efficiency to explore. Some of the different types which have been explored in Insurance efficiency literature are briefly described below.

1. Klumpes (2004) defines *profit efficiency* as the ratio of actual profits to the maximum potential profits that could be earned. Thus, the profit efficiency ratio estimates the proportion of potential profits that are realized. Profit efficiency is also maximized as one, where actual profits equal potential profits.
2. Cummins and Rubio-Misas (2006) define *Technical Efficiency,* as the ratio of the input usage of a specified firm producing the same output vector to the input usage of a reference set of fully efficient firms (i.e., firms operating on the efficient production frontier). Technical efficiency can be decomposed into pure technical efficiency and scale efficiency.
3. Cummins and Rubio-Misas (2006) also look at *Cost Efficiency* for a given firm, which they define as the ratio of a given firm's actual costs to the costs of a reference set of fully efficient firms (i.e., firms operating on the efficient cost frontier) with the same output quantities and input prices. Firms achieve cost efficiency by adopting the best practice technology (technical efficiency) and choosing the optimal mix of inputs (*allocative efficiency*), conditional on outputs and input prices. Cost efficiency is therefore the product of technical and allocative efficiency.
4. Shim (2011a) defined *Revenue Efficiency* as the ratio of actual revenue to maximum possible revenue for a given level of outputs and inputs.

Cost efficiency has been the focus of the majority of previously published UK studies (see Table 2-1), suggesting that the efficient management of costs is considered to be an important part of the industry. This is not surprising, considering that insurance is not considered to be highly profitable compared to other sectors of the economy, and did not make it onto the list of the 10 most profitable UK sectors of 2018[26]. It is therefore reasonable to assume that keeping costs down would be a key part of a firm's business strategy in this industry. In addition, cost efficiency also appears to be the focus of the UK Life Insurance industry in the post-Global Financial Crisis period, based on the discussion in section 1.1.8. It will therefore form the focus of this research project. Once the type of efficiency to investigate is chosen, an approach is then required to measure this efficiency. Different methods exist – these are discussed in section 3.3 below.

3.3 Efficiency Methodologies

Eling and Luhnen (2010) discuss the two groups of approaches that can be used to measure efficiency. These are summarised below.

Econometric approaches: where a production, cost, revenue, or profit function with a specific structure is specified, and assumptions are made about the distributions of the inefficiency and error terms within the specified function. Examples include:

- Stochastic Frontier Approach (SFA)
- Distribution-Free Approach (DFA)
- Thick Frontier Approach (TFA)
- Flexible Fourier Approach (FFA)

The SFA, DFA and TFA approaches concern the distributional forms of the random error term and the inefficiency term, while the FFA is an example of an approach about the

[26] Source: https://citywire.co.uk/wealth-manager/news/the-10-most-profitable-sectors-in-the-uk/a1146420

functional form of the efficient frontier. Cummins and Weiss (2002) summarise the differences between the approaches as being around their distributional assumptions of the inefficiency and random error components.

Mathematical programming approaches: where a programming approach is used to measure the relationship of outputs to assigned inputs. Eling & Luhnen (2010) highlight that programming approaches put significantly less structure on the specification of the efficient frontier and do not decompose the inefficiency and error terms. Examples include:

- Data Envelopment Analysis (DEA)
- Free Disposal Hull (FDH)
- Range Adjusted Measure (RAM)

The FDH can be seen as a simplified version of the DEA, which is itself a linear programming approach. The RAM is also a variant of the DEA, which aims to give an indication of where input excesses and output deficits lie.

Given the different types of techniques available, it is worth understanding the significance of choosing one technique over another on the findings of the study. Although there is little insurance efficiency literature that comprehensively compares the different approaches, Cummins and Zi (1998) conducted one such study. It focused on a sample of U.S. Insurer data using different econometric and mathematical programming techniques. While they found that different econometric techniques produced reasonably consistent results, there were significant inconsistencies between econometric and mathematical programming approaches. They also found inconsistencies between the DEA and FDH approaches within the mathematical programming category.

As discussed in section 2.3.1, insurance efficiency studies done to date appear to be dominated by mathematical programming approaches in general and DEA in particular.
A common theme for the choice of the DEA approach appears to be absence of having to define the distribution of the inefficiency term and a random error term, which is usually required for an econometric approach, and is subjective. Although the SFA approach makes transparent the stochastic nature of the underlying data generation process (DGP) of the variables and their relationship, it is also restrictive in the sense that specific assumptions are made about the functional relationship between inputs and a single output as well as the distribution of the variables and the error term. In comparison, although the underlying DGP of the DEA approach is non-stochastic in nature, the DEA offers the flexibility of data-compatible functional relationship between a set of inputs and a set of outputs.

Although DEA is the dominant methodological approach on the whole, the picture can differ when looking at the sub-groups of efficiency research. For example, the SFA (an econometric approach) has been used in all previous UK-focussed studies discussed in section 2. That said; this study uses the DEA approach for a number of reasons. Firstly, the DEA approach can be used to decompose Cost Efficiency into its various components (i.e. technical and allocative efficiency). This appears to be the first UK study to do this, and will help practitioners to understand the cost-saving capacity at a more granular level. Secondly, the DEA is also more suited to answering the research question on the development of efficiency over time. Thirdly, although most of the previous UK studies appear to be silent on the statistical significance of the error term, one study - by Ward (2002) - assumes that the random error term tends to zero over the period covered by the analysis. This supports the use of the DEA approach in future UK studies (or at least suggests that it is as valid as econometric approaches in the UK context), which does not separate the random error term from the inefficiency term. Fourthly, choosing this approach will make this UK study consistent with most efficiency studies conducted in other countries on this key methodological aspect. Finally, recent developments in semi-parametric methods (e.g. Simar and Wilson, 2007) can improve the asymptotic properties of the DEA method. While DEA efficiency scores will form the basis of findings from this study, the use of the SFA approach in previous UK studies is also acknowledged. High-level cost efficiency scores using the SFA approach will therefore be produced, in order to compare them against the DEA scores, as well as efficiency scores from previous UK studies.

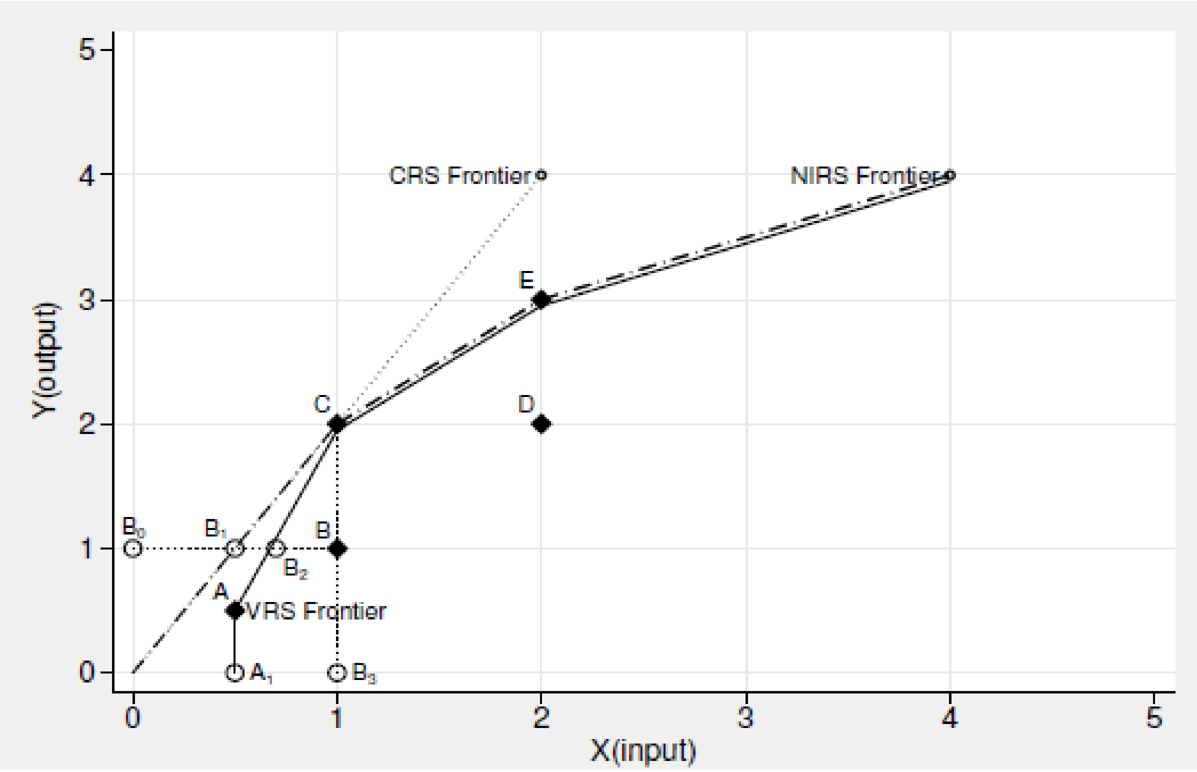
In the DEA literature, the assumption of returns to scale (RTS) is also critically important for the analysis, as the RTS directly affects the efficient frontier. The literature has considered three scenarios of the RTS:

1. *Constant Returns to Scale* (CRS): This model produces efficiency scores under the key assumption that every firm – or Decision Making Unit (DMU) – in the data sample is operating at optimum scale i.e. scale efficiency = 100% across the board. Under this model, an increase in inputs would result in a proportional increase in outputs. (Charnes et al., 1978). The model is also called 'CCR', after the authors Charnes et al. (1978).
2. *Variable Returns to Scale* (VRS): This model is similar to CRS, but removes the optimal scale efficiency restriction, thus allowing a change in inputs to lead to a disproportionate change in outputs (Banker et al., 1984) . The model is also called 'BCC', after it also derived its name from the authors that popularised the concept.

3. *Non-increasing Returns to Scale (NIRS)*: The specification of NIRS in Cummins and Rubio-Misas (2006) appears to suggest that this is a variation of VRS, which attempts to describe the direction of the variable returns to scale (i.e. whether increasing or decreasing returns to scale exist).

The relationship between the efficient frontiers from these three models can be illustrated diagrammatically, as shown in Figure 3-2 below.

Figure 3-2: Efficient Frontier Comparison



Source: Ji and Lee (2010)

If A, B, C, D and E are individual firms, then A, C and E are fully efficient based on the VRS-DEA model, while (B_2, B) is the maximum input reduction that firm B can make without affecting output, and thus also become VRS-efficient. As well as being on the VRS frontier, Firm C is also on the CRS and NIRS frontiers, demonstrating that it is possible for a firm to be efficient under any assumption. That said, Firms A and E provide examples of why it is important to define the efficiency frontier assumption, because while both are VRS-efficient, neither is CRS-efficient and only Firm E is NIRS efficient. In addition, Firm B would need to reduce inputs even more in this case (B_1, B) to become CRS-efficient, with the efficiency not helped by cutting output towards B_3. Firm A demonstrates the feature of a disproportionate relationship between inputs and outputs, where output can be increased from A_1 to A without increasing inputs.

This study will use the VRS model, and the choice of the model is influenced by both theory and practice. The VRS model is consistent with Fukuyama (1997)'s argument, that private firms (like UK insurance companies[27]) do not set out to get constant returns to scale when making business decisions (i.e. they expect to make a profit after meeting all their financial obligations). Fukuyama (1997) argues that CRS might be socially desirable from a policymaker's perspective, as it is consistent with zero profits in the long-term, thus passing maximum value to policyholders. The nature of the UK insurance industry (i.e. privately held firms and billions of pounds in annual profits, as discussed in section 1.1) suggests that the VRS model is more appropriate. In addition, the use of CRS would also ignore the fact that some scale inefficiencies are potentially artificial, because some insurance companies that operate as separate legal entities are already part of a bigger group. For example, the SynThesys 10.1 database of UK insurance regulatory returns suggests that Aviva plc was a parent to six legal entities in 2015[28]. In Aviva plc's case, any measurement of scale efficiency on their Life Insurance businesses is also complicated by Aviva plc being a broad financial services group that includes non-life insurance, asset management and overseas legal entities[29]. From an empirical perspective, Hardwick and Li (1997) found that most firms

[27] There does not appear to be any record of a UK insurance company being owned by the State.
[28] SynThesys version 10.1, by Standard and Poor's
[29] Source: https://www.aviva.com/

(even some large ones) in the UK Life Insurance Industry exhibit Increasing Returns to Scale, suggesting that a CRS or NIRS assumption is inappropriate. VRS will therefore be used in this study. The next step is to specify the models in more detail. This is discussed in sections 3.4 and 3.5 below.

3.4 Specification of the Efficiency Measurement model

As discussed in section 3.2, Cost Efficiency is the product of Technical and Allocative Efficiency. Cummins and Rubio-Misas (2006) also note that under CRS, Technical Efficiency can be further decomposed into Pure Technical Efficiency and Scale Efficiency. This leads to the following formula:

$$\textit{Cost Efficiency} = \underbrace{\textit{Pure Technical Efficiency x Scale Efficiency}}_{\textit{Technical Efficiency}} \textit{ x Allocative Efficiency}$$

The first step in specifying the overall model is to set out the formula for Technical Efficiency, and then decompose it into Pure Technical and Scale Efficiency. Finally, Cost Efficiency formula will be set out, and Allocative Efficiency will then be derived as Cost Efficiency/ Technical Efficiency.

Technical Efficiency is measured using an input-oriented distance function that was previously used in this area of research by Cummins and Rubio-Misas (1996), having been introduced by Shepard (1970). The function is given by:

$$D_r^t(x_i^s, y_i^s) = sup\left\{\theta_i^s : \left(\frac{x_i^s}{\theta_i^s}, y_i^s\right) \in V_r^t(y_i^s)\right\} = (\inf\{\theta_i^s : (\theta_i^s x_i^s, y_i^s) \in V_r^t(y_i^s)\})^{-1} \qquad (1)$$

Where:

- x_i^s is a vector of inputs for Firm i in time period s

- y_i^s is a vector of outputs for Firm i in time period s
- (x_i^s, y_i^s) is the input-output vector that follows from the inputs and outputs defined in the two bullet points above
- For any $y^s \in \mathbb{R}_+^N$, $V_r^t(y_i^s)$ denotes the subset of all input vectors $x^s \in \mathbb{R}_+^K$ which yield at least y^s using a production technology characterised by variable returns to scale, *v.* K is the number of inputs and N is the number of outputs.
- $r = c$ for CRS, $r = v$ for VRS and $r = n$ for NIRS

Cummins and Rubio-Misas (2006) note that when s and t represent the same time period (s = t), then the Distance Function in Equation 1 follows Farrell's (1957) radial measure of input technical efficiency, since the function is the reciprocal of the minimum equi-proportional contraction of the input vector x_i^t, given outputs y_i^t. Technical Efficiency $TE_r^t(x_i^t, y_i^t)$ is therefore defined as $TE_r^t(x_i^t, y_i^t) = 1/D_r^t(x_i^t, y_i^t)$. Technical Efficiency on the CRS frontier is then estimated for each firm in the sample by solving the following linear programming problem:

$$(D_c^t(x_i^t, y_i^t))^{-1} = TE_c^t(x_i^t, y_i^t) = \min \theta_i^t \qquad (2)$$

Subject to:

$$Y^t \lambda_i^t \geq y_i^t$$

$$X^t \lambda_i^t \leq \theta_i^t x_i^t$$

$$\lambda_i^t \geq 0$$

Where X^t is a K x I input matrix and Y^t is an N x I output matrix for all firms in the sample, x_i^t is a K x 1 input vector while y_i^t is a N x 1 output vector for Firm i, λ_i^t is an I x 1 production intensity vector, and I is the number of firms in the sample.

Having specified overall technical efficiency, this can then be decomposed into pure technical efficiency and scale efficiency using the following formula:

$$TE_c^t(x_i^t, y_i^t) = TE_v^t(x_i^t, y_i^t)SE^t(x_i^t, y_i^t) \quad (3)$$

Where:

$TE_v^t(x_i^t, y_i^t)$ is the technical efficiency relative to a VRS frontier (pure technical efficiency) and $SE^t(x_i^t, y_i^t)$ is the scale efficiency. Pure technical efficiency can be solved using Equation 2, by adding an additional constraint on the intensity vector $\sum_i \lambda_i = 1$. A variation of this approach is to make this additional constraint $\sum_i \lambda_i \leq 1$. This variation will produce pure technical efficiency relative to an NIRS frontier.

Below are some interpretations of potential findings from the model, as discussed by Cummins and Rubio-Misas (2006):

- If $SE^t(x_i^t, y_i^t) = 1$ using the$\sum_i \lambda_i = 1$ restriction, then CRS exists.
- If $SE^t(x_i^t, y_i^t) \neq 1$ using the$\sum_i \lambda_i = 1$ restriction, then VRS exists.
- If $SE^t(x_i^t, y_i^t) = 1$ using the $\sum_i \lambda_i \leq 1$ restriction, then NIRS, and specifically increasing returns to scale (IRS), are present.
- If $SE^t(x_i^t, y_i^t) \neq 1$ using the $\sum_i \lambda_i \leq 1$ restriction and NIRS technical efficiency >$TE_c^t(x_i^t, y_i^t)$, then decreasing returns to scale (DRS) are present.

The next step is to describe the approach for obtaining Cost Efficiency. Cummins and Rubio-Misas (2006) describe a two-step procedure. The first step is to solve the problem:

$$min_{x_i^t} \sum_{k=1}^{K} w_{ki}^t x_{ki}^t \quad (4)$$

Where w_i^t is the input price vector, and all other terms are as previously defined. This is subject to:

$$Y^t \lambda_i^t \geq y_i^t$$

$$X^t \lambda_i^t \leq x_i^t$$

$$\lambda_i^t \geq 0$$

The convexity vector constraint works in the same way here as it does for technical efficiency, so the same additional constraints discussed after Equation 3 will be required to obtain VRS and NIRS cost efficiencies. The solution vector from Equation 4 (say $x_i^{t^*}$) is the cost-minimising input vector for input price vector w_i^t and the output vector y_i^t. The second step is to calculate the ratio:

$$CE_c^t(x_i^t, y_i^t) = (w_i^t, x_i^{t^*})/(w_i^t, x_i^t) \tag{5}$$

This produces the CRS cost efficiency for firm i.

The primary model specification is now complete, since all efficiency scores can now be obtained. The next subsection briefly describes the SFA approach that will be used to produce alterative cost efficiency results for comparison purpose.

3.5 Validation: Specification of the SFA model

The SFA efficiency scores will be calculated using the same data set used in the DEA model, but using a pooled data (as opposed to a panel data) approach. The efficiency scores will be extracted from a Cobb-Douglas Cost Function, which is described in a bit more detail later in this subsection. Section 2.3.1 provides evidence of all previous UK studies appearing to use the SFA method. In addition, the Cobb-Douglas Cost Function was used in two of the previous fives UK studies (Hardwick and Li (1997) and Ward (2002)), while another two could have used it (the form of the cost function is unclear in Letza et al. (2001) and Klumpes (2004)). This ensures that the findings using the secondary model are loosely comparable to previous UK studies.

The cost function of each insurance company can be specified as described by Ward (2002):

$$Ln\ c = Ln\ C(y_i, w_k) + Ln\ \mu_c + Ln\ e_c \tag{6}$$

Where:

- c is the total cost, which is measured in line with Bahloul et al. (2013) as the sum of total operating expenses, cost of debt capital (i.e. investment income) and cost of equity capital (i.e. net overall income);
- y_i is a vector of firm outputs;
- w_k is a vector of input prices;
- $Ln\ \mu_c$ is the inefficiency term;
- $Ln\ e_c$ is the random error term.

Applying the Cobb-Douglas functional form to equation 6 above produces the following estimable cost function:

$$Ln\ C = a + \sum_{i=1}^{i} \beta_{1i} Ln\ y_i + \sum_{k=1}^{k} \beta_{2k} Ln\ w_k + Ln\ \mu_c + Ln\ e_c \tag{7}$$

Efficiency scores (EFF) will then be extracted from equation 7 using the Distribution Free Method (which assumes that the random error term averages out to zero over the 2007 - 2015 period), as follows:

$$EFF_{c,k} = \exp(In\ \mu_c^{min} - In\ \mu_{c,k}) \tag{8}$$

Where $In\,\mu_{c,k}$ denotes the time-averages of the inefficiency term for each individual firm from the pooled regression, and $In\,\mu_c^{min}$ is the minimum of these averages which is associated with the most cost-efficient firm.

With both model specifications complete, the next step is to determine the inputs and outputs that will go into the models – this is discussed in 3.6 and 3.7 below.

3.6 Choice of Inputs

The majority of studies described in Table 2-1 identify Labour and Financial Capital as insurance inputs, with a reasonable number identifying a third category named Physical Capital or Business Services & Materials (e.g. rentals, advertising). Financial Capital has often been divided into policyholder-supplied debt capital and financial equity capital (e.g. Klumpes (2004)). This study will use Labour, Physical Capital, Financial Debt Capital and Financial Equity Capital as inputs, which is consistent with three out of five previous UK focussed studies (Ward (2002) consider Labour and Capital more broadly, without the granularity proposed in this study, while Letza et al. (2001) does not specify which inputs and outputs were used), and consistent with many other non-UK studies in Table 2-1. The input prices to go with the chosen inputs are as follows:

- *Cost of Labour*: This is measured as Average Weekly Earnings in the Local Authority where a firm's registered office is based.
- *Cost of Physical Capital*: This cost will not be measured separately, but assumed to be covered by the cost of labour. While there appears to be an agreement in literature that physical capital or business services costs are any costs that are not directly related to direct labour costs related to delivering services to the policyholders and not financial capital costs, there does not appear to be an agreed

approach in the literature to define this. For example, Cummins et al. (2009) define this as labour costs associated with business services for a sample of U.S data, while Cummins et al. (2010) define this as non-labour related expenses for a different sample of U.S. data. In the two published UK studies in Table 2-1 that explicitly allow for physical capital, Klumpes (2004) does not appear to specify how this is set, while Hardwick et al. (2011) use office rent per square foot in the region where a firm's office is based (thus associating non-labour related costs with office accommodation costs). For efficiency comparison purposes, varying the cost of labour by region arguably captures the effects of office location too, since some recent industry surveys show office rentals to vary by region, with London being the most expensive too (just like wages)[30]. In the wider European literature, some authors argue that the cost of Business Services should be considered as a combined variable with the cost of Labour (e.g. Bahloul et al. (2013) and Bahloul and Bouri (2016)). In light of the varied approaches available, the data available for the UK life insurance industry, and given the significance of labour-related costs (which Hardwick and Li (1997) suggested was 80% of total costs in the UK insurance industry), this study will align itself with recent published European literature and not consider the cost of physical capital separately, but instead consider it jointly with the cost of labour.

- *Cost of Financial Capital (referred to in the rest of this paper as the 'Cost of Capital')*: This cost will be calculated as the ratio of expected investment income to total invested assets. This approach moves away from traditional industry-wide measures of cost of capital (e.g. as in Hardwick and Li (1997) and Ward (2002)) and is more in line with relatively recent studies (e.g. Cummins et al. (2009) and Hardwick et al.

[30]Source: http://www.colliers.com/en-gb/uk/insights/offices-rents-map

(2011)), which attempt to proxy the cost at firm level, by considering non-profit policyholders as the main owners of debt capital through the reserves set up from premiums collected, with the investment income from those reserves representing the yield on that debt. In addition, the expected investment income also captures the return expected by shareholders and with-profits policyholders, who are considered to be owners of Equity Capital. The cost of capital definition in this study therefore covers these two types of financial capital.

3.7 Choice of Outputs

There is considerable debate in the literature about the choice of outputs in the insurance industry, due to their intangibility. The first step in choosing the relevant outputs is to choose the output measurement approach. Eling and Luhnen (2010) note the four common output measurement approaches as follows:

- *Intermediation Approach*: This approach views an insurance company as a financial intermediary that manages assets and investments on behalf of policyholders, and pays claims and benefits as and when they fall due.
- *User-Cost Approach*: This approach defines an output as investment return or a claim or benefit that falls below the opportunity cost of funds invested to gain that return or pay the claim or benefit.
- *Value-Added Approach*: This approach defines outputs more broadly as services that contribute significant added value, based on costs that will have been allocated to them. These value-added services to the policyholder can either be classed as *risk-pooling/bearing* (e.g. spreading the financial risk of an unexpected death amongst a number of policyholders), or *financial intermediation* (e.g. investing pension

contributions on behalf of a policyholder). The *value-added approach* appears to be an enhancement of the *intermediation approach* discussed above.

- *Physical Approach*: This considers physical measurable metrics (e.g. the number of outstanding policies in Bikker and van Leuvensteijn (2008)) as outputs.

Using the *intermediation approach* would potentially be sub-optimal, because the role of an insurance company is arguably broader than financial intermediation (Cummins and Weiss, 1998). For example, a claim on a term life insurance policy will be designed to pay out many times more than the premiums paid for that policy. In addition, such product lines produce little in the way of investment gains to contribute to any claims, again due to the relatively small size of the premiums when compared with the corresponding claims. A claim on such a policy is therefore a result of the insurance company offering a service where they collect premiums from a large number of people seeking similar insurance, and pay claims from that pool of collected premiums[31]. This appears to go beyond financial intermediation. In terms of the empirical literature, there appear to only be nine published papers that use the intermediation approach, and the majority are concentrated in specific countries (e.g. two of the three Canadian papers, and three of the four Japanese papers, use this approach. The remaining four are U.S. papers. See Table 2-1 for details). This approach might therefore be appropriate in markets where insurance is viewed mainly as a financial intermediary. However, the limited use of the approach suggests that its use would require robust justification, especially when it has not previously been used in a particular market such as the U.K.

[31] This is based on industry experience of the researcher.

The *User-Cost approach* is worth considering, since it appears to look at efficiency from the perspective of optimally utilising the capital employed. This therefore goes hand-in-hand with capital being a key input in the industry. However, it does not appear to have been used by any published empirical studies in this research area to date, and is likely to be difficult to implement in practice, because the data required when using this approach (e.g. product revenues and opportunity costs) is not always available, and even when it is, is unlikely to be publicly available (Eling and Luhnen, 2010). For this study, a UK insurance firm's regulatory return is arguably the richest source of data when doing an industry-wide study (this data source is discussed further in section 3.10). A sample regulatory return was reviewed as part of this study[32] and this demonstrated that any analysis of product revenues can only be done at a very high level (i.e. Life Assurance products versus Pension products, not different variants within these categories) and no data is available for opportunity cost. The user-cost approach could therefore not be employed in this study.

The *Physical approach* is also worth considering, since the physical number of (say) policies, can have a strong correlation with the number customer service staff (and therefore the related wages) required to service them. Some authors (e.g. Cummins et al. (1996), Cummins and Rubio-Misas (2006) and Brito et al. (2013)) actually argue that a Physical Approach (using this example of the number of policies) would constitute an ideal measure of output if the data is available. However, like the User-Cost approach, the data required to implement this approach is also likely to be commercially sensitive, and therefore not in the public domain. The sample UK regulatory return discussed in the previous paragraph again demonstrates that data required to use this approach in the UK Life Insurance context does

[32] The 2009 submission by Wesleyan Assurance Society:
https://www.wesleyan.co.uk/pdf/wesleyan_assurance_society_fsa_returns_2009.pdf

not appear to be publicly available. Both this and the User-Cost approach could be employed when comparing the efficiency of different product lines within the same company by an in-house researcher (for example). In terms of the empirical literature, only four previously published papers appear to have used this approach before, none of which are based on the UK Life Insurance Industry (see Table 2-1).

This leaves the *value-added approach*, which appears to be the most commonly used approach in insurance industry efficiency research (as seen in Table 2-1). It addresses the potential shortcomings of the intermediation approach by taking into account the risk bearing/pooling service that insurance companies provide. It also gets round the issue of data availability that the user-cost and physical approaches face, by being flexible in terms of the data that can be used, thus allowing the most suitable available data to be used. Eling and Luhnen (2010) point out though that wide acceptance and use does not necessarily mean validity. Although there does not appear to be a lot of literature that critically compares the value-added approach with other approaches, a couples of papers appear to have done so, by comparing the value-added approach with the financial intermediation approach, with opposing conclusions.

Brockett et al. (2005) argued the case for the financial intermediation approach, by viewing an insurance company as a financial intermediary where the outputs are:

- *Solvency*, which can be a primary concern for regulators of insurance companies,
- *Claims-paying ability*, which can be a primary concern for policyholders, and
- *Return on Investment (ROI),* which can be a primary concern for investors

Brockett et al. (2005) argue that an insurance company is less of production entity, and more of a financial intermediary, and they conclude that an intermediation approach acknowledges that interests of insurance firms, their policyholders and shareholders potentially conflict, and the strategic decision makers for the firm must balance one concern versus another when managing the insurance company. Leverty and Grace (2010) did a similar comparison of the output approaches to that performed by Brockett et al. (2005), but appear to have opposing conclusions. As well as concluding that the theoretical concern regarding the value-added approach's use of losses as a measure of output is not validated empirically, they brought in a firm's continued existence into the argument, by concluding that efficient value-added approach firms are less likely to go insolvent, while firms characterized as efficient by the financial intermediation approach are generally more likely to fail.

While this study acknowledges that the wide use of the value-added approach does not necessarily mean it is the best approach, it still intends to use it, on the grounds that:

- the debate of whether or not other methods are more appropriate appears to be in its relative infancy;
- the approach appears to be currently considered as best practice in this area of research, and appears to have been used in all previously published UK studies; and
- the approach is in line with the researcher's view of an insurance firm, from a practitioner perspective.

Having chosen the output measure approach, the remaining challenge is to measure the value-added services. Since *risk-pooling/bearing* and *financial intermediation* services are intangible, proxies need to be chosen to represent them, and there's considerable debate in the literature about the appropriate proxies to use. For example, while some published authors have argued that premiums cannot be a measure of output since they also include a margin for the insurer's profit (e.g. Yuengert (1993)), subsequent published studies have used premiums as a risk-pooling output measure anyway (e.g. Hardwick and Li (1997) and Gaganis et al. (2013)). This study acknowledges the debate on the different proxies that could be used (the variety of which can be seen in Table 2-1), and aims to justify the proxies for outputs chosen for the purpose of this study.

The proxy for risk-pooling in this study will be *policyholder claims*. As discussed above when ruling out the *Intermediation Approach* of looking at outputs, the payment of policyholder claims is a good example of an insurance company fulfilling its role as a risk-pooling/risk-bearing provider. In addition, this proxy has been used in this way in a good number of studies before (see Table 2-1), and was used in three of the four UK studies discussed in the literature review that published details of their outputs. A slight modification from previous published UK studies is using aggregate claims data across all product lines. This was done because the regulatory returns appear to have changed since the previous published studies, and currently group products into UK Life, UK Pensions and Overseas (previous studies like Ward (2002) and Hardwick et al. (2011) appear to show a different split of Life, Pensions and Private Health Insurance). Mono-line businesses that have emerged in recent years (e.g. Pension Insurance Corporation) and firms that do not conduct overseas business (who make up the majority) would therefore have a lot of zeros in the data, which would be problematic when applying natural logarithms on them for purposes of efficiency estimation. In addition, this study is not looking to compare efficiency levels by product line, so does not require this split. Aggregate claims data will therefore be used in this study.

The proxy for financial intermediation in this study will be *Invested Assets*. This proxy appears to have been used extensively for this purpose in the literature, including in at least one of the previous five UK-specific published studies, as can be seen in Table 2-1. This appears to be seen as a reasonable proxy, because an insurance company primarily invests assets on behalf of policyholders, and this measures the assets under management for which financial intermediation or investment decisions must be taken (Cummins et al. (2009)).

The methodology discussed up to this point allows for efficiency scores to be produced. The next step is to formally set out the research questions or hypotheses to be answered using these efficiency scores. This is the subject of 3.8 below.

3.8 Construction of Hypotheses

The research questions in this study are influenced by some of the issues around efficiency in the UK insurance industry in the post 2008 world from a Financial and Capital Management perspective. They are not meant to be exhaustive, but aim to cover some key areas that will help practitioners to understand the nature of the industry from an efficiency perspective, as part of a wider set of tools in effectively managing their businesses.

As discussed in Section 1, much change has occurred in the industry in the post 2008 period in the name of cutting costs and efficiency. One observation from the data appears to be a consolidation of the market, which has seen the number of insurers reduce over time. Section 1.1.8 also discusses how cost reduction is thought to be a key driver in the consolidation of the UK Life industry in recent years. In practice, a consolidation would be expected to reduce a firm's labour costs (a key input, as discussed in section 3.6), which should improve cost efficiency. The aggregation of risks between combined entities might also lead to risk diversification benefits, which would reduce any risk based capital requirements (and thus the associated cost of capital). Hardwick and Li (1997) looked at the impact of the size of an organisation (using premiums as a proxy for size) on cost efficiency in the UK Insurance industry, and concluded that size did not have a statistically significant impact (although the larger companies were more efficient). However, their study was conducted before the implementation of risk-based capital measures discussed above, which arguably increase the potential efficiency of large companies with diverse risks. There is therefore a need to understand if this consolidation activity, which results in larger firms than before, is yielding this expected efficiency improvement outcome from the point of statistical significance. This leads to the first hypothesis:

$$H_1: Larger\ UK\ Life\ Firms\ are\ more\ cost\ efficient\ than\ smaller\ UK\ Life\ firms$$

The next hypothesis relates to the use of reinsurance. Reinsurance has grown to become a large global sub-sector of insurance and discussed at length by Cummins and Weiss (2000) and Biener et al. (2017). In the UK, the drive for reinsurance in recent years can arguably be traced to the move towards risk-based capital (i.e. ICAS pre-2016 and Solvency II post-2016 as previously discussed in Section 1.1). By using reinsurance, insurance companies pass on some or all of the risks taken on when writing new business, to another insurer. This can therefore reduce a key insurance input (i.e. capital) without affecting output. Insurers are expected to continue to turn to reinsurance, with the *European Life Insurance Back Book*

Management 2017 finding that one of the practical implications of the Solvency II regime has been an increased use of reinsurance. Although the relationship between Reinsurance and efficiency does not appear to have been directly investigated in the published insurance literature, Cummins and Nini (2002) found a statistically significant relationship between high levels of reinsurance and low levels of capital utilisation. Less capital should therefore result in reduced costs associated with raising capital (a key input). It is therefore worth understanding if Reinsurance is a statistically significant driver of cost efficiency.

$$H_2: Reinsurance\ increases\ the\ Cost\ Efficiency\ of\ a\ UK\ insurance\ company$$

In a similar way to Reinsurance discussed above, insurance companies have also been increasingly using derivatives to manage the Capital input of their business in the aftermath of the financial crisis. Along with Reinsurance, increased use of hedging (one type of derivative) was found by the *European Life Insurance Back Book Management 2017* to be one of the key practical implications of Solvency II. In this situation, insurance companies usually turn to capital markets (usually investment banks) to effectively insure against risks that Reinsurance does not normally cover, e.g. Balance Sheet volatility to interest rates. The nature of the Solvency II Balance Sheet has resulted in increased interest rate volatility, particularly for annuity providers, because under ICAS, the focus was on reducing interest rate volatility by matching asset and liability cashflows. This is still required under Solvency II, but the introduction of the interest rate-sensitive Risk Margin (effectively an additional regulatory capital requirement) onto the Balance Sheet has increased the need to manage the related volatility[33]. That said, managing volatility comes at increased cost (i.e. to compensate the investment bank for taking away the unwanted volatility from the

[33] Solvency II and Current Economic Environment – Impact on Consumers' by the Institute & Faculty of Actuaries.

insurance company), without necessarily changing the output expected by the policyholder (e.g. single premium products that are currently paying a fixed defined monthly pension to a policyholder). Derivatives could therefore have a negative impact on Cost Efficiency. The impact of derivative usage in the UK Life Insurance industry does not appear to have been previously investigated in the published insurance literature. That said, Hardwick and Adams (1999) found that derivative usage in the UK Insurance industry was positively related to a firm's size. A negative relationship between derivative use and cost efficiency could therefore help to explain why larger firms do not end up with significantly better cost efficiency than smaller firms (based on findings by Hardwick and Li (1997)). In addition, Hardwick and Adams (1999) found that UK Life insurance companies that made more use of derivatives, made less use of reinsurance. It is therefore important to understand the impact of this capital management tool on efficiency; because it will help practitioners to understand if this tool aids efficiency, and potentially influence the balance between use of reinsurance and derivatives if one tool improves efficiency, and the other does not. That said, data limitations mean only the impact of using or not using derivatives can be explored, and not the extent of the use (which would require data of notional amounts for positions opened in a given year, which is not available in the UK Insurance Industry data, as described by Shiu (2007)).

$$H_3\text{: } Derivative\ use\ increases\ the\ Cost\ Efficiency\ of\ a\ UK\ insurance\ company$$

The financial crisis also brought a couple of key capital management metrics of an organisation into sharp focus;

1. the solvency position

2. the level of liquidity

There were key examples of companies failing or needing a bailout during the crisis because they were at risk of insolvency (e.g. AIG in the USA), while others were solvent, but appear to have run into difficulties because of a lack of liquidity (e.g. Northern Rock in the UK[34]). Although it occurred before the Global Financial Crisis, a UK insurance company called Equitable Life was forced close to new business after failing to have enough liquidity to honour annuity payments (Shiu, 2006). In addition, a firm with a high liquidity ratio is expected to find it easier to rebalance an asset portfolio (which it might need to do in times of crisis) than a firm with a low liquidity ratio. For example, the liquidity could be used to replace a corporate bond that was being used to back annuity payments, but defaulted during a crisis. Some of the regulatory responses since the crisis have therefore focussed on these two aspects, by enhancing both solvency and liquidity regulation (as discussed in section 2.1). As discussed in section 3.6 above, the cost of Capital is a key input into a firm's operations, so holding more capital than required (and therefore the associated cost), would appear to make a firm more inefficient than before. In addition, the current low investment return environment post 2008 discussed in section 1.1.7 might lead firms to invest in higher return (but more risky) asset classes like Private Equity and Emerging markets Equity for commercial reasons, which would further increase any regulatory risk-based capital. Increased liquidity on the other hand would be expected to reduce costs for a firm, since the associated assets (e.g. cash) are expected to carry less risk (see Figure 1-5), so require less regulatory capital (and thus less cost associated with that capital).

[34] https://www.economist.com/briefing/2007/10/18/lessons-of-the-fall

Solvency in the insurance industry is commonly measured as the level of free assets a company holds over and above regulatory capital requirements (Shiu, 2006). In the UK Life Insurance industry, reported solvency is based on regulatory rules, which consider solvency as the level of free assets above a risk-based capital buffer that is calculated using rules set by the European regulator post-2016, and UK regulator pre-2016 (as discussed in Section 2). Liquidity, on the other hand, does not appear to have a universally accepted definition. Shiu (2006) investigated the determinants of liquidity in the UK Life Insurance industry (this appears to be the only empirical study that specifically looked at this industry), and defined liquidity as cash plus marketable securities (bonds and equity shares), with the definition of 'bond' not explicitly stated. In practice, the definition could be considered to be too broad, since a large discount in the value of (say) a long-dated corporate bond might be required to make it liquid. A company with limited solvency capacity might therefore not define such a bond as 'liquid'. The definition of 'bond' in this study is therefore restricted to government and government-backed bonds, which are considered risk-free in practice.

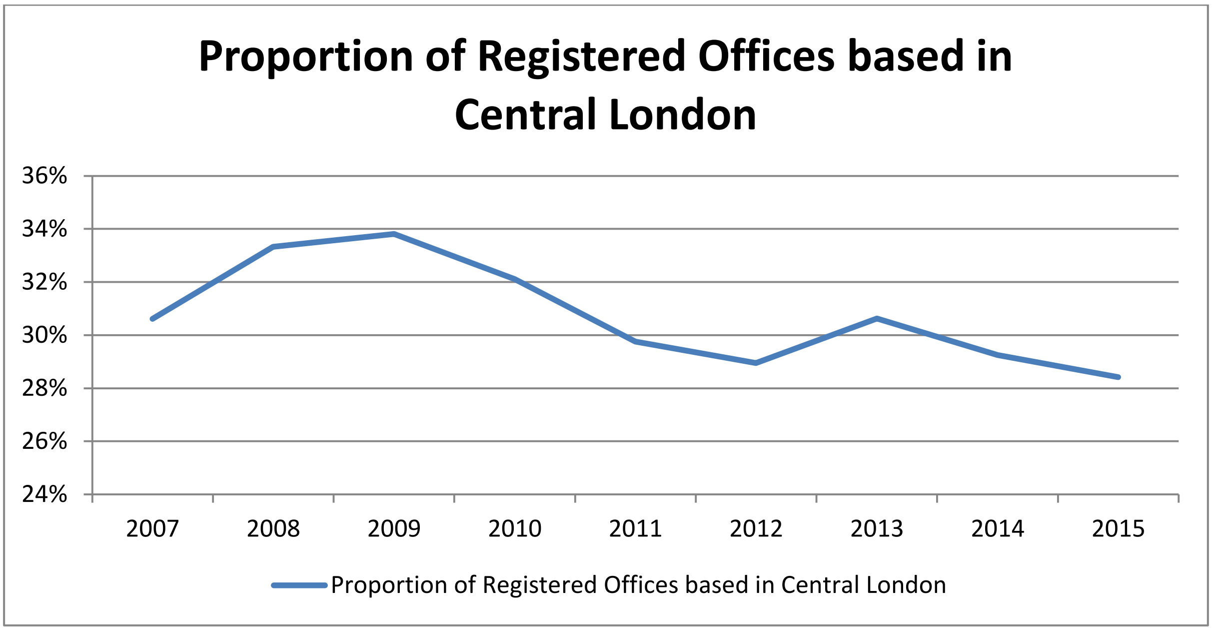
The discussion above leads to the following two hypotheses:

$$H_4\text{: } Higher\ solvency\ decreases\ the\ Cost\ Efficiency\ of\ a\ UK\ insurance\ company$$

$$H_5\text{: } Higher\ levels\ of\ liquidity\ increase\ the\ Cost\ Efficiency\ of\ a\ UK\ insurance\ company$$

The final hypothesis that will be investigated relates to office location. The data used to assign wages to each company, showed a relatively high proportion of registered offices in Central London throughout the sampling period, starting off at 31%, before peaking at 34% in 2009, and then gradually reducing to 28% by 2015 (see Figure 3-3 below).

Figure 3-3: Central London Registered Office Proportion



Central London appears to be the most expensive location from the perspective of Labour costs (according to ONS data), so this is potentially contributing to cost inefficiencies for the relevant companies (given that Labour is a key input for the industry). Hardwick and Li (1997) tested a similar hypothesis in their study, by comparing the efficiency levels of London-based companies with those of regional-based companies. They did not find a statistically significant difference in the efficiency levels, although London-based companies were less efficient. Technological advances since that study have arguably reduced the costs associated with non-labour-related costs, and thus potentially increasing the significance of labour-related costs in driving efficiency. In addition, these same technological advances may have made it possible for regional companies to operate more efficiently, due to (for example) Broadband internet connections reaching more regional areas than before. The downward trend in Central London registered offices in Figure 3-3 also suggests that moving out of Central London is a tool that companies might be using to improve cost efficiency. There is therefore a need to re-examine the relationship between the office location of an organisation and the efficiency levels. This leads to the following hypothesis:

$$H_6: A\ Central\ London\ Registered\ Office\ reduces\ the\ Cost\ Efficiency\ of\ a\ UK\ insurance\ company$$

The Regression formula can therefore be set out as follows:

$$EFF_{it} = \gamma_1 Ln(Premiums)_{it} + \gamma_2 ReinsuranceRatio_{it} + \gamma_3 DerivativeUse_{it} + \gamma_4 FreeAssetRatio_{it} + \gamma_5 LiquidityRatio_{it} + \gamma_6 CentralLondon_{it}$$

Where:

- γ_x Is this the co-efficient for hypothesis H_x, and i denotes a firm at time *t*
- *Ln (Premiums)* is the natural logarithm of total Net Written Premiums (NWP) in a given year, and represents the size of the firm, as in Hardwick and Li (1997)
- *ReinsuranceRatio* represents the extent of reinsurance usage in an organisation, and is represented by the ratio of ceded reinsurance premiums written for the year to total annual gross premiums written, as in Hardwick and Adams (1999)
- *DerivativeUse* is a dummy variable that sets derivative users as 1 and non-derivative users as 0 in a given year, and represents the extent of derivative use in the industry, as described in Shiu (2007).
- *FreeAssetRatio* represents the solvency of an organisation in a given year, and is the ratio of free assets a UK Insurance company holds over the regulatory minimum margin, as a proportion of assets allocated to cover the minimum margin, in line with Shiu (2006) and Hardwick et al. (2011).
- *LiquidityRatio* represents the level of liquidity in an organisation in a given year, and is calculated as the ratio of the sum of cash in hand, Deposits not subject to time

restriction on withdrawal with approved institutions, Bank and approved credit and financial institution deposits, government or government-backed bonds (also known as Approved bonds) and equity shares to total admissible assets. This follows a similar definition as in Shiu (2006), with the exception of strictly defining the types of bonds included.

- *CentralLondon* is a dummy variable that is set to 1 for a company with their registered office in Central London, and zero otherwise. This is a similar approach to the one used by Hardwick and Li (1997) for the same industry.

With the hypotheses now defined; the next step to set out the regression approach to evaluate these hypotheses. This is discussed in section 3.9 below.

3.9 Regression Approach

The regression approach to use with DEA efficiency scores is also debated in the insurance efficiency literature, and there appears to be no consensus as to the most appropriate approach to use (see Table 2-2). Some studies have used the censored (Tobit) approach (e.g. Huang et. al (2011)), which aims to account for the fact that the dependent variable (DEA efficiency scores) can only be in the range of 0 and 1, thus getting around the key shortcoming of using an uncensored Ordinary Least Squares (OLS) model that was described by Maddala (1983) as leading to biased parameter estimates since OLS assumes a normal and homoskedastic distribution of the disturbance and the dependent variable. However, recent studies have also employed a new approach designed by Simar and Wilson (2007), which involves a truncated regression of contextual variables on efficiency estimates, which is followed by bootstrapping and re-estimation of the regression coefficients. Simar and Wilson (2007) were trying to get round the perceived weaknesses of the Tobit approach, which is summarised by Luhnen (2009) as the use of conventional approaches to inference, which are invalid due to complicated and unknown serial correlations among estimated efficiency scores.

Although the use of censored models appears reasonable for cost efficiency scores, some authors have argued against such models. For example, McDonald (2009) argues against both the Tobit approach and the alternative introduced by Simar and Wilson (2007), and instead argues for the use of an OLS approach or variants of it. In terms of the Tobit approach, McDonald (2009) argues that the process of deriving efficiency scores is not itself a censored process. He argues that efficiency scores are fractional data, so using a censored approach is inappropriate. In the case of the method introduced by Simar and Wilson (2007), McDonald (2009) argues that although the method might work for the specific scenario that is covered by Simar and Wilson (2007), it is not robust to departures from that specific scenario. McDonald (2009) also describes Simar and Wilson (2007)'s method as a very complex seven-stage estimation procedure, with double bootstrapping. This arguably contributes to its inflexibility at the implementation stage. However, Simar and Wilson (2011) back up the approach introduced by Simar and Wilson (2007), by comparing Simar and Wilson (2007)'s truncated approach with Banker and Natarajan (2008)'s OLS approach and concluding that the truncated approach was robust, and it was the OLS approach that was in fact suitable in very restricted conditions. This lack of consensus suggests that a study can choose from a wide variety of regression approaches with sufficient justification.

Based on the above discussion, this study picked one method, and justified its use. The method that was chosen is the Tobit approach for panel data, which was chosen for a number of reasons. Firstly, the dataset is in the panel form, that is, variations in the data arise from two dimensions: cross-sectional and time; and the potential influence of unobserved, time-invariant individual firm characteristics on the estimation results needs to be considered (Greene, 2003). Secondly, it takes the censored (0, 1) nature of cost efficiency scores into consideration. Thirdly, it has been used in a number of relevant previous studies, as can be seen in Table 2-2, including in recent published literature e.g. Chen et al. (2014), suggesting that the approach can be used with sufficient justification. Fourthly, it will be unique in the UK literature to use this approach, and will lead to a UK study being in line with other recent global literature in using this approach. Finally, it arguably strikes the right balance between methodological robustness from an academic perspective, and ease of understanding for non-academic practitioners, who are the intended target audience of this research.

Whilst the Tobit approach was used to perform the regression analysis of this study, the Random Effects panel model, Simar and Wilson's Bootstrapping (2007), and OLS approaches were used as validation tools. The Random Effects approach was chosen because it emerged as the recommended approach from a series of standard statistical tests that are described further in Chapter 4, and supports the use of the Tobit approach, which is a variation of the Random Effects model. On the other hand, the OLS approach was chosen based on the arguments in support of it by McDonald (2009) that have been discussed in this section. Finally, the Simar and Wilson (2007) approach was chosen because it aims to addresses some of the perceived weaknesses of the Tobit approach, which Simar and Wilson (2007) describe as the potential bias of the efficiency scores when using the traditional DEA approach, and the serial correlation of the scores, which has the potential to invalid the results of the regression stage of the analysis. The approach does not appear to be appropriate for this study, because Badunenko and Tauchmann (2018) note that the approach was designed to measure technical efficiency using cross-sectional data, whereas this study is exploring cost efficiency using panel data. In addition, this study can only implement the regression part of the Simar and Wilson (2007) approach, with the efficiency scores calculated outside this model, due to the panel nature of the data. However, the results are included alongside OLS results, to provide a comparison of the Tobit results with two cross-sectional regression approaches that have previously been used in the literature.

With the methodology of both stages of this study now fully defined, the next step is to describe the data used as part of implementing this methodology. This data is discussed in Section 3.10 below.

3.10 Data

The inputs and outputs of insurance companies discussed in 3.6 and 3.7 can arguably be found in two main sources of data: Annual Report and Accounts, and Regulatory Returns. A key challenge of using the Accounts is that only companies listed on the Stock Exchange, and/or those that have issued debt to the market (so have an obligation to disclose data to Rating agencies such as Standard & Poor's) publish their annual accounts. This is a particular challenge for the UK insurance industry, where using such data would exclude significant types of insurance companies, such as Mutual organisations that – by design – are not listed. In addition, some of these organisations do not appear to have any rated external debt in the sample period (e.g. Police Mutual[35]). It would also exclude significant players in the industry that are wholly-owned subsidiaries of non-UK parents. They will therefore not be listed on any Stock Exchange in their own right, and might not issue debt directly to the markets, so would not need to submit accounts to rating agencies. An example is Canada

[35] Police Mutual does not appear on UK insurance companies covered by Standard & Poor's Market Intelligence

Life UK[36]. That said, publicly available accounts are submitted to rating agencies by some of the larger mutual organisations who now use external debt as a source of raising capital (e.g. Liverpool Victoria[37]), as a well as a large spectrum of listed and unlisted insurance companies, which in total account for around 60% of Gross Written Premiums[38]. Such accounts could therefore be used as a data source that represents the UK insurance industry.

Regulatory returns appear to get round some of the shortcomings that are presented by accounting data, since every insurance company is expected to submit these returns (which can also be viewed as accounting data in a format prescribed by the Regulator) and make them publicly available. The data therefore represents the whole industry, with no risk of sampling error. The findings might arguably be more credible too, since – for example – some studies have found that higher leveraged companies are more efficient (e.g. Luhnen, 2009), so using rating agency accounts could be challenged as basing UK insurance efficiency findings on firms that are arguably more efficient than the rest anyway. In addition, regulatory data in the UK provides a single template for all firms to complete. The data is therefore standardised and easy to analyse. The same might not be true for Reports and Accounts, which should be comparable because they are usually based on a single set of rules or guidelines[39], but the output is not in template format, so there is likely to be a variety of data outputs and analysis from firm to firm. This study will therefore use Regulatory Returns data.

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[36] Canada Life UK is a wholly owned subsidiary of Great-West Life: https://www.greatwestlifeco.com/.
[37] Based on Standard & Poor's Market Intelligence
[38] Based on Standard & Poor's Market Intelligence
[39] For example, there is the Generally Accepted Accounting Practice in the UK (UK GAAP). Source: https://www.icaew.com/technical/financial-reporting/uk-gaap

The main source of data will come from Standard and Poor's' *SynThesys*[40] database version 10.1, which contains historical empirical data of the whole UK insurance industry's regulatory returns. This data source has been used in previous published UK studies (most recently by Hardwick et al. (2011)), thus supporting its credibility as well as making this study consistent with previous studies in this key area. That said, an alternative data source with similar information could have been obtained from the credit rating agency A.M Best[41]. As a validation check, a regulatory return from an insurer's website[42] was downloaded and cross-checked against what was stored for this company by S&P, and this validation test passed. The secondary data source is the UK's Office of National Statistics (ONS)[43], which will provide Gross Weekly Earnings data needed to calculate the price for labour. There do not appear to be more credible data sources than this one for this purpose, and this data source (or its predecessors) has been used for a similar purpose in previous UK insurance efficiency studies (e.g. Hardwick and Li (1997)). Hardwick et al. (2011) appear to have used a sub-section of ONS wage data (called *Regional Trends*) that was specific to the financial sector, but also allowed for regional variation. This would have arguably been an ideal source for wage data in this study. However, that particular section of ONS data appears to have been discontinued in 2011[44], and is therefore not available for a significant period of the sample period. This secondary data source is supported by three supplementary public data sources (i.e. Companies House[45], Mutuals Public Register[46] and The Financial Services

[40] Further details can be found here:
https://marketintelligence.spglobal.com/documents/products/SynThesys_Life_v2.pdf
https://marketintelligence.spglobal.com/documents/products/SynThesys_Non-Life_v2.pdf
[41] Source: http://www.ambest.com/sales/BIR/default.asp
[42] The 2009 submission by Wesleyan Assurance Society:
https://www.wesleyan.co.uk/pdf/wesleyan_assurance_society_fsa_returns_2009.pdf
[43] Source: https://www.ons.gov.uk/
[44] https://data.gov.uk/dataset/4d550211-015f-4e15-8339-da4bd0245ed3/regional-trends
[45] https://www.gov.uk/government/organisations/companies-house
[46] https://www.fca.org.uk/firms/mutuals-public-register

Register[47]), which help to assign the most appropriate earnings data for each company's office location in the UK. This office location data was collected manually, by looking at individual company information on the websites of Companies House, the Mutuals Public Register and the Financial Services Register, and recording the most recent office address, as well as previous addresses, where evidence of such addresses exist. If no evidence of previous addresses was available, it was assumed that the firm was based at the same registered office throughout the sample period.

All data sources cover the period 2007 – 2015. Although the exact start of the Global Financial crisis is by nature difficult to pinpoint, the filing of bankruptcy by Lehman Brothers on 15 September 2008[48] is widely regarded as the event that set the crisis in motion globally, having begun with the collapse of the subprime mortgage market in the United States in 2007, which triggered a recession in that country[49]. In the UK, the base Bank of England interest rate, which the Bank uses to control monetary policy and inflation (which is itself a measure of the increase in consumer spending power), peaked at 5.75% in September 2007. The first interest rate cut of 0.25% came in December 2007 as consumer confidence waned, and gradually kept falling until it reached 0.25% in December 2016. The first interest rate increase since the crisis came in November 2017, but the base rate – at 0.5% - remained very low[50]. It could therefore be argued that – just like in the United States - the financial crisis also began to be felt in the UK in 2007. Although there appears to be some debate in the literature about the exact start point, the 2007 start point is supported by some authors in the insurance industry literature (e.g. Berry-Stolzle et al. (2011), Drake et

[47] https://register.fca.org.uk/
[48] https://www.investopedia.com/articles/economics/09/lehman-brothers-collapse.asp
[49] https://www.federalreservehistory.org/essays/subprime_mortgage_crisis
[50] http://www.propertyinvestmentproject.co.uk/property-statistics/uk-interest-rate-history-graph/

al. (2017) and Gonzalez et al. (2017)), on the basis that the crisis started in the USA with the collapse of the subprime mortgage market. This literature and the discussion above based on industry data and analyses are the basis for choosing 2007 as the start point of the period of investigation in this study. Less judgement was required when choosing the end point of the data period, which has been chosen to capture the longest period since the crisis, given the data available at the point of data collection. As at March 2018 (when data was collected), *SynThesys* had regulatory returns data up to 2015. This would provide 9 years of industry data, which is slightly shorter than the 11 years in Hardwick et al. (2011)'s UK study, but longer than the periods used by all the other UK-focussed published studies discussed in section 2 (5 years in Hardwick and Li (1997), Letza et. al (2001) and Klumpes (2004), and 8 years in Ward (2002)).

The data was used in both Stage 1 and Stage 2 of the analysis, and was implemented in the 'STATA/IC version 15.1' software package. The user-written add-ins that produced the DEA scores and the Simar and Wilson regression analysis are included in Appendices 1 and 3 respectively. Specific data items used from the data sources discussed above are detailed in the Tables 3-2 and 3-3 below.

Table 3-2: Efficiency Measurement Data Items

Data Item	Source	Form Name in Source	Name of Data Item in Source
Total Operating Expenses*	Regulatory Returns (SynThesys Life)	40	Expenses Payable (Total Business)
Cost of Capital (£)*	Regulatory Returns (SynThesys Life)	48	Sum{Assets backing NP liabs: Total (Total Business, column 3), Assets backing WP liabs: Total (Total Business, column 3)}
Policyholder Claims	Regulatory Returns (SynThesys Life)	40	Claims Incurred (Total Business)
Invested Assets	Regulatory Returns (SynThesys Life)	13	Sum{Total admissible assets (as per line 89) (Total LT), Admissible Assets in excess of market & counterparty limits (Total LT)}
Cost of Capital (%)	Regulatory Returns (SynThesys Life)	48	Sum{Assets backing NP liabs: Total (Total Business, column 3), Assets backing WP liabs: Total (Total Business, column 3)} **/** Sum{Assets backing NP liabs: Total (Total Business, column 2), Assets backing WP liabs: Total (Total Business, column 2)}
Cost of Labour	Annual Survey of Hours and Earnings (ASHE) (Office of National Statistics)	Table 7.1a	Weekly pay - Gross (£) - For all employee jobs: United Kingdom

*This is only used in the SFA validation test as part of total cost components

Table 3-3: Efficiency Regression Data Items

Data Item	Source	Form Name in Source	Name of Data Item in Source
Net Written Premiums	Regulatory Returns (SynThesys Life)	Ratios 7	Net Total Premiums
Reinsurance Ratio	Regulatory Returns (SynThesys Life)	Ratios 7	(Gross Total Premiums – Net Total Premiums)/Gross Total Premiums
Derivative Use	Regulatory Returns (SynThesys Life)	13	IF {OR(Other investments: Rights under derivative contracts (Total LT), Other investments: Rights under derivative contracts (Total OLT))>0,1,0}
Free Asset Ratio	Regulatory Returns (SynThesys Life)	2	Excess (deficiency) of capital resources to cover LT business CRR (13-41) **/** Capital resources to cover LT business capital resources requirement (11+12)
Liquidity Ratio	Regulatory Returns (SynThesys Life)	13	Sum{Other investments: Equity shares, Other investments: Fixed interest securities – approved, Other investments: Variable interest securities – approved, Other investments: Bank & approved credit & financial inst deposits <= 1 month, Other investments: Bank & approved credit & financial inst deposits > 1 month, Other assets: Deposits not subject to time restriction on withdrawal, Other assets: Cash in hand)} **/** Sum{Total admissible assets (as per line 89) (Total LT), Admissible Assets in excess of market & counterparty limits (Total LT)}
Central London	Office Locations and Salary Data (Compiled manually for this research – See section 4)	N/A	IF (Central London, 1,0)

With the outline of the data to be used now complete, the next section discusses ethics associated with this data collection, and the study as a whole.

3.11 Ethics Discussion

Ethics are defined by Bulmer (1992) as a matter of principled sensitivity to the rights of others. This ethics section will look at key ethical issues of research in general, how they could affect this study, and potential solutions or mitigation techniques to those issues.

3.11.1 Fundamental Issues for Ethical Research

As a minimum, this study meets the guidelines of the University of Hertfordshire's Ethics Approval process, which stipulates that Ethics Approval is not required for a study such as this, where only secondary and publicly available data is used[51]. However, Bryman and Bell (2007) suggest that university ethics policies tend to be written in abstract terms, and mainly designed to prevent misconduct. Other ethics codes have therefore also been consulted as part of this research, to expand on any points that might only be implicit in the University of Hertfordshire's Ethics Approval process.

This section will discuss fundamental issues of ethical research, and splits these issues into five categories as outlined by the University of Worcester[52].

1.** Research must be **justified

The ESRC Framework for research ethics (2015) states that research should be worthwhile and provide value that outweighs any risk or harm.

[51] Source: http://www.studynet1.herts.ac.uk/ptl/common/ethics.nsf/Teaching+Documents/DAEF2B93EB7E88F98025811E0044EA2B/$FILE/2018-09-18 Ethics Approval Training Self Directed.ppt

[52] Source: https://www2.worc.ac.uk/researchportal/735.htm

A literature review is a key part of this justification, since it is used to identify a gap in the literature, which the research attempts to fill. Iphofen (2011) looks at the ethical perspective of a literature review, by noting that research must demonstrate the ways in which it builds upon or adds to existing research findings. The BERA ethics guidelines (2011) add that it is also ethical to properly cite other people's literature that is used as part of this process.

Justification of the research conducted in this study is contained in Chapter 2, where a detailed literature review highlighted the contribution to empirical literature and practice that this study is aiming to achieve.

*2. **Informed consent** must be given by participants*

The Academy of Management Code of Ethics (2006) specifically mentions that a researcher should seek informed consent from participants, in language that the participant understands, documenting all relevant decisions along the way.

All of the data used in this study is secondary and publicly available data, so the issue of informed consent does not arise. That said, this study has a responsibility to the organisations in the data sample, so will not be reporting any information or results that would individually show them in a bad light. For example, even though efficiency scores will be produced for each individual firm in each year from 2007 – 2015 (which show some firms with cost efficiency that is considerably lower than others), these individual efficiency scores by firm will not be included in this report, but instead include summary data for the whole industry.

3.** Participation in research must be **voluntary

Voluntary participation in research is closely linked to informed consent. BERA guidelines (2011) actually cover the two concepts together as *voluntary informed consent*, recognising that informed consent can arguably not be separated from voluntary participation. Saunders, Lewis & Thornhill (2009) also discuss the voluntary nature of participation and the right to withdraw partially or completely from the process. It could be argued that the issue of voluntary participation does not apply to publicly available data. However, this further highlights the need to use the subsequent results produced by the study in a way that respects the participants in the secondary data.

4. ***Confidentiality*** *must be ensured*

As an actuary, the researcher is expected to comply with the Actuaries Code, which expects data users to respect the privacy of organisations. This is again linked to 2 and 3 above, and emphasises the need to avoid calling out individual firms' efficiency scores. The only information related to each firm that will be disclosed, is the registered office locations used as part of this study. However, as well as being a matter of public record that has not been computed as part of this study, an office location does not in itself say anything about a firm's efficiency performance or indeed performance on any measure. On the other hand, disclosure is important for the purpose of this study, because this is data that was manually collected as part of this study, and not obtained from a database that has been previously used in the literature such as *SynThesys*. It is therefore necessary to present the results of this data collection, so it can be open to challenge where applicable.

5. Participants and the researcher(s) should **not come to any harm** during the research

BERA guidelines (2011) and the BPS Ethics Code (2009) cover this point of harm in detail when relating to participants of primary data collection. Although there are arguably fewer considerations at an individual level when secondary data is used, some fundamental key points are still relevant. For example, The Actuaries Code expects the researcher to speak up to the relevant authorities if there is reasonable cause to believe there has been unlawful, unethical or improper behaviour. In this research context, this would apply to anyone associated with this research, including secondary contacts or the researcher's employer. As discussed in earlier points of this section, the findings will be presented in a way that does not harm the reputations or organisations of either the data owners, or the businesses contained in the data. Iphofen (2011) also suggests that disseminating research findings can itself lead to ethical issues. For example, industry participants might question why the research only looks at the empirical aspect of cost efficiency, without getting the views of industry practitioners on the empirical results. To mitigate these issues at dissemination, the scope of the research, and the underpinning theories have been carefully defined.

The personal safety of the researcher as a result of conducting this research has also been considered, and the conclusion is the risk is very low, due – for example - to the industry-wide nature of the research, whose findings are not focussed on specific individuals, or specific organisations.

3.11.2 Other Ethics Considerations

Additional considerations relevant to this study, which may be considered to be in addition to, or implicit in the issues discussed in 3.11.1 include:

Disclosure of sponsors and biases

BERA guidelines (2011) discuss the role of sponsors of research, and how important it is to have written agreements in this case. Any conflict of interest that arises should be disclosed. In the case of this study, the researcher's employer partly funded tuition fees for the duration of this study. That said, this employer is only one of several in the data set, and their key driver for contributing to the tuition was the researcher's career development, in line with the firm's policy to support business-related further education. There has therefore been no influence by the employer in any part of this study.

Data handling and access through technology

ESRC Framework for research ethics (2015) discusses how researchers need to consider the ethical issues which arise, for example, in the interpretation of anonymity, and whether participants would consider data in the public domain to be private. The meaning of informed consent in this context and the important issue of what permissions a researcher has over the data supplied by the data producer therefore needs to be considered. All firm-specific data has been collected from regulatory returns, which firms have themselves made regularly available on their websites[53]. It is therefore reasonable to assume that the issue of anonymity or consideration of this data as private does not arise.

With regards to data handling, BERA guidelines (2011) talk about how researchers must comply with the legal requirements in relation to the storage and use of personal data as set down by the Data Protection Act (1998) and any subsequent similar acts. No personal data has been collected as part of this study, so issues around Data Protection are unlikely to be relevant. That said, all research data has been securely stored on a password-protected

[53] Example Regulatory return on a firm's website: https://www.wesleyan.co.uk/pdf/wesleyan_assurance_society_fsa_returns_2009.pdf

computer, to help ensure that compliance with the Data Protection Act is done in spirit, even though there does not appear to be a legal requirement to do so.

With the methodology and data now defined, Chapter 4 provides results of the data analysis and the calculations done using the methodology and data described in this chapter.

Chapter 4: Results

4 Results

4.1 Secondary Data Analysis

4.1.1 Office Location Data

The results section begins with presenting the Office Location and Earnings data collected for this study. Table 4-1 provides details of the Registered Office location data. As discussed in section 3.10, this office location data was collected manually, by looking at individual company information on the websites of Companies House, the Mutuals Public Register and the Financial Services Register, and recording the most recent office address, as well as previous addresses, where evidence of such addresses exist.

Although the data is comprehensive and considered robust enough to use for the purpose of this study, it does have a few limitations. Firstly, the Mutuals Public Register and the Financial Services Register to do not appear to offer the same depth of historical registered office address data that can be found on the Companies House website. In this instance, it was assumed that the firm was based at the same registered office throughout the sample period. Some firms on these registers might therefore have inaccurate historical office location data. That said, this is considered to be a minor limitation, because only 35 of the 171 legal entities in the raw data sample had data sourced from either the Mutuals Public Register or the Financial Services Register, and the assumption would be correct for some of these 35 firms. Secondly, the registered office location might not necessarily be where the majority of a firm's operations take place. For example, the registered office of Legal and General Assurance was in Central London throughout the data sample, but the bulk of their operations appear to have been based in Kingswood (Surrey, UK) in this period[54]. This could

[54] Source: https://www.legalandgeneralgroup.com/media-centre/press-releases/archive?id=50345

therefore lead to some firms getting incorrect efficiency scores assigned to them, and could also affect the overall level of efficiency in the industry. While this limitation is acknowledged, the chosen approach is still considered to be better than the alternative that has been used in some previous UK studies, which implicitly assume that all firms are based in one geographical location, due to assigning the same labour cost to all firms. Table 4-2 will demonstrate that earnings can vary significantly by office location, and this supports the argument to allow earnings to vary by office location. In addition, the most recently published U.K. study in this area by Hardwick et al. (2011) allows for the geographical differentiation, so this study would be in line with that.

This office location data is then used to map it to the appropriate earnings data to use as the cost of labour in the efficiency measurement calculation. This is discussed in 4.1.2 below.

Table 4-1: Registered Office Location Data

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Abbey Life	Companies House	00710383	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
AberdeenAM L&P	Companies House	03526143	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
AberdeenAM P Pens	Companies House	04276956	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
ACE Europe Life	Companies House	05936400	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
AIG Life	Companies House	06367921	Eastleigh	Eastleigh	Eastleigh	Eastleigh	Eastleigh	Central London	Central London	Central London	Central London
American Life Ukbr	Companies House	AC000744	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Assurant Life	Companies House	03264844	Windsor	Windsor	Windsor	Windsor	Windsor	Windsor	Slough	Slough	Slough
Aviva Annuity	Companies House	03253948	York	York	York	York	York	York	York	York	York
Aviva International	Companies House	00021487	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Aviva Inv Pens	Companies House	01059606	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Aviva Life&Pens	Companies House	03253947	York	York	York	York	York	York	York	York	York
Aviva Peak No 1 UK	Companies House	SC119820	Perth	Perth	Perth	Perth	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Aviva Peak No 2 UK	Companies House	02668470	York	York	York	York	Bristol	Bristol	Bristol	Bristol	Bristol
AXA Wealth	Companies House	01225468	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Basingstoke
B&CE Ins	Companies House	03093365	Crawley	Crawley	Crawley	Crawley	Crawley	Crawley	Crawley	Crawley	Crawley
Baillie Gifford	Companies House	SC182496	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
BL Telford	Companies House	00151731	Telford	Telford	Telford	Telford	Central London	Central London	Central London	Central London	Central London
BlackRock Life	Companies House	02223202	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
BlackRock Pens	Companies House	02348841	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Canada Life	Companies House	00973271	Potters Bar	Potters Bar	Potters Bar	Potters Bar	Potters Bar	Potters Bar	Potters Bar	Potters Bar	Potters Bar
CGNU Life Ass	Companies House	00226742	York	York	York	York	York	York	York	York	York
Cler Med Mgd Fd	Companies House	01580284	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Insurance	**Data Source**	**Company**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**

Company		number									
ComInsofAmerica Ukbr	Companies House	BR000634	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames	Kingston Upon Thames
Compass	Companies House	04492261	Swansea	Swansea	Swansea	Swansea	Swansea	Swansea	Swansea	Swansea	Swansea
Covea Life	Companies House	00911235	West Malling	West Malling	Richmond Upon Thames	Richmond Upon Thames	Richmond Upon Thames	Richmond Upon Thames	Richmond Upon Thames	Richmond Upon Thames	Richmond Upon Thames
CU Life Ass	Companies House	SC053601	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Eagle Star Ins	Companies House	00082051	Fareham	Fareham	Fareham	Fareham	Fareham	Fareham	Fareham	Fareham	Fareham
Ecclesiastical Life	Companies House	00243111	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester
Equitable Life	Companies House	00037038	Aylesbury	Aylesbury	Aylesbury	Aylesbury	Aylesbury	Aylesbury	Aylesbury	Aylesbury	Aylesbury
F&C Mgd Pen	Companies House	01020044	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
FIL Life Ins	Companies House	03406905	Hildenborough	Hildenborough	Hildenborough	Hildenborough	Hildenborough	Hildenborough	Hildenborough	Hildenborough	Hildenborough
Financial Ass	Companies House	04873014	Chiswick	Chiswick	Chiswick	Chiswick	Chiswick	Chiswick	Chiswick	Chiswick	Chiswick
Forester Life	Companies House	02997655	Bromley	Bromley	Bromley	Bromley	Bromley	Bromley	Bromley	Bromley	Bromley
Friends L&P	Companies House	00475201	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking
Friends Life Ass Soc	Companies House	00776273	Dorking	Dorking	Dorking	Dorking	Dorking	Central London	Central London	Central London	Central London
Friends Life BHA	Companies House	02774803	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Friends Life Co	Companies House	03291349	Dorking	Dorking	Dorking	Dorking	Dorking	Central London	Central London	Central London	Central London
Friends Life Ltd	Companies House	04096141	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking
Friends Life WL	Companies House	03116645	Dorking	Dorking	Dorking	Dorking	Central London	Central London	Central London	Central London	Basingstoke
FriendsP Life Ass	Companies House	00782698	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking
FriendsP RE	Companies House	05165822	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Halifax Life	Companies House	02233654	Halifax	Halifax	Halifax	Halifax	Halifax	Halifax	Halifax	Halifax	Halifax
Hamilton Life	Companies House	01656838	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Windsor
Hannover Life RE	Companies House	01752067	Virginia Water	Virginia Water	Virginia Water	Virginia Water	Virginia Water	Virginia Water	Virginia Water	Virginia Water	Virginia Water
Health Shield	Companies House	04145366	Crewe	Crewe	Crewe	Crewe	Crewe	Crewe	Crewe	Crewe	Crewe
Hermes Assured	Companies House	03248669	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Hodge Life Ass	Companies House	00837457	Cardiff	Cardiff	Cardiff	Cardiff	Cardiff	Cardiff	Cardiff	Cardiff	Cardiff
HSBC Life	Companies House	00088695	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Invesco PerpetualLife	Companies House	03507379	Henley-On-Thames	Henley-On-Thames	Central London	Central London	Central London	Central London	Central London	Central London	Central London
JPMorgan Life	Companies House	03261506	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Just Retirement	Companies House	05017193	Reigate	Reigate	Reigate	Reigate	Reigate	Reigate	Reigate	Reigate	Reigate
Leg&Gen Ass	Companies House	00166055	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Leg&Gen PensMgt	Companies House	01006112	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Liverpool Vic Life	Companies House	00597740	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth
London Gen Ins	Companies House	01865673	Egham	Egham	Egham	Egham	Egham	Egham	Egham	Egham	Harrow
London Gen Life	Companies House	02443666	Egham	Egham	Egham	Egham	Egham	Egham	Egham	Egham	Harrow
London Life	Companies House	01179800	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Peterborough	Peterborough	Peterborough
Lucida	Companies House	05936566	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Managed Pen Fds	Companies House	04486031	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
MetLife Ltd	Companies House	SC053601	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
MGM Adv Life	Companies House	08395855	Worthing	Worthing	Central London	Central London	Central London	Central London	Central London	Central London	Central London
MGM Ass	Companies House	01279948	Central London	Worthing	Worthing	Worthing	Worthing	Worthing	Worthing	Worthing	Worthing
Mobius Life	Companies House	03104978	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Monarch Ass	Companies House	00862397	Sale	Sale	Sale	Sale	Sale	Sale	Sale	Sale	Sale
Nat Farmers	Companies House	00111982	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon	Stratford-Upon-Avon
Nat Prov Life	Companies House	03641947	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Peterborough	Peterborough	Peterborough	Peterborough
NM Pens	Companies House	04240147	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford
Old Mutual Wealth L&P	Companies House	04163431	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton
Old Mutual Wealth Life	Companies House	01363932	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton
Omnilife Ins	Companies House	02294080	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Pacific Life RE	Companies House	00825110	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Partnership Life Ass	Companies House	05465261	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Pens Ins Corp	Companies House	05706720	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Phoenix Life Ass	Companies House	00001419	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Peterborough	Peterborough	Peterborough	Peterborough
Phoenix Life Ltd	Companies House	01016269	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham
Phoenix Pens Ltd	Companies House	03649535	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham
Phoenix&London Ass	Companies House	00894616	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham
Pinnacle Ins	Companies House	01007798	Borehamwood	Borehamwood	Borehamwood	Borehamwood	Borehamwood	Borehamwood	Borehamwood	Borehamwood	Borehamwood
Protection Life	Companies House	02199286	Preston	Preston	Bromley	Bromley	Croydon	Croydon	Croydon	Croydon	Croydon
Pru Annuities	Companies House	02554213	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Pru Pens	Companies House	00992726	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Pru Retire Income	Companies House	SC047842	Craigforth	Craigforth	Craigforth	Craigforth	Craigforth	Craigforth	Craigforth	Craigforth	Craigforth
QBE RE Europe	Companies House	01378853	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
ReAssure Ltd	Companies House	00754167	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford
RGA RE UK	Companies House	11118621	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Rothesay Ass	Companies House	06054422	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Rothesay Life	Companies House	06127279	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Royal London CIS	Companies House	08629353	Central London	Central London	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester
Royal LondonMut	Companies House	00099064	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Royal LondonPPens	Companies House	SC048729	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Sanlam L&P	Companies House	00980142	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol
Save&Pros Ins	Companies House	00322226	Preston	Preston	Preston	Preston	Preston	Central London	Central London	Central London	Central London
Save&Pros Pens	Companies House	00615364	Preston	Preston	Preston	Preston	Preston	Central London	Central London	Central London	Central London

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Schroder PensMgmt	Companies House	05606609	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
SCOR GLfe RE UK	Companies House	01334736	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Scot Equitable	Companies House	SC144517	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Scot Mutual	Companies House	SC133846	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow
Scot Prov	Companies House	04013361	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham
Scot Wid Unit Fds	Companies House	SC074809	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Scot Widows Anns	Companies House	SC199550	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Scot Widows Ltd	Companies House	03196171	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
St Andrews Life	Companies House	03104670	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Esher	Esher
Stand LifeInvFd	Companies House	SC068442	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Stand LifePensFd	Companies House	SC046447	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Standard Life 2006	Companies House	SZ000004	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Standard LifeAss Ltd	Companies House	SC286833	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Suffolk Life Anns	Companies House	01011674	Ipswich	Ipswich	Ipswich	Ipswich	Ipswich	Ipswich	Ipswich	Ipswich	Ipswich
SunLifeCanada UK	Companies House	00959082	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke
SW Funding plc	Companies House	SC199549	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Swiss RE Life&H	Companies House	03360983	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Threadneedle Pens	Companies House	00984167	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
TransatlanticLife	Companies House	00874429	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
UBS Asset Mgmt	Companies House	03280762	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
UNUM Ltd	Companies House	00983768	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking	Dorking
Wesleyan Ass	Companies House	ZC000145	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
XL RE	Companies House	BR003097	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Zurich Ass Ltd	Companies House	02456671	Cheltenham	Cheltenham	Swindon	Swindon	Swindon	Swindon	Swindon	Swindon	Swindon
Guard Lkd Life	Companies House	01397655	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes
Guard Pens Mgt	Companies House	00985480	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes
Guardian Ass	Companies House	00038921	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes	Lytham St. Annes
IntegraLife UK	Companies House	00798365	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
LifeInsIndia Ukb	Companies House	BR001875	Wembley	Wembley	Wembley	Wembley	Wembley	Wembley	Wembley	Wembley	Wembley
NM Life	Companies House	00777895	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford	Telford
NPI Ltd	Companies House	03725037	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham
Pens Mgt (SWF)	Companies House	SC045361	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Pru (AN)	Companies House	01347088	Birmingham	Birmingham	Birmingham	Birmingham	Central London	Central London	Central London	Central London	Central London
Pru Hb'n Life	Companies House	00793051	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
SLFC Ass UK	Companies House	00830572	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Basingstoke	Gloucester	Gloucester	Gloucester	Gloucester
Ancient Ord Forest	Mutuals Public Register	511F	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton	Southampton
British FS	Mutuals Public Register	392F	Bedford	Bedford	Bedford	Bedford	Bedford	Bedford	Bedford	Bedford	Bedford
Cirencester	Mutuals Public Register	149F	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester
Dentists Provident	Mutuals Public Register	407F	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Druids Sheffield	Mutuals Public Register	795F	Rotherham	Rotherham	Rotherham	Rotherham	Rotherham	Rotherham	Rotherham	Rotherham	Rotherham
Exeter FS	Mutuals Public Register	91F	Exeter	Exeter	Exeter	Exeter	Exeter	Exeter	Exeter	Exeter	Exeter
Family Ass	Mutuals Public Register	939F	Brighton	Brighton	Brighton	Brighton	Brighton	Brighton	Brighton	Brighton	Brighton
Kingston Unity	Mutuals Public Register	775F	Wakefield	Wakefield	Wakefield	Wakefield	Wakefield	Wakefield	Wakefield	Wakefield	Wakefield
Liverpool Vic FS	Mutuals Public Register	61COL	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth
National Deposit	Mutuals Public Register	369F	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol	Bristol

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Nott Oddfellows	Mutuals Public Register	30640R	Leicester	Leicester	Leicester	Leicester	Leicester	Leicester	Leicester	Leicester	Leicester
Original Holloway	Mutuals Public Register	145F	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester	Gloucester
Police Mutual	Mutuals Public Register	727F	Lichfield	Lichfield	Lichfield	Lichfield	Lichfield	Lichfield	Lichfield	Lichfield	Lichfield
Rechabite	Mutuals Public Register	218F	Bury	Bury	Bury	Bury	Bury	Bury	Bury	Bury	Bury
Red Rose	Mutuals Public Register	43COL	Blackburn	Blackburn	Blackburn	Blackburn	Blackburn	Blackburn	Blackburn	Blackburn	Blackburn
Royal Liver	Mutuals Public Register	35COL	Liverpool	Liverpool	Liverpool	Liverpool	Liverpool	Liverpool	Liverpool	Liverpool	Liverpool
Scot Friendly	Mutuals Public Register	3COLS	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow	Glasgow
Sheffield Mut	Mutuals Public Register	810F	Barnsley	Barnsley	Barnsley	Barnsley	Barnsley	Barnsley	Barnsley	Barnsley	Barnsley
Teachers Prov	Mutuals Public Register	372F	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth	Bournemouth
CommWorkers	Mutuals Public Register	471F	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon
Countrywide Ass	Companies House	02261746	Preston	Preston	Preston	Preston	Preston	Preston	Preston	Preston	Preston
Dentists&Gen Mut	Mutuals Public Register	456F	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)	Stonebridge (Warwickshire)
Domestic&Gen Life	The Financial Services Register	191236	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon	Wimbledon
General RE Life UK	The Financial Services Register	202925	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Homeowners	Mutuals Public Register	964F	Harrogate	Harrogate	Harrogate	Harrogate	Harrogate	Harrogate	Harrogate	Harrogate	Harrogate
IndeOrder Man U	Mutuals Public Register	223F	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester	Manchester
M&S Life Ass	Companies House	02868383	Central London	Central London	Central London	Central London	Chester	Chester	Chester	Chester	Chester
Metro Police	Mutuals Public Register	496F	Orpington	Orpington	Orpington	Orpington	Orpington	Orpington	Orpington	Orpington	Orpington
Nationwide Life	The Financial Services Register	177850	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Paternoster	Companies House	05656083	Manchester	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Pharm&Gen Prov	Mutuals Public Register	462F	St Albans	St Albans	St Albans	St Albans	St Albans	St Albans	St Albans	St Albans	St Albans

Insurance Company	Data Source	Company number	2015	2014	2013	2012	2011	2010	2009	2008	2007
Phoenix Life AssX	Companies House	SC134205	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh	Edinburgh
Pioneer	Mutuals Public Register	747F	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge
Prudential	Companies House	00015454	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
RelMutInsSoc	Companies House	00491580	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells
Royal Art Widows	Companies House	00606367	Salisbury	Salisbury	Salisbury	Salisbury	Salisbury	Salisbury	Salisbury	Salisbury	Salisbury
Shepherds	Mutuals Public Register	240F	Cheadle	Cheadle	Cheadle	Cheadle	Cheadle	Cheadle	Cheadle	Cheadle	Cheadle
St James Place	Companies House	02628062	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester	Cirencester
Transport	Mutuals Public Register	434F	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London	Central London
Tunbridge Wells	Mutuals Public Register	190F	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells	Tunbridge Wells
Wiltshire	Mutuals Public Register	746F	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge	Trowbridge
Kensington	Mutuals Public Register	79COL	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough	Middlesbrough
RailwayEnginemen	Mutuals Public Register	708F	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham	Birmingham

4.1.2 Earnings Data

Table 4-2 includes the earnings data collected from the Office of National Statistics (ONS), which has been mapped to the office location data in Table 4-1. While this data comes from a credible source that has been used in previous U.K studies in this area, some limitations are acknowledged. As discussed in Section 3.10, Hardwick et al. (2011) appear to have used a sub-section of ONS wage data (called *Regional Trends*) that was specific to the financial sector, but also allowed for regional variation. This would have arguably been an ideal source for wage data in this study. However, that particular section of ONS data appears to have been discontinued in 2011[55], and is therefore not available for a significant period of the sample period. The data used is therefore considered to be the most appropriate data available. In addition, earnings data is by local authority, and not strictly by postal town. Some office location earnings might therefore reflect a wider geographical area than just the postal town in question. For example, Borehamwood and Potters Bar both come under the Hertsmere local authority. That said, the data provides valuable information about the variety of earnings data by geographical location, and it is clear to see from Table 4-2 that Central London earnings are much higher than in other areas, suggesting that it is worth investigating if the Central London office location is contributing to inefficiency. Having discussed the supplementary data used in this study, Section 4.2 incorporates this data into the main data set, and begins to draw out some findings from this study.

[55] https://data.gov.uk/dataset/4d550211-015f-4e15-8339-da4bd0245ed3/regional-trends

Table 4-2: Earnings Data by Local Authority (Average Weekly Earnings, in GBP)

Original Location Name	Location Name in ONS Data	2015	2014	2013	2012	2011	2010	2009	2008	2007
Aylesbury	Aylesbury Vale	502.6	475.4	491.9	505.5	489.2	489.8	471.3	437.6	447.5
Barnsley	Barnsley	461.2	451.8	435.4	426.2	423.3	423.1	421.1	409.2	397
Basingstoke	Basingstoke and Deane	579.5	579.9	584.9	582.2	557.5	564	558.1	589.7	531.9
Bedford	Bedford UA	493.4	476.3	483.2	444.9	445.8	457.8	456.5	416	415.2
Birmingham	Birmingham	510.4	478.8	517.7	500.9	486.2	481	477.1	465.2	443.1
Blackburn	Blackburn with Darwen UA	473.7	458.4	477.6	446.4	432.7	443.5	413.2	400.6	377.7
Borehamwood	Hertsmere	554.4	527.4	492.9	540.3	522.4	602.1	546.7	533.8	465.8
Bournemouth	Bournemouth UA	469	447.1	437.7	429	426.3	434.3	484.4	516.3	486.4
Brighton	Brighton and Hove UA	472.8	450.3	439.6	449.1	420.3	436.9	437.8	428.5	399.7
Bristol	Bristol, City of UA	515.6	518.2	520.1	502.4	490.5	501.9	485	481.7	467.6
Bromley	Bromley	531.9	481.7	481.2	499.6	480	470.4	470	472.6	461.4
Bury	Bury	467.1	457.6	434.2	419.4	419.9	411.5	408.6	427.8	403.9
Cardiff	Cardiff / Caerdydd	493.8	482.6	494.7	477.5	461.4	458.6	463.9	464.9	430
Central London	City of London	1106.2	1153.4	1146.5	1131.2	1188.8	1172.4	1138.7	1132	1018.3
Cheadle	Stockport	425.9	451.8	447.6	446.5	444.1	453.3	447	439.5	431.7
Cheltenham	Cheltenham	454.7	483.5	496	468.6	455.1	468.7	506.5	476.5	430.2
Chester	Cheshire West and Chester UA	450.4	444.5	448.6	426.9	425.2	416.9	429.7	420.8	437.4
Chiswick	Hounslow	708.5	622.3	596.6	629.1	671.4	657.8	641.6	582.8	582
Cirencester	Cotswold	425.5	396.4	412	374.2	345.4	370.2	378	401	355.4
Craigforth	Stirling	460.2	444.6	488	530.4	502	494.4	458.7	431.3	412.6
Crawley	Crawley	637.2	614.2	634.7	555.2	561.9	563.3	556.8	550.8	519.6
Crewe	Cheshire East UA	474	477	488.6	461.8	463.8	452.2	437.8	461.9	455.2
Croydon	Croydon	500.8	513.5	531.6	535.6	515.7	526	516.7	497.7	468.7
Dorking	Mole Valley	657.5	666.1	685.8	705.5	687.2	686.4	703.3	616.9	569.7
Eastleigh	Eastleigh	507.6	502.1	444.6	435.1	442.2	474.1	416.7	386	383.6
Edinburgh	Edinburgh, City of	566.2	556.6	565	547	543	526.9	525.2	509.8	509.3

Original Location Name	Location Name in ONS Data	2015	2014	2013	2012	2011	2010	2009	2008	2007
Egham	Runnymede	704.7	702.8	709.5	694.7	663.4	662.7	645.8	624.2	643.2
Esher	Elmbridge	577	568.6	582.4	567.6	574.6	553.2	541.1	576.2	591.9
Exeter	Exeter	493.5	466.6	463.7	455.6	454.1	467.1	454	419	410.3
Fareham	Fareham	518.3	538.9	486.7	486.2	449	450.4	448	459.5	406.6
Glasgow	Glasgow City	513.8	516	516.8	487.5	476.5	474	474	448.5	422.2
Gloucester	Gloucester	515	486.8	491.8	478.2	482.7	470.4	454.5	465.7	455.1
Halifax	Calderdale	436.7	460.3	438	451.7	429.6	448.1	461.7	443.5	390.9
Harrogate	Harrogate	425.4	399.3	404	393	390.3	405.3	412.8	420.6	391.9
Harrow	Harrow	463.3	421.6	434	472.5	479.3	464.6	494.4	489.3	461.6
Henley-On-Thames	South Oxfordshire	509.8	469	456.5	473.5	437.2	419.4	408.5	390.1	397.4
Hildenborough	Tonbridge and Malling	501.5	492.7	480.3	490.8	467.6	470.5	465.8	476.1	426.1
Ipswich	Ipswich	454.9	448.4	446.1	452.5	415.5	433.6	418.9	432.1	411.9
Kingston Upon Thames	Kingston upon Thames	479.7	507.6	508.9	521.2	521.7	528.5	528.8	487.2	507.5
Leicester	Leicester UA	458.9	448.5	457.1	445.3	434.7	438.1	432	414.9	392.9
Lichfield	Lichfield	450.9	447.6	450.2	425.9	433.4	450.5	437.7	425.9	383
Liverpool	Liverpool	487.2	485.3	481.9	469.8	467.9	479.5	473.4	452.7	430.6
Lytham St. Annes	Fylde	582.1	585.1	476.6	486.3	530.8	550.4	572.7	573.1	510.3
Manchester	Manchester	539.6	528.3	531.6	515	502.1	500.4	510.6	489.4	502.8
Orpington	Bromley	531.9	481.7	481.2	499.6	480	470.4	470	472.6	461.4
Perth	Perth and Kinross	460	432.6	415.2	403.9	396.6	405.7	402.8	420.5	394.7
Peterborough	Peterborough UA	483.1	479.7	486.1	455.9	461.1	448.4	460.9	420.3	440
Potters Bar	Hertsmere	554.4	527.4	492.9	540.3	522.4	602.1	546.7	533.8	465.8
Preston	Preston	466.1	430.1	434.9	441.2	417.8	464.8	444	430.8	396.1
Reigate	Reigate and Banstead	630.6	578.7	580.6	666.5	586.7	574.8	549.8	544.1	606.8
Richmond Upon Thames	Richmond upon Thames	565.7	545.9	550	568.4	540.3	565.5	568.3	571.6	523.8
Rotherham	Rotherham	441.8	444.3	426.3	424.7	409.3	423.5	409.5	398	389.6
Sale	Trafford	488.1	469.9	468.7	479.6	467.8	549.4	478.7	488.7	481.1
Salisbury	Wiltshire UA	456.2	425.8	431.3	429.2	426.3	430.3	426.8	429.5	414.4

Original Location Name	Location Name in ONS Data	2015	2014	2013	2012	2011	2010	2009	2008	2007
Slough	Slough UA	633.2	601.8	648.6	634.5	652.5	596.2	624	617.8	593.9
Southampton	Southampton UA	487.9	497.1	486	478.7	464.7	467	467.6	458.2	484.9
St Albans	St Albans	444.8	449.1	486.1	461.8	485.1	466	465.5	502.3	406.5
Stonebridge (Warwickshire)	Coventry	505.4	516.1	520.3	499	489.8	499.9	473.9	468.4	461.6
Stratford-Upon-Avon	Stratford-on-Avon	518.7	508.6	517.7	497.4	457.8	469.3	472.2	500.5	475.6
Swansea	Swansea / Abertawe	431.4	426.1	412.8	408.4	404.2	399.3	398.8	380.8	373.6
Swindon	Swindon UA	536.3	504.6	516.2	495.6	501.6	498.1	490.6	502	497.1
Telford	Telford and Wrekin UA	477.2	453.1	463.5	442.7	422.6	415.9	414	434.1	432
Trowbridge	Wiltshire UA	456.2	425.8	431.3	429.2	426.3	430.3	426.8	429.5	414.4
Tunbridge Wells	Tunbridge Wells	491.8	488.4	515	501.2	490.9	508.6	473.9	474.5	487.4
Virginia Water	Runnymede	704.7	702.8	709.5	694.7	663.4	662.7	645.8	624.2	643.2
Wakefield	Wakefield	460.1	447.8	466.4	435.7	438.2	430.3	405.3	414.2	424.8
Wembley	Brent	556.9	528	525.7	485.8	477.9	473.9	496.9	480.8	463.1
West Malling	Tonbridge and Malling	501.5	492.7	480.3	490.8	467.6	470.5	465.8	476.1	426.1
Wimbledon	Merton	495.4	498.2	489.1	509	515.8	508.6	443.3	433.5	474.9
Windsor	Windsor and Maidenhead UA	675.2	632.6	671.9	700.1	685.2	667.7	608.1	682.7	560.8
Worthing	Worthing	464	449.5	468.2	438.6	421.7	420.1	423.3	405	387.4
York	York UA	458.9	447.1	458.1	454	435.4	439.9	445.7	432.9	428.2
Middlesbrough	Middlesbrough UA	456.8	412.1	421.8	433.2	412.3	415.2	413.3	406.7	369.1

4.2 Efficiency Measurement and Regression Data

4.2.1 Efficiency Measurement Data

Table 4-3 below summarises the efficiency measurement data used in this study. There are some limitations and assumptions made in collecting this data, which are discussed further below. Firstly, firms have only been included in the data set if they have non-zero entries in the relevant regulatory returns data. This reduces the overall total number of legal entities in the study from a maximum of 171, to a maximum of 147. Secondly, the data includes all legal entities transacting UK Life business. This is inconsistent with what appears to be the most recently published UK study in this area by Hardwick et al. (2011), which has a number of exclusions as follows:

1. trust and pensions funds that offer life insurance products
2. specialized (often small local community or public sector) life and pensions providers (e.g., Police Mutual) for which complete data were either not available and/or the level of premium income written was insignificant
3. reinsurance companies that do not write direct insurance
4. subsidiaries of foreign insurers whose headquarters are not in the UK, which are said to be excluded to avoid the potentially confounding effects of transnational structures and operations on the derived measures of efficiency.

This study used all the available firm data because, while it acknowledges potential reasons for exclusions, there are also counter-arguments to those used by Hardwick et al. (2011), which would support using all the data. For example, subsidiaries of UK insurers, with headquarters in the UK, could also potentially make use of transnational structures and operations (e.g. the Aviva subsidiaries in the UK could make use of shared services with fellow subsidiaries within the global Aviva group[56]). In addition, even small standalone firms might make use of outsourcing facilities abroad in an effort to improve cost efficiency[57]. There could therefore be an argument on this basis to remove even more firms from the data, which is arguably counter-productive when the aim is to investigate the efficiency of as many firms as possible that are operating in this industry. A general limitation of insurance efficiency research is this emergence of UK companies making use of offshore outsourcing arrangements, thus making it difficult to measure their true inputs. All data will therefore be used, with an acknowledgement of this limitation. In addition, specialised life providers are increasingly becoming important players in the industry (e.g. Pension Insurance Corporation, which is a specialist Bulk Annuity provider[58]), and are competing for the same business as traditional firms (e.g. Aviva is also a Bulk Annuity provider[59], so competes directly with Pension Insurance Corporation in that market), so it seems reasonable to compare their performance. The same argument could also be applied to trust and pensions funds that offer life insurance products, because they could use any potential efficiency advantage to offer more competitive prices for similar products to those on offer from traditional firms. Finally, reinsurers are subject to many of the cost pressures of direct insurers (e.g. they are likely to need similar systems to value a set of reinsured policyholder liabilities). For this particular study, which is focussing on potential Financial and Risk Management drivers, direct insurers and reinsurers would use the tools in a similar way (e.g. reinsurers can also reinsure to other reinsurers). There is an argument to exclude reinsurers if the inputs and outputs used in the efficiency measurement are gross of

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[56] An illustration of Aviva's global reach can be found here: https://www.aviva.com/.../aviva.../Aviva-plc-CMD-2017-break-out-presentations.pdf
[57] Source: https://www.insurancejournal.com/magazines/mag-features/2006/11/19/152997.htm
[58] Source: https://www.pensioncorporation.com/
[59] An example bulk annuity transaction by Aviva can be found here: https://www.aviva.com/newsroom/news-releases/2018/05/Aviva-wins-bulk-annuity-deal-with-ms-pension-scheme/

reinsurance, because that could potentially lead to double-counting (i.e. a block of business could appear in the data of both the direct insurer and reinsurer). However, this study is using inputs and outputs that are net of reinsurance to avoid the double-counting issue.

The inclusion of all data that was excluded by Hardwick et al. (2011) has also been performed by other recent published work (e.g. the study by Biener et al. (2016) on efficiency in the Swiss insurance industry, which appears to be the published work that is closest to this study). This study therefore utilises all available data.

A number of interesting observations can be drawn from Table 4-3. Firstly, there is a reduction in the number of firms over time, despite the outputs appearing to increase over the same period. This appears to be consistent with the industry activity discussed in section 1.1.8, which suggests that there is an industry focus on trying to obtain efficiencies via consolidation activity. Secondly, the standard deviation on Total Cost Components and Outputs are relatively large (at least double the mean in all cases). This suggests a wide variety of sizes of firms in the data set, and therefore potential for even more consolidation activity in the future. Thirdly, the data also suggests that the cost of capital is significantly higher than operating expenses in monetary terms. This is surprising at first glance, because in practice, the focus tends to be geared more towards the management of operating expenses. That said, the definition of Capital in this case is broad, as in addition to traditional debt capital such as loans, both shareholders and policyholders are also considered to be equity and debt capital owners respectively, in line with recent literature as discussed in section 3.6. The cost of capital could therefore potentially be large in monetary terms, because even a small return on assets used to back policyholder reserves can be significant in comparison to operating expenses.

Table 4-3: Efficiency Measurement Data Summary

			Total Cost Components		Input Prices		Outputs	
Year	DMU Count		Operating Expenses (£m)	Cost of Capital (£m)	Labour (£ per week)	Capital (% p.a.)	Net Claims (£m)	Invested Assets (£m)
2007	147	*Mean:*	91	177	637	5	1,243	9,321
		Std Dev:	193	447	259	1	3,085	22,505
		Total:	13,373	26,006			182,733	1,370,186
2008	147	*Mean:*	91	173	699	4	1,266	8,027
		Std Dev:	190	455	311	1	3,694	19,092
		Total:	13,326	25,407			186,141	1,180,040
2009	139	*Mean:*	83	161	712	3	1,103	8,951
		Std Dev:	174	428	311	2	3,490	22,876
		Total:	11,564	22,335			153,317	1,244,165
2010	137	*Mean:*	87	158	715	3	1,149	9,959
		Std Dev:	182	417	321	2	3,675	24,817
		Total:	11,900	21,640			157,412	1,364,371
2011	121	*Mean:*	93	181	703	3	1,290	11,234
		Std Dev:	193	475	324	2	4,074	27,603
		Total:	11,210	21,885			156,049	1,359,254
2012	114	*Mean:*	104	178	686	3	1,493	12,454
		Std Dev:	224	473	293	2	4,682	30,251
		Total:	11,852	20,331			170,166	1,419,741
2013	111	*Mean:*	114	169	702	3	1,587	13,150
		Std Dev:	295	475	302	2	5,040	32,154
		Total:	12,666	18,735			176,170	1,459,640
2014	106	*Mean:*	101	173	688	2	1,492	14,356
		Std Dev:	209	460	305	2	5,286	34,382
		Total:	10,696	18,355			158,123	1,521,768
2015	95	*Mean:*	103	206	683	3	1,763	16,724
		Std Dev:	215	514	274	2	5,157	37,655
		Total:	9,773	19,528			167,479	1,588,790
Total	**1,117**							

Fourthly, the mean cost of labour throughout the period suggests that the 'average' insurance firm is based around the Greater London area (e.g. Slough, Dorking, and Virginia Water). If a Central London office location does turn out be a significant contributor to inefficiency, then the affected firms would potentially have a plausible alternative of improving efficiency by moving the few miles from Central London to Greater London. In addition, the large standard deviation (which is nearly half the mean in some years) suggests that there is a possibility of improving efficiency by relocating the registered office to cheaper locations from a Labour cost perspective. Fifthly, the cost of capital percentage gradually reduced over the sample period. This is consistent with the fall in interest rates over the period, given the link between interest rates and the cost of capital discussed in Section 1.1.7. It is also interesting to note that – over time – while the average cost of capital percentage went down, its standard deviation went up. This suggests that while most firms have reduced this input, there might still be some scope for other firms to improve their cost efficiency by doing the same.

Pearson correlations were used to perform some initial analysis on the data summarised by Table 4-3, and the results can be found in Table 4-4 below.

Table 4-4: Pearson Correlations of Insurance Inputs and Outputs

	Insurance Inputs		Insurance Outputs	
	Labour	**Capital**	**Claims**	**Invested Assets**
Labour	100%	(20%)	21%	16%
Capital		100%	(11%)	(6%)
Claims			100%	90%
Invested Assets				100%

These correlations resulted in the following observations:

- The 'Risk-Pooling' (claims) and 'Financial Intermediation' (invested assets) arms of the industry appear to go hand-in-hand (+90% correlation),

- Cost of Capital appears to be reducing over time, with the Cost of Labour going the other way, although the correlation between the two costs is weak (-20% correlation).

- There are weak positive correlations between the Cost of Labour and the level of claims, as well as the Cost of Labour and the level of invested assets. This suggests that – although the relationship is positive - increasing labour does not necessarily lead to an increase in output.

- On the other hand, there are weak negative correlations between the Cost of Capital and the level of claims, as well as the Cost of Capital and the level of invested assets. This is not surprising, since the cost of capital is reducing over time, which could potentially allow firms to raise more capital to originate new business.

The second bullet point suggests that improvement of cost efficiencies are likely to be driven by solutions that reduce labour costs. The next step in the analysis is to summarise the regression data used. This is discussed in Section 4.2.2 below.

4.2.2 Efficiency Regression Data

Table 4-5 summarises the data used in Stage 2 of the study, in conjunction with the results from Stage 1. This was reasonably clean data, with one limitation arising from the reinsurance data. Reinsurance proportions appear to be distorted by non-standard items coming into the data. For example, Equitable Life has a large negative reinsurance ratio in 2015, because of a recapture of a block of business which had been previously reinsured. This came through as a negative reinsurance premium in the data[60]. Although the impact is difficult to work out in most cases, there are 93 data points that result in counterintuitive

[60] Source: http://www.equitable.co.uk/media/51360/pra-return-v1.pdf

reinsurance ratio (either less than 0, or greater than 1). Other measures of reinsurance which might avoid some of these issues appear to be more problematic from an efficiency measurement perspective. For example, a reinsurance ratio based on claims or reserves in a given year could be reflecting reinsurance arrangements entered into over multiple time periods in the past, and not just the year in question. A retrospective approach also means it is looking at how past (as opposed to current) business decisions are affecting current efficiency levels. The premium approach (and associated data limitations that come with it) is therefore still considered to be the most appropriate approach. In line with Shiu (2011), who conducted a study on Reinsurance and Capital Structure in the UK non-life insurance industry, the 93 data points discussed above are excluded from the regression analysis. In addition, five data points have also been removed from the regression analysis due to having negative premiums. This leaves a total of 1,019 data points for the regression stage of the analysis.

A number of observations were made from the data in Table 4-5. Firstly, the liquidity ratio has dropped from 30% in 2007 to 23% in 2015. This could be driven by the low interest rate environment since the Global Financial Crisis, which has probably led to firms attempting to improve competitive advantage by investing more in illiquid assets. Secondly, the use of Financial Derivatives appears to have increased in the 2008 – 2012 period (around 40%, from an average of 30%). This could be explained by firms attempting to manage market volatility during the Global Financial Crisis as well as the Sovereign Debt Crisis. Thirdly, although there was a small drop in solvency in 2008, the industry appears have had a healthy solvency position of more than 50% of free assets throughout. It however raises the question of whether capital is being utilised optimally in the industry, if such a high proportion of it sits as free assets on the Balance Sheet. Finally, there appears to be a relatively high concentration of registered offices in Central London (around 30%), where labour costs are also the highest.

Table 4-5: Regression Data Summary

Year	DMU Count	LN (Premiums)	Reinsurance Ratio	Derivative Use	Free Asset Ratio	Liquidity Ratio	Central London Office
2007	133	18.42	0.18	0.33	0.58	0.30	0.32
2008	129	18.47	0.18	0.40	0.52	0.29	0.33
2009	126	18.33	0.18	0.38	0.55	0.27	0.33
2010	131	18.36	0.19	0.40	0.55	0.25	0.33
2011	109	18.19	0.17	0.37	0.55	0.26	0.29
2012	104	18.48	0.16	0.38	0.56	0.24	0.29
2013	103	18.01	0.16	0.32	0.60	0.23	0.31
2014	97	18.09	0.16	0.34	0.59	0.22	0.29
2015	87	18.05	0.15	0.30	0.59	0.23	0.30
Total	**1,019**						

With the regression data defined, the next section discusses the validation checks done on this data, and the statistical tests used to justify the choice of the regression approach.

4.2.3 Efficiency Regression: Variable Validation

The validation of the regression variables involved performing a number of tests to check for Heteroskedasticity, multicollinearity and autocorrelation. These tests are set out in Abdoush (2017) and discussed in turn below.

1. Multicollinearity Test

The multicollinearity test aims to test the issue described by Hair et al. (2009) as the high correlation of two or more variables, which could affect the estimation of regression parameters. The test is conducted by calculating the Variance Inflation Factor (VIF), which is set out in Wooldridge (2002) as follows:

$$VIF = \frac{1}{1 - R_i^2}$$

Where R_i^2 is the unadjusted R^2 when one variable is regressed against all the other independent variables in the model. Gujarati (2003) suggests that there is a multicollinearity problem if the mean VIF is greater than 10. Table 4-6 below shows the VIF test for the regression variables in this study, and the results suggest that there is no issue with multicollinearity.

Table 4-6: Multicollinearity Test

Variable	**VIF** (if VIF < 10, there is no multicollinearity)
LN (Premiums)	1.62
Reinsurance Ratio	1.05
Derivative Use	1.35
Free Asset Ratio	1.12
Liquidity Ratio	1.41
Central London Location	1.09
Mean VIF	**1.27**

2. Heteroscedasticity Test

The next test involved testing for heteroscedasticity within the data, which Johnson (1972) suggested could invalidate statistical tests of significance that assume that the modelling errors are uncorrelated and uniform, and that their variances do not vary with the effects of being modelled. The Breush-Pagan/Cook-Weisberg test can be used to test for heteroscedasticity (Breush and Pagan (1979), and Cook and Weisberg (1983)). The results of applying to the test to this study are in Table 4-7 below, and they suggest that there is no evidence of heteroscedasticity.

Table 4-7: Heteroscedasticity Test

	Breush-Pagan/Cook-Weisberg test for Heteroscedasticity *(if <0.05, there is heteroscedasticity)*
Null Hypothesis: Constant Variance	Prob > chi2 = 0.9663

3. Autocorrelation Test

The final test in this section tests autocorrelation (also called serial correlation) between the variables. Drukker (2003) suggests that autocorrelation in panel data can cause bias in the standard errors, resulting in less efficient results. In addition, the non-separability of variables when conducting two-stage DEA efficiency analyses has been highlighted as a limitation by a number of authors. For example, Grant et al. (2017) suggest that the assumption that the support of the inputs and outputs used to produce the DEA estimates does not depend on the independent variables used in the regression stage of the analysis is unrealistic. A test for evidence of autocorrelation in the data was therefore conducted, in order to mitigate this limitation. Results of the Wooldridge test for autocorrelation are shown below, and they suggest that there is no autocorrelation in the data.

Table 4-8: Autocorrelation Test

	Wooldridge test for autocorrelation in panel data *(if <0.05, there is autocorrelation)*
Null Hypothesis: No first order autocorrelation	Prob > F = 0.8059

With the validation of the regression variables complete, the next step involves justifying the choice of the regression approach. This is discussed in section 4.2.4 below.

4.2.4 Efficiency Regression: Model Choice Validation

Below is a sequence of model specification tests that were performed when selecting an appropriate Regression model to use with the panel data from Stage 1 of this study, as specified by Abdoush (2017).

1. **Breusch-Pagan Lagrange Multiplier (LM) Test**

The LM test is used to check the model for random effects based on the simple OLS (pooled) estimator (Gujarati, 2003). If $\hat{u}_{it}$ is the $_{it}$th residual from the OLS regression, then the Lagrange multiplier test for one-way random effects is:

$$\mathrm{LM} = \frac{NT}{2(T-1)}\left(\frac{\sum_{i=1}^{N}[\sum_{t=1}^{T}\hat{u}_{it}]^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{u}_{it}} - 1\right)^2$$

In which failure to reject the null hypothesis, i.e. the result is higher than 0.05, suggests that there are no significant differences across units and, thus, no panel effect, which means OLS regression has to be done instead. On the other hand, if the null hypothesis is rejected, the Hausman Test can then be conducted to determine whether a fixed or random effects panel regression approach is appropriate.

2. **Hausman Test**

The Durbin–Wu–Hausman test (also called the Hausman specification test) is a statistical hypothesis test that has to be done first in order to determine whether the panel regression belongs to the fixed effects or random effects model (Hausman, 1978). This in turn helps to capture the effects of firm and time specific heterogeneities (Gujarati, 2003). The Hausman Test is calculated as follows:

$$H = (\beta RE - \beta FE)'[Var(\beta FE) - Var(\beta RE)]^{-1} (\beta RE - \beta FE)$$

Where:

- βFE are the coefficient estimates of the time-varying covariates from the fixed effects model.
- βRE are the corresponding estimated coefficients from the random effects model.
- Var(βFE) and Var(βRE) are the estimate of the asymptotic (large sample) variances and covariance of the estimated coefficients.

Therefore, if there is no correlation between the independent variable (s) and the unit effects, then estimates of β in the fixed effects model (βFE) should be similar to estimates of β in the random effects model (βRE) (Greene, 2008). In other words, if the result is equal or less than 0.05, the null hypothesis is rejected and the fixed effects model should be used since there is a significant difference between estimates of β in the two models.

3. **F-Test**

An F-test is any statistical test in which the test statistic has an F-distribution under the null hypothesis. It is most often used when comparing statistical models that have been fitted to a data set, in order to identify the model that best fits the population from which the data was sampled (Lomax, 2007). Suppose the fixed effects model is formulated as follows:

$$y_{it} = X'_{it}\beta + u_i + \varepsilon_{it}$$

The null hypothesis of the F-test following fixed effects regression is that in the proposed model, the observed and unobserved fixed effects ($u_i + \varepsilon_{it}$) are equal to zero, i.e. they are equal across all units. Therefore, rejecting this hypothesis, when Prob>F is equal or less than

0.05, means that the fixed effects are non-zero, so the composite error terms (u_i + ε_{it}) are correlated.

4. Testing for Time-Fixed Effects (Testparm)

Finally, in order to see if time fixed effects are needed when running a fixed effects model, a joint test is needed to check whether the time dummies for all years are equal to zero or not (Torres-reyna, 2007). If so, no time fixed effects are needed. On the other hand, if the Prob>F is equal or less than 0.05, the null hypothesis is rejected, meaning that coefficients for all years are not jointly equal to zero and, thus, time fixed effects have to be added to the model.

Table 4-9 below shows results of the model specification tests described above, when applied to the data in 4.2.2. These results suggest that a Random Effects approach is the most appropriate regression method to use. The Tobit approach is then chosen as the main regression model to use on the back of this, on the basis that it is a variant of the standard Random Effects approach that takes the censored outcome nature of cost efficiency scores into account.

Table 4-9: Regression Model Specification Results

Specification Test	Regression Model
Breusch-Pagan LM test for random effects versus OLS *[if≤0.05 ⟹ use Random Effects]*	Prob>chibar2 = 0.0000
Hausman test for fixed versus random effects model *[If ≤0.05 ⟹ Fixed Effects]*	Prob>chi2 = 0.1682
F-Test for fixed effects versus OLS *[if Prob>F ≤0.05 ⟹ use Fixed Effects]*	-
Testparm (Testing for Time-Fixed Effects) *[if≤0.05 ⟹ time fixed_effects needed]*	-
Model Choice	**Random Effects**

4.3 Efficiency Measurement Results

Table 4-10 provides a summary of the DEA results, which were produced by running the user-written STATA code described in Appendix 1. This section discusses some observations from these results. On the whole, the industry appears to be nearly fully efficient from an allocative efficiency perspective, with the allocative efficiency being close to 100% throughout, and having a small standard deviation in each year. This suggests that firms in this industry are choosing the optimal mix of input resources required to produce the necessary outputs. There is therefore very little scope to improve cost efficiency from this perspective. However, there appears to be a different picture though on technical efficiency, which starts off at 70% in 2007, before gradually decreasing to a low of 65% in 2011, and then gradually recovering after that to reach 75% in 2015. This therefore paints a picture of the technical efficiency of firms gradually reducing in the aftermath of the Global Financial Crisis, before starting to recover, and ending up with better efficiency than they started with over the course of the post-Global Financial Crisis period. It is therefore worth understanding the technical drivers of cost efficiency or inefficiency in this period, to enable firms to understand the drivers that worked effectively (the gradual increase from 2011 suggests that there were levers that were pulled that worked well), the drivers that were not so effective, and potentially other drivers that firms had not considered, which could help or hinder efficiency. This will then be useful information to factor in when considering actions to take to improve cost efficiency.

The overall cost efficiency was relatively stable during the sample period (average: 66%, minimum: 60%, maximum: 72%). This is slightly lower than results produced by previous UK studies (e.g. 70% in Hardwick and Li (1997), and 76% in Ward (2002)). Results of the validation test using the SFA approach (which is more comparable to previous UK studies) are in Table 4-11 below, with the full STATA output in Appendix 2. The average cost efficiency on that approach was 72%, which is more in line with the results of previous studies, and suggests that cost efficiency in the industry has remained reasonably stable over time, with around 30% capacity to improve it. In terms of operating expenses, this implies that there could be potential efficiency savings (without affecting the level of output) of around £2.9bn across the industry, based on 2015 data in Table 4-3 (i.e. 30% x £9.773bn). The SFA results produced as part of this study also provide comfort that the SFA and DEA methods are not producing vastly different results. In practice, presenting potential operational expense efficiency savings on either approach (i.e. (1-66%) x £9.773bn = 3.3bn, and (1-72%) x 9.773bn = £2.7bn, based on 2015 data), or presenting them as a range (i.e. between £2.7bn and £3.3bn), is unlikely to alter the overall message of a large potential to improve cost efficiency in the industry. In the underlying results, only 33 data points from a total of 1,117 had an efficiency score of 1. In addition, the number of fully efficient firms varies from three to five in any given year (from a total of 95 to 147, depending on the year), and only one firm is fully efficient throughout the sample period. This suggests that there is scope for a large number of firms to improve their cost efficiency.

There was an immaterial limitation that emerged as part of analysing these results, in the form of one observation with an efficiency score of 0. This was one efficiency score in the 2014 data subset where an efficiency score could not be computed, so the linear programming calculation set it to zero. Whilst this is a limitation to the results, it is a very minor one, because the results are not weighted, and it is only one observation out of 1,117, and a sensitivity of setting the zero score to 1 (i.e. the most this score could have been if it could have been computed) showed that the 2014 cost efficiency score would change from 67% to 68%, and the overall efficiency score would remain unchanged at 66%. This is therefore accepted as an immaterial limitation to the results.

Table 4-10: DEA Efficiency Scores

Year	DMU Count		Cost Efficiency	Allocative Efficiency	Technical Efficiency
2007	147	*Mean:*	67%	94%	70%
		Std Dev:	21%	8%	20%
2008	147	*Mean:*	67%	96%	68%
		Std Dev:	23%	8%	23%
2009	139	*Mean:*	64%	96%	66%
		Std Dev:	22%	5%	22%
2010	137	*Mean:*	62%	95%	66%
		Std Dev:	22%	12%	22%
2011	121	*Mean:*	60%	93%	65%
		Std Dev:	21%	15%	21%
2012	114	*Mean:*	65%	95%	69%
		Std Dev:	22%	12%	21%
2013	111	*Mean:*	69%	95%	72%
		Std Dev:	23%	12%	21%
2014	106	*Mean:*	67%	94%	72%
		Std Dev:	23%	14%	22%
2015	95	*Mean:*	72%	96%	75%
		Std Dev:	22%	9%	21%
Observations	1,117	*Mean:*	66%	95%	69%
		Std Dev:	22%	11%	21%

Table 4-11: Stochastic Frontier Analysis (SFA) Results

	SFA Coefficients
LN (Labour)	-0.3029***
	0.0855
LN (Cost of Capital)	0.5287***
	0.0348
LN (Claims)	-0.0203
	0.0351
LN (Assets)	0.7805***
	0.0397
Constant	2.1330***
	0.6889
LN (sigma2 v)	-0.1778*
	0.0937
LN (sigma2 u)	-0.1470
	0.2456
sigma_v	0.9149
	0.0429
sigma_u	0.9292
	0.1141
sigma2	1.7005
	0.1567
Lambda	1.0155
	0.1506
Observations	1,117

*** 1% significance level, ** 5% significance level, *10% significance level, all using a one-sided t-distribution test

Cost Efficiency	72%
Std Dev	13%

The next step of the analysis is to discuss observations from the regression results that used the efficiency scores from this section as dependent variables. These regression results are discussed in section 4.4 below.

4.4 Efficiency Regression Results

Table 4-12 below provides regression coefficients of each independent variable, with the error term below each coefficient. It also shows the statistical significance of each variable in the regression. Details of the user-written STATA code for the Simar and Wilson (2007) bootstrapping technique and the STATA outputs for the regression analysis can be found in Appendices 3 and 4 respectively. The observations from these results are discussed below.

Table 4-12: Efficiency Regression Results

	Expected Sign	Panel Tobit	Validation Model: Random Effects	Validation Model: OLS	Validation Model: Simar and Wilson
LN (Premiums)	+	0.0036*	0.0024	0.0075***	-0.0003
		0.0020	0.0020	0.0016	0.0014
Reinsurance Ratio	+	-0.0297*	-0.0345**	-0.075***	-0.0587***
		0.0155	0.0148	0.0147	0.0124
Derivative Use	+	-0.0115	-0.0105	-0.0308***	-0.0149**
		0.0084	0.0083	0.0084	0.0073
Free Asset Ratio	-	0.0116	0.0100	0.0243	0.0050
		0.0151	0.0148	0.0162	0.0137
Liquidity Ratio	+	-0.0061	-0.0064	0.0193	0.0064
		0.0179	0.0175	0.0159	0.0139
Central London Office	-	-0.4063***	-0.4052***	-0.4201***	-0.4251***
		0.0138	0.0132	0.0078	0.0068
Total Observations		1,019	1,019	1,019	1,019
• Left-censored		1	-	-	1
• Right-censored		32	-	-	32
• Uncensored		986	1,019	1,019	986
R-squared		-	0.7514	0.7576	-

*** 1% significance level, ** 5% significance level, *10% significance level, all using a one-sided t-distribution test

One observation was left-censored, having an efficiency score of zero. This observation was discussed in Section 4.3 as a minor limitation, having been set to zero because the score could not be computed. The same conclusion of this being an immaterial limitation also applies to the regression analysis. At the other end, only 32 data points from a total of 1,019 were right-censored as a result of having an efficiency score of 1. This is one lower than the 33 discussed in 4.3, due to one data point being removed as part of the data clean-up process for the regression analysis.

Three of the six hypotheses tested returned statistically significant results, thus supporting the thesis that Financial and Risk Management, Firm Size and Office Location are drivers of either cost efficiency or cost inefficiency of firms in the UK Life Insurance industry in the period after the Global Financial Crisis. Each hypothesis is discussed in turn below.

The firm size finding is significant at the 10% level, and supports the hypothesis that larger firms are more cost-efficient than smaller firms. The consolidation activity discussed in section 1.1.8 might have therefore contributed to the recovery in the industry-wide efficiency since 2011. In addition, the analysis in 4.2.1 suggests that there is scope for more consolidation activity, and since section 1.1.8 suggests that consolidation remains the focus of the industry going forward, further efficiency gains might also emerge in future as a result. This finding is consistent with the corresponding finding for this industry in Hardwick and Li (1997)'s study in terms of the positive contribution to cost efficiency, but is inconsistent in terms of statistical significance, because the finding was statistically insignificant in the previous finding. This provides an example of how findings can change over time and the need to reassess efficiency and inefficiency drivers when new information emerges.

The reinsurance finding is also significant at the 10% level, but the impact is not what was expected, with the findings rejecting the hypothesis that reinsurance increases the cost efficiency of a UK insurance company. This finding is initially surprising, given the discussion in section 3.8. However, the European Regulatory Capital regime pre - January 2016 did not give credit for reinsurance in Regulatory Capital Requirements[61] (so only the cost of reinsurance came through, with the benefit of reduced risk/volatility not quantified or reflected on the Balance Sheet). The Solvency II regime from January 2016 does give credit to reinsurance in the Regulatory Capital calculation[62], so a future study (when enough years have passed to create sufficient data) could consider whether reinsurance remains a negative influence on cost efficiency.

Although the Derivative Use finding is not statistically significant, the coefficient also goes against what was expected, although unlike reinsurance, it was difficult to determine what to expect, given the apparent lack of relevant literature on this subject (as discussed in section 3.8). The treatment of derivatives in the regulatory capital calculation is consistent with reinsurance before and after January 2016, so it is unsurprising that the findings are also consistent. A future study proposed for reinsurance should therefore also consider derivatives under the Solvency II regime.

The free asset finding suggests that there is insufficient evidence to support the hypothesis that free assets hinder cost efficiency. Brockett et al. (2004) came to a similar conclusion in a study based on U.S. data. That said, the positive sign of the coefficient raises the question of whether it is cheaper to raise capital (and hold it on the Balance Sheet as a volatility buffer) than pay for Reinsurance or Derivatives. Put another way, it would appear better from an efficiency perspective to use the solvency volatility buffer approach (since free assets do not

[61] Source: https://www.handbook.fca.org.uk/handbook/INSPRU/1/1.html?date=2009-12-14
[62] Source: https://www.pwc.com/il/en/insurance/assets/qis5frank1.pdf

significantly affect cost efficiency one way or the other) than use derivatives or reinsurance (which negatively impact cost efficiency).

There is also insufficient evidence from the results to support the hypothesis that higher liquidity leads to higher cost efficiency. This suggests that the reduction in liquid assets over the sample period (and the corresponding increase in illiquid assets) is not having an impact on cost efficiency. This is an important finding, since – in practice – illiquid assets would be expected to be more labour-intensive to manage than liquid assets (e.g. specialist staff required to agree the terms of an illiquid asset such as an Equity Release Mortgage discussed in section 1.1.5). It is therefore important to find that any additional cost inefficiencies from increasing illiquid asset holdings are statistically insignificant.

Finally, the results support the hypothesis that a Central London registered office location decreases cost efficiency at the 1% level. This finding is consistent with Central London having the highest wages (a key insurance input). Hardwick and Li (1997) found a similar finding, but it was not statistically significant at the time. Reasons why the finding is now significant might include the different approaches of looking at the Cost of Labour, since the earnings data in the Hardwick and Li (1997) study did not vary by location, whereas this data varies by local authority in this study. Changes to the economy in general, which now make it more cost-effective to operate from outside Central London than it might have done over 20 years ago (e.g. Broadband in more UK locations[63]), might also be a factor. The affected companies may wish to consider moving their registered offices outside Central London. Technological advances (such as Broadband in more UK locations) and new working

[63] Current UK Broadband coverage is around 95%. Source: https://www.gov.uk/guidance/broadband-delivery-uk

patterns (e.g. working more from home[64]) arguably support a more geographically diverse workforce.

Table 4-12 also shows the validation results, which show the regression results using the Random Effects, OLS and Simar and Wilson approaches. The coefficients of the independent variables across all the models appear to be of a similar size, with the main variations coming from the statistical significance of these coefficients. That said, all four models are consistent in suggesting that Reinsurance and a Central London office location have a statistically significant negative relationship with cost efficiency, and that the relationships between cost efficiency and the Free Asset and Liquidity Ratios are statistically insignificant. In addition, Derivatives Use has a negative sign in all models, and is statistically significant at the 1% and 5% significance level in two of the four models. Practitioner audiences could arguably put more weight on these findings, because they appear to withstand the debate in the academic literature about the most appropriate regression approach to use.

This chapter has so far analysed specific aspects of the findings of this study, and attempted to link them to findings from existing literature where relevant. The next section attempts to have a broader discussion about the findings.

4.5 Discussion

4.5.1 Findings

By using the DEA approach to efficiency measurement, this study appears to be the first one in the UK to explore the key components of cost efficiency separately (i.e. technical and allocative efficiency). It therefore appears to be the first study to report that the UK Life Insurance industry appears to have near-perfect allocative efficiency. Although it is difficult

[64] The increasing trend of remote working in the UK is discussed here: https://www.hso.co.uk/leased-lines/technology-news/homeworking-news/50-of-uk-workforce-to-work-remotely-by-2020

to make comparisons with other industries, which use different data sets and different sample periods, it is still worth noting how this level of allocative efficiency compares to other key important markets, where the comparative information is available. In this regard, the picture appears to vary across Europe, with some markets appearing to have similar near-perfect allocative efficiency, while others have efficiency scores that are much lower in comparison. For example, the Swiss Life Insurance Industry had near-100% efficiency, based on Biener et al. (2016). On the other hand, other markets appear to have more modest allocative efficiency. An example can be seen in the German Life insurance market, where allocative efficiency averaged 51%, based on Diboky (2007). From a global perspective, a study of the U.S. Life insurance industry by Cummins et al. (2010) found allocative efficiency in the Life and Health market to be around 62%. Given that the German insurance market is a key competitor to the UK market in Europe, and that the U.S. is the leading insurance market globally and a key global competitor (as discussed in section 1.1.1), the UK insurance industry can arguably be considered to be a global leader on this measure of efficiency, and one that other industries could learn from in order to improve their allocative efficiency.

Although the UK Life Insurance market appears to be highly allocative efficient, there appears to be capacity to improve overall cost efficiency. The findings of this study suggest that cost efficiency using up to date data is not too dissimilar to the cost efficiency found in similar studies for this industry. This suggests that the industry is capable of adjusting to the changing economic environment to maintain a level of efficiency (e.g. the consolidation activity after the Global Financial Crisis, as discussed in section 1.1.8). However, the absence of a significant improvement in cost efficiency since those earlier studies, suggests that the industry is reactive (as opposed to proactive) to changes in the economic environment. This might be due to what the industry perceives is required to significantly improve efficiency, which is usually associated with significant change-related projects. For example, all previous studies on this industry focus on organisational form (e.g. shareholder firm versus mutual, as covered by Hardwick et al. (1997)) or Distribution Systems (as covered by Ward (2002)). In addition, current industry activity discussed in section 1.1.8 suggests that the industry is looking to Consolidation as a potential source of efficiency. All these activities would – in practice - require very significant business decisions and changes. Practitioners are therefore unlikely to implement them unless they absolutely need to. However, there might be smaller changes available that do not require fundamental changes to a firm's business to significantly improve cost efficiency, as this study has found. For example, reviewing reinsurance arrangements can be a management action, which does not normally require fundamental changes to the business. Having a toolkit of these easy-to-implement efficiency drivers might encourage firms to be more proactive from a cost efficiency perspective, as well as more agile in times of crisis. For example, the trend of cost efficiency scores suggest that cost efficiency was on a downward trend after the Global Financial Crisis until 2011, when it finally started to recover. A toolkit that is easier to implement might have improved the industry's efficiency earlier than this point. This study has shown that the category of Financial and Risk Management offers such tools, and further research could explore the impact of other initiatives that could be implemented without major business changes, such as Human Resource and Process Management or Product Pricing, which have been explored in other markets as discussed in section 2.3.2.

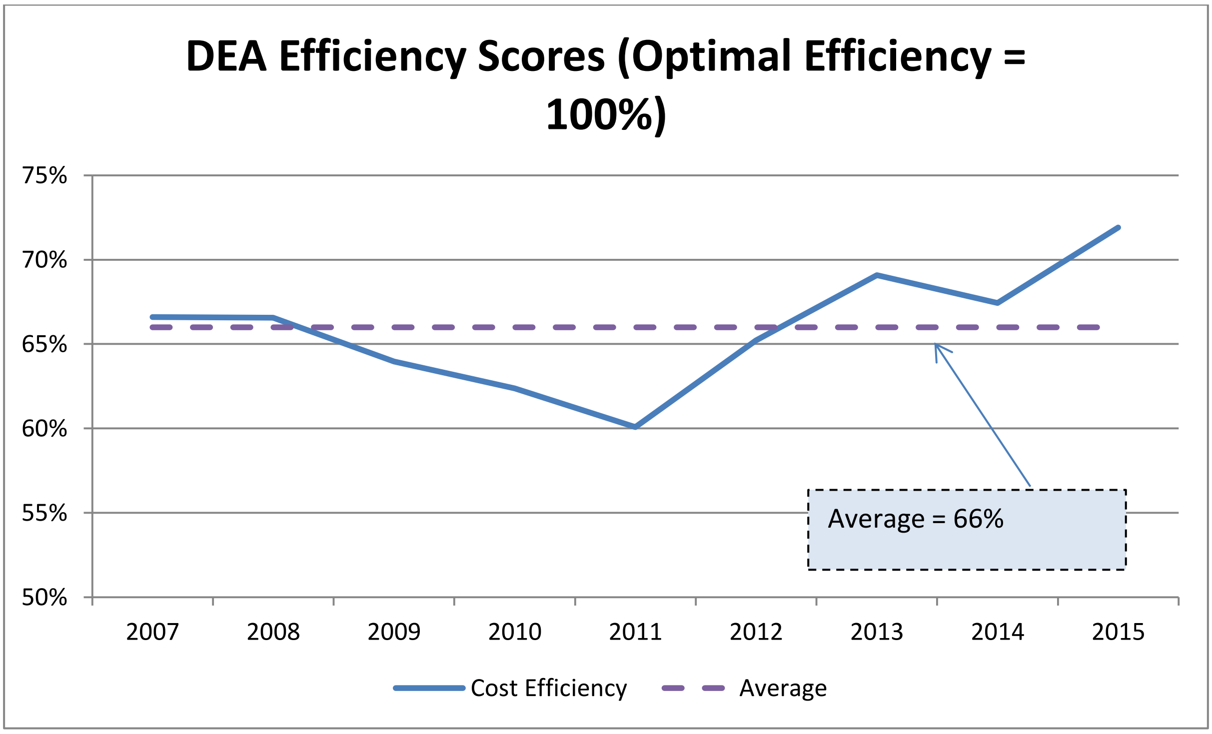
Future studies could also explore whether easily available industry data such as a market index could be used to predict the trend of cost efficiency. An example of this can be seen in

Figure 4-1, which shows the FTSE100 index falling sharply in the aftermath of the Global Financial Crisis, before starting to recover, in a similar way to how cost efficiency itself has progressed since the crisis, as plotted in Figure 4-2.

Figure 4-1: FTSE 100 Index from Year-end 2007 to Year-end 2015

Source: S&P Market Intelligence

Figure 4-2: Cost Efficiency in the UK Life Insurance Industry



A Pearson correlation of the underlying data of these graphs can be seen in Table 4-13 below, which suggests a strong association between them. This raises the question of whether a combination of efficiency scores from a published academic piece of work, and a widely published market index, such as the FTSE 100, could be used to derive an easy and real-time approximation of overall cost efficiency in the industry.

Table 4-13: Cost Efficiency and the FTSE 100 Correlation

	Cost Efficiency	FTSE 100 Index	FTSE Index Date
2007	67%	6425.38	31-Dec-07
2008	67%	4427.00	29-Dec-08
2009	64%	5416.12	28-Dec-09
2010	62%	5955.77	27-Dec-10
2011	60%	5548.82	26-Dec-11
2012	65%	6015.59	31-Dec-12
2013	69%	6732.24	30-Dec-13
2014	67%	6573.60	29-Dec-14
2015	72%	6276.98	28-Dec-15
		Correlation	**40%**

Although this study attempted to explore statistically robust efficiency drivers, cost efficiency could also arguably be driven by a firm's inputs not being as volatile as its outputs, and particularly the value of invested assets. For example, assuming no asset defaults and no increase to the cost of capital, the same number of assets will need to be managed, even if the value of those assets has decreased. A similar number of staff will therefore be required, so a reduction in efficiency appears to be unavoidable for some firms because the wage data in section 4.2.1 has shown that – even during the crisis – salaries remained relatively stable. This is therefore likely to create an opportunity for some firms to outperform a potential phenomenon that affects the rest of the market, and reducing the overall efficiency of the industry as a result.

Although firm-based results have not been published in this study, practitioners could make use of the methods and data in this study to conduct similar analysis on efficiency measurement, to deduce how they compare with peers. This could help firms understand which competitor firms they need to learn from to improve their efficiency, or indeed how much effort to put on finding efficiencies, if a firm is already operating on the efficient frontier. For example, one firm appears to be the only one to have had 100% cost efficiency throughout the sample period. It would be useful for the firm's owners, board members and management to be aware of this, to aid with (say) setting expectations for the performance of senior managers with regards to finding additional efficiency savings. If the firm is already holding a market-leading position on this front, it might be more difficult to extract additional efficiency savings from it, so managers tasked with finding these additional savings, could potentially be set up to fail.

4.5.2 Comparison with other studies

This study is consistent with previous UK studies in that it focusses on the Life segment of the market, and appears to use similar inputs and outputs that were used in most of the papers. However it appears to deviate from these previous studies in three key areas:

1. It updates the data by using post-Global Financial Crisis period (none of the previous studies appear to do that), so new insights are gleaned, even where a determinant has been explored before, because much could have changed in the intervening period.
2. It aligns the methodology to the latest methods being used globally, and away from traditional methods of calculating efficiency or performing regression analyses.

3. All previous studies appear to have explored either the categories of Organisational Form and Corporate Governance, or Distribution Systems. This study deviates away from that by looking at Financial and Risk Management.

In terms of other published papers that focus on Financial and Risk Management (FRM), this study appears to be unique. While there are some key cross-overs (e.g. 6 of the 8 Financial and Risk Management papers also look at the determinants of Cost Efficiency), this study appears to be the first to explore reinsurance, derivative use and liquidity as potential drivers of (in) efficiency. It also appears to be the first study that explores the FRM determinants of a single European country (the one other European study that looks at FRM, by Eling and Jia (2018), is a Europe-wide study that incorporates 16 countries).

The published work that appears to be closest to this study was arguably produced by Biener et al. (2016), which looked at the determinants of efficiency and productivity in the Swiss insurance industry. There are a number of similarities between that study and this one. For example, a two-stage efficiency analysis on the insurance industry of a single Western European country was conducted, using the non-parametric DEA approach in the first stage, supplemented by the latest Simar and Wilson truncated bootstrapping regression technique (which was used for validation purposes in this study). The core data was also obtained from regulatory returns, and covers the whole industry, and the efficiency scores are calculated using similar inputs and outputs to this study, which use a value-added approach to outputs. In addition, the second stage also explores one of the more recent categories of research in the area of efficiency in the insurance industry (Product Pricing and Target Markets). Finally, the data set contains up to date data that captures part of the post Global Financial Crisis period (their study uses a 1997 – 2013 sample period).

While there appear to be a number of similarities between this study and the one by Biener et al. (2016), there are also key differences. For example, Biener et al. (2016) focus on a different European Market, where the regulations are similar, but not perfectly aligned (Switzerland sits outside the EU, and has its own insurance regulatory regime, which is enforced by the Swiss Financial Market Supervisory Authority[65]). This could affect the significance of some of the determinants. In addtion, the data in the Swiss study covers both Life and Non-life insurance, whereas the focus in this study is on life insurance. That could affect both the level of efficiency (a previous Europe-wide study by Fenn et al. (2008) found that the UK non-life insurance industry was one of the most efficient in Europe, while the life insurance industry was one of the least efficient) as well as the significance of determinants. The study by Biener et al. (2016) also assigns an industry-wide wage variable to all firms, whereas this study attempts to be more precise by assigning wages to firms according the local authority where each registered office is found. This was important to do in this study, since there appears to be a large disparity between regions (and specifically between Central London and the rest of the country), so this could have a bearing on the significance of the Office Location finding. The Swiss study also bases its results on a much longer sampling period than in this study (1997 – 2013). This suggests that a longer sample period coud have also been used in this study if it was considered valuable to do so. However, the focus in this study is on the post Global Financial Crisis period, and the chosen length of the sample is considered appropriate, based on the discussion in section 3.10. Biener et al. (2016) extend their study to measuring productivity over time using the Malmquist index of Total Factor Productivity. This is not covered in this study, as the focus

[65] Source: https://www.finma.ch/en/supervision/insurers/cross-sectoral-tools/swiss-solvency-test-sst/

for the UK insurance market practitioners (of which the researcher is a part) appears to be on improving operational (i.e. cost) efficiency as discussed in section 1.1.8, so this research (and many others in the literature that has been reviewed) can stand on its own by focusing on the measurement of the efficiency, and the potential drivers that significantly help or hinder it. Finally, in addition to Cost Effiency, their study also measures and considers the determinants of Revenue Efficiency. This has also not been explored in this study (along with Profit Efficiency) because the current focus of the industry appears to be on operational efficiency, as discussed in the bullet point above. Further studies can explore these additional topics when the industry's focus shifts from operational efficiences to other types of efficiency.

4.5.3 Strengths and Limitations

The analysis conducted under this research features both strengths and limitations. The first contribution of the study is the breadth of industry coverage. The data covers the whole UK Life Insurance Industry, thus removing any sampling error from that perspective. It also implies that the findings are widely generalizable in this industry. An additional strength of this study is the use of the latest and widely accepted methodology in the research area. This will hopefully make the findings more acceptable to fellow researchers in the area. This study also brings an industry practitioner perspective to this research area, which appears to be dominated by academic researchers. Chapter 1 of this paper, the choice of research questions and the justification of methodological choices are likely to reflect this practitioner perspective.

In terms of limitations, the first one is a general one for this type of research. As with any purely empirical study, it answers the 'what' question, not the 'why', which practitioners and fellow researchers would arguably also have an interest in, and is often addressed very briefly as part of the results analysis and discussion. The ‘why’ element is proposed as a topic of future research. In addition, this study is a snapshot in a continuously moving economic and regulatory landscape (e.g. the solvency regime in Europe was completely revamped as at 1 January 2016, and part of the effect was to change the way Reinsurance and Derivatives were viewed from a Required Capital perspective). The findings are therefore only likely to be relevant to a short period, and would need to be updated once enough new data emerges (maybe around 2025, when there will be a similar volume of data post-2016 to the pre-2016 data in this study). Finally, although section 4.2.4 justifies the regression approach chosen, this study may still be considered to have a methodological weakness due to the issue of non-separability of between the first stage and second stage of the analysis, as discussed by Grant et al. (2017). Having discussed various aspects of the results in this section, the next and final chapter builds on this, by providing conclusions to this study.

Chapter 5: Conclusions

5 Conclusions

This chapter starts by recapping on the purpose of this study, as well as the research questions. The purpose of this study is to conduct an empirical investigation on the level of cost efficiency in the UK Life Insurance industry during and after the Global Financial Crisis, as well as test the statistical significance of a sample of potential drivers of efficiency that are largely drawn from the area of Financial and Risk Management. This purpose has helped to shape the two key research questions in this study. The first question asks about the level of cost efficiency in the industry at the end of each year, from 2007 to 2015, and what the average level was over the whole period. The second question looks to explore the statistical significance of reinsurance cover, financial derivative use, free assets on the Balance Sheet, the level of liquid assets, the size of a company and a Central London office location on insurance firms' cost efficiency inefficiency. The rest of this section summarises the findings of this research, the implications this research has on theory and practice, and suggestions for future research.

5.1 Research Key Findings

5.1.1 Chapter 1 Summary

Chapter 1 provides the context of the UK insurance industry, and highlights its significance both as a leading European and leading global insurance industry. It then goes on to discuss recent developments in the industry, which highlight why – even though previous studies have been conducted - another look at cost efficiency in this industry might be appropriate at this time. The chapter suggests that, in a challenging economic environment, one aspect that firms are pursuing to keep their businesses profitable appears to be the improvement of cost efficiency. A survey of industry practitioners by one of the 'Big 4' Financial Advisory firms – PwC - highlights that the industry focus is on consolidation, with the objective to "integrate functions and improve efficiency through outsourcing and generate shareholder and policyholder value through generating expense and tax efficiencies"[66]. It is therefore important for the industry to understand whether there is actually any capacity to improve efficiency, and consider if some of the tools being employed will help firms to meet their objective.

5.1.2 Chapter 2 Summary

Chapter 2 starts by providing a theoretical framework for conducting empirical efficiency research on the UK Insurance Industry. This framework starts by identifying the UK economy as liberal, in line with Hall and Soskice (2001), and justifies why the Efficient Structure Hypothesis, which was developed by Demsetz (1973), is an appropriate underpinning theory of performance for the chosen industry, when other theories can be applied. The chapter then reports the details of the relevant global published and peer-reviewed empirical literature review, which is presented in two grids – one that looks at Efficiency Measurement, while the other looks at Efficiency/Inefficiency drivers. The efficiency measurement review highlights the different types of efficiency and efficiency measurement techniques that exist, including the debate in the literature about the appropriate techniques to use, as well as the appropriate method of choosing insurance inputs and outputs. Consequently, this study identifies the following gaps in the literature; firstly, no published paper focussing on the UK Life Insurance Industry since 2011; secondly, no UK Life Insurance industry study that covers the post-Global Financial Crisis period, when a number of economic and regulatory changes occurred that might affect cost efficiency; and finally, no UK study has used the popular Data Envelopment Analysis (DEA) method of efficiency measurement. There also appears to be scope to increase non-U.S. literature, because nearly 30% of literature reviewed was based on U.S. insurance industry data.

[66] Source: Page 18 of https://www.pwc.co.uk/audit-assurance/assets/pdf/european-life-book-survey-2017.pdf

The review of Efficiency/Inefficiency drivers in the literature found a variety of regression approaches used, with efficiency scores as the dependent variable in the regression analysis. A number of regression methods could therefore be used, with justification. In terms of efficiency drivers, the findings from the papers are grouped into the following categories (in order of popularity in the empirical literature), which were introduced by Eling and Luhnen (2010), unless stated otherwise:

1. Organisational Form and Corporate Governance
2. General level of efficiency, and evolution over time
3. Methodology and Assumptions
4. Scale and Scope Economies
5. Regulation Change
6. Market Structure
7. Financial and Risk Management
8. Distribution Systems
9. Product Pricing and Target Markets (created in this study)
10. Mergers and Acquisitions
11. Intercountry Comparisons
12. Human Resources and Process Management (created in this study)

The findings in each of these categories are consistent across different studies in some cases, but also conflicted in others. This arguably suggests that – even though quantitative research methods were used by all previous studies, efficiency research is not an exact science, given the considerable debate on various aspects of the methodology. The contrasting findings within the same geographical area also suggest that the findings are only generalizable for firms within the industry in question, and not necessarily outside it. And even then, the generalisability might only apply for a certain time period, because regulatory changes might affect some of the actions taken by firms, and therefore the data that feeds into the analysis. The analysis also highlights that there does not appear to be a UK study that has looked outside of Organisation Form and Corporate Governance or Distribution Systems for potential efficiency/inefficiency drivers. In addition, Financial and Risk Management appears to have only been explored by a handful of studies, and only one, by Eling and Jia (2018) appears to focus on Europe, and even that includes data from 16 countries (including the UK), so is not focussed on a specific country. The rest of the chapter explores the European segment of the literature in more detail, by critically analysing the findings, and helps to support the research purpose and questions of this study.

5.1.3 Chapter 3 Summary

Chapter 3 sets out the methodology that is used in this research. The key methodology decisions that have been made are as follows:

Data Sources: The financial information of insurance companies could either be obtained from accounting information, or regulatory returns. This study has opted for regulatory returns, because of the unavailability of accounting data for unlisted or mutual insurers. The next decision relates to the source of the regulatory returns. There appear to be a couple of credit rating agencies that collate UK insurance regulatory returns, namely Standard and Poor's (S&P) and A.M Best. S&P (and specifically, their SynThesys Life Database, version 10.1) has been chosen because the researcher could easily get access to their data as part of their employment at Canada Life, but the A.M Best data would have worked too. As a validation check, a regulatory return from an insurer's website[67] has been downloaded and cross-checked against what was stored for this company by S&P, and this validation test has passed.

Sample Period: Because the focus of this study is on the Global Financial Crisis and beyond, the data period starts off at 2007 (the start of the Global Financial Crisis, as discussed in section 3.10). The end-point of the period of the study has been chosen to capture the longest period since the crisis, given the data available at the point of data collection. As at March 2018 (when data was collected), The SynThesys Database had regulatory returns data up to 2015. This would provide 9 years of industry data, which is slightly shorter than the 11 years in Hardwick et al. (2011)'s UK study, but longer than the periods used by all the other UK-focussed published studies discussed in section 2 (5 years in Hardwick and Li (1997), Letza et. al (2001) and Klumpes (2004), and 8 years in Ward (2002)).

Choice of Insurance Outputs: There appears to be considerable debate in the literature about the choice of insurance outputs. Claims and Invested Assets have been chosen as the outputs, by looking at an insurance company as a value-adding entity, with Claims representing the Risk-Pooling service offered by an insurance company, while Invested Assets represents the Financial Intermediation service. These choices have been influenced by a combination of what has been previously used in the literature (especially in the UK and the U.S.A) and the researcher's understanding (as a practitioner) of the purpose and function of an insurance company. There appears to be less debate about Insurance inputs

[67] The 2009 submission by Wesleyan Assurance Society:
https://www.wesleyan.co.uk/pdf/wesleyan_assurance_society_fsa_returns_2009.pdf

in the literature, and the chosen inputs of Labour and Financial Capital appear to be widely accepted.

Efficiency Measurement Methodology: There is discussion in the literature about whether to use parametric (e.g. Stochastic Frontier Analysis or SFA) or non-parametric (e.g. DEA) approaches to measuring efficiency. The main limitation with the parametric approach appears to be the number of key assumptions that are required in the cost or production function (e.g. the distribution of the error term), while the main limitation of the non-parametric approach is the loss of the statistical qualities that you get with a parametric approach. While the overall efficiency scores have been calculated using both the SFA and DEA approaches in this study, the DEA results form the basis of this research for a number of reasons. Firstly, the DEA approach can be used to decompose Cost Efficiency into its various components (i.e. technical and allocative efficiency). This appears to be the first UK study to do this, and will help practitioners to understand the cost-saving capacity at a more granular level. Secondly, DEA also appears to be more suited to answering the research question on the development of efficiency over time. Thirdly, although most of the previous UK studies appear to be silent on the statistical significance of the error term, one study - by Ward (2002) - assumes that the random error term tends to zero over the period covered by the analysis. This supports the use of the DEA approach in future UK studies (or at least suggests that it is as valid as econometric approaches in the UK context), which does not separate the random error term from the inefficiency term. Finally, choosing this approach will make this UK study consistent with most recent efficiency studies conducted in other countries on this key methodological aspect.

Regression Methodology: Although a variety of regression approaches appear to be acceptable in the literature, there is some discussion in the literature about the regression approach if the censored (0, 1) nature of efficiency scores is taken into consideration. Some papers appear to use a Tobit approach, while others use the truncated bootstrap approach introduced by Simar and Wilson (2007). This study uses both approaches, but bases the findings on the Tobit approach. The shortcomings of the Tobit approach are acknowledged (principally the use of conventional approaches to inference, which are invalid due to complicated and unknown serial correlations among estimated efficiency scores), but section 4.2.4 provides statistical justification for why it is the appropriate method to use in this study. A Random Effects approach and a simple OLS approach are also used alongside the Simar and Wilson approach for validation purposes.

In terms of ethics considerations, the study is based on publicly available secondary data, and therefore does not need ethics approval from the University of Hertfordshire. That said, there is an acknowledgment in the chapter about general ethical considerations that are considered, even if formal approval is not required.

5.1.4 Chapter 4 Summary

Chapter 4 starts with analysing the data that has been collected for the purpose of this study. The core data set was downloaded from the SynThesys Life Database (version 10.1), as discussed in 5.1.3 above. In addition, the study uses earnings population from the Office of National Statistics as the cost of labour, with data manually collected from Companies House, the Mutuals Public Register and the Financial Services Register being used to assign earnings (which are by local authority) to a firm. The data shows a wide variety of firm sizes and registered office locations (although there appears to be a high concentration of registered offices with a Central London address). The data also provides useful insights in the level and/or use of common Financial Risk Management tools.

From the DEA analysis, the findings suggest that the average cost efficiency in this period is 66%. It starts out at 67% in 2007, before gradually decreasing to a low of 60% in 2011, and then recovering to reach 72% in 2015. In the second stage, a Central London office location and Reinsurance Cover are found to have a negative and statistically significant relationship with cost efficiency, while Firm Size has a statistically significant positive relationship. The office location finding is consistent with wages (which appear to be highest in Central London) being a key input for an insurance company, while the reinsurance finding suggests that the cost of reinsurance outweighs the quantifiable benefits. The Firm Size finding suggests that larger firms are more cost-efficient than smaller firms. Finally, the findings suggest that Solvency and Liquidity do not significantly contribute to (in) efficiency.

The most interesting finding related to reinsurance, because it is unexpected, based on the literature review that has been conducted. However, the UK Regulatory Capital regime pre January 2016 did not give credit for reinsurance in Regulatory Capital Requirements (So only cost came through the financial statements, with the benefit of reduced risk/volatility not quantified). The regime after January 2016 (known as Solvency II) does give credit to reinsurance (and derivatives) in the Regulatory Capital calculation, so a future study (when enough years have passed to create sufficient data) could consider reinsurance and derivatives again. If this switches from negative to positive significance, it will highlight the role of regulators in influencing cost efficiency.

The overall cost efficiency over the sample period of 66% is slightly lower than results produced by previous UK studies (e.g. 70% in Hardwick and Li (1997), and 76% in Ward (2002)). The validation test using the SFA (which was also used in previous studies) produced an average efficiency of 72%, which is more consistent with previous studies, and suggests the slight difference between the results of this study and those of previous studies might be partly due to methodological differences. There are research papers dedicated to exploring the significance of differences between the two approaches, and the findings appear to be inconclusive (some see statistically significant differences, while others do not).

Hardwick and Li (1997) found a similar finding for Office Location, but it was not statistically significant at the time. Reasons why the finding is now significant might include different approaches of looking at the Cost of Labour, since the earnings data in the Hardwick and Li (1997) study did not vary by Office Location, and changes to the economy in general, which now make it more cost-effective to operate from outside Central London than it might have done over 20 years ago (e.g. Broadband in more UK locations[68]). The affected companies may wish to consider moving their registered offices outside Central London. Technological advances (such as Broadband in more UK locations) and new working patterns (e.g. working more from home[69]) arguably support a more geographically diverse workforce. Hardwick and Li (1997) also found a similar finding for Firm Size, but it was again not statistically significant at the time. This might also be explained by technological advances (e.g. computing power might mean companies might now be able to use similar computer

[68] Current UK Broadband coverage is around 95%. Source: https://www.gov.uk/guidance/broadband-delivery-uk

[69] The increasing trend of remote working in the UK is discussed here: https://www.hso.co.uk/leased-lines/technology-news/homeworking-news/50-of-uk-workforce-to-work-remotely-by-2020

hardware regardless of the volume of data being processed. This could therefore lead to larger firms being more efficient). The solvency finding is not statistically significant and is consistent with similar findings from previous literature in this regard (e.g. Brockett et al. (2004)).

Reinsurance, Liquidity and Derivative Use do not appear to have been previously explored as determinants of cost efficiency in the insurance industry literature. This study therefore appears to make a novel contribution to this body of literature. In addition, the chapter also includes a correlation of 40% between cost efficiency scores and the FTSE 100 index, thus raising the question of whether cost efficiency since the most recent published results in academic literature can be approximated by a combination of the published result and the (pure or adjusted) movement of a published index since that result. This is proposed as a subject of future research.

5.2 Implications for Theory

This study appears to be the first in the UK Life insurance industry to consider cost efficiency during and after the Global Financial Crisis, as well as the first UK study to focus on potential FRM (in) efficiency drivers. It also adds to the body of empirical literature in this area in the UK (there appear to only be 5 pieces of published work that focus on the UK), and also adds to a relative new sub-area of research in Financial and Risk Management (there appear only be eight previously published studies globally, and only one of those appears to be focussed on the EU).

5.3 Implications for Practice

The findings suggest that reducing the use of some common FRM tools could help firms improve their operational efficiency. That said; this could change if EU Insurance Regulators fully recognise the benefits of risk mitigation techniques in Regulatory Capital requirements (which they have now done, as from 1 January 2016, so FRM determinants should be explored again in future). Long-term solutions to improve a firm's efficiency could include moving an office from Central London (where around 30% of registered offices for firms are based) to Greater London or a regional location, or increasing Firm Size by either growing organically, or merging with other firms. The methods in this study could also be easily implemented by fellow practitioners to monitor efficiency of their firms versus competitors on an ongoing basis.

5.4 Research Limitations

There are a number of limitations that emerged as part of this research. These are summarised in turn below.

A general limitation of insurance efficiency research appears to be the emergence of UK companies making use of offshore outsourcing arrangements for operational purposes, thus making it difficult to measure their actual inputs (and therefore accurate efficiency scores) of some firms. The efficiency results of any insurance efficiency study should therefore be read with this limitation in mind. Another general limitation comes with the efficiency measurement approach, regardless of which one is chosen. The main limitation with the parametric approach appears to be the number of key assumptions that are required in the cost or production function (e.g. the distribution of the error term), while the main limitation of the non-parametric approach is the loss of the statistical qualities that you get with a parametric approach. Since a non-parametric (DEA) approach is used, it comes with the relevant limitation. An additional methodological limitation relates to the non-separability assumption in the two-stage DEA approach of exploring drivers of efficiency or inefficiency. A recent study by Grant et al. (2017) includes support for the argument by Simar and Wilson (2011), which suggests that the main problem of the two-stage regression based DEA studies is that they pre-assume that the 'separability assumption' among the inputs/outputs and the control variables holds. Based on this assumption, Grant et al. (2017) suggest that these studies unrealistically assume that the support of the inputs/outputs used to produce the DEA estimates does not depend on the environmental/control variables used in the regression stage of the analysis. This is mitigated in this study by performing another of tests to ensure that the regression approach is statistically robust (i.e. multicollinearity and serial correlation tests).

Recent years have seen the rise of well-diversified Financial Services Groups, which – in addition to Life insurance – offer a number of other financial services. For example, one group offers asset management, life insurance and non-life insurance[70]. It is therefore possible that some inefficiency at the life insurance entity might be caused by deliberate cross-subsidies to maximise efficiency at the group level.

There are a number of limitations associated with the earnings data used in this study. Firstly, the Mutuals Public Register and the Financial Services Register to do not appear to offer the same depth of historical registered office address data that can be found on the Companies House website. In this instance, it was assumed that the firm was based at the same registered office throughout the sample period. There were 35 firms in this study that had data collected from these registers, and some of these firms might therefore have inaccurate historical office location data, which in turn might lead to them having inaccurate

[70] An example is Aviva plc. Source: https://www.aviva.com/

earnings data allocated to them. Secondly, the registered office location might not necessarily be where the majority of a firm's operations take place. For example, the registered office of Legal and General Assurance was in Central London throughout the data sample, but the bulk of their operations appear to have been based in Kingswood (Surrey, UK) in this period[71]. This could therefore lead to some firms getting incorrect efficiency scores assigned to them, and could also affect the overall level of efficiency in the industry. Thirdly, a previous UK study by Hardwick et al. (2011) appears to have used a sub-section of ONS wage data (called *Regional Trends*) that was specific to the financial sector, but also allowed for regional variation. This would have arguably been an ideal source for wage data in this study. However, that particular section of ONS data appears to have been discontinued in 2011[72], and is therefore not available for a significant part of the sample period. The data used is therefore considered to be the most appropriate data available. The final limitation relates to how the data is grouped, i.e. by local authority, and not strictly by postal town. Some office location earnings might therefore reflect a wider geographical area than just the postal town in question. For example, Borehamwood and Potters Bar both come under the Hertsmere local authority. That said, the benefit of being able to vary earnings by office location appears to far outweigh all these earnings-related limitations, given the role that labour costs have in the efficiency calculation, and the variety of earnings data by location. Data limitations also meant that only the impact of using or not using derivatives could be explored in the regression stage of the study, and not the extent of the use, which would have arguably been more valuable to practitioners. The extent of derivative use would require data of notional amounts for positions opened in a given year,

[71] Source: https://www.legalandgeneralgroup.com/media-centre/press-releases/archive?id=50345
[72] https://data.gov.uk/dataset/4d550211-015f-4e15-8339-da4bd0245ed3/regional-trends

as described by Shiu (2007). This data does not appear to be publicly available for the UK Insurance Industry, based on the regulatory returns data used in this study.

There are a number of ways of calculating the reinsurance ratio, and each comes with limitations. For example, a ratio based on claims or reserves in any given year, can potentially capture the impact of historical reinsurance arrangements, so potentially distorts the impact of reinsurance on efficiency in that year. On the other hand, using reinsurance premiums, which get past the historical data limitation, can potentially be distorted by unusual entries, which – based on one example looked at as part of this study – could be explained by firms needing to account for one-off transactions that cannot be captured anywhere else in the regulatory returns, so end up in the reinsurance premium line. The latter approach was considered to be more appropriate based on the literature review, so the relevant limitations apply. On the back of the reinsurance limitation, the cleansing of the data before the Efficiency Regression stage of the analysis meant that some firms in the first stage of the analysis were omitted from the second stage, with the total number of data points reducing from 1,117 in the first stage to 1,019 in the second stage. This was primarily due to some reinsurance ratios above 100%, as a result of the limitations associated with the chosen reinsurance ratio approach. This is not expected to materially alter the findings of the second stage, due to the large number of data points that remain.

The final limitation relates to the efficiency calculation model. One efficiency score was set to zero by the model, because it could not be computed based on the data provided. Sensitivity testing was done on both the efficiency score and the regression analysis, by setting this score to 100%, and this was found to have no impact on the overall findings, so the data was left unaltered. This chapter concludes with the potential areas of future research.

5.5 Future Research

There are a number of potential future studies that have emerged as part of this study. Firstly, this study attempts to analyse the impact of all Financial and Risk Management tools where data was available via the chosen data source. However, there were other Financial and Risk Management areas that appear to be of interest to practitioners, but which cannot be investigated due to lack of data. For example, in practice, UK life insurance companies appear to be moving into alternative illiquid investments to seek higher returns for policyholders and shareholders, due to low rates of return in traditional assets, which have been driven by the low interest rate environment (as discussed in section 1.1.7). It would therefore have been useful to explore the impact of (say) the level of Equity Release Mortgages on cost efficiency, to investigate whether this more bespoke approach to investing significantly affects cost efficiency one way or another. This could be the subject of future research, if the necessary data becomes available.

Secondly, this study found that reinsurance negatively impacts cost efficiency, with derivative use also having a negative coefficient, but suggests that the regulatory capital regime could be a key contributor to how these two Financial and Risk Management tools are viewed from an efficiency perspective. The regulatory capital regime changed significantly on 1 January 2016, with the introduction of Solvency II, and this had an impact on how reinsurance and derivatives are viewed for regulatory capital purposes. A future study – when sufficient post-2016 data emerges – could re-examine the relationship between these two tools and cost efficiency. The future study could follow a similar methodological approach to this study, and obtain data from similar sources (e.g. Standard and Poor's are starting to collect Solvency II regulatory data[73]).

Thirdly, chapter 4 includes a correlation of 40% between cost efficiency scores and the FTSE 100 index, and raises the question of whether cost efficiency since the most recent published results can be approximated by a combination of the published result and the (pure or adjusted) movement of a published index since that result. This is proposed as a subject of future research.

Fourthly, as with any purely empirical study, this study sheds some light on what the level of efficiency is in the industry, and what drives efficiency or inefficiency. What it does not do, is explore why some efficiency or inefficiency drivers behave the way they do, although it does make some suggestions. A future research project, using a qualitative approach that gets the views of practitioners – possibly through structured or semi-structured interviews – could help to explain why certain patterns or trends have been seen in the results.

Fifthly, previous UK-focussed efficiency studies in Life insurance appear to have focussed of efficiency or inefficiency drivers that required major changes to how a business was run, i.e. organisational form, corporate governance or distribution systems. Future research could explore the impact of efficiency or inefficiency drivers that could be implemented without major business changes, as this study has done with Financial and Risk Management. These drivers include Human Resource and Process Management or Product Pricing, which have

[73] Source: https://www.spglobal.com/marketintelligence/en/campaigns/regulatory-solutions

been explored in other insurance markets, so lessons could be learnt from the relevant studies before applying them to the UK insurance market.

Finally, this study has focussed on Cost Effiency in the Life Insurance Industry, and also looks at its component parts – namely technical and allocative efficiency, with consideration for scale efficiency done as part of choosing the appropriate Returns to Scale assumption (which – in this study – meant that scale efficiency scores did not need to be computed). However, this study does not explore the other two main categories of efficiency – namely Revenue and Profit efficiency - because the current focus on the industry appears to be on operational efficiency, in light of the challenging economic environment after the Global Financial Crisis. Future studies could therefore explore these additional efficiency categories when the industry focus shifts from operational efficiences to other types of efficiency.

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Appendices

Appendix 1: STATA Syntax and Code for DEA

STATA Command:

dea_allocative CostofLabour CostofCapital = Claims InvestedAssets , model (cost) rts (vrs) unitvars(LabourUnit CapitalUnit)

Program Code:

```
*! version 1.0.0  26SEP2011
*! Author: Choonjoo Lee
capture program drop dea_allocative
program define dea_allocative, rclass
   version 10.0

/** Terms Description:
 * ---------------------------------------------------------------------------
 * RTS: Return To Scale
 * CRS: Constant Return to Scale
 * VRS: Variant Return to Scale
 * ---------------------------------------------------------------------------
 */

// syntax checking and validation---------------------------------------------
// input varlist = output varlist
// example:
//    dea_allocative Employee Area = Sales Profits, model(c) values(1 2)
//    dea_allocative Employee Area = Sales Profits, model(r) values(2 2)
// ---------------------------------------------------------------------------
   // returns 1 if the first nonblank character of local macro `0' is a comma,
   // or if `0' is empty.
          if replay() {
      dis as err "ivars and ovars required."
      exit 198
   }

   // get and check invarnames
   gettoken word 0 : 0, parse("=,")
   while ~("`word'" == ":" | "`word'" == "=") {
      if "`word'" == "," | "`word'" == "" {
            error 198
      }
      local invarnames `invarnames' `word'
      gettoken word 0 : 0, parse("=,")
   }
   unab invarnames : `invarnames'
```

```
#del ;
syntax varlist(min=1) [if] [in] [using/],
                  MODel(string)             // ignore case sensitive {COST|REVENUE|PROFIT}
[
                  VALues(numlist >0)     //
                  UNITVars(varlist numeric) // unit variables for unit values
                  RTS(string)                 // ignore case sensitive,[{CRS|CCR}|{BCC|VRS}]
   TOL1(real 1e-14)    // entering or leaving value tolerance
   TOL2(real 1e-8)    // B inverse tolerance: 2.22e-12
   TRACE              // Whether or not to do the log
                  DETAIL                              // Detail Result Report
   SAVing(string)      // log file name
   REPLACE            // Whether or not to replace the log file
];
#del cr

local num_invar : word count `invarnames'
local i 1
while (`i'<=`num_invar') {
   local invarn : word `i' of `invarnames'
   local junk : subinstr local invarnames "`invarn'" "", ///
      word all count(local j)
   if `j' > 1 {
      di as error ///
         "cannot specify the same input variable more than once"
      error 498
   }
   local i = `i' + 1
}

// default model - CRS(Constant Return to Scale)
if ("`rts'" == "") local rts = "CRS"
else {
   local rts = upper("`rts'")
   if ("`rts'" == "CCR") local rts = "CRS"
   else if ("`rts'" == "BCC") local rts = "VRS"
   else if (~("`rts'" == "CRS" | "`rts'" == "VRS")) {
      di as err "option rts allow for case-insensitive " _c
      di as err "CRS (eq CCR) or VRS (eq BCC) or nothing."
      exit 198
   }
}

if ("`using'" != "") use "`using'", clear
if (~(`c(N)' > 0 & `c(k)' > 0)) {
   dis as err "dataset required!"
   exit 198
}
```

```
    // make value matrix, check invarnames count and values count as model
    tempname vmat
    local sizeof_values : list sizeof values
    local sizeof_unitvars : list sizeof unitvars
    if (`sizeof_values' > 0 & `sizeof_unitvars' > 0) {
            dis as err "values and unitvars cannot be used at the same time."
exit 198
    }

    if (`sizeof_values' > 0) {
            foreach value of numlist `values' {
                    matrix `vmat' = (nullmat(`vmat'), `value')
            }
    }
    else if (`sizeof_unitvars' > 0){
            mkmat `unitvars', mat(`vmat')
    }
    else {
            dis as err "values and unitvars should be used at least."
exit 198
    }

    local model = upper("`model'")
    if ("`model'" == "C") local model = "COST";
    else if ("`model'" == "R") local model = "REVENUE";
    else if ("`model'" == "P") local model = "PROFIT";
    if ("`model'" == "COST") {
            if (colsof(`vmat') != `num_invar') {
                    di as error "the number of input variable the same with " _c
                    di as error "the number of values in unitvars."
                    error 498
            }
    }
    else if("`model'" == "REVENUE") {
            local num_outvar : list sizeof varlist
            if (colsof(`vmat') != `num_outvar') {
                di as error "the number of output variable should be " _c
                    di as error "the same with the number of values in unitvars."
                    error 498
            }
    }
    else if("`model'" == "PROFIT") {
            local num_outvar : list sizeof varlist
            if (colsof(`vmat') != (`num_invar' + `num_outvar')) {
                    di as error "cannot different the sum of " _c
                    di as error "number of in/output variable and number of values."
                    error 498
```

```
		}
	}
	else {
		di as err "option model allow for case-insensitive " _c
		di as err "{C|COST or R|REVENUE or P|PROFIT}"
		exit 198
	}

// end of syntax checking and validation --------------------------------------

   set more off
   capture log close dea_allocative
   log using "dea_allocative.log", replace text name(dea_allocative)
   preserve

   if ("`if'" != "" | "`in'" != "") {
      qui keep `in' `if'  // filtering : keep in range [if exp]
   }

	if ("`model'" == "COST") {
		dea_cost, ivars(`invarnames') ovars(`varlist') rts(`rts') ///
		model(`model') unitcost(`vmat') tol1(`tol1') tol2(`tol2') ///
		`trace' `detail' saving(`saving') `replace'
	}
	else if("`model'" == "REVENUE") {
		dea_revenue, ivars(`invarnames') ovars(`varlist') rts(`rts') ///
		model(`model') unitprice(`vmat') tol1(`tol1') tol2(`tol2') ///
		`trace' `detail' saving(`saving') `replace'
	}
	else { // if("`model'" == "PROFIT")
		dea_profit, ivars(`invarnames') ovars(`varlist') rts(`rts') ///
		model(`model') unitvalue(`vmat') tol1(`tol1') tol2(`tol2') ///
		`trace' `detail' saving(`saving') `replace'
	}

   return add

   restore, preserve
   log close dea_allocative
end

***************************************************************************
*****
* DEA Cost - Data Envelopment Analysis Cost Model
***************************************************************************
*****
program define dea_cost, rclass
   #del ;
```

```
   syntax , IVARS(string) OVARS(string) RTS(string)
                          MODel(string) UNITCost(name)
   [
      TOL1(real 1e-14) TOL2(real 1e-8)
                 TRACE DETAIL SAVing(string) REPLACE
   ];
   #del cr

   preserve

   // -----------------------------------------------------------------------

   tempname dmuIn dmuOut frameMat
         tempname dearslt minIn theta
   mkDmuMat `ivars', dmumat(`dmuIn') sprefix("i")
   mkDmuMat `ovars', dmumat(`dmuOut') sprefix("o")
   local dmuCount = colsof(`dmuIn')
         local minrank = 1
         local detailYn = ("`detail'" != "") | ("`trace'" != "")

         // 1. Get Min Input
   mata: _l_mkframemat("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'")
         mata: _l_dealp ("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'", ///
                 "`unitcost'", `tol1', `tol2', "`trace'")

if (`detailYn') {
         di as result "Min Cost DEA Result:"
         matrix `dearslt' = J(`dmuCount', 1, .), r(dealprslt) // rank column
         mata: _setup_dearslt_names("`dearslt'", "`dmuIn'", "`dmuOut'")
         matrix list `dearslt', noblank nohalf noheader f(%9.6g)
}

         matrix `dearslt' = r(dealprslt)
         local i = (2 + `dmuCount')
         matrix `minIn' = `dearslt'[1...,`i'..(`i' + rowsof(`dmuIn') - 1)]

         // 2. Get Theta
         local ort = "IN"
         local stage = 1
         local minsubscript = 0 // false
         mata: _mkframemat("`frameMat'", "`dmuIn'", "`dmuOut'", ///
                         "`rts'", "`ort'")
         deamain `dmuIn' `dmuOut' `frameMat' `rts' `ort' `stage'  ///
                         `tol1' `tol2' `minsubscript' `trace'
         matrix `dearslt' = r(deamainrslt)
         matrix `theta' = `dearslt'[1...,1]

         // 3. Calculate Cost
```

```
        mata: _l_calc_cost("`unitcost'", "`dmuIn'", "`minIn'", "`theta'", `detailYn')
        matrix `dearslt' = r(mat)

    // ----------------------------------------------------------------------
    // REPORT
    // ----------------------------------------------------------------------
    di as result ""
    di as input "options: RTS(`rts')"
    di as result "`rts' DEA-Cost Efficiency Results:"
    matrix list `dearslt', noblank nohalf noheader f(%9.6g)

    if ("`saving'" != "") {
                    restore, preserve
        save_result `dearslt' `saving' `replace'
    }
    return matrix dearslt = `dearslt'

    restore, preserve
end

************************************************************************
*****
* DEA Revenue - Data Envelopment Analysis Revenue Model
************************************************************************
*****
program define dea_revenue, rclass
    #del ;
    syntax , IVARS(string) OVARS(string) RTS(string)
                            MODel(string) UNITPrice(name)
    [
        TOL1(real 1e-14) TOL2(real 1e-8)
                    TRACE DETAIL SAVing(string) REPLACE
    ];
    #del cr

    preserve

    // ----------------------------------------------------------------------

    tempname dmuIn dmuOut frameMat
        tempname dearslt maxOut eta
    mkDmuMat `ivars', dmumat(`dmuIn') sprefix("i")
    mkDmuMat `ovars', dmumat(`dmuOut') sprefix("o")
    local dmuCount = colsof(`dmuIn')
        local minrank = 1
        local detailYn = ("`detail'" != "") | ("`trace'" != "")

        // 1. Get Max Output
```

```
   mata: _l_mkframemat("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'")
          mata: _l_dealp ("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'", ///
                   "`unitprice'", `tol1', `tol2', "`trace'")

if (`detailYn') {
          di as result "Max Price DEA Result:"
          matrix `dearslt' = J(`dmuCount', 1, .), r(dealprslt) // rank column
          mata: _setup_dearslt_names("`dearslt'", "`dmuIn'", "`dmuOut'")
          matrix list `dearslt', noblank nohalf noheader f(%9.6g)
}



          matrix `dearslt' = r(dealprslt)
          local i = (2 + `dmuCount')
          matrix `maxOut' = `dearslt'[1...,`i'..(`i' + rowsof(`dmuOut') - 1)]

          // 2. Get Eta
          local ort = "OUT"
          local stage = 1
          local minsubscript = 0 // false
          mata: _mkframemat("`frameMat'", "`dmuIn'", "`dmuOut'", ///
                            "`rts'", "`ort'")
          deamain `dmuIn' `dmuOut' `frameMat' `rts' `ort' `stage'  ///
                            `tol1' `tol2' `minsubscript' `trace'
          matrix `dearslt' = r(deamainrslt)
          matrix `eta' = `dearslt'[1...,1]

          // 3. Calculate Cost
          mata: _l_calc_revenue("`unitprice'", "`dmuOut'", "`maxOut'", "`eta'", `detailYn')
          matrix `dearslt' = r(mat)

   // -----------------------------------------------------------------------
   // REPORT
   // -----------------------------------------------------------------------
   di as result ""
   di as input "options: RTS(`rts')"
   di as result "`rts' DEA-Revenue Efficiency Results:"
   matrix list `dearslt', noblank nohalf noheader f(%9.6g)

   if ("`saving'" != "") {
                   restore, preserve
      save_result `dearslt' `saving' `replace'
   }
   return matrix dearslt = `dearslt'

   restore, preserve
end
```

```
***********************************************************************
*****
* DEA Profit - Data Envelopment Analysis Profit Model
***********************************************************************
*****
program define dea_profit, rclass
   #del ;
   syntax , IVARS(string) OVARS(string) RTS(string)
                            MODel(string) UNITValue(name)
   [
      TOL1(real 1e-14) TOL2(real 1e-8)
                  TRACE DETAIL SAVing(string) REPLACE
   ];
   #del cr

   preserve

   // ---------------------------------------------------------------------

   tempname dmuIn dmuOut frameMat
          tempname dearslt
   mkDmuMat `ivars', dmumat(`dmuIn') sprefix("i")
   mkDmuMat `ovars', dmumat(`dmuOut') sprefix("o")
   local dmuCount = colsof(`dmuIn')
          local minrank = 1
          local detailYn = ("`detail'" != "") | ("`trace'" != "")

          // 1. Get Max Profit
   mata: _l_mkframemat("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'")
          mata: _l_dealp ("`model'", "`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'", ///
                "`unitvalue'", `tol1', `tol2', "`trace'")

if (`detailYn') {
          di as result "Max Profit DEA Result:"
          matrix `dearslt' = J(`dmuCount', 1, .), r(dealprslt) // rank column
          mata: _setup_dearslt_names("`dearslt'", "`dmuIn'", "`dmuOut'")
          matrix list `dearslt', noblank nohalf noheader f(%9.6g)
}

          matrix `dearslt' = r(dealprslt)

          // 2. Calculate Profit
          mata: _l_calc_profit("`unitvalue'", "`dmuIn'", "`dmuOut'", ///
                         "`dearslt'", `detailYn')
          matrix `dearslt' = r(mat)

   // ---------------------------------------------------------------------
   // REPORT
```

```
    // ----------------------------------------------------------------------
    di as result ""
    di as input "options: RTS(`rts')"
    di as result "`rts' DEA-Profit Efficiency Results:"
    matrix list `dearslt', noblank nohalf noheader f(%9.6g)

    if ("`saving'" != "") {
                    restore, preserve
      save_result `dearslt' `saving' `replace'
    }
    return matrix dearslt = `dearslt'

    restore, preserve
end

**************************************************************************
*****
* Save Result
**************************************************************************
*****
program define save_result, rclass
        args dearslt saving replace

        // if the saving file exists and replace option not specified,
        // make the backup file.
        if ("`replace'" == "") {
                local dotpos = strpos("`saving'",".")
                if (`dotpos' > 0) {
                        mata: _file_exists("`saving'")
                }
                else {
                        mata: _file_exists("`saving'.dta")
                }
                if r(fileexists) {
                        local curdt = subinstr("`c(current_date)'", " ", "", .) + /*
                                */ subinstr("`c(current_time)'", ":", "", .)
                        if (`dotpos' > 0) {
                                #del ;
                                local savefn = substr("`saving'", 1, `dotpos' - 1) +
                                                        "_bak_`curdt'" +
                                                        substr("`saving'",`dotpos', .);
                                #del cr
                                qui copy "`saving'" "`savefn'", replace
                        }
                        else {
                                local savefn = "`saving'_bak_`curdt'" + ".dta"
                                qui copy "`saving'.dta" "`savefn'", replace
                        }
```

```
            }
        }

        svmat `dearslt', names(eqcol)
        capture {
            renpfix _
            renpfix CUR cur_
            renpfix TECH tech_
            renpfix MIN min_
        }
        capture save `saving', replace
end

***********************************************************************
*****
* DEA Main - Data Envelopment Analysis Main
***********************************************************************
*****
program define deamain, rclass
    args dmuIn dmuOut frameMat rts ort stage tol1 tol2 minsubscript trace

    tempname efficientVec deamainrslt

    // stage step 1.
    if ("`trace'" == "trace") {
        di _n(2) as txt "RTS(`rts') ORT(`ort') 1st stage."
    }
    mata: _dealp("`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'", "`ort'", ///
        1, `tol1', `tol2', "`minsubscript'", "`efficientVec'", "`trace'")
    matrix `deamainrslt' = r(dealprslt)

    // stage step 2.
    if ("`stage'" == "2") {
        if ("`trace'" == "trace") {
            di _n(2) as txt "RTS(`rts') ORT(`ort') 2nd stage."
        }
        matrix `efficientVec' = `deamainrslt'[1...,1]

        mata: _dealp("`frameMat'", "`dmuIn'", "`dmuOut'", "`rts'", "`ort'", ///
            2, `tol1', `tol2', "`minsubscript'", "`efficientVec'", "`trace'")
        matrix `deamainrslt' = r(dealprslt)
    }

    return matrix deamainrslt = `deamainrslt'
end

***********************************************************************
*****
```

```
* Data Import and Conversion
*************************************************************************
*****

// Make DMU Matrix ---------------------------------------------------------
program define mkDmuMat
   #del ;
   syntax varlist(numeric) [if] [in], DMUmat(name)
   [
      SPREfix(string)
   ];
   #del cr

   qui ds
   // variable not found error
   if ("`varlist'" == "") {
      di as err "variable not found"
      exit 111
   }

   // make matrix
   mkmat `varlist' `if' `in', matrix(`dmumat') rownames(dmu)
   matrix roweq `dmumat' = "dmu"
   matrix coleq `dmumat' = `=lower("`sprefix'") + "slack"'
   matrix `dmumat' = `dmumat''
end

// Start of the MATA Definition Area ------------------------------------------
version 10
mata:
mata set matastrict on

// -------------------------------------------------------------------------
// Internal mata and stata combination.
// -------------------------------------------------------------------------

/**
 * calculate min cost
 */
function _l_calc_cost(
                    string scalar unitCost,
                    string scalar dmuIn,
                    string scalar minIn,
                    string scalar theta,
                    real scalar detail )
{
          real matrix UC, DI, MI, TT // input
          real matrix TI, CC, TC, MC // cost calculate result
```

```
        real matrix CCR, TCR, MCR  // sum of cost calculate result
real matrix OE, AE, TE, FR // cost efficiency final result

        string matrix DMU_CS            // dmu column stripes
string matrix FR_CS             // ce final result matrix column stripes
string matrix FR_RS             // ce final result matrix row stripes
        string matrix CS                // temp column stripes

        // input
        UC = st_matrix(unitCost)
        DI = st_matrix(dmuIn)'
        MI = st_matrix(minIn)
        TT = st_matrix(theta)

        // cost calculate result
        TI = TT:*DI // Thechnical Input
        CC = UC:*DI // Current Cost
        TC = UC:*TI // Technical Cost
        MC = UC:*MI // Min Cost

        // sum of cost calculate result
        CCR = rowsum(CC)
        TCR = rowsum(TC)
        MCR = rowsum(MC)

        // cost efficiency result
        OE = (MCR:/CCR) // Overall Efficiency
        AE = (MCR:/TCR) // Allocative Efficiency
        TE = (TCR:/CCR) // Technical Efficiency

        // final result
        FR = (DI, CCR, TT, TI, TCR, MI, MCR, OE, AE, TE)

        if (detail) {
                printf("\n{res}Input:\n");
    printf("\n{res}Unit Cost:\n"); UC
    printf("\n{res}DMU In:\n"); DI
                printf("\n{res}Min In:\n"); MI
                printf("\n{res}Theta:\n"); TT

                printf("\n{res}Temp Result:\n");
    printf("\n{res}Current Cost:\n"); CC
                printf("\n{res}Technical Cost:\n"); TC
                printf("\n{res}Min Cost:\n"); MC

                printf("\n{res}Final Result:\n"); FR
        }
```

```
        // return result
    st_matrix("r(mat)", FR)

        // ----------------------------------------------------------------------

        DMU_CS = st_matrixrowstripe(dmuIn)
        FR_RS = st_matrixcolstripe(dmuIn)

        CS = DMU_CS\("","cost")
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "CUR"))
        FR_CS = CS;

        CS = ("","theta")\DMU_CS\("", "cost")
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "TECH"))
        FR_CS = FR_CS\CS

        CS = DMU_CS\("", "cost")
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "MIN"))
        FR_CS = FR_CS\CS

        FR_CS = FR_CS\("","OE")\("","AE")\("","TE")

        // name the row and column of dea result matrix
    st_matrixrowstripe("r(mat)", FR_RS)
    st_matrixcolstripe("r(mat)", FR_CS)
}

/**
 * calculate max revenue
 */
function _l_calc_revenue(
            string scalar unitPrice,
            string scalar dmuOut,
            string scalar maxOut,
            string scalar eta,
            real scalar detail )
{
        real matrix UP, DO, MO, ET // input
        real matrix TO, CP, TP, MP // revenue calculate result
        real matrix CPR, TPR, MPR  // sum of revenue calculate result
    real matrix OE, AE, TE, FR // revenue efficiency final result

        string matrix DMU_CS          // dmu column stripes
    string matrix FR_CS           // ce final result matrix column stripes
    string matrix FR_RS           // ce final result matrix row stripes
        string matrix CS              // temp column stripes

        // input
```

```
        UP = st_matrix(unitPrice)
        DO = st_matrix(dmuOut)'
        MO = st_matrix(maxOut)
        ET = st_matrix(eta)

        // cost calculate result
        TO = ET:*DO // Thechnical Output
        CP = UP:*DO // Current Price
        TP = UP:*TO // Technical Price
        MP = UP:*MO // Max Price

        // sum of cost calculate result
        CPR = rowsum(CP)
        TPR = rowsum(TP)
        MPR = rowsum(MP)

        // cost efficiency result
        OE = (CPR:/MPR) // Overall Efficiency
        AE = (TPR:/MPR) // Allocative Efficiency
        TE = (CPR:/TPR) // Technical Efficiency

        // final result
        FR = (DO, CPR, ET, TO, TPR, MO, MPR, OE, AE, TE)

        if (detail) {
                printf("\n{res}Output:\n");
    printf("\n{res}Unit Price:\n"); UP
    printf("\n{res}DMU Out:\n"); DO
                printf("\n{res}Max Out:\n"); MO
                printf("\n{res}Eta:\n"); ET

                printf("\n{res}Temp Result:\n");
    printf("\n{res}Current Price:\n"); CP
                printf("\n{res}Technical Price:\n"); TP
                printf("\n{res}Max Price:\n"); MP

                printf("\n{res}Final Result:\n"); FR
        }

        // return result
st_matrix("r(mat)", FR)

        // ----------------------------------------------------------------------

        DMU_CS = st_matrixrowstripe(dmuOut)
        FR_RS = st_matrixcolstripe(dmuOut)

        CS = DMU_CS\("","price")
```

```
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "CUR"))
        FR_CS = CS;

        CS = ("","eta")\DMU_CS\("", "price")
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "TECH"))
        FR_CS = FR_CS\CS

        CS = DMU_CS\("", "price")
        replacesubmat(CS, 1, 1, J(rows(CS), 1, "MAX"))
        FR_CS = FR_CS\CS

        FR_CS = FR_CS\("","OE")\("","AE")\("","TE")

        // name the row and column of dea result matrix
    st_matrixrowstripe("r(mat)", FR_RS)
    st_matrixcolstripe("r(mat)", FR_CS)

}

/**
 * calculate max profit
 */
function _l_calc_profit(
                string scalar unitValue,
                string scalar dmuIn,
                string scalar dmuOut,
                string scalar dearslt,
                real scalar detail )
{

        real matrix UV, DI, DO, DR      // input: Unit Value, DMU In/Out, DEA Result
        real matrix UC, UP, CP          // Unit Cost, Unit Price, Current Profit
        real matrix MI, MC                      // Min In, Min Cost
        real matrix MO, MR, MP                  // Max Out, Max Revenue, Max Profit
        real matrix CPR, MCR, MRR       // Current Profit Result, Min Cost Result,
                                                        // Max Revenue Result
    real matrix OE, FR                  // result: Overall Efficiency, Final Result

    string matrix FR_CS         // ce final result matrix column stripes
    string matrix FR_RS         // ce final result matrix row stripes
        string matrix CS                // temp column stripes

        real scalar dmus, invars, outvars, vars

        // input
        UV = st_matrix(unitValue)
        DI = st_matrix(dmuIn)
        DO = st_matrix(dmuOut)
```

```
        DR = st_matrix(dearslt)

        dmus    = cols(DI)
        invars  = rows(DI)
        outvars = rows(DO)
        vars    = invars + outvars
        if (vars != cols(UV)) {
                _error(3200, sprintf("%s%s",
                        "size of in/out of dmu and size of unit values ",
                        "are not match!" ))
        }

        UC = UV[,1..invars]
        UP = UV[,1+invars..vars]
        CP = (UV' :* (-DI\DO))'

        DR = DR[,2..1+dmus]
        DR = ((DI\DO)*(DR'))' // restore

        MI = DR[,1..invars]
        MO = DR[,1+invars..vars]

        // profit calculate result
        MC = UC :* MI
        MR = UP :* MO

        // sum of profit calculate result
        CPR = rowsum(CP)
        MCR = rowsum(MC)
        MRR = rowsum(MR)

        // profit efficiency result
        MP = MRR :- MCR
        OE = CPR :/ MP

    // final result
        FR = (MO, MRR, MI, MCR, MP, CPR, OE)

        // Logging
        if (detail) {
                "Output:"
                "Unit Value:"; UV
                "Unit Cost:"; UC
                "Unit Profit:"; UP
                "Current Profit:"; CP

                "DMU In:"; DI
  "DMU Out:"; DO
```

```
			"DEA Result:"; DR
			"Min In:"; MI
			"Max Out:"; MO

			"Temp Result:";
	"Min Cost:"; MC
			"Max Revenue:"; MR

			"Final Result:"; FR
		}

		// return result
	st_matrix("r(mat)", FR)

		// ----------------------------------------------------------------------

		FR_RS = st_matrixcolstripe(dmuIn)

		CS = st_matrixrowstripe(dmuOut)
		replacesubmat(CS, 1, 1, J(rows(CS), 1, "MAX_H"))
		FR_CS = CS\("MAX","revenue");

		CS = st_matrixrowstripe(dmuIn)
		replacesubmat(CS, 1, 1, J(rows(CS), 1, "MIN_H"))
		FR_CS = FR_CS\CS\("MIN","cost");

		FR_CS = FR_CS\("MAX", "profit")\("CUR","profit")\("", "OE")

		// name the row and column of dea result matrix
	st_matrixrowstripe("r(mat)", FR_RS)
	st_matrixcolstripe("r(mat)", FR_CS)
}

/**
 * make frame matrix and set matrix value at the param frameMat
 * rts - return to scale, ort - orientation
 */
function _l_mkframemat(
			string scalar model,
			string scalar frameMat,
			string scalar dmuIn,
			string scalar dmuOut,
			string scalar rts )
{
	real matrix F, DI, DO
	real scalar dmus, variables, slackins, slackouts
	real scalar frows, fcols
```

```
DI = st_matrix(dmuIn)
DO = st_matrix(dmuOut)
if (cols(DI) != cols(DO)) {
   _error(3200, "in and out count of dmu is not match!")
}

dmus = cols(DI) // or cols(DO), because cols(DI) == cols(DO)
slackins = rows(DI); slackouts = rows(DO)

        if (model == "COST") variables = slackins
        else if (model == "REVENUE") variables = slackouts
        else variables = 0 // if (model == "PROFIT")

if (rts == "CRS") {
           // target coefficient\slackins\slackouts
   frows = 1 + slackins + slackouts
                   // target coefficient,theta,dmus,slackins,slackouts,rhs
   fcols = 1 + 1 + dmus + variables + slackins + slackouts + 1
}
else if (rts == "VRS") {
                   // target coefficient\slackins\slackouts\sum of lamda
   frows = 1 + slackins + slackouts + 1
                   // target coefficient,theta,dmus,variables,slackins,slackouts,rhs
   fcols = 1 + 1 + dmus + variables + slackins + slackouts + 1
}
else {
   _error(3498, "invalid rts optoin.")
}

// make frame matrix for CRS(CCR)
F = J(frows, fcols, 0)
F[1, 1] = 1
replacesubmat(F, 2, 3, DI)
replacesubmat(F, 2+slackins, 3, DO)
        if (model == "COST") {
                   replacesubmat(F, 2, 3+dmus, -I(variables))
                   replacesubmat(F, 2, 3+dmus+variables, I(slackins))
                   replacesubmat(F, 2+slackins, 3+dmus+variables+slackins, -I(slackouts))
        }
        else if (model == "REVENUE") {
                   replacesubmat(F, 2+slackins, 3+dmus, -I(variables))
                   replacesubmat(F, 2, 3+dmus+variables, I(slackins))
                   replacesubmat(F, 2+slackins, 3+dmus+variables+slackins, -I(slackouts))
        }
        else { // if (model == "PROFIT")
                   replacesubmat(F, 2, 3+dmus, I(slackins))
                   replacesubmat(F, 2+slackins, 3+dmus+slackins, -I(slackouts))
        }
```

```
   // adjustment
         if (rts == "VRS") {
      replacesubmat(F, frows, 3, J(1, dmus, 1))
      F[frows,fcols] = 1
   }

   // return result
   st_matrix(frameMat, F)
}

// ---------------------------------------------------------------------------
// Internal mata only.
// ---------------------------------------------------------------------------

/**
 * DEA Loop - Data Envelopment Analysis Loop for DMUs
 */
function _l_dealp (
                string scalar model,
                string scalar frameMat,
                string scalar dmuIn,
                string scalar dmuOut,
                string scalar rts,
                string scalar valueMat,
                real scalar tol1,
                real scalar tol2,
                string scalar trace )
{
   real matrix F, DI, DO, M, VARS, LPRSLT, DEALPRSLT, ARTIF, VM, RVM
   real scalar dmus, slackins, slackouts, slacks, artificials, artificialrow
   real scalar frows, fcols, i, dmui, variables, minYn, vari
   real colvector effvec, slackidx
   string scalar tracename

         struct BoundCond matrix boundF, boundM
         struct LpParamStruct scalar param

   F  = st_matrix(frameMat)
   DI = st_matrix(dmuIn)
   DO = st_matrix(dmuOut)
   if (cols(DI) != cols(DO)) {
      _error(3200, "in and out count of dmu is not match!")
   }
         if (!(rts == "CRS" || rts == "VRS")) {
                _error(3498, "rts must be one of CRS, VRS")
         }
         VM = st_matrix(valueMat)
```

```
// basic value setting for artificial variabels
frows = rows(F); fcols = cols(F)
dmus = cols(DI) // or cols(DO), because cols(DI) == cols(DO)
	if (rows(VM) != dmus) {
		VM = J(dmus, 1, VM);
	}

	slackins = rows(DI); slackouts = rows(DO)
	if (model == "COST") {
		minYn = 1 // minimized
		variables = slackins
	}
	else if (model == "REVENUE") {
		minYn = 0 // maximized
		variables = slackouts
	}
	else { // if (model == "PROFIT")
		minYn = 0 // maximized
		variables = 0
	}

tracename = rts

	// ---------------------------------------------------------------------
	// define number of slacks by rts
	slacks = variables + slackins + slackouts

	// define number of artificials by rts, ort, stage
	if (rts == "CRS") {
		artificials = slackouts; artificialrow = 2+slackins;
	}
	else if (rts == "VRS") {
		artificials = slackouts+1; artificialrow = 2+slackins
	}
	if (artificials > 0) {
		ARTIF = J(1, artificials, 1) \ J(frows-1, artificials, 0)
		replacesubmat(ARTIF, artificialrow, 1, I(artificials))
		F = F[,1..fcols-1], ARTIF, F[,fcols]
		frows = rows(F); fcols = cols(F) // revise frows, fcols
	}
	// ---------------------------------------------------------------------
boundF = J(1, fcols, BoundCond());
	// set the boundary for the efficiency variable(theta, eta):
	// -INFINITE <= efficiency <= INFINITE
	boundF[1,2].val = 0; boundF[1,2].lower = 0; boundF[1,2].upper = .

	// set boundary for the weight variable(lamda, mu):
```

```
	// 0 <= weight <= INFINITE
	for (i=3; i<dmus+3; i++) {
		boundF[1,i].val = 0; boundF[1,i].lower = 0; boundF[1,i].upper = .
	}

	// set boundary for the non-structural variable(slack, artificial).
	// 0 <= slacks and atrificials <= INFINITE
	for (i=dmus+3; i<fcols; i++) {
		boundF[1,i].val = 0; boundF[1,i].lower = 0; boundF[1,i].upper = .
	}
	// liststruct(boundF); // for debug

	// set the lp's parameters
	param.rts          = rts
	param.isin         = minYn // min
	param.stagestep    = 1 // 1 step
	param.dmus         = dmus
	param.slacks       = slacks
	param.artificials  = artificials
	param.tol1         = tol1
	param.tol2         = tol2
	param.isminsubscript = 0 // false
	param.trace        = trace
	// liststruct(param); // for debug
	// ---------------------------------------------------------------------
DEALPRSLT = J(0, 1+ dmus + slacks, 0)
	for (dmui=1; dmui<=dmus; dmui++) {
		M = F; boundM = boundF

		if (model == "COST") {
			replacesubmat(M, 2+slackins, fcols, DO[,dmui])
		}
		else if (model == "REVENUE") {
			replacesubmat(M, 2, fcols, DI[,dmui])
		}
		else { // if (model == "PROFIT")
			replacesubmat(M, 2, fcols, DI[,dmui])
			replacesubmat(M, 2+slackins, fcols, DO[,dmui])
		}

		// execute LP
		VARS   = lp_phase1(M, boundM, dmui, tracename, param)
		if (VARS[1,1] == .) {
			LPRSLT = J(1, cols(DEALPRSLT), .)
		}
		else {
			if (model != "PROFIT") {
				vari = dmus + 2 // variable start index
```

```
                                        for (i = 1; i <= variables; i++) {
                                                M[1,] = M[1,] + ((VARS :== vari++) * VM[dmui,i])
                                        }
                                        LPRSLT  =  l_lp_phase2(M,  boundM,  VARS,  dmui,  tracename,
param);
                                }
                                else { // if (model != "PROFIT")
                                        vari = 2 // dmu start index
                                        RVM = -VM[dmui,1..slackins], VM[dmui,1+slackins::cols(VM)]
                                        RVM = colsum(RVM' :* F[2..1+slackins+slackouts,3..2+dmus])
                                        for (i = 1; i <= dmus; i++) {
                                                M[1,] = M[1,] + ((VARS :== vari++) * RVM[1,i])
                                        }
                                        LPRSLT  =  l_lp_phase2(M,  boundM,  VARS,  dmui,  tracename,
param);
                                }
                        }
                        DEALPRSLT = DEALPRSLT \ LPRSLT
                }

   st_matrix("r(dealprslt)", DEALPRSLT)
}

real matrix function l_lp_phase2 (
                        real matrix M,
                        struct BoundCond matrix boundM,
                        real matrix VARS,
                        real scalar dmui,
                        string scalar aTracename,
                        struct LpParamStruct scalar param )
{
   real matrix orgVARS, LPRSLT
   real scalar j, phase
          real vector slackidx
   string scalar tracename, msg
          struct LpResultStruct scalar lpresult

   orgVARS = VARS

   tracename = aTracename + "-PII"
   if (param.trace == "trace") {
      displayas("txt")
      printf("\n----------[PHASE II]----------")
      printf("\n[DMUi=%g]%s: initialize matrix.\n",
         dmui, tracename); M
      printf("\n[DMUi=%g]%s: VARS.\n", dmui, tracename); VARS
   }
```

```
    phase = 2
    lpresult = lp(M, boundM, VARS, dmui, phase, tracename, param)

    // ---------------------------------------------------------------------------
    // phase 2 final.
    // ---------------------------------------------------------------------------
        if(lpresult.rc) {
            LPRSLT = J(1, 1+param.dmus+param.slacks, .)
        }
        else {
            // lpresult = theta(1) + dmus + slacks
            LPRSLT = J(1, 1+param.dmus+param.slacks, 0)
            for (j=1; j<=rows(lpresult.XB) ; j++) {
                if (VARS[1,j+1] > 0) LPRSLT[1, VARS[1,j+1]] =lpresult.XB[j, 1]
            }
        }

    if (param.trace == "trace") {
      msg = sprintf("[DMUi=%g]%s-FINAL", dmui, tracename);
      printf("\n%s: original VARS.\n", msg); orgVARS
      printf("\n%s: VARS.\n", msg); VARS
      printf("\n%s: XB.\n", msg); lpresult.XB
      printf("\n%s: LPRSLT.\n", msg); LPRSLT
    }

    return(LPRSLT)
}

end
// End of the MATA Definition Area ---------------------------------------------
```

Appendix 2: STATA output the SFA approach

Definitions of data inputs:

- *ln_TCM* is the natural log of the sum of the Total Cost Components summarised in Section 4.2.1 (Table 4-3).
- *ln_labour* is the natural log of the cost of labour summarised in Section 4.2.1 (Table 4-3).
- *ln_CoC* is the natural log of the cost of capital summarised in Section 4.2.1 (Table 4-3).
- *ln_assets* is the natural log of the invested assets summarised in Section 4.2.1 (Table 4-3).

```
. frontier ln_TCM ln_labour ln_CoC ln_claims ln_assets, cost

Iteration 0:   log likelihood = -1665.1251
Iteration 1:   log likelihood = -1660.9726
Iteration 2:   log likelihood = -1660.7467
Iteration 3:   log likelihood = -1660.7457
Iteration 4:   log likelihood = -1660.7457

Stoc. frontier normal/half-normal model          Number of obs     =      1,117
                                                 Wald chi2(4)      =    3995.86
Log likelihood = -1660.7457                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
      ln_TCM |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   ln_labour |  -.3028528   .0854708    -3.54   0.000    -.4703726    -.135333
      ln_CoC |   .5286531    .034791    15.20   0.000     .4604639    .5968422
   ln_claims |  -.0203436   .0350826    -0.58   0.562    -.0891043    .0484172
   ln_assets |   .7805304   .0396585    19.68   0.000     .7028011    .8582597
       _cons |    2.13298   .6889067     3.10   0.002     .7827481    3.483213
-------------+----------------------------------------------------------------
    /lnsig2v |  -.1777789   .0937017    -1.90   0.058    -.3614308     .005873
    /lnsig2u |  -.1469574   .2456432    -0.60   0.550    -.6284092    .3344943
-------------+----------------------------------------------------------------
     sigma_v |   .9149467    .042866                      .8346729    1.002941
     sigma_u |   .9291559   .1141204                      .7303696    1.182046
      sigma2 |   1.700458    .156727                      1.393279    2.007638
      lambda |    1.01553   .1505744                      .7204097     1.31065
------------------------------------------------------------------------------
LR test of sigma_u=0: chibar2(01) = 8.99                Prob >= chibar2 = 0.001
```

Appendix 3: STATA Code for the Simar & Wilson approach

```
*****************************************************************************
*****************************************************
**      SIMAR      &      WILSON      (2007)      TWO-STAGE      EFFICIENCY      ANALYSIS
***************************************************************************
*****************************************************************************
*****************************************************
*! version 2.20 2018-11-06 ht
*! version 2.19 2018-04-20 ht
*! version 2.18 2018-04-07 ht
*! version 2.17 2018-03-24 ht
*! version 2.16 2018-03-13 ht
*! version 2.15 2018-01-05 ht
*! version 2.14 2017-11-27 ht
*! version 2.13 2017-09-19 ht
*! version 2.12 2017-09-15 ht
*! version 2.11 2017-09-07 ht
*! version 2.10 2017-08-06 ht
*! version 2.9 2017-07-22 ht
*! version 2.8 2017-06-30 ht
*! version 2.7 2017-06-19 ht
*! version 2.6 2017-06-14 ht
*! version 2.5 2017-06-08 ht
*! version 2.4 2017-06-01 ht
*! version 2.3 2017-04-13 ht
*! version 2.2 2017-01-17 ht
*! authors Harald Tauchmann & Oleg Badunenko
*! Simar & Wilson two-stage Efficiency Analysis

capture program drop simarwilson
program simarwilson, eclass
** CHECK VERSION (For Handling Unicode Variables) **
if `c(stata_version)' < 14.2 {
   local str "str"
   local substr "substr"
   local ustr ""
   local subinstr "subinstr"
   version 12
}
else {
   local str "ustr"
   local substr "usubstr"
   local ustr "ustr"
   local subinstr "usubinstr"
   version 14.2
}
```

```
if !replay() {
                quietly {
        ** SET DEFAULTS FOR # OF REPETITIONS **
        local defaultbcreps = 100
        local defaultreps = 1000
        ** STORE COMMANDLINE ENTRY **
                        local cmd "simarwilson"
                        local cmdline "`cmd' `*'"
        ** SYNTAX DEFINITION **
        syntax anything(equalok) [if] [in] [pweight iweight], /*
        */ [REPS(integer `defaultreps')] [noUNIT] [noTWOsided] [LEVel(real `c(level)')] [DOTs] [SAVEAll(name)] [CINormal] [BBOOTstrap] [noCONStant] [noRTNorm] [OFFset(varname)] [DIFficult] [COLlinear] [CONSTraints(passthru)] [TECHnique(passthru)] [ITERate(passthru)] [TOLerance(passthru)] [LTOLerance(passthru)] [NRTOLerance(passthru)] [NONRTOLerance(passthru)] [FROM(passthru)] [CFORMAT(string asis)] [PFORMAT(string asis)] [SFORMAT(string asis)] [VSQUISH] [noOMITted] [BASELevels] [TRNoisily]/*
        */ [ALGorithm(integer 1)] [INVert] [LOGscore] [noPRInt] [noDEAPrint] [Rts(string)] [Base(string)] [BCReps(integer `defaultbcreps')] [REFerence(name)] [TEname(name)] [TEBC(name)] [BIASte(name)] [BCSAVEAll(name)] [EXTOLerance(real 37.5)]
        ** TEMPORARY FILES, MATRICES, and VARIABLES **
        ** TEMPVARS **
                        tempvar __tempid __tempwgh __rnn __yoff __iyy __truncfit __ntruncfit __yboot __esamp __deascore __indepnomis __deamark __reference __creference
        ** TEMPNAMES **
                        tempname __borg __coef __sig __cov __bbm __bbias __rank __Cns __BB __VB __BM __cip __ndeao __nmdeao __ndearefo __cnps
        ** TEMPNAMES FOR PLUGIN **
        tempname __yobs __xobs __nO __nI __nobs __yref __xref __nref __rt __ba __ifqh __intovar __teB __MatStar __ystar __xstar __DEAB __DEABC __DEABIAS
        ** TEMPFILES **
                        tempfile __resufile
        ** HANDLE MORE **
        local moreold `c(more)'
        set more off
        ** DISPLAY-FORMAT for WARNINGS **
                local ls   = c(linesize)-7
                local lshl = c(linesize)-7-3
        ** PARSEING ANYTHING **
        gettoken deasyntax varlist : anything, parse(")") match(paren) bind
        if "`paren'" == "" {
           local varlist "`deasyntax'"
           local deasyntax ""
        }
        else {
           gettoken left right : deasyntax, parse("(")
           if "`right'" != "" {
              display as error "{p 0 2 2 `ls'}invalid syntax{p_end}"
```

```
                                        exit 198
    }
  }
  ** CHECK VARLIST FOR MISPLACED CHACRACTERS **
  local mpcv = 0
  foreach cc in = "[" "]" "!" "+" "\" "&" "%" "}" "{" {
    local mpc = `str'pos("`varlist'","`cc'")
    local mpcv = `mpcv' + `mpc'
  }
  if `mpcv' > 0 {
                                        display as error "{p 0 2 2 `ls'}invalid syntax or invalid names in
{bf:`varlist'}{p_end}"
    exit 198
  }
  ** CHECK FOR EMPTY VARLIST **
  if "`varlist'" == "" {
    local vlempty = 1
    if "`constant'" == "noconstant" {
                                        display as error "{p 0 2 2 `ls'}neither indepvars nor constant
specified{p_end}"
      exit 198
    }
  }
  if "`deasyntax'" == "" & wordcount("`varlist'") == 1 & "`constant'" == "noconstant" {
                                        display as error "{p 0 2 2 `ls'}neither indepvars. nor constant
specified{p_end}"
      exit 198
  }
  ** PARSE DEA-SYNTAX **
  local deasyntax : list retokenize local(deasyntax)
  if "`deasyntax'" != "" & "`deasyntax'" != " " {
    gettoken oispec refspec : deasyntax, parse("(") match(paren) bind
    if "`oispec'" == "" & "`refspec'" != "" {
      local oispec "`refspec'"
      local refspec ""
    }
    if "`refspec'" != "" {
      display as error "{p 0 2 2 `ls'}option (ref_outputs = ref_inputs) not allowed;
`refspec' ignored{p_end}"
    }
    gettoken outps inps : oispec, parse("=")
    gettoken left inps : inps, parse("=")
    local outps : list uniq local(outps)
    local inps : list uniq local(inps)
   local nO  = `ustr'wordcount("`outps'")
   local nI  = `ustr'wordcount("`inps'")
    ** CHECK FOR OUTPUTS AND INPUTS BEEING MUTUALLY EXCLUSUVE **
    local oiintersec : list local(outps) & local(inps)
```

```
            if "`oiintersec'" != "" {
                display as error "{p 0 2 2 `ls'}lists of outputs and inputs must be mutually exclusive{p_end}"
                exit 198
            }
            ** CHECK FOR OUTPUT- AND INPUT-VARIABLES BEEING DEFINED AND NUMERIC OR SYNTAX BEING INVALID **
            cap confirm numeric variable `outps' `inps'
            if _rc != 0 {
                display as error "{p 0 2 2 `ls'}invalid syntax or not defined or non-numeric variable(s) in {bf:(`oispec')}{p_end}"
                exit _rc
            }
            ** CHECK FOR EMPTY INPUT- OR OUTPUT-LIST **
            if `nO' <= 0 | `nI' <= 0 {
                                display as error "{p 0 2 2 `ls'}at least one input and one output required{p_end}"
                exit 198
            }
        }
        ** HANDLE OPT. ALGORITHM **
        if `algorithm' != 1 & `algorithm' != 2 {
                                display as error "{p 0 2 2 `ls'}invalid value for option alg() specified; only 1 or 2 is allowed{p_end}"
                                exit 198
        }
        if `algorithm' == 2 & "`deasyntax'" == "" {
                                display as error "{p 0 2 2 `ls'}algorithm #2 requires (outputs = inputs){p_end}"
                                exit 198
        }
        if `algorithm' == 1 {
            local alg2opt ""
            if `bcreps' != 100 {
                local alg2opt "`alg2opt' bcreps(`bcreps')"
            }
            if "`tebc'" != "" {
                local alg2opt "`alg2opt' tebc(`tebc')"
            }
            if "`biaste'" != "" {
                local alg2opt "`alg2opt' biaste(`biaste')"
            }
            if "`bcsaveall'" != "" {
                local alg2opt "`alg2opt' bcsaveall(`bcsaveall')"
            }
            if "`alg2opt'" != "" & "`print'" != "noprint" {
                                  display as error "{p 0 2 2 `ls'}warning: no bias-correction with alg. #1;`alg2opt' ignored{p_end}"
```

```
            }
        }
        ** HANDLE VARIABLES TO GENERATE **
        if "`tename'" != "" & "`deasyntax'" != "" {
            confirm new variable `tename'
        }
        if "`tebc'" != "" & "`deasyntax'" != "" & "`algorithm'" == "2" {
            confirm new variable `tebc'
        }
        if "`biaste'" != "" & "`deasyntax'" != "" & "`algorithm'" == "2" {
            confirm new variable `biaste'
        }
        ** HANDLE TERADIAL OPTIONS IF NOT USED **
        if "`deasyntax'" == "" {
            local deaopt ""
            if "`rts'" != "" {
                local deaopt "`deaopt' rts(`rts')"
            }
            if "`base'" != "" {
                local deaopt "`deaopt' base(`base')"
            }
            if "`reference'" != "" {
                local deaopt "`deaopt' reference(`reference')"
            }
            if "`tename'" != "" {
                local deaopt "`deaopt' tename(`tename')"
            }
            if "`deaopt'" != "" & "`print'" != "noprint" {
                display as error "{p 0 2 2 `ls'}warning: external dea scores used;`deaopt'
ignored{p_end}"
            }
        }
        ** HANDLE TERADIAL OPTIONS **
        if "`deasyntax'" != "" {
            if "`rts'" == "" {
                local rts "CRS"
            }
            if upper(substr("`rts'",1,1)) == "C" {
                local rts "CRS"
            }
            if upper(substr("`rts'",1,1)) == "N" {
                local rts "NIRS"
            }
            if upper(substr("`rts'",1,1)) == "V" {
                local rts "VRS"
            }
            if "`base'" == "" {
                local base "output"
```

```
            }
            if upper(substr("`base'",1,1)) == "O" {
               local base "output"
            }
            if upper(substr("`base'",1,1)) == "I" {
               local base "input"
            }
            if "`base'" == "output" {
               if "`invert'" == "" {
                  local unit "nounit"
               }
               else {
                  local unit ""
               }
            }
            if "`base'" == "input" {
               if "`invert'" == "" {
                  local unit ""
               }
               else {
                  local unit "nounit"
               }
            }
                        if `bcreps' < 1 {
                                display as error "{p 0 2 2 `ls'}bcreps(`bcreps') too small for bias
correction{p_end}"
               exit 498
                        }
                        if `bcreps' < 100 & "`print'" != "noprint" & "`algorithm'" == "2" {
                                display as error "{p 0 2 2 `ls'}warning: bcreps(`bcreps') too
small for meaningful bias correction{p_end}"
                        }
         }
         ** HANDLE OPTION INVERT **
         if "`deasyntax'" != "" {
            if "`invert'" == "" {
               local expinvert = 1
               local printinvert "Farrell "
            }
            else {
               local expinvert = -1
               local printinvert "Shephard "
            }
         }
         else {
            if "`invert'" != "" & "`print'" != "noprint" {
```

```
            display as error "{p 0 2 2 `ls'}warning: opt. invert has no effect with externally estimated scores; invert left-hand-side variable manually to switch from Farrell to Shephard efficiency{p_end}"
         }
      }
      ** HANDLE OPTION TRNOISILY **
      if "`trnoisily'" != "" {
         local trn "noisily"
      }
                     ** DE-FACTOR-VARIABLERIZE VARLIST **
      if "`vlempty'" != "1" {
         local varlist : list uniq local(varlist)
         defvar `varlist'
         local varlist2 "`r(dfvl)'"
      }
      ** CHECK FOR NON-NUMERIC VARIABLES *
      cap confirm numeric variable `varlist2'
      if _rc != 0 & "`varlist2'" != "" {
         display as error "{p 0 2 2 `ls'}non-numeric variable(s) in varlist {bf:`varlist2'}{p_end}"
         exit _rc
      }
      ** HANDLE OPTION TENAME **
      if "`tename'" != "" {
          local savete "`tename'"
      }
      ** HANDLE OPTION LOGSCORE **
      if "`logscore'" != "logscore" {
         local trlim = 1
         local trlefte ""
      }
      else {
         local trlim = 0
         local trlefte "exp"
      }
                     ** HANDLE OPTION NOTWOSIDED **
      if ("`twosided'" == "notwosided") & (`algorithm' == 2) & ("`unit'" == "") & ("`print'" != "noprint") {
         display as error "{p 0 2 2 `ls'}warning: opt. notwosided not recommendable with alg. #2; in step 3.1 (alg. #2) sampling is from the twosided-truncated normal distribution{p_end}"
      }
      ** CHECK FOR EXCESSIVE NUMBER OF INPUTS AND OUTPUTS **
      if "`deasyntax'" != "" {
         mark `__deamark'
         markout `__deamark' `outps' `inps' `varlist2' `offset'
         if "`if'" == "" {
            local iffill "if"
         }
```

```
            else {
               local iffill "`if' &"
            }
            count `in' `iffill' `__deamark'==1
            if `nO' + `nI' >= r(N) {
               noi display as error  "{p 0 2 2 `ls'}number of DMUs (`r(N)') must be larger than sum of number of outputs (`nO') and inputs (`nI'){p_end}"
               exit 409
            }
         }
         ** HANDLE OPTION REFERENCE **
         if "`deasyntax'" == "" {
            gen `__reference' = 1
         }
         else {
            if "`reference'" == "" {
               gen `__reference' = 1
            }
            else {
               cap egen `__creference' = group(`reference')
               if _rc == 111 {
                  display as error "{p 0 2 2 `ls'}invalid reference spec.; {bf:`reference'} not found{p_end}"
                  exit 111
               }
               replace `__creference' = `__creference' -1
               cap tab `__creference'
               if r(r) > 2 | _rc == 134 {
                  display as error "{p 0 2 2 `ls'}invalid reference spec.; {bf:`reference'} not binary{p_end}"
                  exit 198
               }
               if r(r) < 2 {
                  display as error "{p 0 2 2 `ls'}no variation in {bf:`reference'}; opt. reference ignored{p_end}"
                  gen `__reference' = 1
               }
               else {
                  ** CHECK WETHER REFERENCE SET INCLUDES DMUs EXLUDED by IF or IN **
                  count `in' `iffill' (`__creference' == 1 & `__deamark'==1)
                  local nrefs = r(N)
                  count `in' `iffill' (`__creference' == 0 & `__deamark'==1)
                  local nrefs0 = r(N)
                  count if (`__creference' == 1 & `__deamark'==1)
                  local nrefa = r(N)
                  if `nrefa' > `nrefs' & "`print'" != "noprint" {
                     display as error "{p 0 2 2 `ls'}warning: simarwilson does not allow for ref. DMUs that are not included in the estimation sample{p_end}"
```

```
                }
                if `nrefs' == 0 & `nrefs0' > 0 {
                   display as error "{p 0 2 2 `ls'}reference set empty; opt. reference
ignored{p_end}"
                   gen `__reference' = 1
                }
                else {
                   if `nrefs' <= (`nO' + `nI') {
                      display as error "{p 0 2 2 `ls'}number of reference DMUs (`nrefs') must be
larger than sum of number of outputs (`nO') and inputs(`nI'); opt. reference ignored{p_end}"
                      gen `__reference' = 1
                   }
                   else {
                      gen `__reference' = `__creference'
                   }
                }
             }
          }
       }
                        ** HANDLE LEVEL **
                        if `level' >= 10 & `level' <= 99.99 {
          local level = round(`level',0.01)
          local level = substr("`level'",1,5)
                        }
                        else {
          if "`print'" != "noprint" {
             noisily display as error "{p 0 2 2 `ls'}warning: level(`level') not allowed, outside
[10,99.99] interval{p_end}"
          }
                                 local level = `c(level)'
                        }
       ** CHECK NUMBER of REPS **
       if `reps' < 2 {
          display as error "{p 0 2 2 `ls'}reps(`reps') too small for computing standard
errors{p_end}"
                                 exit 498
       }
                        if ("`cinormal'" != "cinormal" & `reps' < `defaultreps') & "`print'" !=
"noprint" {
                                 display as error "{p 0 2 2 `ls'}warning: reps(`reps') too small for
meaningful percentile CIs{p_end}"
                        }
                        ** HANDLE WEIGHT **
                        if "`weight'" != "" {
                                 gen double `__tempwgh' `exp'
                                 local weight2 = substr("`weight'",1,2)
                        }
                        else {
```

```
					gen `__tempwgh' = 1
					local weight2 "pw"
				}
				local exp2 "`__tempwgh'"
				** HANDLE TRUNCREG OPTIONS **
				local opttrunc "`constraints' `collinear' `noomitted' `difficult'
`technique' `tolerance' `ltolerance' `ntolerance' `nonrtolerance' `from'"
	local itetrunc "`iterate'"
				** TOKENIZE VARLIST **
	if "`deasyntax'" == "" {
				tokenize `varlist'
				local yy "`1'"
				local xx : list local(varlist) - local(yy)
	}
				** HANDLE DEPENDENT VARIABLE **
	if "`deasyntax'" == "" {
				foreach fo in "##" "#" "." {
					local check = `str'pos("`yy'","`fo'")
					if `check' != 0 {
						if "`fo'" == "##" | "`fo'" == "#" {
							display as error "{p 0 2 2 `ls'}depvar may not be
an interaction{p_end}"
							exit 198
						}
						else {
							display as error "{p 0 2 2 `ls'}depvar may not be
a factor variable{p_end}"
							exit 198

						}
					}
				}
	}
				** HANDLE OFFSET VARIABLE **
				foreach fo in "##" "#" "." {
					local check = `str'pos("`offset'","`fo'")
					if `check' != 0 {
						if "`fo'" == "##" | "`fo'" == "#" {
							display as error "{p 0 2 2 `ls'}interactions not
allowed in option offset(){p_end}"
							exit 101
						}
						else {
							display as error "{p 0 2 2 `ls'}factor variable not
allowed in option offset(){p_end}"
							exit 101

						}
```

```
                }
            }
            ** DE-FACTOR-VARIABLERIZE VARLIST **
    if "`vlempty'" != "1" {
        defvar `varlist'
        local varlist2 "`r(dfvl)'"
    }
            ** SELECT ESTIMATION SAMPLE **
            gen `__tempid' = _n
            preserve
            if "`if'" != "" {
                keep `if'
            }
            if "`in'" != "" {
                keep `in'
            }
            keep `__tempid' `__tempwgh' `varlist2' `offset' `outps' `inps'
`__reference'
            ** DROP MISSINGS **
    cap drop `__deamark'
    mark `__deamark'
    markout `__deamark' `outps' `inps' `varlist2' `offset' `__reference'
    keep if `__deamark' == 1
    sort `__reference' `__tempid'
    ** EXECUTE TERADIAL to OBTAIN UN-CORRECTED DEA-SCORES **
    if "`deasyntax'" != "" {
        teradial `outps' = `inps', rts(`rts') base(`base') tename(`__deascore')
reference(`__reference')
        mata : st_numscalar("`__nmdeao'", colmissing(st_data(.,"`__deascore'")))
        mata : st_numscalar("`__ndeao'", colnonmissing(st_data(.,"`__deascore'")))
        if `__ndeao' <= 0 {
            di as error "{p 0 2 2 `ls'}data envelopment analysis failed{p_end}"
            restore
            exit 498
        }
        if `__nmdeao' > 0 & "`print'" != "noprint" {
            local mnmdeao = `__nmdeao'
            di as error "{p 0 2 2 `ls'}warning: estimation of scores failed for `mnmdeao'
DMUs{p_end}"
        }
        mata : st_numscalar("`__ndearefo'",
colnonmissing((st_data(.,"`__deascore'"):/(st_data(.,"`__reference'")))))
        replace `__deascore' = (`__deascore')^(`expinvert')
        keep if `__deascore' <.
        if "`savete'" != "" {
            ** SAVE DEA SCORE PERMANANTELY **
            gen double `savete' = `__deascore'
            label variable `savete' "`printinvert'`base'-oriented efficiency score under `rts'"
```

```
            }
            ** FEED-IN DEA-SCORES **
            local yy "`__deascore'"
            local varlist : list local(__deascore) | local(varlist)
            local xx : list local(varlist) - local(yy)
        }
                        ** CHECK DEPENDENT VARIABLE **
        if "`deasyntax'" == "" & "`print'" != "noprint" {
            count if `yy' == 100
            local ny100 = r(N)
            count if `yy' > 25 & `yy' <= 100
            local sylarge = r(N)
            count if `yy' <.
            local sylarge = floor(100*`sylarge'/r(N))
        }
                        sum `yy' if `yy' <.
                        if r(min)< 0 {
            if "`deasyntax'" == "" {
                                display as error "{p 0 2 2 `ls'}nonpositive efficiency scores in
{bf:`yy'}{p_end}"
            }
            else if "`savete'" != "" {
                display as error "{p 0 2 2 `ls'}nonpositive efficiency scores in {bf:`savete'}{p_end}"
            }
            else {
                display as error "{p 0 2 2 `ls'}nonpositive efficiency scores found{p_end}"
            }
                                restore
                                exit 482
                        }
        if "`deasyntax'" == "" & "`print'" != "noprint" {
            if (r(min) > 0 & r(max) == 100 | `ny100' > 0 | `sylarge' > 50) {
                display as error "{p 0 2 2 `ls'}warning: for `ny100' obs {bf:`yy'} = 100, for
`sylarge'% of obs {bf:`yy'} > 25; check whether efficiency is inappropriately measured in
percent; if so rescale var. {bf:`yy'}{p_end}"
            }
        }
                        if r(min) < 1 & r(max) > 1 {
                                if "`unit'" == "" & "`print'" != "noprint" {
                if "`deasyntax'" == "" {
                                        display as error "{p 0 2 2 `ls'}warning: values of
{bf:`yy'} not bounded to unit interval{p_end}"
                }
                else if "`savete'" != "" {
                    display as error "{p 0 2 2 `ls'}warning: values of {bf:`savete'} not bounded to
unit interval{p_end}"
                }
                else {
```

```
                                    display as error "{p 0 2 2 `ls'}warning: efficiency
scores not bounded to unit interval{p_end}"
            }
                        }
                        if "`unit'" == "nounit" & "`print'" != "noprint" {
            if "`deasyntax'" == "" {
                                    display as error "{p 0 2 2 `ls'}warning: values of {bf:`yy'}
not bounded to [1,+inf) interval{p_end}"
            }
            else if "`savete'" != "" {
              display as error "{p 0 2 2 `ls'}warning: values of {bf:`savete'} not bounded to
[1,+inf) interval{p_end}"
            }
            else {
              display as error "{p 0 2 2 `ls'}warning: efficiency scores not bounded to [1,+inf)
interval{p_end}"
            }
                        }
                    }
                    if r(min) >= 0 & r(max) <= 1 & "`unit'" == "nounit" {
                        local unit ""
                    }
                    if (r(min) >= 1 & "`unit'" == "") {
                        local unit "nounit"
                    }
        ** TAKE LOG IF OPTION LOGSCORE **
        if "`logscore'" == "logscore" {
          replace `yy' = log(`yy')
        }
                    ** RUN PRECEDING OLS REGRESSION **
                    if "`offset'" != "" {
                        gen double `__yoff' = `yy' - `offset'
                    }
                    else {
                        gen double `__yoff' = `yy'
                    }
                    cap reg `__yoff' `xx' [`weight2' = `exp2']
        ** DETERMINE SAMPLESIZE **
        sum `exp2' if e(sample)
        local wsall = r(sum)
        local nnall = r(N)
        sum `exp2' if e(sample) & `yy' == `trlim'
        local wslim = r(sum)
        local nnlim = r(N)
                    if "`unit'" == "nounit" {
          sum `exp2' if e(sample) & `yy' < `trlim'
          local wsirreg = r(sum)
          local nnirreg = r(N)
```

```
        }
        else {
           sum `exp2' if e(sample) & `yy' > `trlim' & `yy' <.
           local wsirreg = r(sum)
           local nnirreg = r(N)
        }
                        ** RUN INITIAL TRUNCATED REGRESSION **
                        if "`unit'" == "" {
           if ("`twosided'" == "notwosided") | ("`logscore'" == "logscore") {

                           cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ul(`trlim') `constant'
offset(`offset') `opttrunc' `itetrunc'
           }
           else {
              cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ll(0) ul(1) `constant' offset(`offset')
`opttrunc' `itetrunc'
           }
                        }
                        else {
                              cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ll(`trlim')
`constant' offset(`offset') `opttrunc' `itetrunc'
                        }
                        if _rc != 0 | e(converged) != 1 {
           if e(converged) != 1 {
                                 display as error "{p 0 2 2 `ls'}convergence not achieved in
truncated regression{p_end}"
           }
           else {
              display as error "{p 0 2 2 `ls'}truncated regression failed{p_end}"
           }
                              ereturn clear
                              restore
           if _rc != 0 {
              exit _rc
           }
           else {
                                 exit 430
           }
                        }
        gen `__esamp' = 1 if e(sample)
                        local sig = e(sigma)
                        predict `__truncfit', xb
                        gen double `__ntruncfit' = `trlim'-`__truncfit'
                        matrix `__borg' = e(b)
        ** RECALCULATE SAMPLESIZE **
                        sum `exp2' if e(sample)
        local wgtsum = r(sum)
                        local tsamps = r(N)
```

```
** CHECK FOR EXTREMEY LARGE VALUES OF PREDICTED EFFICIENCY VALUES **
if `algorithm' == 1 {
   local nolimdmu "& `yy' != `trlim'"
}
if "`unit'" != "nounit" & ("`twosided'" != "notwosided" | `algorithm' ==2) & "`logscore'" != "logscore" {
   count if max(abs(`__ntruncfit'),abs(`__ntruncfit'-1)) >= `extolerance'*`sig' & `__ntruncfit' <. `nolimdmu'
   local diextval "max(abs((1-xb)/sigma),abs((-xb)/sigma))"
}
else {
   count if abs(`__ntruncfit') >= `extolerance'*`sig' & `__ntruncfit' <. `nolimdmu'
   local diextval "abs((`trlim'-xb)/sigma)"
}
if r(N) > 0 {
            display as error "{p 0 2 2 `ls'}extreme values for fitted efficiency encountered: `diextval' > `extolerance' for at least one DMU; bootstrap likely to fail; consider changing specification and check for possible outlier(s){p_end}"
            ereturn clear
            restore
            exit 498
}
        ** EXTRACT "EX-POST" VARLIST **
        local cn : colnames e(b)
local xx2 : subinstr local cn "_cons" "", all word
local xx2 : list retokenize xx2
if "`algorithm'" == "1" {
        ** TRANSFER RESULTS **
   local ic = e(ic)
   local k_eq = e(k_eq)
   local converged = e(converged)
   local rc = e(rc)
        local ll = e(ll)
   local df_m = e(df_m)
   local k_aux = e(k_aux)
   ** CHECK for CONSTRAINTS **
   if "`e(Cns)'" != "" {
      matrix `__Cns' = e(Cns)
      local iconstr "iconstr"
   }
}
        ** RUN SIMAR & WILSON BOOTSTRAPP **
local floop = 3-`algorithm'
** EXECUTE LOOP DEPENDING ON CHOICE of ALGORITHM ONE or TWO TIMES **
forvalues loop = `floop'/2 {
   if `loop' == 2 {
      ** PREVENT EXCESSIVE # of ITERATIONS in BOOTSTRAP
      local ic2 = max(3*`ic',25)
```

```
			if "`itetrunc'" == "" {
				local itetrunc "iterate(`ic2')"
			}
			else {
				local striter "`itetrunc'"
				local striter = regexr("`striter'","iterate","")
				local striter = `striter'
				if `striter' > `ic2' {
					local itetrunc "iterate(`ic2')"
				}
			}
		}
		** ACCOUNT FOR DIFFERENT NUMB. OF REPS. **
		if `loop' == 1 {
			local repsloop = `bcreps'
			local loopmark " (bias correction)"
		}
		else {
			local repsloop = `reps'
			if `algorithm' == 2 {
				local loopmark " (conf. intervals)"
			}
			else {
				local loopmark ""
			}
		}
		** DISPLAY ITERATION HEADER **
						if "`dots'" == "dots" {
						noisily: display _newline as text "Bootstrap`loopmark'
replications (" as result "`repsloop'" as text ")"
			noisily: display as text "{hline 4}{c +}{hline 3} 1 {hline 3}{c +}{hline 3} 2 {hline 3}{c
+}{hline 3} 3 {hline 3}{c +}{hline 3} 4 {hline 3}{c +}{hline 3} 5"
		}
		** START BOOSTRAP ITERATIONS **
		local bb = 1
		local cc = 0
					while `bb' <= `repsloop' {
			local cc = `cc'+1
			** ABORT BOOTSTRAP if MANY FAILURES **
						if `cc'-`bb' > `repsloop' {
				noi display as text " `cc'"
				noi display as error "{p 0 2 2 `ls'}excessive # of failed bootstr. reps; bootstr.
aborted{p_end}"
				local repsloop = `bb'
				local nbstrf = `cc'-`bb'
				if `bb' <= 2 {
					foreach mmat in `__BB' `__BM' `__MatStar' `__DEABC' `__DEABIAS'
`__DEAB' {
```

```
cap mata : mata drop `mmat'
}
ereturn clear
restore
exit 498
}
else {
continue, break
}
}
cap drop `__rnn'
** DRAW FROM TRUNCATED NORMAL DISTRIBUTION **
if "`unit'" == "" {
if ("`twosided'" == "notwosided" & `loop' == 2) | ("`logscore'" == "logscore") {
gen double `__rnn' = invnormal(runiform()*(normal(`__ntruncfit'/`sig')))*`sig'
}
else {
gen double `__rnn' = invnormal(normal((`__ntruncfit'-1)/`sig')+runiform()*(normal(`__ntruncfit'/`sig')-normal((`__ntruncfit'-1)/`sig')))*`sig'
}
}
else {
gen double `__rnn' = -invnormal((1-runiform())*normal(-`__ntruncfit'/`sig'))*`sig'
}
** CHECK FOR FAILURE IN GENERATING PSEUDO ERRORS **
count if `__rnn' >=. & `__ntruncfit' <.
local simfail = r(N)
** SWITCH TAIL if FAILURE IN GENERATING PSEUDO ERROR **
if `simfail' > 0 {
if "`unit'" == "" {
if ("`twosided'" == "notwosided" & `loop' == 2) | ("`logscore'" == "logscore") {
replace `__rnn' = -invnormal(1-(runiform()*(normal(`__ntruncfit'/`sig'))))*`sig' if (`__rnn' >=. & `__ntruncfit' <.)
}
else {
replace `__rnn' = -invnormal(1-(normal((`__ntruncfit'-1)/`sig')+runiform()*(normal(`__ntruncfit'/`sig')-normal((`__ntruncfit'-1)/`sig'))))*`sig' if (`__rnn' >=. & `__ntruncfit' <.)
}
}
else {
replace `__rnn' = invnormal(1-((1-runiform())*normal(-`__ntruncfit'/`sig')))*`sig' if (`__rnn' >=. & `__ntruncfit' <.)
```

```
   }
   ** CHECK AGAIN FOR FAILURES IN GENERATING PSEUDO ERRORS **
   count if `__rnn' >=. & `__ntruncfit' <.
   local simfail = r(N)
}
** CONTINUE IF FAILURE IN GENERATING PSEUDO ERRORS (Loop 2) **
if `simfail' > 0 & `loop' != 1 {
** DISPLAY ITERATION DOTS **
                                   if "`dots'" == "dots" {
                                             if `cc'/50 == round(`cc'/50) {
                                                       noisily: display as error "x" as text " `cc'"
                                             }
                                             else {
                                                       noisily: display as error "x" _continue
                                             }
                                   }
   continue
}
                         cap drop `__yboot'
** GENERATE BOOTSTRAP EFFICIENCY SCORES **
                         gen double `__yboot' = `__truncfit'+ `__rnn'
** LOOP 1: ESTIMATE BIAS-CORRECTED DEA-SCORES **
if `loop' == 1 {
   ** HANDLE PLUGIN te_radial **
   if `cc' == 1 {
      handleplugin
      ** CREATE MATRIZES FOR PLUGIN **
     mkmat `outps', matrix(`__yobs') nomissing
     mkmat `inps', matrix(`__xobs') nomissing
      mkmat `outps' if `__reference' == 1, matrix(`__yref') nomissing
      mkmat `inps'  if `__reference' == 1, matrix(`__xref') nomissing
      scalar `__nO' = colsof(`__yobs')
      scalar `__nI' = colsof(`__xobs')
      scalar `__nobs' = rowsof(`__yobs')
      scalar `__nref' = rowsof(`__yref')
      scalar `__ifqh' = 1
      scalar `__intovar' = 0
      matrix `__teB' = J(`__nobs', 1, .)
      matrix `__ystar' = `__yref'
      matrix `__xstar' = `__xref'
      ** HANDLE RTS within PLUGIN **
     if "`rts'" == "CRS" {
               scalar `__rt' = 3
     }
     else if "`rts'" == "NIRS" {
                         scalar `__rt' = 2
     }
               else if "`rts'" == "VRS" {
```

```
                                        scalar `__rt' = 1
                        }
                                else {
                                        display as error "{p 0 2 2 `ls'}invalid returns to
scale{p_end}"
                                        exit 198
                                }
                  ** HANDLE BASE within PLUGIN **
                  if "`base'" == "output" {
                     scalar `__ba' = 2
                  }
                  else if "`base'" == "input" {
                     scalar `__ba' = 1
                  }
                  else {
                     display as error "{p 0 2 2 `ls'}invalid base{p_end}"
                     exit 198
                  }
               }
               ** CONTINUE IF FAILURE IN GENERATING PSEUDO ERRORS (LOOP 1) **
               if `simfail' > 0 {
               ** DISPLAY ITERATION DOTS **
                                        if "`dots'" == "dots" {
                                                if `cc'/50 == round(`cc'/50) {
                                                        noisily: display as error "x" as text " `cc'"
                                                }
                                                else {
                                                        noisily: display as error "x" _continue
                                                }
                                        }
                  continue
               }
               ** DETERMINE OBSERVATION-RANGE for REFERENCE  **
               local fref = `__nobs'-`__nref'+1
               local lref = `__nobs'
               ** RESCALE VARS IN REFERENCE SET **
               if `__ba' == 1 {
                  ** CONSIDER LOGS IF OPTION LOGSCORE
                  if "`logscore'" != "logscore" {
                     mata : `__MatStar' = st_matrix("`__xref'") :* (st_data((`fref',`lref'), "`yy'") :/
st_data((`fref',`lref'),"`__yboot'")) :^(`expinvert')
                  }
                  else {
                     mata : `__MatStar' = st_matrix("`__xref'") :* exp((st_data((`fref',`lref'),
"`yy'") - st_data((`fref',`lref'),"`__yboot'"))) :^(`expinvert')
                  }
                  mata : st_matrix("`__xstar'",`__MatStar')
               }
```

```
		if `__ba' == 2  {
		   ** CONSIDER LOGS IF OPTION LOGSCORE
		   if "`logscore'" != "logscore" {
		     mata : `__MatStar' = st_matrix("`__yref'") :* (st_data((`fref',`lref'), "`yy'") :/ st_data((`fref',`lref'),"`__yboot'")) :^(`expinvert')
		   }
		   else {
		      mata : `__MatStar' = st_matrix("`__yref'") :* exp((st_data((`fref',`lref'), "`yy'") - st_data((`fref',`lref'),"`__yboot'"))) :^(`expinvert')
		   }
		   mata : st_matrix("`__ystar'",`__MatStar')
		}
		** CALL PLUGIN TO PERFORM DEA **
		plugin call te_radial, `__yobs' `__xobs' `__nO' `__nI' `__nobs' `__ystar' `__xstar' `__nref' `__rt' `__ba' `__ifqh' `__intovar' `__teB'
		** CONTINUE IF FAILED **
				if matmissing(`__teB') == 1 | rowsof(`__teB') != `__nobs' {
		   ** DISPLAY ITERATION DOTS **
					if "`dots'" == "dots" {
						if `cc'/50 == round(`cc'/50) {
							noisily: display as error "x" as text " `cc'"
						}
						else {
							noisily: display as error "x" _continue
						}
					}
		   continue
				}
		** DISPLAY ITERATION DOTS **
				if "`dots'" == "dots"  {
					if `cc'/50 == round(`cc'/50) | `bb' == `repsloop' {
						noisily: display as text ". `cc'"
					}
					else {
						noisily: display as text "." _continue
					}
				}
		** COLLECT BOOTSTRAP DEA-SCORES **
		if "`bcsaveall'" == "" {
				if `bb' == 1 {
		      mata : `__DEAB' = st_matrix("`__teB'") :^(`expinvert')
				}
				else {
		      mata : `__DEAB' = `__DEAB' + st_matrix("`__teB'") :^(`expinvert')
				}
		}
		else {
				if `bb' == 1 {
```

```
mata : `__DEAB' = st_matrix("`__teB'") :^(`expinvert')
                    }
                    else {
mata : `__DEAB' = (`__DEAB', st_matrix("`__teB'") :^(`expinvert'))
                    }
    }
}
** LOOP 2: TRUNCTED REGRESSION **
if `loop' == 2 {
    ** RUN TRUNCREG for BOOTRSTRAP SAMPLE **
                    if "`unit'" == "" {
                        if  ("`twosided'"  ==  "notwosided")  |  ("`logscore'"  ==
"logscore") {
cap truncreg `__yboot' `xx2' [`weight2' = `exp2'] if `yy' < `trlim', ul(`trlim')
`constant' offset(`offset') `opttrunc' `itetrunc'
        }
        else {
cap truncreg `__yboot' `xx2' [`weight2' = `exp2'] if `yy' < 1 & `yy' > 0, ll(0)
ul(1) `constant' offset(`offset') `opttrunc' `itetrunc'
        }
                    }
                    else {
                        cap truncreg `__yboot' `xx2' [`weight2' = `exp2'] if `yy' >
`trlim', ll(`trlim') `constant' offset(`offset') `opttrunc' `itetrunc'
                    }
    ** CONTINUE IF FAILED **
                    if _rc != 0 | e(converged) != 1 {
        ** DISPLAY ITERATION DOTS **
                        if "`dots'" == "dots" {
                            if `cc'/50 == round(`cc'/50) {
                                noisily: display as error "x" as text " `cc'"
                            }
                            else {
                                noisily: display as error "x" _continue
                            }
                        }
        continue
                    }
    ** DISPLAY ITERATION DOTS **
                    if "`dots'" == "dots"  {
                        if `cc'/50 == round(`cc'/50) | `bb' == `repsloop' {
                            noisily: display as text ". `cc'"
                        }
                        else {
                            noisily: display as text "." _continue
                        }
                    }
    ** COLLECT BOOTSTRAP COEFFICIENT ESTIMATES **
```

```
						if `bb' == 1 {
								mata : `__BB' = st_matrix("e(b)")
						}
						else {
								mata : `__BB' = (`__BB' \ st_matrix("e(b)"))
						}
				}
				** STOP BOOTSTRAP IF NUMB. of REQUESTED REPLICATIONS is REALIZED **
						local bb = `bb'+ 1
						if `bb' == `repsloop'+1 {
					local nbstrf = `cc'-(`bb'-1)
								continue, break
						}
					}
			if `loop' == 1 {
				if "`biaste'" != "" {
					** CALCULATE BIAS in DEA SCORES **
					if "`bcsaveall'" == "" {
						mata : `__DEABIAS' = `__DEAB'/(`bb'-1) - `trlefte'(st_data(., "`yy'"))
					}
					else {
						mata : `__DEABIAS' = (mean(`__DEAB''))' - `trlefte'(st_data(., "`yy'"))
					}
					** SAVE BIAS in DEA SCORE PERMANATELY **
					gen double `biaste' =.
					mata : st_store(.,"`biaste'",`__DEABIAS')
					label variable `biaste' "bootstrap bias estimate for `printinvert'`base'-oriented
efficiency score under `rts'"
				}
				** CALCULATE BIAS CORRECTED DEA-SCORES **
				if "`bcsaveall'" == "" {
					mata : `__DEABC' = `trlefte'(st_data(., "`yy'")) - (`__DEAB'/(`bb'-1) -
`trlefte'(st_data(., "`yy'")))
				}
				else {
					mata : `__DEABC' = `trlefte'(st_data(., "`yy'")) - ((mean(`__DEAB''))' -
`trlefte'(st_data(., "`yy'")))
				}
				** CHECK FOR NON-POSITIVE BC-SCORES AND ISSUE WARNING **
				mata : st_numscalar("`__cnps'", min(`__DEABC'))
				if `__cnps' < 0 & "`print'" != "noprint" {
					if "`base'" == "input" {
						display as error "{p 0 2 2 `ls'}warning: bias-correction yields at least one
negative score; consider specifying opt. invert or switching to base(output){p_end}"
					}
					else {
						display as error "{p 0 2 2 `ls'}warning: bias-correction yields at least one
negative score; consider dropping opt. invert or switching to base(input){p_end}"
```

```
		}
	}
	** WRITE BIAS CORRECTED SCORES TO DATA **
	mata : st_store(.,"`yy'",`__DEABC')
	if "`tebc'" != "" {
		** SAVE BIAS CORRECTED DEA SCORE PERMANATELY **
		gen double `tebc' = `yy'
		label variable `tebc' "`printinvert'bias-corrected `base'-oriented efficiency
score under `rts'"
	}
	** COUNT NEGATIVE SCORES **
	if `__cnps' < 0 {
		count if `yy' < 0
		local nnneg = r(N)
	}
	** RE-COUNT LIMIT-SCORES (Count will be zero unless some error occurs) **
	sum `exp2' if `yy' == 1
	local wslim = r(sum)
	local nnlim = r(N)
	** RE-COUNT IRREGULAR SCORES **
	if "`unit'" == "nounit" {
		sum `exp2' if `yy' < 1
		local wsirreg = r(sum)
		local nnirreg = r(N)
	}
	else {
		sum `exp2' if `yy' > 1 & `yy' <.
		local wsirreg = r(sum)
		local nnirreg = r(N)
	}
	** TAKE LOGS IF OPTION LOGSCORE **
	if "`logscore'" == "logscore" {
		replace `yy' = log(`yy')
	}
	** RE-RUN INITIAL TRUNCATED REGRESSION **
			if "`unit'" == "" {
		if ("`twosided'" == "notwosided") | ("`logscore'" == "logscore") {

				cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ul(`trlim') `constant'
offset(`offset') `opttrunc' `itetrunc'
		}
		else {
			cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ll(0) ul(1) `constant'
offset(`offset') `opttrunc' `itetrunc'
		}
			}
			else {
```

```
                    cap `trn' truncreg `yy' `xx' [`weight2' = `exp2'], ll(`trlim')
`constant' offset(`offset') `opttrunc' `itetrunc'
                }
                if _rc != 0 | e(converged) != 1 {
            if e(converged) != 1 {
                        display as error "{p 0 2 2 `ls'}convergence not achieved in
truncated regression{p_end}"
            }
            else {
               display as error "{p 0 2 2 `ls'}truncated regression failed{p_end}"
            }
                    ereturn clear
            mata : mata drop `__DEAB' `__DEABC' `__MatStar'
            if "`biaste'" != "" {
               mata : mata drop `__DEABIAS'
            }
                    restore
                    if _rc != 0 {
               exit _rc
            }
            else {
                        exit 430
            }
                }
                local sig = e(sigma)
          cap drop `__truncfit' `__ntruncfit'
                predict double `__truncfit', xb
                gen double `__ntruncfit' = `trlim'-`__truncfit'
                matrix `__borg' = e(b)
          ** RE-CALCULATE SAMPLESIZE **
                sum `exp2' if e(sample)
          local wgtsum = r(sum)
                local tsamps = r(N)
          ** CHECK FOR EXTREMELY LARGE VALUES OF PREDICTED EFFICIENCY VALUES **
          if "`unit'" != "nounit" & "`twosided'" != "notwosided" & "`logscore'" != "logscore"
{
            count if max(abs(`__ntruncfit'),abs(`__ntruncfit'-1)) >= `extolerance'*`sig' &
`__ntruncfit' <.
          }
          else {
            count if abs(`__ntruncfit') >= `extolerance'*`sig' & `__ntruncfit' <.
          }
          if r(N) > 0 {
                    display as error "{p 0 2 2 `ls'}extreme values for fitted
efficiency encountered: `diextval' > `extolerance' for at least one DMU; bootstrap likely to
fail; consider changing specification and check for possible outlier(s){p_end}"
                        ereturn clear
            mata : mata drop `__DEAB' `__DEABC' `__MatStar'
```

```
        if "`biaste'" != "" {
          mata : mata drop `__DEABIAS'
        }
                    restore
                    exit 430
      }
                ** TRANSFER RESULTS **
      local ic = e(ic)
      local k_eq = e(k_eq)
      local converged = e(converged)
      local rc = e(rc)
                local ll = e(ll)
      local df_m = e(df_m)
      local k_aux = e(k_aux)
      ** CHECK for CONSTRAINTS **
      if "`e(Cns)'" != "" {
        matrix `__Cns' = e(Cns)
        local iconstr "iconstr"
      }
      cap drop `__esamp'
                  gen `__esamp' = 1 if e(sample)
    }
    if `loop' == 2 {
                ** CALCULATE BOOTSTRAP MEAN & BIAS **
                mata : `__BM' = mean(`__BB')
                mata : st_matrix("`__bbm'",`__BM')
                local colsob = colsof(`__borg')
                local colsbb = colsof(`__bbm')
      if `colsob' != `colsbb' {
        foreach mmat in `__BB' `__BM' `__MatStar' `__DEABC' `__DEABIAS' `__DEAB' {
          cap mata : mata drop `mmat'
        }
        ereturn clear
                      restore
        di as error "{p 0 2 2 `ls'}conformability error; bias correction failed{p_end}"
        exit 503
      }
      else {
                mat `__bbias' =  `__bbm' - `__borg'
                ** CALCULATE COVARIANCE-MATRIX **
        mata : `__VB' = quadvariance(`__BB')
        mata : st_matrix("`__cov'",`__VB')
                ** CALCULATE PERCENTILE CONFIDENCE INTERVALS **
        cipsimarwilson `level' `__BB' `__cip'
      }
    }
  }
  ** CLEAR MATA **
```

```
if "`algorithm'" == "2" {
   mata : mata drop `__MatStar' `__DEABC'
   if "`biaste'" != "" {
      mata : mata drop `__DEABIAS'
   }
   if "`bcsaveall'" != "" {
      mata : `__DEAB' = `__DEAB''
      capture mata : mata drop `bcsaveall'
      mata : mata rename `__DEAB' `bcsaveall'
   }
   else {
      mata : mata drop `__DEAB'
   }
}
if "`saveall'" == "" {
   mata : mata drop `__BB' `__VB' `__BM'
}
else {
   mata : mata drop `__VB' `__BM'
   capture mata : mata drop `saveall'
   mata : mata rename `__BB' `saveall'
}
                    ** RENAME RESULTS **
if "`algorithm'" == "1" {
   local scoretype "score"
}
else {
   local scoretype "bcscore"
}
                    local nc = colsof(`__borg')-1
                    local psig = 1+`nc'
                    mat `__coef' = `__borg'[1...,1..`nc']
                    mat `__sig' = `__borg'[1...,`psig'..`psig']
** RENAME COLUMNS FOR e(b) AND e(V) **
if `c(stata_version)' < 15 {
   mat coleq `__sig' = sigma
   mat colname `__sig' = _cons
}
else if `c(userversion)' < 15 {
   mat coleq `__sig' = sigma
   mat colname `__sig' = _cons
}
else {
   mat coleq `__sig' = /
   mat colname `__sig' = sigma
}
if "`deasyntax'" != "" & "`algorithm'" == "1" {
   if "`tename'" == "" {
```

```
        mat coleq `__coef' = `scoretype'
        local yynew "`scoretype'"
    }
    else {
        mat coleq `__coef' = `tename'
        local yynew "`tename'"
    }
}
else if "`deasyntax'" != "" & "`algorithm'" == "2" {
    if "`tebc'" == "" {
        mat coleq `__coef' = `scoretype'
        local yynew "`scoretype'"
    }
    else {
        mat coleq `__coef' = `tebc'
        local yynew "`tebc'"
    }
}
else {
    mat coleq `__coef' = `yy'
    local yynew "`yy'"
}
                mat `__borg' = (`__coef',`__sig')
                local cn : colfullnames `__borg'
                matrix colnames `__cov' = `cn'
                matrix rownames `__cov' = `cn'
                matrix rownames `__cip' = `cn'
                matrix colnames `__cip' = cip`level':ll cip`level':ul
                matrix `__cip' = `__cip''
                matrix colnames `__bbias' = `cn'
matrix colnames `__bbm' = `cn'
 ** RESTORE ORIGNIAL SAMPLE **
if "`deasyntax'" == "" | ("`algorithm'" == "1" & "`tename'" == "") {
    keep `__tempid' `__esamp'
}
if "`deasyntax'" != "" & "`algorithm'" == "1" & "`tename'" != "" {
    keep `__tempid' `__esamp' `savete'
}
if "`algorithm'" == "2" {
    local keepvar "`__tempid' `__esamp'"
    if "`savete'" != "" {
        local keepvar "`keepvar' `savete'"
    }
    if "`tebc'" != "" {
        local keepvar "`keepvar' `tebc'"
    }
    if "`biaste'" != "" {
        local keepvar "`keepvar' `biaste'"
```

```
    }
    keep `keepvar'
  }
  sort `__tempid'
          save `__resufile'
  restore
  merge 1:1 `__tempid' using `__resufile', nogenerate update replace force
  replace `__esamp' = 0 if `__esamp' != 1
  ** CALCULATE NUMBERS OF OBSERVATIONS **
  if "`weight2'" == "iw" {
    local samps = round(`wgtsum')
    local N_lim = round(`wslim')
    local N_all = round(`wsall')
    local N_irreg = round(`wsirreg')
  }
     else {
    local samps = `tsamps'
    local N_lim = `nnlim'
    local N_all = `nnall'
    local N_irreg = `nnirreg'
     }
  ** POST RESULTS TO e() **
          ereturn clear
  if "`iconstr'" == "iconstr" {
    ereturn post `__borg' `__cov' `__Cns', properties(b V) obs(`samps')
esample(`__esamp') findomitted
  }
  else {
           ereturn post `__borg' `__cov', properties(b V) obs(`samps')
esample(`__esamp') findomitted
  }
          ** WALD TEST of NULL-MODEL **
          if `df_m' > 0 {
              test [`yynew']
              local wchi2 = `r(chi2)'
              local wp = `r(p)'
          }
          else {
              local wchi2 = .
              local wp = .
          }
          ** RANK OF e(V) **
          mata : st_matrix("`__rank'",rank(st_matrix("e(V)")))
          ** SCALARS **
  ereturn scalar N = `samps'
  ereturn scalar N_lim = `N_lim'
  ereturn scalar N_all = `N_all'
  ereturn scalar N_irreg = `N_irreg'
```

```
if "`weight'" != "" {
   ereturn scalar wgtsum = `wgtsum'
}
ereturn scalar sigma = `sig'
ereturn scalar ll = `ll'
ereturn scalar ic = `ic'
ereturn scalar converged = `converged'
ereturn scalar rc =  `rc'
ereturn scalar rank = `__rank'[1,1]
ereturn scalar k_eq = `k_eq'
ereturn scalar df_m = `df_m'
ereturn scalar k_aux = `k_aux'
ereturn scalar chi2 = `wchi2'
ereturn scalar p = `wp'
                     ereturn scalar N_reps = `reps'
ereturn scalar N_misreps = `nbstrf'
ereturn scalar level = `level'
ereturn scalar algorithm = `algorithm'
** SCALARS (DEA) **
if "`deasyntax'" != "" {
   if "`algorithm'" == "2" {
      ereturn scalar N_dea = `__nobs'
      if "`nnneg'" != "" {
         ereturn scalar N_deaneg = `nnneg'
      }
      else {
         ereturn scalar N_deaneg = 0
      }
      ereturn scalar N_dearef = `__nref'
      ereturn scalar N_bc  = `bcreps'
   }
   else {
      ereturn scalar N_dea = `__ndeao'
      ereturn scalar N_dearef = `__ndearefo'
   }
   ereturn scalar ninps  = `nI'
   ereturn scalar noutps = `nO'
}
                     ** MATRICES **
                     ereturn matrix ci_percentile = `__cip'
                     ereturn matrix bias_bstr = `__bbias'
ereturn matrix b_bstr = `__bbm'
** MACROS (DEA) **
if "`deasyntax'" != "" {
   ereturn local outputs "`outps'"
   ereturn local inputs "`inps'"
   ereturn local base "`base'"
   ereturn local rts "`rts'"
```

```
    if "`tename'" != "" {
        ereturn local tename "`tename'"
    }
    if "`tebc'" != "" {
        ereturn local tebc "`tebc'"
    }
    if "`biaste'" != "" {
        ereturn local biaste "`biaste'"
    }
}
ereturn local bcsaveall `bcsaveall'
ereturn local saveall `saveall'
                    ereturn local offset `offset'
ereturn local cinormal `cinormal'
ereturn local bbootstrap `bbootstrap'
if "`deasyntax'" == "" {
    ereturn local depvarname "`yy'"
}
if "`deasyntax'" != "" & "`tename'" != "" & "`algorithm'" == "1" {
    ereturn local depvarname "`tename'"
}
if "`deasyntax'" != "" & "`tebc'" != "" & "`algorithm'" == "2" {
    ereturn local depvarname "`tebc'"
}
if "`deasyntax'" != "" {
    ereturn local deatype "internal"
}
else {
    ereturn local deatype "external"
}
ereturn local scoretype "`scoretype'"
** MACROS (else) **
ereturn local predict "truncr_p"
ereturn local marginsok "default XB E(passthru)"
if "`unit'" == "nounit" {
    ereturn local marginsdefault "predict(e(`trlim',.))"
}
else if ("`twosided'" == "notwosided") | "`logscore'" == "logscore" {
    ereturn local marginsdefault "predict(e(.,`trlim'))"
}
else {
    ereturn local marginsdefault "predict(e(0,1))"
}
                    if "`weight'" != "" {
    ereturn local wexp  "`exp'"
    ereturn local wtype "`weight'"
                    }
                    if "`unit'" == "" {
```

```
				ereturn local unit "unit"
			}
			else {
				ereturn local unit `unit'
			}
	if "`e(unit)'" == "unit" {
	   ereturn local depvar "efficiency"
	}
	else {
	   ereturn local depvar "inefficiency"
	}
	if "`invert'" == "invert" {
	   ereturn local invert "Shephard"
	}
	else {
	   ereturn local invert "Farrell"
	}
			if ("`twosided'" == "notwosided") | ("`unit'" == "nounit") |
("`logscore'" == "logscore") {
				ereturn local truncation "onesided"
			}
			else {
				ereturn local truncation "twosided"
			}
	if "`logscore'" == "logscore" {
	   ereturn local logscore `logscore'
	}
	ereturn local cmd `cmd'
	ereturn local cmdline `cmdline'
	ereturn local shorttitle "Simar & Wilson (2007) eff. analysis"
	ereturn local title "Simar & Wilson (2007) two-stage efficiency analysis"
	   }
	   set more `moreold'
	 }
   else {
      ** HANDLE RE-DISPLAY OF RESULTS **
      if "`e(cmd)'" != "simarwilson" {
			error 301
		}
		else {
			syntax, [LEVel(real `e(level)')] [CINormal] [BBOOTstrap]
[CFORMAT(string asis)] [PFORMAT(string asis)] [SFORMAT(string asis)] [VSQUISH] [noPRINT]
[noDEAPrint] [noOMITted] [BASELevels]
	** GENERATE TEMPORARY MATRIX FOR PERCENTILE CIs **
	tempname __cip
			** HANDLE LEVEL **
			if `level' >= 10 & `level' <= 99.99 {
	   local level = round(`level',0.01)
```

```
            local level = substr("`level'",1,5)
                        }
                        else {
            if "`print'" != "noprint" {
              noisily display as error "{p 0 2 2 `ls'}warning: level() outside [10,99.99] interval not allowed{p_end}"
            }
                                    local level = `e(level)'
                        }
          /*
          if "`e(cinormal)'" == "cinormal" {
            local cinormal "cinormal"
          }
          */
                  }
  }
  ** DISPLAY RESULTS **
         ** SET DISPLAY-OPTIONS (Deactivated!) **
         if "`cformat'" == "" | "`cformat'" != "" {
      if "`cformat'" != "" & "`cformat'" != "%9.0g" & "`print'" != "noprint" {
        di as text "{p 0 2 2 `ls'}sorry, spec. cformat(`cformat') ignored{p_end}"
      }
                  local cformat "%9.0g"
         }
         if "`pformat'" == "" | "`pformat'" != "" {
      if "`pformat'" != "" & "`pformat'" != "%5.3f" & "`print'" != "noprint" {
        di as text "{p 0 2 2 `ls'}sorry, spec. pformat(`pformat') ignored{p_end}"
      }
                  local pformat "%5.3f"
         }
         if "`sformat'" == "" | "`sformat'" != "" {
      if "`sformat'" != "" & "`sformat'" != "%8.2f" & "`print'" != "noprint" {
        di as text "{p 0 2 2 `ls'}sorry, spec. sformat(`sformat') ignored{p_end}"
      }
                  local sformat "%8.2f"
         }
  ** SET DEFAULT DEPVARNAME (IF NOT SAVED TO e()) **
  if "`e(depvarname)'" != "" {
    if "`e(logscore)'" != "logscore" {
      local edepvarname "`e(depvarname)'"
    }
    else {
      local edepvarname "ln(`e(depvarname)')"
    }
  }
  else {
    if "`e(logscore)'" != "logscore" {
      local edepvarname "`e(scoretype)'"
```

```
    }
    else {
      local edepvarname "ln(`e(scoretype)')"
    }
  }
        ** SET PARAMETERS FOR SKIPPING (determine values for _skip()) **
        if "`e(unit)'" == "unit" {
                local inq "<"
        }
        else {
                local inq ">"
        }
  if "`e(logscore)'" != "logscore" {
                local trlim = 1
        }
        else {
                local trlim = 0
        }
  ** ABBREVIATE TOO-LONG DEPVARNAME **
  local shortdvn = abbrev("`edepvarname'",20)
        local inei "inefficient if `shortdvn'"
        if "`e(df_m)'" != "" {
        if `e(df_m)' > 0 {
                local fskip = 1+floor(log10(`e(df_m)'))
        }
        else {
                local fskip = 1
        }
        }
        else {
                local fskip = 1
        }
        local tabwidth = 78
        local statwidth = 37
        local statwidth2 = 12
  local statwidthtext = 27
  local statwidthval = 10
        local statskip = `tabwidth'-`statwidth'
  local ciskip  = 7 - strlen("`level'")
  local ciskip2 = 7 - strlen("`e(level)'")
        local rr = 0
  ** LOOP OVER STATISTICS TO BE DISPLAYED **
        foreach disp in "Number of obs" "Number of efficient DMUs" "Number of bootstr.
reps" "Wald chi2(" "Prob > chi2(" "Number of super-eff. DMUs" {
          local rr = `rr'+1
                if `rr' == 1 {
                        local statskip`rr' = `statskip' - `str'len("`e(shorttitle)'")
                }
```

```
		local disp`rr' "`disp'"
		local ldisp`rr'= strlen("`disp'")
		local skip`rr' = `statwidth' - `statwidth2' - `ldisp`rr''
		if `rr' == 2 {
			local statskip`rr' = `statskip' - `str'len("(algorithm #`e(algorithm)')")
		}
		if `rr' == 4 | `rr' == 5 {
			local skip`rr' = `statwidth' - `ldisp`rr'' - `fskip' - 1 - `statwidth2'
		}
		if `rr' == 4 {
			local statskip`rr' = `statskip' - `str'len("`inei'") - 4
		}
		if `rr' == 5 {
			local statskip`rr' = `statskip' - strlen("`e(truncation)'") - 11
		}
	}
	** DISPLAY RESULTS on SCREEN **
  if "`e(wtype)'" != "" {
    di as text "(sum of wgt is" as text %10.7e `e(wgtsum)' as text ")"
  }
	display _newline as text "`e(shorttitle)'" _skip(`statskip1') as text "`disp1'" _skip(`skip1') as text " =  " as result %8.0f `e(N)'
  display as text "(algorithm #" as result "`e(algorithm)'" as text ")" _skip(`statskip2') as text "`disp2'" _skip(`skip2') as text " =  " as result %8.0f `e(N_lim)'
	**display _skip(`statskip') as text "`disp2'" _skip(`skip2') as text " =  " as result %8.0f `e(N_lim)'
  if `e(N_irreg)' > 0 & `e(N_irreg)' <. {
     display _skip(`statskip') as text "`disp6'" _skip(`skip6') as text " =   " as result %8.0f `e(N_irreg)'
  }
  display _skip(`statskip') as text "`disp3'" _skip(`skip3') as text " =   " as result %8.0f `e(N_reps)'
  if ("`e(unit)'" == "nounit") | ("`e(logscore)'" == "logscore") {
	display _skip(`statskip') as text "`disp4'" as result %`fskip'.0f `e(df_m)' as text ")" _skip(`skip4') as text " =  " as result %8.2f `e(chi2)'
     display as text "`inei'" as result " `inq' " as text "`trlim'" _skip(`statskip4') as text "`disp5'" as result %`fskip'.0f `e(df_m)' as text ")" _skip(`skip5') as text " =  " as result %8.4f `e(p)' _newline
  }
  else {
	display as text "`inei'" as result " `inq' " as text "`trlim'" _skip(`statskip4') as text "`disp4'" as result %`fskip'.0f `e(df_m)' as text ")" _skip(`skip4') as text " =  " as result %8.2f `e(chi2)'
	display as text "`e(truncation)' truncation" _skip(`statskip5') as text "`disp5'" as result %`fskip'.0f `e(df_m)' as text ")" _skip(`skip5') as text " =  " as result %8.4f `e(p)' _newline
  }
  ** DISPLAY DEA RESULTS on SCREEN **
  if "`deaprint'" == "" {
```

```
display as text "{hline `tabwidth'}"
local deatitleprint "Data Envelopment Analysis:"
display as text "Data Envelopment Analysis:" _continue
if "`e(noutps)'" == "" & "`e(ninps)'" == "" {
   local exdeaprint "externally estimated scores"
   local exdeaskip = `tabwidth' - `str'len("`deatitleprint'") - `str'len("`exdeaprint'")
   display _skip(`exdeaskip') as text "`exdeaprint'" _newline
}
else {

   ** DISPLAY ORINENTATION **
   local ortprint "`e(base)' oriented (`e(invert)')"
   local ortskip = `str'len("`ortprint'")
   ** DISPLAY RETURNS TO SCALE **
   if "`e(rts)'" == "VRS" {
      local rtsprint "variable returns to scale"
   }
   if "`e(rts)'" == "NIRS" {
      local rtsprint "nonincreasing returns to scale"
   }
   if "`e(rts)'" == "CRS" {
      local rtsprint "constant returns to scale"
   }
   local rtsskip = `str'len("`rtsprint'")
   ** DISPLAY BIAS CORRECTION **
   if "`e(N_bc)'" != "" {
      local ibcprint "bias corrected efficiency measure"
   }
   else {
      local ibcprint "no bias correction"
   }
   local ibcskip = `str'len("`ibcprint'")
   ** DISPLAY NUMBER of DMUs **
   local dmuprint "Number of DMUs"
   local dmuskip1 = `tabwidth' - `statwidth' - `str'len("`deatitleprint'")
   local dmuskip2 = `statwidthtext' - `str'len("`dmuprint'") -1
   local dmuskip3 = `statwidthval' - `str'len("`e(N_dea)'")
   display _skip(`dmuskip1') as text "`dmuprint'" _skip(`dmuskip2') as text "="
_skip(`dmuskip3') as result "`e(N_dea)'"
   ** DISPLAY NUMBER of REFERENCE DMUs **
   local refprint "Number of ref. DMUs"
   local refskip2 = `statwidthtext' - `str'len("`refprint'") -1
   local refskip3 = `statwidthval' - `str'len("`e(N_dearef)'")
   if "`e(N_bc)'" != "" {
      local refskip1 = `tabwidth' - `statwidth'
      display _skip(`refskip1') as text "`refprint'" _skip(`refskip2') as text "="
_skip(`refskip3') as result "`e(N_dearef)'"
   }
```

```
        else {
           local refskip1 = `tabwidth' - `statwidth' - `ortskip'
           display as text "`ortprint'" _skip(`refskip1') as text "`refprint'" _skip(`refskip2') as
text "=" _skip(`refskip3') as result "`e(N_dearef)'"
        }
        ** DISPLAY NUMBER of OUTPUTs **
        local outpsprint "Number of outputs"
        local outpsskip2 = `statwidthtext' - `str'len("`outpsprint'") -1
        local outpsskip3 = `statwidthval' - `str'len("`e(noutps)'")
        if "`e(N_bc)'" != "" {
           local outpsskip1 = `tabwidth' - `statwidth' - `ortskip'
           display as text "`ortprint'" _skip(`outpsskip1') as text "`outpsprint'"
_skip(`outpsskip2') as text "=" _skip(`outpsskip3') as result "`e(noutps)'"
        }
        else {
           local outpsskip1 = `tabwidth' - `statwidth' - `rtsskip'
           display as text "`rtsprint'" _skip(`outpsskip1') as text "`outpsprint'"
_skip(`outpsskip2') as text "=" _skip(`outpsskip3') as result "`e(noutps)'"
        }
        ** DISPLAY NUMBER of INPUTs **
        local inpsprint "Number of inputs"
        local inpsskip2 = `statwidthtext' - `str'len("`inpsprint'") -1
        local inpsskip3 = `statwidthval' - `str'len("`e(ninps)'")
        if "`e(N_bc)'" != "" {
           local inpsskip1 = `tabwidth' - `statwidth' - `rtsskip'
           display  as text "`rtsprint'" _skip(`inpsskip1') as text "`inpsprint'" _skip(`inpsskip2')
as text "=" _skip(`inpsskip3') as result "`e(ninps)'"
        }
        else {
           local inpsskip1 = `tabwidth' - `statwidth' - `ibcskip'
           display  as text "`ibcprint'" _skip(`inpsskip1') as text "`inpsprint'" _skip(`inpsskip2')
as text "=" _skip(`inpsskip3') as result "`e(ninps)'" _newline
        }
        if "`e(N_bc)'" != "" {
           ** DISPLAY NUMBER of REPS (BIAS CORRECTION) **
           local bcprint "Number of reps (bc)"
           local bcskip1 = `tabwidth' - `statwidth' - `ibcskip'
           local bcskip2 = `statwidthtext' - `str'len("`bcprint'") -1
           local bcskip3 = `statwidthval' - `str'len("`e(N_bc)'")
           display as text "`ibcprint'" _skip(`bcskip1') as text "`bcprint'" _skip(`bcskip2') as text
"=" _skip(`bcskip3') as result "`e(N_bc)'" _newline
        }
     }
  }
         if "`cinormal'" == "cinormal" {
     ** DISPLAY REGRESSION TABLE WITH NORMAL-APPROX-CIs **
     local ccn = abbrev("`e(depvar)'",12)
     local colsk = 13 - `str'len("`ccn'")
```

```
        display as text "{hline 13}{c TT}{hline 64}"
        if "`bbootstrap'" == "" {
            display _column(13) as text " {c |}  Observed" _skip(3) "Bootstrap" _skip(25) "Normal
approx."
        }
        else {
            display _column(13) as text " {c |} Bootstrap" _skip(3) "Bootstrap" _skip(25) "Normal
approx."
        }
        display _column(`colsk') as text "`ccn' {c |}" _skip(6)  "Coef." _skip(3) "Std. Err." _skip(6)
"z" _skip(4) "P>|z|" _skip(`ciskip') "[" as result `level' as text "% Conf. Interval]"
        display as text "{hline 13}{c +}{hline 64}"
        local ccn = `substr'(abbrev("`edepvarname'",12),1,12)
        local colsk = 13 - `str'len("`ccn'")
        display as result "`ccn'" as text _skip(`colsk') "{c |}"
        ** GEN TEMPORARY MATRICES FOR DISPLAY
        tempname __dima __dima2 __dima3 __dima4 __bt
        if "`bbootstrap'" == "" {
            matrix `__bt' = e(b)'
        }
        else {
            matrix `__bt' = e(b_bstr)'
        }
        mata : st_matrix("`__dima2'" , diagonal(st_matrix("e(V)")):^0.5)
        mata : st_matrix("`__dima3'" , st_matrix("`__bt'"):/st_matrix("`__dima2'"))
        mata : st_matrix("`__dima4'", 2*normal(-1*abs(st_matrix("`__dima3'"))))
        matrix `__dima' = (`__bt',`__dima2', `__dima3', `__dima4',`__bt'+ invnormal((1-
0.01*`level')/2)*`__dima2',`__bt'- invnormal((1-0.01*`level')/2)*`__dima2')
    }
    else {
        ** DISPLAY REGRESSION TABLE WITH PERCENTILE-CIs **
        ** RECALCULATE PERCENTILE CIs if REQUIRED **
        if "`e(level)'" != "`level'" & "`e(saveall)'" != "" {
            cipsimarwilson `level' `e(saveall)' `__cip'
            local nlevel "`level'"
            mat scip = `__cip'
        }
        else {
            mat `__cip' = e(ci_percentile)'
            local nlevel "`e(level)'"
        }
        local ccn = abbrev("`e(depvar)'",12)
        local colsk = 13 - `str'len("`ccn'")
        display as text "{hline 13}{c TT}{hline 64}"
        if "`bbootstrap'" == "" {
            display _column(13) as text " {c |}  Observed" _skip(3) "Bootstrap" _skip(27)
"Percentile"
        }
```

```
        else {
          display _column(13) as text " {c |} Bootstrap" _skip(3) "Bootstrap" _skip(27)
"Percentile"
        }
        display _column(`colsk') as text "`ccn' {c |}" _skip(6)  "Coef." _skip(3) "Std. Err." _skip(6)
"z" _skip(4) "P>|z|" _skip(`ciskip') "[" as result `nlevel' as text "% Conf. Interval]"
        display as text "{hline 13}{c +}{hline 64}"
        local ccn = `substr'(abbrev("`edepvarname'",12),1,12)
        local colsk = 13 - `str'len("`ccn'")
        display as result "`ccn'" as text _skip(`colsk') "{c |}"
        tempname __dima __dima2 __dima3 __dima4 __bt
        if "`bbootstrap'" == "" {
          matrix `__bt' = e(b)'
        }
        else {
          matrix `__bt' = e(b_bstr)'
        }
        mata : st_matrix("`__dima2'" , diagonal(st_matrix("e(V)")):^0.5)
        mata : st_matrix("`__dima3'" , st_matrix("`__bt'"):/st_matrix("`__dima2'"))
        mata : st_matrix("`__dima4'", 2*normal(-1*abs(st_matrix("`__dima3'"))))
        matrix `__dima' = (`__bt',`__dima2',`__dima3',`__dima4',`__cip')
      }
      local cn = rowsof(`__dima')
      local cns : rownames `__dima'
      tokenize `cns'
      forvalues cc = 1(1)`cn' {
        if `cc' == `cn' {
          local ccn "/sigma"
        }
        else {
          local ccn = abbrev("``cc''",12)
        }
        local colsk = 13 - `str'len("`ccn'")
        if ("`omitted'" == "" | `substr'("`ccn'",1,2) != "o.") & ("`baselevels'" == "baselevels" |
`str'pos("`ccn'","b.") == 0) {
          display _column(`colsk') as text "`ccn' {c |}" /*
          */ _skip(2) as result `cformat' `__dima'[`cc',1] /*
          */ _skip(2) as result `cformat' `__dima'[`cc',2] /*
           */ _skip(1) as result `sformat' `__dima'[`cc',3] /*
           */ _skip(3) as result `pformat' `__dima'[`cc',4] /*
           */ _skip(4) as result `cformat' `__dima'[`cc',5] /*
           */ _skip(3) as result `cformat' `__dima'[`cc',6]
        }
        if `cc' == `cn'-1 {
          if "`e(offset)'" != "" {
            local ccn = abbrev("`e(offset)'",12)
            local colsk = 13 - `str'len("`ccn'")
```

```
            display _column(`colsk') as text "`ccn' {c |}" _skip(2) as result `cformat' 1 _skip(2) as
text "(offset)"
         }
         display as text "{hline 13}{c +}{hline 64}"
      }
      if `cc' == `cn' {
         display as text "{hline 13}{c BT}{hline 64}"
      }
   }
   ** DISPLAY WARNING if CHANGE in LEVEL for PECENTILE CIs is REQUESTED WITHOUT
SPCIFYING SAVEALL() **
   if replay() & "`e(level)'" != "`level'" & "`cinormal'" != "cinormal" & "`e(saveall)'" == "" {
      noisily display as error "{p 0 2 2 `ls'}saveall() not previously specified; cannot change
level for percentile CIs; use opt. cinormal{p_end}"
   }
   ** SAVE SOME RESULTS IN r() **
   putr `__dima' `level'
end

**************************************************************************
**********************************
**                 PERCENTILE                 CONFIDENCE                 INTERVALLS
*************************************************************************
**************************************************************************
**********************************
capture program drop cipsimarwilson
program cipsimarwilson, nclass
version 12
          args level BB cip
          ** TEMPORARY NAMES **
   tempname __CIB __CIBI __cc __rr
   mata : st_numscalar("`__cc'",cols(`BB'))
   mata : st_numscalar("`__rr'",rows(`BB'))
   local nb = `__cc'
          local llo = 1+floor(`__rr'*((100-`level')/200))
          local ulo =    ceil(`__rr'-`__rr'*((100-`level')/200))
   local cw = min(max(((1-`level'/100)*`__rr'-((`__rr'-`ulo')+(`llo'-1))),0),2)
          forvalues cc = 1(1)`nb' {
      mata : `BB' = sort(`BB',`cc')
      if `llo' > 1 & `ulo' < `__rr' {
      mata      :      `__CIBI'      =      (0.5+0.25*`cw')*(`BB'[`llo',`cc'],`BB'[`ulo',`cc'])+      (0.5-
0.25*`cw')*(`BB'[`llo'-1,`cc'],`BB'[`ulo'+1,`cc'])
      }
      else {
         mata : `__CIBI' = (`BB'[`llo',`cc'],`BB'[`ulo',`cc'])
      }
                 if `cc' == 1 {
                          mata : `__CIB' = `__CIBI'
```

```
			}
			else {
				mata : `__CIB' = (`__CIB' \ `__CIBl')
			}
		}
		mata : st_matrix("`cip'", `__CIB')
	mata : mata drop `__CIB' `__CIBl'
end

***************************************************************************
*********************************
**                              DE-FACTOR-VARIABLERIZE                              VARLIST
***************************************************************************
*
***************************************************************************
*********************************
capture program drop defvar
program defvar, rclass
	syntax varlist(fv)
	local fvl "`varlist'"
		local dfvl ""
	foreach fo in "##" "#" {
		local fvl : subinstr local fvl "`fo'" " ", all
	}
		while "`fvl'" != "" {
			gettoken fi fvl : fvl, parse(" ") bind
			gettoken ll rr : fi, parse(".") bind
			if `c(stata_version)' < 14.2 {
				local str "str"
			}
			else {
				local str "ustr"
			}
			if `str'len("`rr'") != 0 {
				local dfvl "`dfvl' `rr'"
			}
			else {
				local dfvl "`dfvl' `fi'"
			}
		}
		local dfvl : subinstr local dfvl "(" "", all
	local dfvl : subinstr local dfvl ")" "", all
	local dfvl : subinstr local dfvl "." "", all
	local dfvl : list uniq dfvl
	return local dfvl "`dfvl'"
end
***************************************************************************
********************************
```

```
**                    HANDLE                    PLUGIN                    te_radial
****************************************************************************
*******
****************************************************************************
*********************************
capture program drop handleplugin
program handleplugin, nclass
   local os "upper(substr("`c(os)'",1,3))"
   local vers = c(stata_version)
   if `vers' >= 12 {
          local bit = c(bit)
          *display `bit'
   }
   if `os' == "MAC" {
      cap findfile te_radial.plugin
   }
   else if `os' == "UNI" {
          local mach "upper(substr("`c(machine_type)'",1,3))"
          if `mach' == "MAC" {
                    cap findfile te_radial.plugin
          }
          else {
                    cap findfile te_radial_ubuntu.plugin
          }
   }
   else if `os' == "WIN" {
          if `vers' >= 12 {
                    if `bit' == 64 {
                              cap findfile te_radial_windows.plugin
                    }
                    else {
                              cap findfile te_radial_windows32.plugin
                    }
          }
          else {
                    cap findfile te_radial_windows32.plugin
          }
   }
   else {
          display as error "{p 0 2 2 `ls'}plugin to solve linear programming problem is not
available for your system; contact developers{p_end}"
          exit 199
   }
   if _rc == 0 {
      capture program te_radial, plugin using ("`r(fn)'")
   }
   else {
```

```
        display as error "{p 0 2 2 `ls'}plugin to solve linear programming problem not found;
check if teradial and the associated plugins are installed on your machine{p_end}"
     exit 199
  }
end
*************************************************************************
******************
**                RETURN              RESULTS              IN              r()
*******************************************************************
*************************************************************************
******************
capture program drop putr
program putr, rclass
  args tabout levelout
  mat `tabout' = `tabout''
  mat rownames `tabout' = be se t pvalue ll ul
  return clear
  return matrix table = `tabout'
  return scalar level = `levelout'
end
```

Appendix 4: STATA output for OLS, Tobit and Simar & Wilson Regressions

Definitions of variables can be found in section 3.8.

```
. regress EfficiencyScore ln_NWP ReinsuranceRatio DerivativeUse FreeAssetRatio LiquidityRatio CentralLondon
```

Source	SS	df	MS
Model	38.8124565	6	6.46874276
Residual	12.4179882	1,012	.012270739
Total	51.2304448	1,018	.050324602

Number of obs	=	1,019
F(6, 1012)	=	527.17
Prob > F	=	0.0000
R-squared	=	0.7576
Adj R-squared	=	0.7562
Root MSE	=	.11077

EfficiencyScore	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_NWP	.00754	.0015694	4.80	0.000	.0044604	.0106196
ReinsuranceRatio	-.0754035	.0147247	-5.12	0.000	-.104298	-.046509
DerivativeUse	-.0307979	.0083941	-3.67	0.000	-.0472698	-.014326
FreeAssetRatio	.0242868	.0161661	1.50	0.133	-.0074361	.0560097
LiquidityRatio	.0192655	.0159476	1.21	0.227	-.0120286	.0505595
CentralLondon	-.4201485	.0078233	-53.70	0.000	-.4355003	-.4047967
_cons	.6569404	.0311906	21.06	0.000	.5957347	.7181461

```
. vif
```

Variable	VIF	1/VIF
ln_NWP	1.62	0.617945
LiquidityR~o	1.41	0.711635
Derivative~e	1.35	0.742505
FreeAssetR~o	1.12	0.891622
CentralLon~n	1.09	0.914896
Reinsuranc~o	1.05	0.956647
Mean VIF	1.27	

```
. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of EfficiencyScore

         chi2(1)      =     0.00
         Prob > chi2  =   0.9663
```

```
. simarwilson EfficiencyScore ln_NWP ReinsuranceRatio DerivativeUse FreeAssetRatio LiquidityRatio CentralLondon
> , reps (2000)

Simar & Wilson (2007) eff. analysis      Number of obs            =       986
(algorithm #1)                           Number of efficient DMUs  =        32
                                         Number of bootstr. reps   =      2000
inefficient if EfficiencyScore < 1       Wald chi2(6)              =   4346.07
twosided truncation                      Prob > chi2(6)            =    0.0000
```

Data Envelopment Analysis: externally estimated scores

efficiency	Observed Coef.	Bootstrap Std. Err.	z	P>|z|	Percentile [95% Conf.	Interval]
Efficiency~e						
ln_NWP	-.0003247	.0014213	-0.23	0.819	-.0030809	.002437
Reinsuranc~o	-.0586673	.0124332	-4.72	0.000	-.0825065	-.034841
Derivative~e	-.0149381	.0072644	-2.06	0.040	-.0297389	-.0009981
FreeAssetR~o	.0049877	.0137338	0.36	0.716	-.0220045	.0327015
LiquidityR~o	.0064279	.013884	0.46	0.643	-.0214183	.0327587
CentralLon~n	-.4250727	.0067872	-62.63	0.000	-.4381588	-.4117276
_cons	.7995842	.0280908	28.46	0.000	.7443239	.8547767
/sigma	.0929901	.0022463	41.40	0.000	.0877042	.0967973

```
. xtreg EfficiencyScore ln_NWP ReinsuranceRatio DerivativeUse FreeAssetRatio LiquidityRatio CentralLondon, re

Random-effects GLS regression                   Number of obs     =      1,019
Group variable: insCo                           Number of groups  =        160

R-sq:                                           Obs per group:
     within  = 0.2431                                         min =          1
     between = 0.8208                                         avg =        6.4
     overall = 0.7518                                         max =          9

                                                Wald chi2(6)      =     971.94
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000

------------------------------------------------------------------------------------
 EfficiencyScore |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+------------------------------------------------------------------
          ln_NWP |   .0031863   .0019881     1.60   0.109    -.0007102    .0070828
ReinsuranceRatio |  -.0274777   .0150482    -1.83   0.068    -.0569715    .0020162
   DerivativeUse |  -.0113484   .0082706    -1.37   0.170    -.0275585    .0048617
  FreeAssetRatio |   .0108967   .0147653     0.74   0.461    -.0180427    .0398361
  LiquidityRatio |  -.0051783    .017448    -0.30   0.767    -.0393758    .0290193
   CentralLondon |  -.4058865   .0131852   -30.78   0.000    -.4317289    -.380044
           _cons |    .726364   .0397924    18.25   0.000     .6483724    .8043557
-----------------+------------------------------------------------------------------
         sigma_u |  .08892744
         sigma_e |   .0578821
             rho |   .7024151   (fraction of variance due to u_i)
------------------------------------------------------------------------------------

. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects

        EfficiencyScore[insCo,t] = Xb + u[insCo] + e[insCo,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
               Efficie~e |   .0503246       .2243315
                       e |   .0033503       .0578821
                       u |   .0079081       .0889274

        Test:   Var(u) = 0
                             chibar2(01) =  2001.11
                          Prob > chibar2 =   0.0000
```

```
. hausman fixed

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed          .          Difference          S.E.
-------------+----------------------------------------------------------------
      ln_NWP |    .0041641     .0031863        .0009778        .0017733
Reinsuranc~o |   -.0119041    -.0274777        .0155736        .0090042
Derivative~e |   -.0070256    -.0113484        .0043229         .004174
FreeAssetR~o |    .0070487     .0108967        -.003848        .0064777
LiquidityR~o |   -.0140604    -.0051783       -.0088821        .0106059
CentralLon~n |   -.3630058    -.4058865        .0428806         .018356
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        9.10
                Prob>chi2 =      0.1682
```

```
. xttobit EfficiencyScore ln_NWP ReinsuranceRatio DerivativeUse FreeAssetRatio LiquidityRatio CentralLondon, ll
> (0) ul(1)

Fitting comparison model:

Fitting constant-only model:

Iteration 0:   log likelihood =  5.6090128
Iteration 1:   log likelihood =  6.4301698
Iteration 2:   log likelihood =  6.4303044
Iteration 3:   log likelihood =  6.4303044

Fitting full model:

Iteration 0:   log likelihood =  693.61084
Iteration 1:   log likelihood =  694.48501
Iteration 2:   log likelihood =  694.48512
Iteration 3:   log likelihood =  694.48512

Obtaining starting values for full model:

Iteration 0:   log likelihood =  1232.9701
Iteration 1:   log likelihood =  1245.2463
Iteration 2:   log likelihood =  1245.6769
Iteration 3:   log likelihood =  1245.6779

Fitting full model:

Iteration 0:   log likelihood =  1146.2787
Iteration 1:   log likelihood =  1147.0028
Iteration 2:   log likelihood =  1147.0047
Iteration 3:   log likelihood =  1147.0047

Random-effects tobit regression                 Number of obs     =      1,019
                                                   Uncensored     =        986
Limits: lower = 0                                  Left-censored  =          1
        upper = 1                                  Right-censored =         32

Group variable: insCo                           Number of groups  =        160
Random effects u_i ~ Gaussian                   Obs per group:
                                                              min =          1
                                                              avg =        6.4
                                                              max =          9

Integration method: mvaghermite                 Integration pts.  =         12

                                                Wald chi2(6)      =     890.97
Log likelihood  =  1147.0047                    Prob > chi2       =     0.0000
```

EfficiencyScore	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
ln_NWP	.0036362	.0020491	1.77	0.076	-.00038	.0076524
ReinsuranceRatio	-.0297356	.0155257	-1.92	0.055	-.0601654	.0006943
DerivativeUse	-.0115229	.008473	-1.36	0.174	-.0281295	.0050838
FreeAssetRatio	.0116179	.0151016	0.77	0.442	-.0179807	.0412164
LiquidityRatio	-.0060506	.0178846	-0.34	0.735	-.0411037	.0290025
CentralLondon	-.4063031	.013771	-29.50	0.000	-.4332938	-.3793124
_cons	.7199495	.0410153	17.55	0.000	.639561	.8003381
/sigma_u	.0936761	.0057108	16.40	0.000	.0824831	.1048691
/sigma_e	.0590479	.0014498	40.73	0.000	.0562063	.0618895
rho	.7156506	.0268667			.6608178	.7658481

```
LR test of sigma_u=0: chibar2(01) = 905.04            Prob >= chibar2 = 0.000
```